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● (U) TROOP MARKING AND DETECTION

(Tread Concept)

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April 1965

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(U) TROOP MARKING AND DETECTION

(Troop Concept)

April 1965

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1.0 FOREWORD

The work presented in this report was performed by the Bissett-Berman Corporation, Santa Monica, California, under Air Force Contract AF 08-(635)-3777, Project 698U.

Lt J. R. Clary, Detachment 4, RTD, Bio-Chemical Division, Eglin Air Force Base, Florida, served as Project Engineer.

The purpose of this study was to establish the feasibility or non-feasibility of various techniques for the manufacture, storage, dissemination and detection of several types of chemical reagents, encapsulated in small gelatin capsules. Both dissemination and detection are, in the main, airborne.

Physical and chemical characteristics of the capsules themselves, as well as study of the behavior of the reagents was undertaken, to see if a total weapons system concept was attractive.

The purpose of the system itself, is the marking and detection of indigenous personnel involved in clandestine activities, in areas not easily monitored by electromagnetic or other methods of detection.

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2.0 ABSTRACT

A four-month study involving 2000 man-hours of library research, computation, laboratory study and field testing, was set up to prove the feasibility or non-feasibility of the concept: the marking and detection of individuals with air disseminated encapsulated reagents which remained inactive until released by the activity of the insurgents themselves.

The program was divided into several task areas: concerning the manufacture and characteristics of the capsules, the environmental and micrometeorological factors which would affect capsule life and behavior of released reagents, the airborne disseminating mechanism, and the various methods of reagent detection.

Studies, computations, laboratory tests, and field tests indicate that:

1. Encapsulation is feasible for many types of reagents both as a means of putting chemicals on the ground and keeping them there until released by enemy activity.
2. Physical characteristics of the capsules vary with reagent employed, method of manufacture, age and environmental conditions.
3. Micrometeorological conditions of the environment can affect the diffusion of reagents to a very large degree; this area requires further study.
4. In laboratory testing, a chemical exchanger, suggested for radiological exchange detection, proved to be feasible with a high degree of efficiency.
5. Calculations and preliminary laboratory experiments indicate that a long range spectrometric detection technique appears feasible. Although further study in this area is desirable, practical implementation seems to be within state-of-the-art disciplines.

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6. Fluorescent tracers on the ground appear to be detectable from low flying aircraft at night, thereby providing a night-time capability in detection.
7. Personnel marking by employing encapsulated chemicals is feasible for the detection of insurgent personnel by ground forces.

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5.0 FACTUAL DATA

5.1 INTRODUCTION

5.1.1 The Tactical Problem

One of the most pressing problems that has been identified in counter-guerrilla activity, has been the inability to identify with certainty, the enemy; that is, the insurgent or irregular force.

To keep an area effectively under government control, to disassociate the guerrilla from the local indigenous population, and to deter local support of guerrilla activities, it is essential that a method be found to reveal clearly those individuals cooperating in covert military actions against the government.

The effort in this study has been directed toward developing a program of new techniques in the detection and tracking of personnel who are located in areas where current state-of-the-art surveillance methods are either denied or not easily implemented. In particular, this program has been directed toward the application of various physical techniques for detecting enemy troops by examining gases or other materials resulting from or altered by the existence or activity of those troops.

Any technological concept which is to be employed in underdeveloped areas of the world, such as Southeast Asia, must provide the military forces with an acceptable capability consistent with simplicity. It is believed that the concept which has grown out of this study should fulfill this mission. In operation, the system should prove to be useful in preventing road ambushes; in tracking and plotting jungle paths and roads used by insurgent forces; in indicating security violations of curfew restrictions between fortified hamlets or positions; in noting local force concentrations, bivouacs, or buildups in areas of heavy foliage incapable of surveillance by electromagnetic techniques; in revealing focal areas of activities like the location of underground caches of supplies and weapons; and as a means of marking those individuals who take part in clandestine guerrilla activities in the area in which the system is employed.

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5.1.2 The TREAD Concept

TREAD (Troop REcognition And Detection) is an overall concept developed by The Bissett-Berman Corporation. It entails the encapsulation of various types of chemicals and reagents, the delivery and dissemination of these capsules or seeds to the area of interest, and the detecting of those gases or materials released from their capsules by the activity of enemy personnel.

Chemicals contained within the small encapsulated pellets scattered on the ground, are released when pressure of an individual's footstep or a vehicle, ruptures the capsule wall. The released gas or agent is then detected by appropriate airborne or ground-based detectors. See Figure 1.

Since the inception of this concept, a great many detectable agents have been suggested and many detection techniques postulated. One of the major endeavors of this study was to weed out those techniques which are unfeasible because of encapsulation and dissemination restrictions, because of environmental instability, or poor detectability. Those methods which appeared most attractive for one reason or another, were given intensive study in order to show that feasibility indeed existed and to determine what type of detecting equipment would best serve the purpose.

The entire program was subdivided into a number of task areas, certain of which were given more emphasis than others, although an attempt was made to give serious thought to all.

Figure 2 is a block diagram of what might be considered the Troop Marking system.

Encapsulation is the fountainhead, so to speak, since it is this unique feature which gives the TREAD concept its major advantages, i. e., airborne dissemination, long life on the ground before activation, covertness in position and under detection, easy storage and handling. This area therefore, received much study and effort. It was imperative to know if the reagents of interest could in fact be encapsulated, if the capsules could take buffeting in an air stream, and if the walls could survive adverse environmental conditions such as humidity and temperature extremes. There

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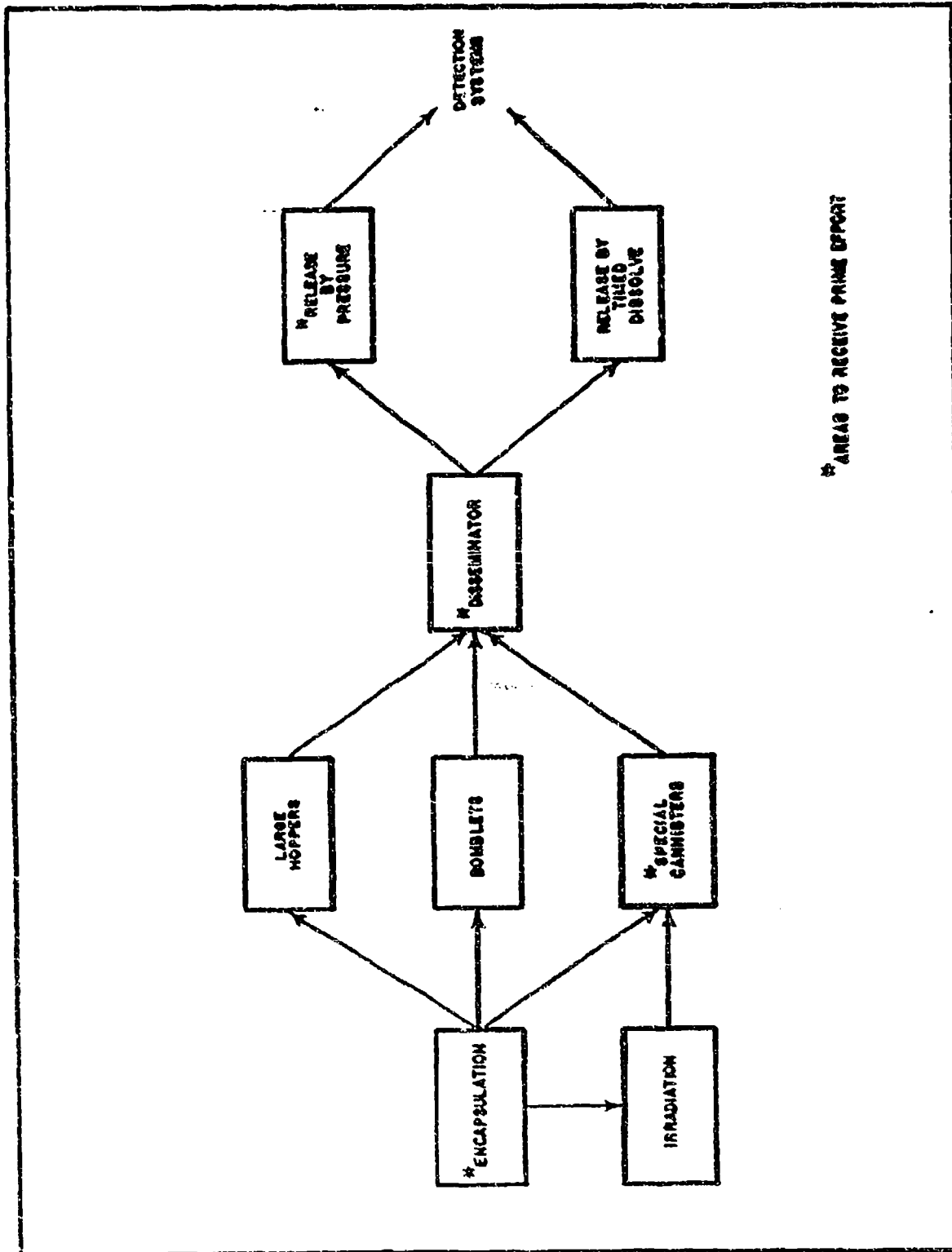
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Figure 1
Illustrative Operational Concept Indicating Release of Ground-Air Tracers

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* AREAS TO RECEIVE PRIME EFFORT

Figure 2
Block Diagram of TREAD Concept - Troop Marking System

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was also a need to determine the optimum shape, size, and wall thickness or shear strength for the capsules. These needs, and others developed during the study, were met by advancements in encapsulation state-of-the-art resulting in a preliminary capsule specification which is included in Section 5.2.3 of this report.

A subsidiary study, the possibility of irradiating capsules or encapsulating radioactive materials for special tracer detection techniques, was given some consideration and will be discussed further in Section 5.5.1.

Under the general heading of storage and dissemination, several techniques were contemplated such as: the use of large hoppers which could hold hundreds of pounds of pure or assorted capsules; bomblets, considering the possibility of modifying the present configuration of reagent container; and finally, specially designed canisters, configured to optimize capsule storage and dissemination. This was felt to be the soundest technical, tactical and economic approach.

The disseminator itself, required a design which was amenable to installation and use in high speed tactical Air Force aircraft. The resulting conceptual dissemination system design is described fully in Section 5.4.2.

Study was given to two types of reagent release, assuming the capsules have been sown under tactical conditions. The pressure rupture already discussed was felt to be the method which most ideally lent itself to the solution of the problem, i. e., the detecting and marking of ground forces.

Another possible technique, spontaneous timed rupture, would have certain definite applications. For example, a helicopter pilot or the pilot of a reconnaissance plane observing enemy activity of any sort, could dust the area with capsules which because of a built-in disintegrating mechanism activated by light, oxygen, moisture or temperature will all burst and release their tracer contents spontaneously within a few minutes of each other at a known delay time. Fighter planes or helicopter lifted

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troop units, led by an airborne tracer detector craft, could fly into the general area, x hours after capsule release, detect the localized area where enemy activity had been observed earlier, and take appropriate military action.

As this was not a task of primary emphasis, inconclusive evidence on the feasibility of the spontaneous release of reagents exists. It is felt that this technique offers a rich potential in the difficult area of airborne or ground-based target marking systems.

Finally, there are the detection systems. See the Block Diagram of Figure 3.

Detection has been subdivided into four broad areas: each of these in turn, broken down into specific techniques.

Airborne Vapor Detection techniques have in common, the need to fly into a cloud of tracer materials in the atmosphere, sample this contaminated air, and detect the tracer contaminants by one means or another. See Figure 1.

Radioactive tracers released from the ground have been considered. Radio Isotope exchange however, for several reasons discussed at length in Sections 5.5.1 and 5.5.2, was felt to be the optimum approach in sampling techniques insofar as detectable threshold limits, handling safety and other factors were concerned.

Other sampling techniques such as freeze out, chromatography, spectroscopy, et cetera, are considered and their limitations discussed.

Another broad area of detection schemes involves Long Range Optical techniques. Obviously, an ideal detection system is one in which a high altitude high speed aircraft, through the use of an automatically scanning optical system, can detect the presence of a tracer contaminated cloud at long range, lock on to this target and take appropriate action.

Preliminary calculations indicate that scattered sunlight provides sufficient radiance as a source for spectral absorption techniques in the long wave ultraviolet, visible and near infrared portions of the spectrum.

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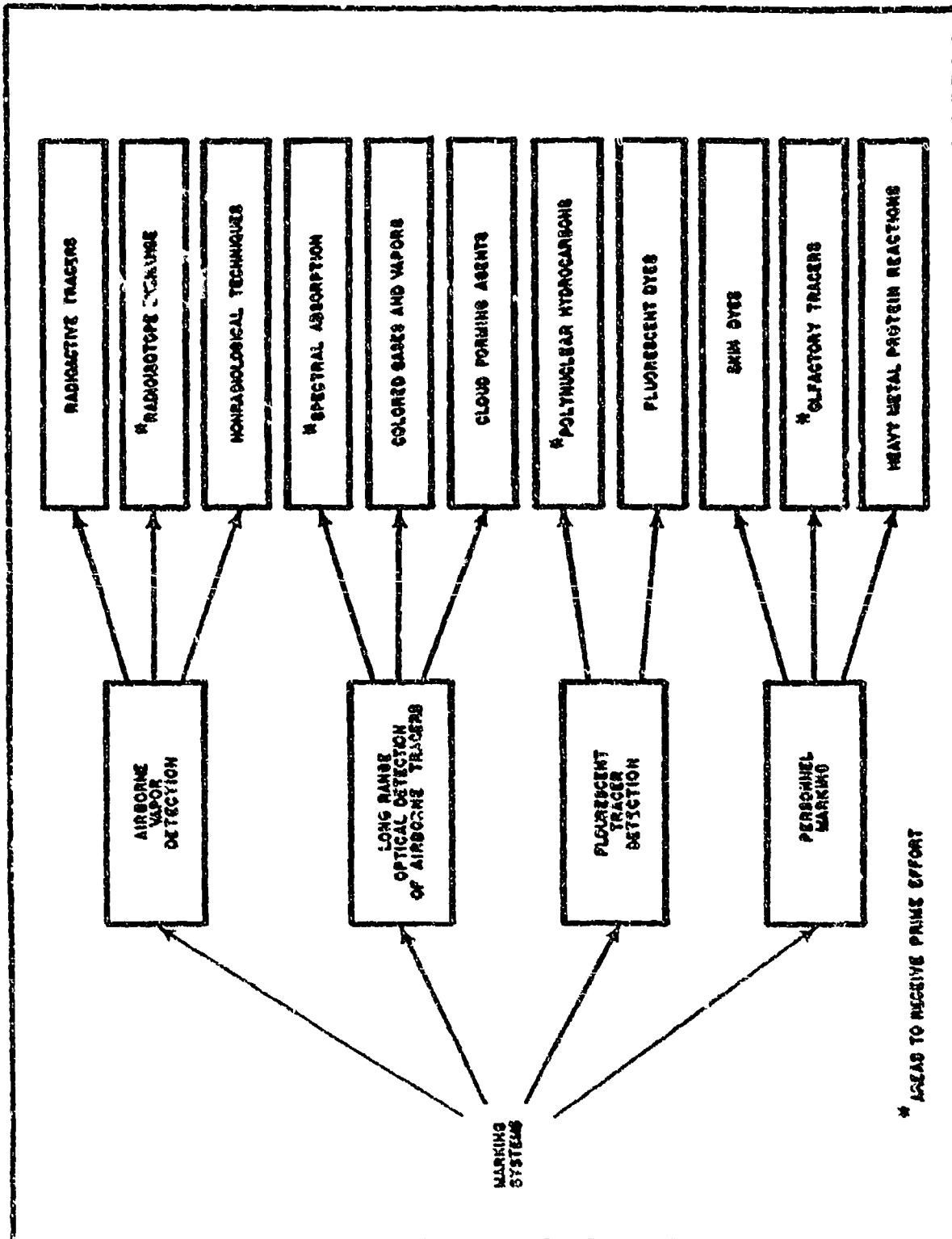


Figure 3
Block Diagram TREAD Concept - Detecting Systems

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A search for appropriate vapors exhibiting narrow band absorption lines in the visible, to date, prove to be fruitless, but I.R. molecular rotation and vibration lines in the near infrared for hydrocarbon materials like benzene and toluene are attractive.

Laboratory tests were performed with these materials, demonstrating feasibility, but further investigation, however, is required to determine whether this technique is applicable to the tactical situation. This work is discussed in Section 5.6.

Other long range techniques, also discussed in Sections 5.6.1 to 5.6.3, involve the creation of clouds, colored vapors and smokes, fluorescent spectroscopy and leaf stainers.

Fluorescent Ground Tracer Detection methods covered in detail in Sections 5.7.1 to 5.7.3, prove not only to be feasible, but very attractive in that they provide a remote night technique for troop activity detection.

The final broad area of detection techniques is Personnel Marking, and is tailored more for detection by ground forces than by aircraft techniques. The security of Air Force personnel, materials, and facilities, however, requires this sort of application. In Section 5.8, are discussed several useful techniques for detecting insurgent personnel by marking them with leuco and other dyes, tanning agents, fluorescent powders, heavy metal protein reactions and olfactory tracers.

5.2 TASK AREA I: CAPSULES

A substantial microencapsulation technology, developed and patented in recent years by the National Cash Register Company with The Stanford Research Institute as a licensee, was believed to be the basis of a unique approach to the preparation and distribution of chemical agents which would be released to the atmosphere by enemy action and detected by suitable instrumentation. Processes were available for producing quantities of minute, approximately spherical capsules, of the order of 0.2 to 2.0 mm in diameter, consisting of droplets of oil-soluble chemicals enclosed within a

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thin polymerized gelatin envelope. The structural and chemical properties of the capsules offered promise of a) dissemination from airborne vehicles, b) useful stable life on the ground, and c) efficient covert release of volatile chemical agents (tracers) to the atmosphere following capsule breakage under the footsteps of aggressor personnel.

5.2.1 Tracers

5.2.1.1 Chemical reagents suitable as tracers or markers of aggressor activity may conveniently be considered as belonging to one of three categories: a) airborne tracers, b) surface or ground markers, and c) personnel markers. In the present study, the major effort was directed toward exploitation of the first two classes, with less attention being paid to the third, since it is not compatible with high-speed aerial surveillance.

5.2.1.2 Assuming that encapsulation is possible, the fundamental requirement of an airborne tracer is that it be detectable at extremely low concentrations (parts per billion) by some feasible combination of apparatus and techniques. Theoretical and practical considerations had shown that chlorinated hydrocarbons constituted the most promising single group of encapsulable airborne tracers. Representative compounds considered for this purpose are listed in Table 1.

Table 1

Compound	Formula	Boiling Point (° C.)	Liquid Density (gm/cm ³)
cis - 1,2 - dichloroethylene	$\text{CHCl} = \text{CHCl}$	60	1.291
chloroform	CHCl_3	61-62	1.489
1,1,1 - trichloroethane	CH_3CCl_3	74.1	1.325
carbon tetrachloride	CCl_4	76.7	1.595
1,2 - dichloroethane	$\text{CH}_2\text{ClCH}_2\text{Cl}$	83-84	1.256
trichloroethylene	$\text{ClCH} = \text{CCl}_2$	87.3-87.5	1.466
1,1,2 - trichloroethane	$\text{CH}_2\text{ClCHCl}_2$	113-114	1.441
tetrachloroethylene	$\text{Cl}_2\text{C} = \text{CCl}_2$	121	1.624

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Capsules containing 1, 1, 1 - trichloroethane were prepared and tested (Section 5.2.3). Cis - 1, 2 - dichloroethylene was used in several encapsulation experiments, but it could not be retained by the capsule during drying.

Some study was also devoted to chemicals which might enter the atmosphere as colored gases or vapors and which could be detected by long-range optical techniques. These included bromine, iodine, and nitrogen dioxide (Section 5.6).

5.2.1.3 Potential ground-staining markers, which might be detected by night aerial surveillance, included the broad class of fluorescent (in the visible and UV spectrum) organic reagents such as fluorescein (uranine), eosin, and perylene.

5.2.1.4 Study was conducted on various types of personnel marking reagents. While these techniques lend themselves more to detection on the ground than by airborne means, positive individual marking is highly desirable under conditions where close in ground surveillance can be effected such as in airfield security.

Marking and staining of personnel by fluorescent agents, dyes, leuco dyes, and unique odorous tracers, were included in the study.

Dyes, such as indigo, which might be encapsulable in the form of its precursor, indoxyl; and silver-containing compounds, which produce skin stains by reduction of silver, were viewed as possible personnel markers (Section 5.8).

5.2.2 Encapsulation Process

The encapsulation process consists essentially in the preparation of an intimately mixed two-phase system, one phase being an oil or an oil-soluble fluid, and the other phase an aqueous dispersion of a colloid-forming agent, for example, gelatin. By precise control of the mixing shear forces, pH, and temperature, thin spherical shells of cross-linked gelatin can be made to form upon the minute oil droplets. The capsules

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thus formed, containing on the order of 90% by weight internal phase, are then collected, washed, and dried. In the final dried condition, the capsules vary widely in diameter, commonly falling in the range of 0.5 - 1.2 mm., although these limits may be increased by suitable variations in the process parameters. As a final step, the finished capsules may be screened or sieved to yield desired size fractions: for the purpose of this study 1 to 2 mm. diameter capsules were needed. A typical process flow diagram is given in Appendix A.

5.2.3 Capsule Properties

The Stanford Research Institute fabricated and delivered small quantities of capsules containing a) toluene, and b) 1, 1, 1 - trichloroethane for physical and chemical evaluation by Bissett-Berman.

Requisite properties included a) sufficient strength and resilience to survive the stresses associated with storage in and turbulent ejection and descent from high-speed aircraft; b) frangibility under shearing and compression forces exerted by ordinary adult footsteps upon capsules resting on grassy terrain; c) retention of volatile contents and structural integrity in the presence of humidity, temperature, and chemical conditions characteristic of tropical soils and vegetation, for periods on the order of ten days.

Dissection and examination of 1.6 mm. capsules revealed average wall thicknesses of $\sim 20\mu$, and volumes of $2 \times 10^{-3} \text{ cm}^3$, i. e., a capacity of 2.5 - 3 mg. for solvents with a density of 1.25 g/ml. Capsules were heated to 350°F . for 10 minutes with a heat gun without degradation. No adverse effect was produced by subjecting capsules to high altitude pressures in a test cycle which consisted of elevation to 75,000 feet ($\sim 40 \text{ mm. Hg}$) in 2 minutes, holding at altitude for 3 hours, and return to sea level in 1 minute.

Weight loss tests showed that the low rate of diffusion of contained organic solvents through capsule walls would result in a virtually negligible loss of tracer content, from the time of capsule manufacture through the

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desired (10-day) period of usefulness on treated terrain. Further, this low loss would obviate the possibility of a spurious background or "noise" level, i. e., a measurable concentration of airborne tracer produced by untrodden capsules. Diffusion losses of typical organic solvents (e. g., carbon tetrachloride, toluene) are in the order of 1% in 14 days at 25° C. (77° F.) and 2-5% in 14 days at 60° C. (140° F.). The hourly loss rate is then $< 3 \times 10^{-5} \text{ hr}^{-1}$ at 25° C. If a total weight of $5 \times 10^2 \text{ g.}$ of agent is present in ground-disseminated capsules, then $\sim 150 \text{ mg.}$ is released to the atmosphere in a 10-hour period during which atmospheric dispersion and dilution would certainly prevent the build-up of a detectable concentration or a false alarm level.

The study of capsule characteristics has led to a tentative capsule specification as follows:

- | | | | |
|----|---|--------------------------|-------------------------|
| 1. | Size | Preferred: | 2.0 to 2.5 mm. diameter |
| | | Limits: | 1.6 to 3.0 mm. diameter |
| 2. | Color | As specified - | |
| | | to opaqueness | |
| 3. | Fluid Content | Preferred: | 3.5 mgm. or more |
| | | Limits: | 3.0 mgm. or more |
| 4. | Shelf Life | 6 months, at | |
| | | which time the following | |
| | | criteria must be met. | |
| a. | Less than 10% loss of fluid content. | | |
| b. | Resiliency maintained as defined by a dropping test. 95% + of capsules selected randomly must, when dropped from a 6 foot height onto a firm surface comparable to vinyl tile flooring, bounce without signs of deformation or loss of content. | | |
| c. | Must survive a 24-hour environmental cycling test through high and low temperature and pressures to be specified at a later date. | | |
| d. | Four weeks in fresh water with no obvious convoluting of the capsule wall. | | |

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5.3 TASK AREA II: ENVIRONMENT

In order reasonably to predict the stability of disseminated capsules and the atmospheric diffusion of released vapors, it was necessary to consider the characteristics of the jungle environment. A preliminary survey and evaluation was performed for such parameters as wind and inversion patterns, native atmospheric components, and soil moisture effects on capsule properties. Published reports of investigations of atmospheric diffusion of rocket exhaust pollutants, insect attractants, and chemical warfare agents were reviewed for this analysis.

5.3.1 Micrometeorology

5.3.1.1 Typical Tropical Environment

The following paragraphs and Figure 4, a generalization of Appendix B, Tropical Weather Statistics, present a summary of the environmental factors which might affect the utilization of capsules for marking and detection in Southeast Asia and other tropical regions. Undoubtedly, additional data are required for a fully comprehensive analysis; however, the results of the present survey indicate the nature and extent of the significant environmental conditions.

Inversion

A distinct temperature inversion is generally experienced beneath the jungle canopy during the daytime, usually from about 0800 to 1700 hours. The inversion layer extends from the ground to the top of the tree canopy which generally is 150 to 200 feet above the ground in mature tropical forests. Normal lapse conditions are to be expected above the canopy. Also normal lapse conditions are likely at night and during rains. (References 4 and 8.)

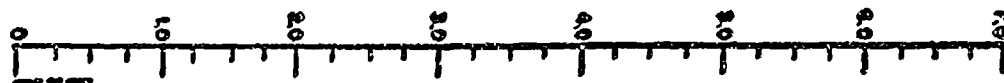
Winds

Winds of measurable forces (greater than 0.5 mph) are seldom experienced beneath the jungle canopy. Gusty winds of from 1 to 3 mph may be experienced beneath the canopy during thunder showers. Such conditions are

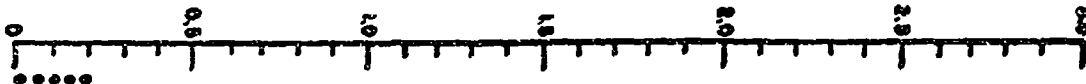
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WIND SPEED (MPH)



RAINFALL (INCHES)



DRY BULB TEMPERATURE (F°)



RELATIVE HUMIDITY (%)

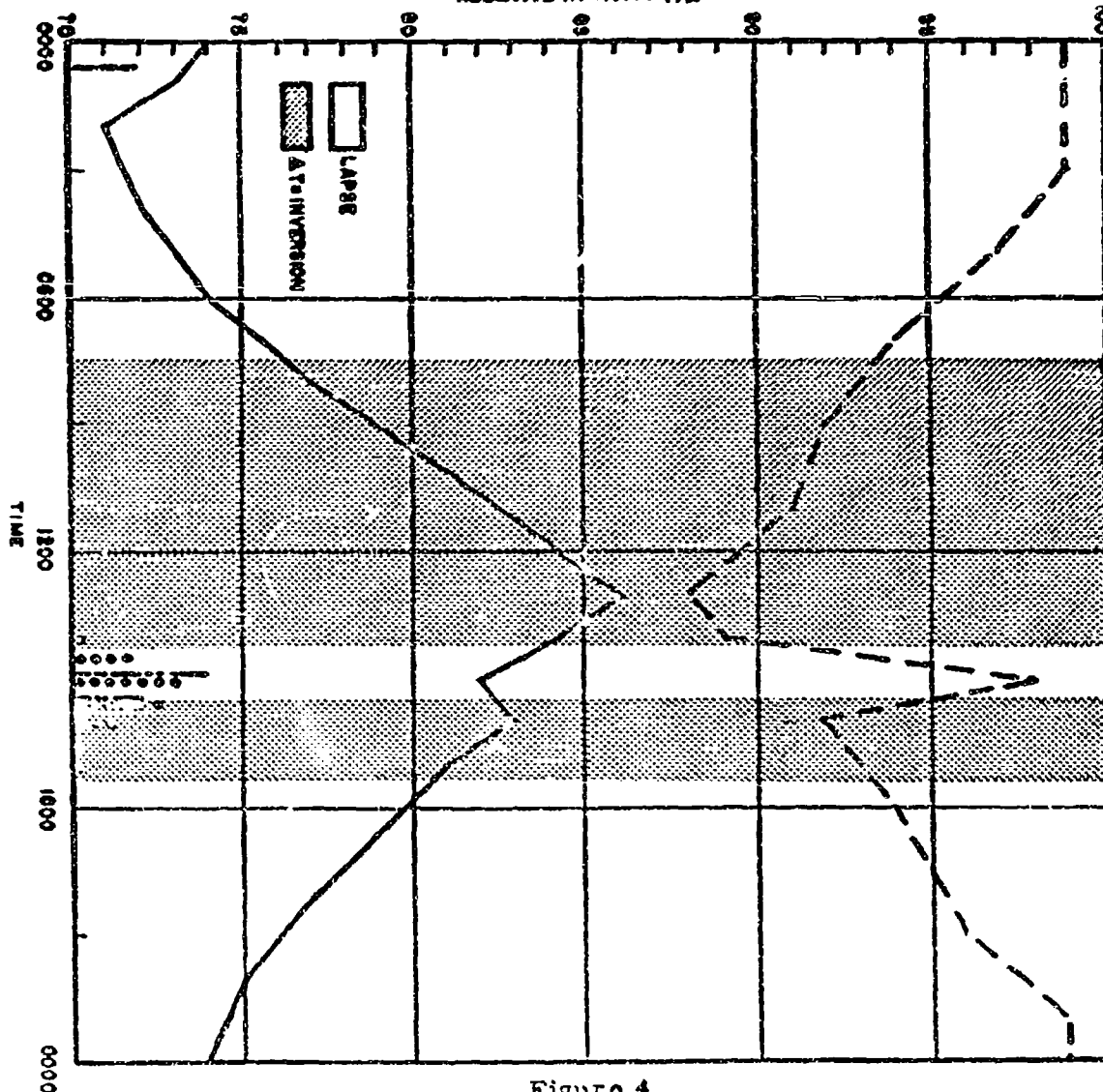


Figure 4

Typical Jungle Weather Parameters

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to be expected in nearly all months in the tropics with a slight peaking during the maximum solar poleward excursion. Available data indicate that winds of 10 to 17 mph are experienced above the canopy at the times of maximum gusts beneath. (References 3, 4, 6, and 8).

Temperature/Humidity

Diurnal temperature ranges of from ten to twenty degrees are to be expected. Beneath the canopy temperatures generally range from 70° to 85° with maximum temperatures in the upper 90°'s. Humidity varies from virtually 100% to lows of from 70% to 80%. As would be expected, sharp humidity and temperature changes are common during showers. (References 1, 4, and 8).

Precipitation

Appendix C presents details on the seasonal nature of precipitation in tropical climates. In general, greatest precipitation occurs during high-sun periods (Appendix D) and is most likely to fall from afternoon thunder showers. Rainfall of as much as one to two inches per hour is not uncommon. (References 2, 5, 7, and 8).

Soil Moisture

It is estimated that tropical soils will always contain large amounts of soil moisture (50% to 75%). Periodic daily surface drying will occur in areas exposed to the sun in all areas and for long periods of time in those areas having Am climates (See Appendix C). Soil temperatures will always be high. The effect of soil moisture on capsules is presented in Section 5.3.2.2. (Reference 3).

Effects of Vegetation

Vegetation will influence the distribution of capsules at ground levels. It appears in the literature, that few systematic studies of the distribution of particles to the ground through the canopy have been undertaken. However, observations of rainfall in the tropics indicate that many species of trees,

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particularly palms, will inhibit the general dispersion of capsules by what may be termed an "umbrella" effect. Furthermore, from observations of the dispersion of rain in sword grass and capsules in bermuda grass, concentrations are possible where the grass blades "catch" the capsules and "funnel" them toward central points. (Reference 3).

In order to get a more meaningful feeling for the problem of dispersal of capsules through a dense canopy cover, tests were conducted on a scaled-down jungle of dense brush and broad leaved shrubbery. Small benzene filled capsules were released at the rate of ~100 capsules per second, from an altitude of 8 feet (about 4 feet above the foliage) with the disseminator moving horizontally in a straight line at 3 feet a second.

In order to make the simulation more like the real conditions and less optimum, tests were carried out right after a rainfall, so that moisture collection on leaves was very apparent.

Careful study of the ground after the tests indicated the following results:

1. Even through the densest canopy, there is efficient penetration to the ground.
2. Instead of clustering of capsules as one would expect from funneling processes, ground distribution appeared fairly uniform in both dense foliage and sparse foliage areas.
3. The chief effect of foliage is not the creation of unequal distribution, but of thinning the distribution over a much greater area.
4. Path width over heavy foliage is perhaps 3 or 4 times as great as over the clearings.
5. Ground distribution under heavy foliage appears to be 10% as concentrated as in clearings.

This would indicate that densely foliated terrain should receive up to 10 times as many capsules as open areas, to ensure equal ground distribution.

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5.3.1.2 Diffusion Studies

In order to establish order of magnitude concentration estimates, it is well to start with the simplest situations and assumptions. This will give a rough idea of the concentrations of tracer materials likely to be available to a detection system.

Assuming the reagent is a chlorinated hydrocarbon like dichloro-ethylene HC = HC with a molecular weight of 95.0.
Cl Cl

If 200 capsules are ruptured at 5 mgm. of reagent per capsule, the total release will be 1.0 gram.

If the air volume into which this is dispersed is $\sim 10^6$ liters (10^3 cubic meters) the concentration is 1×10^{-6} gms./liter.

This volume can be visualized as a cube 10 meters on a side. See Figure 5 (a).

The concentration can be determined in parts per million by the relationship

$$\text{ppm} = \frac{\text{concentration} \times 2.54 \times 10^4}{\text{molecular weight}} = 0.26$$

or ~ 260 parts per billion.

The cube considered here, is only 30 feet on edge, which is an extremely conservative boundary. Assuming a two order of magnitude difference in volume, the concentration would approach 2 or 3 parts per billion, and the cube would be 150 feet on edge. This is coming dangerously close to the practical detection limit by standard chemical means.

A more realistic model may be a conical volume dispersing downwind from a point source. See Figure 5 (b).

If the downwind distance is 100 feet and the height of the plume is 50 feet, the cone volume is

$$\frac{\pi R^2 h}{3} = 6.5 \times 10^4 \text{ cubic feet.}$$

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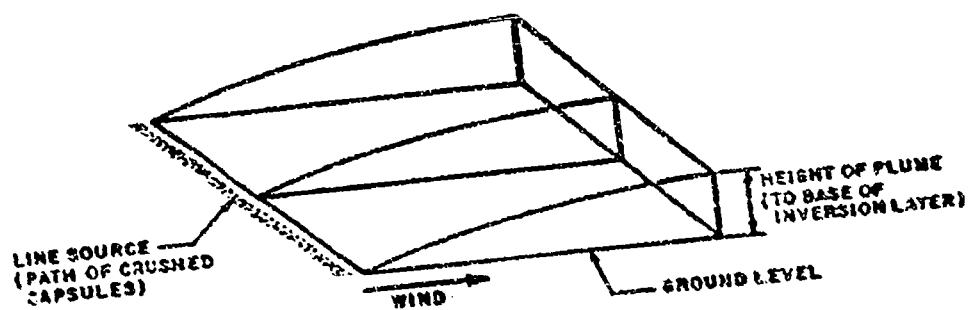
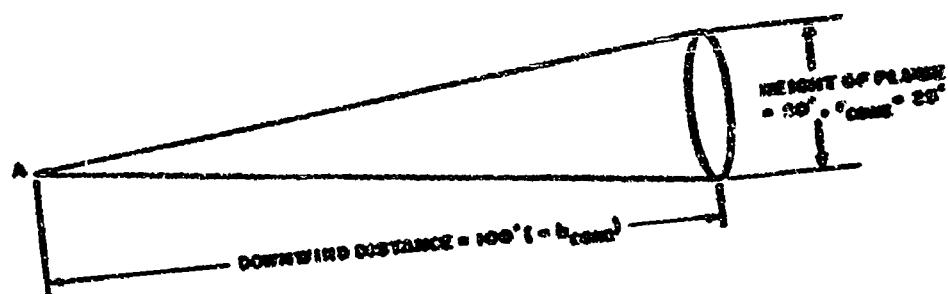
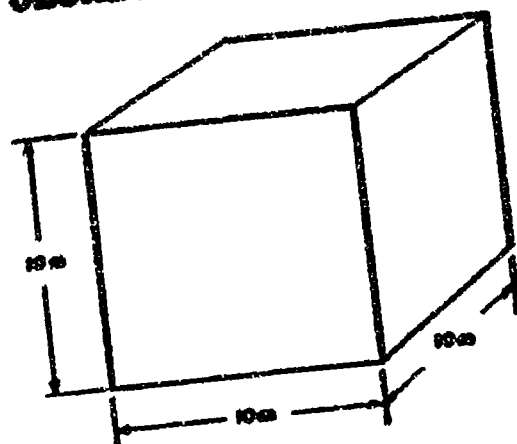


Figure 5. Diffusion Volumes

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Since there are 28.4 liters per cubic foot, this represents a volume of 1.84×10^6 liters, or not quite double the volume of the 30 foot cube. The concentration of 1 gram of chlorinated hydrocarbon in this volume is 140 parts per billion.

An even more accurate representation of the situation is shown in Figure 5 (c).

Personal communication was established with William H. Bossert and Edward O. Wilson of the Biological Laboratories of Harvard University. They have studied extensively the olfactory communication among animals by molecular airborne dispersion and have indicated that even the simplest experimental situation demonstrates the naivete of the basic dispersion point source formulations usually employed. Sutton's equations, however, do provide a first order of approximation in arriving at downwind dilutions.

Because of the importance of their work, personal contact was made with Aerojet General Nucleonics in San Ramon with Mr. L. D. Van Vack, author of Aerojet General Report No. AN-862 (Reference 9) "Evaluation of Field Results From a Meteorological Control Program for Solid Rocket Testing", February 1963. The purpose of the contact was to obtain data on the quantities of contaminant released by the rocket firing tests, so that these could be related to the quantities of contaminant picked up by the air samplers.

We were informed that the 3 KS (1000) propellant grain weighs 16 pounds and that its burning time is 2.3 - 4.4 sec. 10-11% (650-770 g.) of sampleable material is released to the atmosphere by the burning of this grain, the remainder being gases and vapors. The 10 KS (2500) grain weighs 100 pounds of which 10-11% is sampleable, in a release time of 8.8 - 10.3 sec.

High volume air samplers, situated at ground level downwind, sampling at 10 cfm (284 l/min.), drew quantities of from $\sim 2-50 \mu\text{gm}$. (10^{-6} g.) on No. 41 filter paper at distances from ~ 250 to 5,500 feet downwind, as the cloud of effluent passed over the sampling stations. Wind speeds were ~ 10 mph (~ 15 ft./sec.). These experiments were carried

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out under "lapse" conditions (temperature decreasing with height.) Samplers were started as firing began and were continued until the cloud had passed beyond the sampling area, ~10-15 minutes later.

Although it is difficult from this data to calculate the concentration along the cloud axis which was at some appreciable but unknown height above ground, it is clear that the dilution effect is enormous for given periods of time on the order of hours even in nearly stationary winds. In the study cited above, 7×10^2 g. was released and 10×10^{-6} g. was captured by a sampler which took in an air sample of the order of 100 cu. ft. (3 cu. m.). The "average" concentration in the cloud must then have been $\sim 3 \times 10^{-6}$ g./m³ = 3×10^{-9} g./l. = 3×10^{-6} mg/l. The implication in these results is that we will have to design into the airborne tracer sampler, a means for obtaining very large sample rates while flying at relatively low aircraft speeds, i. e., 100 mph (150 ft./sec.). At a sampling rate of 21 cu. ft./min. (600 l/min.) the aircraft will sample 10/l in traversing a cloud 150 ft. long, in one second. This is a very high sampling rate, considering that we wish the air to traverse a combustion column and an exchange bed.

5.3.1.3 Environmental Studies - Theoretical Model

The presence of small air currents at the base of the forest canopy, and an almost ever present inversion layer near the top of the canopy, presents a number of difficulties in tracing a released gas from its point source, the ruptured capsule.

Several formulations have been suggested for predicating the downwind conditions which might result from various release conditions. The point source formulations of O. G. Sutton (Reference 10), as modified by J. Holland (Reference 11), have been based on sound theory, have been frequently tested, and using easily obtainable meteorological input data have proven to give reasonable answers.

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The form of Sutton's equations are in terms of ground level concentrations at specific downwind and crosswind locations. To predict the concentrations to which a downwind observer might be exposed as the result of an instantaneous release of material to the atmosphere, Sutton derived the following relationship:

$$C_i = \frac{2Q \exp \left[\frac{-1}{(uy) + (xz)^{2-N}} \left(\frac{H^2}{C_x^2} + \frac{y^2}{C_y^2} + \frac{(x-ut)^2}{C_x^2} \right) \right]}{\pi^{3/2} C_x C_y C_z (uy + xz)^{1.5 (2-N)}}$$

where:

- C_i = Concentration (gms. - meter⁻³) at time "t" (seconds) at a point "x" (meters) downwind and "y" meters crosswind, as a result of instantaneous release.
- Q = source (gms.)
- C_x, C_y, C_z = diffusion coefficient in the downwind, crosswind and vertical directions.
- u = wind speed (meters - sec.⁻¹)
- N = stability parameter
- H = stabilization cloud height (meters)
- xz = finite volume correction (meters)

where

$$xz = \left(\frac{.288 R^3}{C_x C_y C_z} \right)^{\frac{2}{6-3N}}$$

where

- R = stabilization height (meters)

when

- x = ut , the peak concentration can be evaluated.

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To determine the concentration from a slow continuous release

$$CPC = \frac{2 Q/S \exp \frac{-1}{(x+xz)^{2-N}} \frac{H^2}{C_z^2} \frac{y^2}{C_y^2}}{\pi C_y C_z u (x+xz)^{2-N}}$$

where

Q/S = release rate in gms./sec.

Meteorological data inputs required for the formulation include the stability parameter (N) wind velocity (u), diffusion coefficients (C_x , C_y , C_z), and the height of the base of the capping inversion (He).

Wind velocity and capping inversion base height information is readily available from standard meteorological instrumentation. Care must be exercised in selecting the height at which the wind velocity measurement is taken so that erroneous surface effects are eliminated.

The applicable value of the stability parameter may be determined from a temperature gradient measurement, as follows: (Reference 12).

$-\infty < TD \leq -1.1^\circ F.$	0.2 (lapse)
$-1.1^\circ F. < TD \leq 0$	0.25 (neutral)
$0 < TD \leq 5^\circ F.$	0.33 (mild inversion)
$5^\circ F. < TD \leq \infty$	0.5 (strong inversion)

where

TD = Vertical temperature gradient per 200 feet.

The value for C_i (max) occurs in the isotropic case, at $\frac{Q}{4.26uH^2}$ (Reference 13), and for non-isotropic diffusion,

$$CiMax = \frac{Q}{4.26uH^2} \frac{C}{C_y} \text{ where } C = (C_x C_y)^{1/2}$$

The downwind distance at which the peak concentration (CiMax) occurs is

$$d_{max} = \left(\frac{H^2}{C^2} \right)^{1/2-N}$$

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By studying the diffusion and dispersion of fluorescent particles, Falk (Reference 14) et al have determined a very simple formulation where

$$C_i \text{ Max} = \frac{0.19 Q}{H^2 u}$$

The values of C_i (Max) were found to be accurate experimentally within a factor of 2 of the calculation, about 85% of the time, and within a factor of 3 about 95% of the time.

The diffusion coefficients as observed, versus wind speed and stability factor (N) are from the data of Holland (Reference 15).

For low altitude release, with wind speeds of approximately 1 meter per second the values of C_x , C_y , and C_z during moderate inversion conditions, are respectively 0.12, 0.19, 0.15. For lapse conditions, they are 0.40, 0.80, 0.60. Under neutral conditions they are 0.20, 0.22, and 0.30.

Giving Sutton's formulation some realistic values, we can get some idea of the dilution problem.

Example - Suppose the aircraft has seeded a strip 100 feet wide, at a ground dispersal of 10 capsules per square foot. If a patrol of 10 men cross the strip, each with a 4 foot pace (2 strides = 4 feet) then each man steps down about 50 times in traversing the strip. Ten men will step down 500 times. Assuming each step to break 2 capsules, 1000 capsules are ruptured releasing 5 mgm. each of material, or a total of 5 grams. If the patrol has maintained a close formation, we can treat the area as a single point source of instantaneous release.

If H=R	=	height to base of the inversion = 50 yards
y	=	(detector is downwind only and there is no crosswind diffusion to be concerned with) 0
x	=	100 yards - downwind
N	=	0.33 (moderate inversion factor)
CX=CY=CZ	=	0.1 (meters $n/2$)
u	=	1 meter per sec. (about 2 mph wind)
t	=	1000 seconds = 17 minutes after release
Q	=	5 grams of released gas

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Then according to Sutton's formulation (Reference 10) $C_1 = 2 \mu\text{g/m}^3$ per cubic meter, which represents, probably the minimum limit of chemical detectability.

If more capsules are broken, or if the wind is moving at less than 2 mph, which is very possible, greater ranges of detectability can be realized.

In the above example, the detector has been placed, conveniently downwind and on axis. Should the detector be crosswind, the concentration drops off very steeply. See for example, Figure 6, which is derived from the work at Aerojet General (Reference 12).

The Signal-to-Noise Problem

There are three factors which may contribute to the noise background behind the chemically detected gas signal:

1. gases produced by the normal tropical floral background which affect the detector in question.
2. signal gases which diffuse slowly from the seeded capsule walls, producing slow continuous source detectable gases, and
3. self-rupturing capsules giving instant, full capsule release of detectable gases.

It is obvious, that should the background exist in quantities below detector threshold, or in quantities small in comparison to the signal concentration, there would be little or no false alarm rate.

In regard to normal background constituents of heavily forested areas, there is a dearth of information in the literature. It has only been in the last months that any serious study has been undertaken in the area of air pollution of non-urban atmospheres. Personal contact was made with Dr. Frits Went, Director of the St. Louis, Missouri Botanical Gardens, one of the few authorities in this area.

His information indicates that there is a small but undetermined concentration of volatile organic compounds belonging to the terpene and

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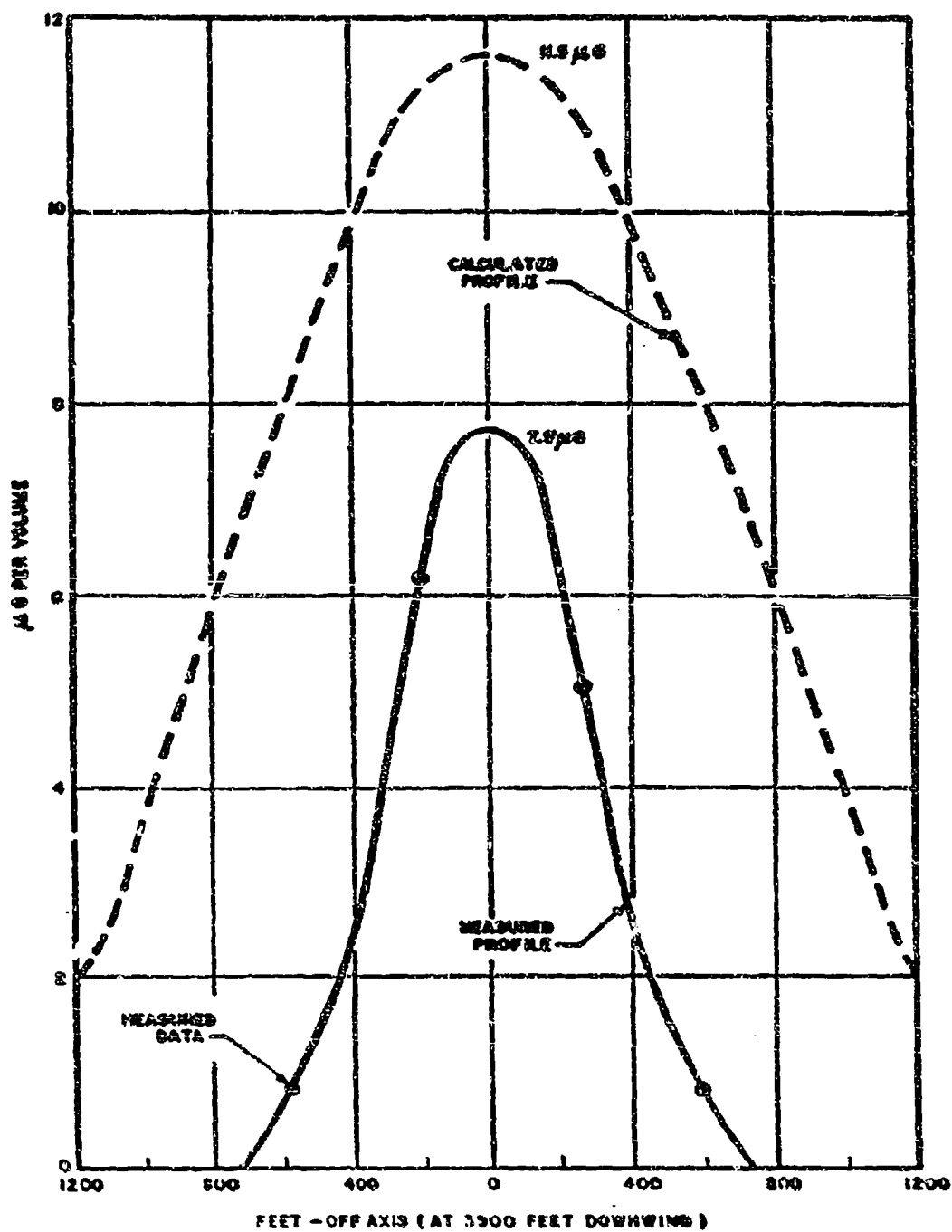


Figure 6
Cross Wind Concentration as a Function of
Distance from Down Wind Axis

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sesquiterpene hydrocarbon groups present in atmospheres of forested areas, largely as a product of plant metabolism, in concentrations in the range 5 - 10 parts per billion.

Chlorinated hydrocarbons like the materials now being encapsulated are highly unlikely constituents of such an environment.

Solid organic materials in the particle size range 0.2 - 0.3 microns are present in concentrations of 0.1 - 0.4 parts per million (100-400 ppb) on a weight basis. The exact nature of these compounds is undetermined, but they are chiefly organic.

Research is presently underway by Dr. R. Rasmussen, under Dr. Went's supervision but no papers are expected to be published before the end of 1963.

This is certainly one critical area in which much information should be gathered to help delineate the problem of natural background in the area of chemical dissemination in tropical environments.

In regard to the problem of background created by the slow diffusion of materials through the capsule walls, it must be determined if the diffusion rate for a known number of capsules in a given time period is comparable to, greater than or less than the instantaneous release of a known number of capsules, by breakage as the result of enemy activities on the ground.

The following diffusion rates in Table 2 are given for hydrocarbon encapsulated materials in gelatin capsules. Values represent loss rate of materials by weight for a 7-day period.

Table 2

Encapsulated Material		Diffusion Loss in 7 Days	Temp.	Source
1. Toluene	less than	0.5%	80°F.	SRI
2. Toluene		0.3%	140°F.	SRI
3. Diethylbenzene		0.6%	80°F.	NCR
4. Diethylbenzene		1.0%	140°F.	NCR
5. Diethylbenzene		1.0%	140°F.	SRI
6. Carbon tetrachloride		0.5%	80°F.	NCR
7. Carbon tetrachloride		1.05%	140°F.	NCR

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Assuming, as was done in earlier calculations that a small squad or patrol, crossing a seeded strip, and breaking two capsules per step, breaks a total of 1000 capsules, each containing 5 mgms. of volatile chlorinated hydrocarbon, then 5 grams are released.

Assume no measurable ground wind, and the base of the inversion at a height of 100 meters (10^4 cm.). Also, assume diffusion coefficients equal in all directions. Thus the concentration of 5 grams of material in a cube 100 meters on a side (10^9 liters) is

$$\text{Conc.} = \frac{5 \times 10^3 \text{ mgms.}}{10^9 \text{ liters}} = 5 \times 10^{-6} \text{ mgms./liter}$$

since

$$\text{P.P.M} = \frac{\text{Concentration} \times 2.54 \times 10^4}{\text{Molecular Weight}}$$

and assuming a material like dichloroethylene with a molecular weight of 97.0

∴ the concentration in PPM = 13×10^{-4} or 1.3 ppb, which is at, or near the threshold level of chemical detection.

The diffusion rate may be calculated from the approximation

$$C_i = \frac{.19 Q}{H^2 u}$$

if

$$C_i = 1.3 \text{ ppb } (1.3 \times 10^{-9})$$

$$Q = 5 \text{ mgms. released}$$

$$H = \text{height to inversion cap} = 1 \times 10^4 \text{ cm.}$$

then u , in the absence of a breeze, represents the diffusion rate in $\text{cm}^2/\text{sec.}$

$$\therefore u = \frac{.19 Q}{H^2 C_i} = 9 \text{ cm}^2/\text{sec. or a rise of 3 cm./sec.}$$

in the vertical direction.

The time necessary for the vapor to reach the inversion level of 10^4 cm. would be

$$\frac{10^4 \text{ cm}}{3 \text{ cm/sec.}} = 3,300 \text{ sec. or 55 minutes}$$

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It is difficult to assign limits to the area which is contributing to the background. It is a function of the sampling rate of the aircraft, the wind speed and direction, diffusion rates, inversion height, and many more subtle factors. For convenience, assume that the entire 100 meter by 100 meter square base of the diffusion cube represents the background source. It contains 10^8 cm^2 . Covered at the rate of 0.01 capsule per cm^2 (10 capsules per square foot), there are 10^6 capsules contributing to the noise.

Assuming a temperature of 90°F . for a chlorinated hydrocarbon, like carbon tetrachloride or dichlorethylene, the diffusion loss should be about 0.7% per week, or 0.1% per day. In 1 hour, only .004% is released. Thus, the background release $(B) = A R D_T Q_C$

where

A	=	area of ground contributing	=	10^8 cm^2
R	=	concentration of capsules		
		cm^{-2}	=	10^{-2}
D_T	=	diffusion loss per time		
		(1 hour)	=	4×10^{-5}
Q_C	=	content of capsule		
		(grams)	=	$5 \times 10^{-3} \text{ gms.}$
Background	=	0.2 gms.		

This compares with a signal release of 5 gms., therefore the $S/N = 25$. Since the signal level is just barely detectable, the noise level at 4% of this, is not detectable.

It must be emphasized that as presented, this calculation is based on a closed system, that is, it is assumed that with longer and longer periods, there is an accumulation of background.

This would occur only in a box. While the inversion cap and the foliage canopy tend to "hold" in the gases, their efficiency as an impervious wall is low, and lateral movements, especially in the presence of breezes would tend to dissipate any small accumulation of this background.

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One can conclude, therefore, in regard to the problem of slow diffusion, even from very large numbers of capsules, the chief concern is detecting low level signals, in the presence of little or no noise.

In regard to the third area of noise contribution, that of a spontaneous rupture either as the result of pressure rupture from the activities of animals or as the result of physical or bacteriological deterioration of capsule walls, a real problem is presented. Only a rather large animal with hard paws or hoofs can shear or crush the capsules. The probability of such occurrences is reasonably low and the false alarm no problem unless a herd of water buffalo has wandered into a seeded area.

If capsules deteriorate spontaneously as a result of physical changes in capsule walls, or bacteriological or enzymatic activity in the soil (as discussed elsewhere in this report), then the probability of all capsules rupturing within a short period of time is high, and spurious signals are likely even though the activity is spread over a large area. One solution for this problem is the treating of capsule walls, for example, with waterproofing coatings (e.g., paraffin), so that long life is assured.

5.3.2 Laboratory and Field Tests

5.3.2.1 Diffusion Studies

In order to study some of the terrain and micrometeorological factors which influence the diffusion of released gases, a water-liquid dye analogue of the air-gas system was put together. There is no justification for drawing concrete conclusions from such a study since it is almost impossible to match liquid dye diffusion coefficients with gas in air coefficients and the totally enclosed volume presents a restricted and therefore unreal situation.

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Nonetheless, this sort of study is of some value if one attempts to make no quantitative comparisons but is only looking for the direction of the problems.

A ten (10) gallon fish tank with plastic walls, and no corrosive metal bindings was set up in the laboratory. The floor of the tank was covered with bleached gravel and a heavy planting of vertical "valisnaria" plants was made to simulate dense jungle growth. Several irregularly spaced clearings were left to allow turbulence effects and eddy currents to build up.

The two 40 watt incandescent lamps situated horizontally just an inch above the water's surface provided not only the requisite light, but created an inversion layer of warm water at the upper surface of about 85°F. and approximately 10°F. warmer than the bottom layers.

This inversion simulates quite well the afternoon air inversion often found in jungle regions.

An inlet syphon at one end of the tank and an outlet syphon at the other constituted a means of creating horizontal cross breezes. Valves on both of these syphon systems allowed accurate control of the "wind" velocity and configuration of the influent tube mouth determined the turbulence imparted to this incoming "wind."

Stirrers could create local turbulence patterns of any desired magnitude, and the turbulence and horizontal wind could be situated at any desired elevation.

In the first series of tests, Crystal Violet was used as the dye because of its heavy molecular weight and its aqueous solubility, plus the intensity of the color contrast.

A single drop was placed in a clearing beneath the foliage. Some of the dye floated from the delivery pipette as it was being withdrawn from the tank. Photograph No. 1 indicated the tank appearance before the introduction of the dye and Photograph No. 2 indicated the position of the dye at T-Zero, on delivery. The spot of dye was clearly visible against the white gravel, while the swirling cloud above was also seen beginning to stream out.

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At this time, the inlet syphon was not open, but the outlet valve was creating a very slight jungle floor breeze which would simulate a mild 2 mph wind.

Photograph No. 3 taken at $T + 1$ minute showed the slow diffusion of the ground spot with movement toward the right, being "blown" toward the outlet tube. The swirling cloud began to stratify horizontally, especially near the upper layers where a counter current moved opposite the breeze direction below it, and was held down by the inversion layer.

Photograph No. 4, taken at $T + 4$ minutes, indicated a rather static condition. The surface spot had diffused toward the right only very slightly, the cloud through the central portion of the tank hung motionless, and the upper cloud had drifted back toward the center somewhat. This would indicate a rather slow moving but complex system of hydrodynamic behavior.

Photograph No. 5 taken 6 minutes later at $T + 10$ minutes, again demonstrated the relatively static conditions prevailing. The dye at the jungle surface had diffused somewhat by Brownian action plus the slight convection effects and the very slight breeze. The middle cloud still hung but began to lose its horizontal nature, and dropped vertical lines slowly among the branches of the trees. The outer rim of the upper horizontal cloud of dye, again moved toward the left side of the tank, opposing the slight breeze below.

Two minutes later, at $T + 12$ minutes, the inlet valve was opened causing a strong wind on the bottom of the tank with a scaled-down velocity simulating 20 mph winds. Photograph No. 6 showed that the diffuse cloud on the jungle floor had been quickly whipped away and no visible trace of it remained. The discoloration remaining was only the stained gravel. There was no "gas" in the vicinity. The wind had also begun dissipating the lower portion of the middle layer clouds, which were still clearly seen. There appeared to be little or no effect on the upper cloud which still hung suspended below the inversion.

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In a second series of tests, crystal violet was dissolved in alcohol rather than water, which it was assumed would increase the diffusion rate of the dye simulating a lower molecular weight gas.

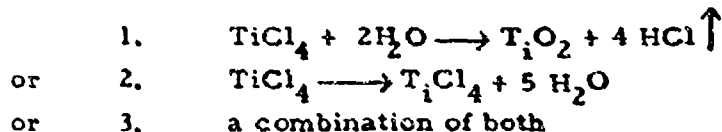
In Photograph No. 7, taken at T-Zero a cloud of the crystal violet-alcohol solution had been deposited in mid-tank. No simulated breeze is blowing. Photograph No. 8 was taken at T + 1 minute and rapid dissipation had already taken place. This continued as is seen in Photograph No. 9 taken at T + 2 minutes.

It is interesting that there was not developed a single diffuse cloud, but rather a large tenuous mass with small pockets of denser nodes, like bunches of grapes. An aircraft flying through such a cloud would sample small rich pockets in a medium of less rich gas.

An artists' drawing of the composite behavior of the cloud at T-0, T + 1, T + 10, and T + 12, in the first run, and T-0, T + 1, T + 2 in the second run are shown in Figures 7 and 8.

In order to understand more of the gas diffusion problem in an area of heavy foliation, a field trip was carried out in the fern forest of Los Angeles' Griffith Park. Here, the moisture content and breeze conditions, can approach a simulated jungle condition, especially when the regional inversion layer is low, as is often the case. On this particular field trip, mild lapse conditions prevailed and a very slight southerly breeze, estimated at 0-2 mph, was blowing at the ground. Site Number 1 was selected because it represented a small clearing in dense fern growth, with extremely moist soil. The clearing was totally shaded and the air temperature was measured at 79.6°F. This was at 1100 hours, Standard Time. The site was situated about 5 feet above a stream and on level ground.

At this point, small amounts of titanium tetrachloride were released on the ground. The reaction with water vapor creates white vapor clouds, the reaction being either



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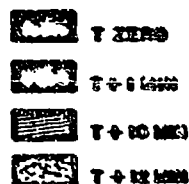
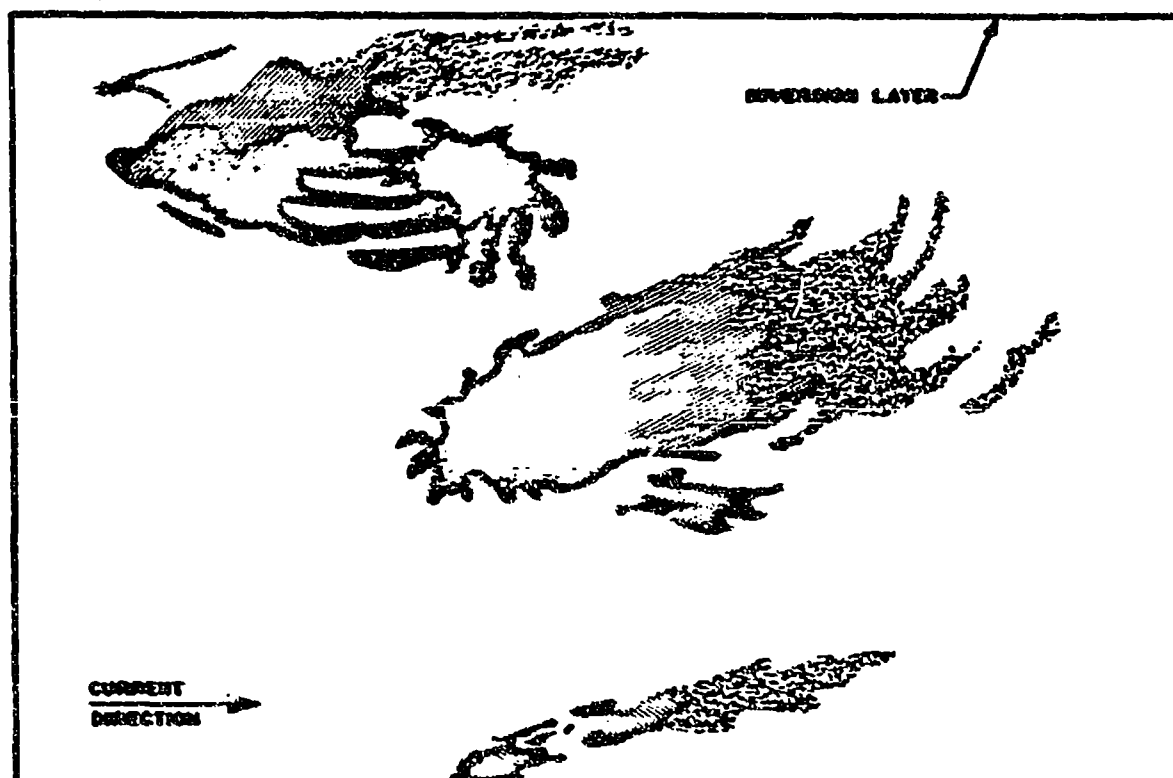
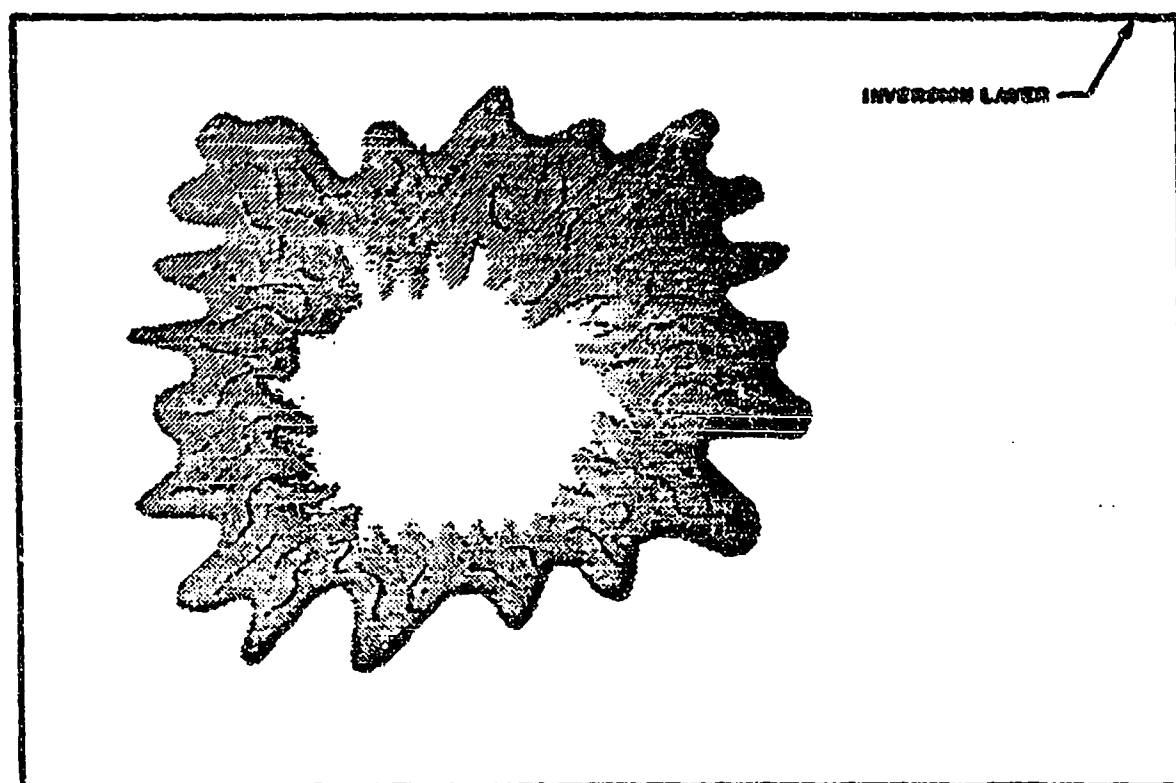


Figure 7
Dye Diffusion Study No. 1
Crystal Violet- H_2O in Water

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 T ZERO
 T + 1 MIN
 T + 2 MIN

Figure 8
Dye Diffusion Study No. 2
Crystal Violet-Alcohol in Water

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Wind patterns indicated a mild steady breeze blowing north. The cloud dispersed and within 10-15 feet was no longer visible. It was noticed that foliage did not stop the cloud, but merely aided in the dispersal.

A second site was then selected at an elevation of 15 feet higher than Site Number 1 and about 20 feet above the stream bed. Here, the soil was still damp but drier than the soil at Site Number 1. Temperature here was 79°F , about 0.6°F . less than the lower site. The foliage here was deciduous the leaves of a laurel type, and a few large rice paper leaves.

The titanium tetrachloride was again released with similar results, except that the wind direction appeared to be more north-easterly than due north as at the lower site.

In order to study wind patterns in greater detail, tetrameric acetaldehyde powder $(\text{CH}_3\text{CHO})_4$ was heated releasing small ash-like particles which floated on the wind currents at about a foot per second in horizontal planes in a north-easterly direction. They could be followed visually for 40 or 50 feet or more, until they were lost in the dense foliage.

In the dry dusty path, near Site Number 2 several one foot squares were marked off and 50 capsules were evenly distributed in the area. Walking across the area, an adult produced a breakage of approximately 10 capsules per step. This was repeated several times with very similar results, i. e., 20% breakage. Counting broken capsules was made easy by the fact that the reagent left a clear dark spot on the almost white chalky dust. At a position 25 feet downwind from Site Number 2, and on a level with it, from 1 minute to 3 minutes after capsule rupture, physiological odor detection of the diethylbenzene was attempted with no positive results.

At a position near Site Number 1, however, 40 or 50 feet downwind of Site Number 2 and 15 feet lower in elevation, at a time 4 to 5 minutes after the capsule rupture referred to, the odor of diethylbenzene was detectable, even though a rich odor background of flora fragrances existed.

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A similar test was subsequently conducted at the University of California Botanical Gardens in Los Angeles. The advantage of this site over the previously chosen one in the Fern Forest lies in the fact that a denser and taller stand of trees (up to 100 feet in elevation) provided a closer approximation to a tropical rain forest. The canopy was considerably thicker, and a final advantage was the slope of the terrain. The garden slopes steeply so that a rise of over 100 feet is accomplished in a narrow defile. Thus an observer standing at the high point can look down at the top of the canopy, to observe rising clouds of smoke. A continuous source of white cloud (titanium tetrachloride in an open dish) at the bottom of the defile, near a running stream, was exposed to air, and observers at the high point were prepared to photograph the cloud as it broke through the canopy.

Unfortunately, as was demonstrated in the first series of tests at the Fern Forest, the dispersion of the cloud in a slight breeze, was so great that photography of the cloud was impossible, the cloud being just barely visible to the eye under optimum conditions.

Wind conditions varied from 0.5 to 3 miles per hour, averaging about 2 mph or 1 meter per second. Its direction varied, moment to moment, swinging in a 180° arc from south to west, to north and back. A lapse condition prevailed.

At 60 feet downwind from the source, the odor of hydrochloric acid was quite distinct.

The sample of liquid titanium tetrachloride volatilized, was approximately 1/20 of a liter, or 50 cc. Since only 60% of this was used up in the 15 minutes of continuous release, the release rate (Q/S) was 0.033 gms. per second.

Assuming the stabilization height (H) to be the canopy at approximately 45 feet or 15 meters, and assuming lapse conditions so that $C_x = 0.4$, $C_y = 0.8$, $C_z = 0.6$, then, since Maximum Concentration ($C_i \text{ max}$) =

$$\frac{Q/S}{4.26 uH^2} \frac{(C_x C_y)^{1/2}}{C_y}$$

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If u (wind speed) = 1 meter per sec.
 C_i (max) = 22×10^{-6} gms./meter³

The downwind distance at which this concentration occurs, is

$$d_{\max} = \left(\frac{H^2}{C^2} \right)^{1/2} N$$

where

$$C = (C_x C_y)^{1/2}$$

N
stabilization
factor = .2 for lapse condition

$$\therefore d_{\max} = 26.3 \text{ meters}$$

Since the odor observation was made at 20 meters, or $\frac{20}{26.3}$ of the distance, and since signal varies as the square of the distance, the observer should have been sensing $\left(\frac{26.3}{20} \right)^2 \times C_i \text{ max} = 1.7 \times 26 \mu\text{gms./meter}^3$ or 38 $\mu\text{gms. per cubic meter.}$

This is equivalent to 25.5 parts per billion.

CONCLUSIONS

The fish tank atmospheric model and the field trips all pointed to a number of problems for which ready answers do not exist.

Neither the literature, nor correspondence with experts in the field of air pollution, nor the field trips give a clear indication of the effect of inversion layers other than the general holding down of the released gas which increases the concentration at or near the release point for periods of time longer than one would expect from mathematical models.

The ability to detect the diethylbenzene odor 40 feet downwind in the Fern Forest after 5 minutes when a foot per second steady breeze should have blown the material clear of the area indicated that either:
a) some of the gas settled into a pocket and remained out of the air stream,
or b) it is improper to treat the release of the reagent, at least on short

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time scales, as an instantaneous release. Treating the volatile reagent release from ruptured capsules as a continuous point source for a matter of minutes, in any case, is more accurate. When considering sampling hours later, the difference becomes academic.

Wind speed and turbulence, as has been shown in the meteorological work carried on at Dugway Proving Grounds, Utah (Reference 16) is the major variable affecting dispersion and dissemination of clouds and particles in the atmosphere.

5.3.2.2 Soil Moisture Experiments

Several experiments have been conducted to determine the effect of soil moisture on the capsules. The initial experiment was run twice; first, from 0900 hours 14 August to 1600 hours 20 August and second from 2000 hours 20 August to 0730 hours 26 August. The procedures for each run and the results are presented below:

Trial 1:

Procedure

Ten aluminum, 3" diameter pans were filled with eight grams of fine, clayey soil. To each of five pairs of pans was added 8, 6, 4, 2, and 0 grams of water respectively. The samples were then thoroughly mixed to approximate a uniform soil moisture. On the resultant pairs of 100, 75, 50, 25 and 0 percent soil moisture samples, a number of capsules were placed. The pans were then placed in an environmental chamber and the oven temperature set at 85°F. At 1200 hours 14 August, after three hours of heating, the oven was opened for a capsule count. At this time it was noted that the oven blower had caused the soil to dry despite the use of a large water reservoir in front of the blower. The oven was turned off and 6, 4, 2, and 1 grams of water added to bring the soil moistures back up to the original levels.

Subsequent to the second addition of water, the oven was left off for the remainder of the test during which time the oven temperature maintained a temperature level of 80°F, slightly higher than room temperature.

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The experiment was run for six days ending at 1600 hours 20 August. Throughout the period, the capsules remaining in each pan were counted and the pans weighed to determine reductions in soil moisture. The results are presented in Table 1 of Appendix E.

Results

As can be seen from Table 1 of Appendix E, breakage of capsules began sometime between 1345 hours 18 August and 0800 hours 19 August in the pans which had had soil moisture of 75% to 85%. At the time the breakage had been noted, the soil moistures had fallen to less than 10% in all four pans. At 0900 hours on 20 August, breakages were noted in the pans which had had 100% soil moisture. At the time of the latter breakages, the soil moisture was six and four percent in the two pans. No breakages were noted in the pans which had had a starting moisture of 25% or 0%.

From these observations it was hypothesized that the breakage is due to the capsule walls absorbing water and expanding, then allowing the contents to expand when exposed to high soil moisture conditions for durations of as little as 2 days, and then rupturing when the surrounding environment moisture drop caused the walls to shrink and break from increased internal pressure.

To test this hypothesis a second trial was run.

Trial 2:

Procedure

The same procedure was used in Trial 2 as was used in Trial 1 with the exceptions that the oven was first heated to 105° and then turned off throughout the trial thus eliminating the need to add water a second time. The oven dropped to 81° in 18 hours and maintained that temperature throughout the experiment.

The test was run from 2000 hours 20 August to 0730 hours 26 August following the procedure outlined in the first soil moisture experiment.

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Results

The results of Trial 2 (Table 2 of Appendix E) were virtually identical to Trial 1. Breakages occurred first in the pans which had had 50% soil moisture and last in those which had had 100% soil moisture. No breakage occurred in those which had had 25% and 0% soil moisture (See Figure 9). From this experiment, it appeared that the capsules of the type used for the test will break independently of external forces when first left to stand in wet soils and then hydrated by the drying of the soil. Since such soil conditions are entirely likely in the tropics, it appeared advisable to devise a capsule wall material which would not exhibit moisture absorption and loss characteristics.

These results were reported to Stanford Research Institute personnel and a discussion revealed the possibility that the cause might not be physical (i. e., the swelling of capsule walls which had imbibed considerable water, followed by a detumescent state leaving the walls thin and brittle, finally rupturing at some weak strain point.)

There is a distinct possibility that the process was biolytic, either the result of bacterial metabolism or enzymatic action in the soil.

The cell wall is a treated gelatin in which peptide linkage has occurred, basically of an aldehyde-amine type. De-aminating bacteria and those bacterial agents which fix nitrates in the soil from ammonia, are highly ubiquitous and would certainly be found in large numbers in tropical soil. They should not be able to affect a breakdown in capsule walls, unless peptide hydrolysis has taken place. It may be that long exposure to high moisture causes this hydrolysis and in the presence of de-aminating soil bacteria, decomposition takes place. There has been evidence that bacterial activity (protolysis) begins when 14% or more water is introduced to the material in capsule walls.

It was felt that we should quickly ascertain whether or not the spontaneous rupturing of capsules in trials 1 and 2 were physical or biological in nature. A third trial, therefore, was run.

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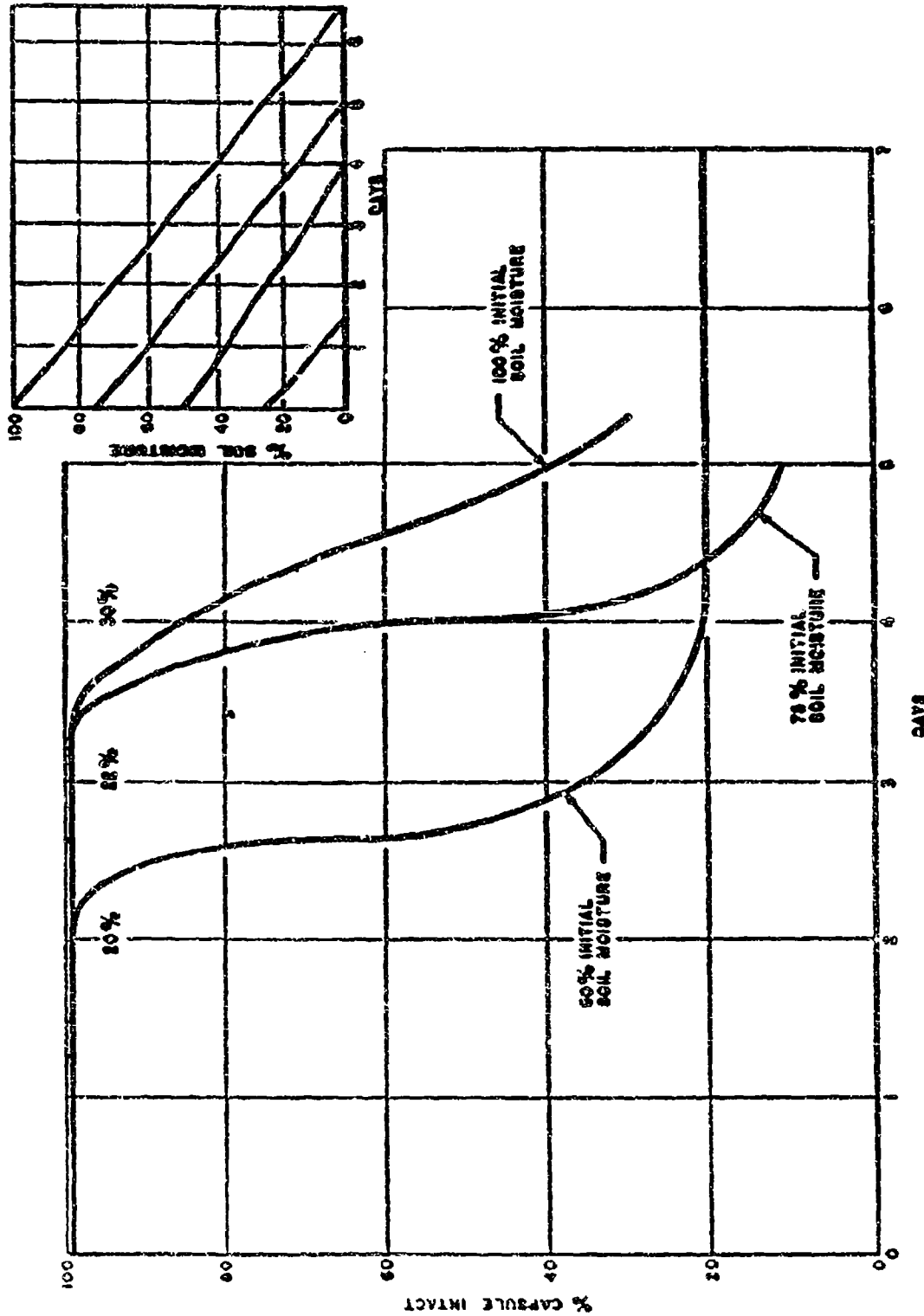


Figure 9
Spontaneous Capsule Rupture in Moist Soil - Trial No. 2

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Trial 3:

Procedure

Eight aluminum pans were weighed and filled with 10 gms. of soil. Distilled water was added to each pan to bring the water content to 60%.

Pans 1 and 2 contained finely screened loam from a flower bed, probably rich in soil organisms. This was later verified when a few milligrams of this soil were cultured in Trypticase Soya Broth medium for 24 hours at 85°C. and resulted in a rapidly growing colony of gas-producing organisms.

Pans 3 and 4 contained an artificial soil (aluminum oxide powder) which would serve as a very poor bacterial substrate.

Pans 7 and 8 contained the screened loam of the flower bed, but it had been washed thoroughly with first, an acid solution, then a strong alkali, then a water bath, an alcohol bath, a final water bath, followed by a drying. This procedure should have removed all of the organic agents present.

In each of these pans were placed 10 of the 1.6 mm. size capsules containing toluene.

Into Pans 5 and 6, containing normal screened loam as in Pans 1 and 2, went 10 capsules whose walls had been pre-treated with Merthiolate Solution, an effective bacteriostatic agent. They were then dried in the light of an ultraviolet lamp.

All 8 pans went into the environmental chamber which had been preheated to 100°F. with high relative humidity.

Results

After 3 days (72 hours) all capsules in all pans were broken, giving every indication of physical rather than bacteriological decomposition.

Under the ultraviolet lamp (Mercury line 3650 Å) the remaining husks of the Merthiolate treated capsules still fluoresced strongly, indicating the presence of the bacteriostatic agent. This seemed to add further weight to the proposition that disintegration of the capsule walls was not the result of bacteriological agents.

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Trial 4:

Procedure

As still another check on the bacterial decomposition hypothesis, three pans of loamy soil were heated in an oven for 4 hours, at 450°F. to 500°F. which should have been sufficient to kill any organism in the soil. Two pans were wet to 50% soil moisture, with distilled water, and the third pan to only 25% soil moisture.

Toluene capsules were deposited on these three beds, and they were immediately covered with a sheet of filter paper, which screened the soil from most air laden organisms, and yet allowed the evaporation of the moisture.

Results

Capsules in the preheated and sterilized soil, within 24 hours, began to lose physical integrity. Some were broken, but most were merely wrinkled, warped and dissipated. Study under a 150x binocular magnifier, indicated that they appeared to have lost most or all of their liquid contents. They were folded like a football with all the air withdrawn. This was true even of the capsules in only 25% soil moisture.

Suspicion was raised as to whether or not the type of capsule might be giving these unusual results. In Trials 1 and 2, the capsules had contained diethylbenzene (D. E. B.). All subsequent tests had utilized toluene. It was conjectured that water absorption by the capsule walls might be making them more pervious to toluene leakage.

Trial 5:

Procedure

In order to find out if capsule content was a factor, and in order to investigate further the possibility of bacterial decomposition, the following test was conducted.

Six aluminum pans were prepared as follows:

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<u>Pan No.</u>	<u>Substrate</u>	<u>Wetting Agent</u>	<u>Capsules</u>
1	Soil	Water 50%	D. E. B.
2	Soil	Water 50%	Toluene
3	Soil	Phenol Solution 50%	D. E. B.
4	Soil	Phenol Solution 50%	Toluene
5	Distilled	Water 100%	D. E. B.
6	Distilled	Water 100%	Toluene

All pans were placed into the environmental chamber at 85°F. after the capsules were seeded into the substrate.

Results

After 24 hours of incubation, all of the toluene capsules in all media including water were collapsed and wrinkled, having lost the fluid toluene. The diethylbenzene capsules, on the other hand, appeared to show no distortion of shape, or loss of elasticity. This indicated that either:

1. water hydration of a capsule wall makes it more pervious to diffusion of some organic materials such as toluene than to others, or
2. the batch of toluene capsules with which we were provided had capsule walls made in a different manner somehow than were the D. E. B. capsule walls.

The latter case would indicate either the use of a modified technique or poor quality control.

While these tests were being conducted, a rainstorm was occurring in the area, and one of the company's flower bed planters was sown with both toluene and D. E. B. capsules. As predicted, after 24 hours (12 of rain and 12 of drying) the D. E. B. capsules were intact, the toluene capsules either disappeared, or appeared as shrivelled husks. Distortion of the toluene capsule's shape began after only 2 or 3 hours in the rain.

It was decided that there was already conclusive evidence to rule out bacterial decomposition. Therefore, we did not go ahead with our plans for growing soil bacteria in inoculated Tryptocase Soya Medium Broth for use in future tests.

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Trial 6:

Procedure

Several toluene capsules were placed into salt solutions. Those placed into dilute solutions of sodium chloride, did not appear to differ appreciably from those in distilled water. The capsules placed in concentrated salt solutions, however, quickly lost much of their transparency, turning opalescent, but kept their sphericity. After 36 hours there was no sign of wrinkling, loss of fluid or elasticity.

This would lead one to believe that the high concentration of salt ions outside of the capsule, causes an osmotic gradient to take place, pulling water out of the capsule wall. This dehydration makes the capsule wall more impervious to the outward diffusion of the toluene.

Capsules treated with salt water and then placed into pans of distilled water, slowly hydrate again, so that after 24 hours, they are again folded and wrinkled, having lost toluene.

Results

After five days, these capsules in concentrated salt solution still showed no sign of disintegration, which represented a survival increase approaching 2 orders of magnitude.

Discussions with Stanford Research personnel revealed that National Cash Register data reported the appearance of permeability of the capsule wall when a hydration figure of 28% water occurred. This value is remarkably close to the value we had surmised from the original soil moisture rupture data (See Figure 9.)

The solubility of the reagent in water appears to affect the speed of this loss, which is a logical expectation. Capsules of toluene ($C_6H_5CH_3$) for example, and benzene (C_6H_6), with solubility rates of 47 milligrams and 82 milligrams per 100 ml. of water respectively (at $20^\circ C.$) are prone to self-rupture to a considerably greater degree than are xylene ($C_6H_4(CH_3)_2$), and diethylbenzene ($C_6H_4(C_2H_5)_2$) and 1, 1, 1 - trichloroethane (CH_3CCl_3) capsules, all of those contents are considered relatively insoluble in water at $20^\circ C.$

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It appears therefore, that there are three methods for increasing capsule longevity in the presence of soil moisture.

1. By putting fatty, waxy, or other hydrophobic materials into the capsule walls. Paraffin has been a successful inclusion, and one batch of fluorescent capsules has been produced in which the reagent (brightener, Fluorol ob) has been dissolved in a cottonseed oil base, and the capsule walls treated with beeswax. These capsules have survived to date (10 days) in fresh water with no sign of disintegration.
2. By modification of the coacervation techniques to tighten the protein linkage, which implies a greater dehydration of the gelatin, and a greater resistance to rehydration.
3. By employing very water insoluble vehicles when solutions, dispersions or emulsifications are called for. The Fluorol OB in cottonseed oil is a good example. The insolubility in water of cottonseed oil should provide a degree of protection, even without a waxy coating. Other suitable bases would be the aliphatics like pentane, heptane and octane.

Particular effort was directed toward waterproofing the chlorinated hydrocarbon capsules. An experimental batch, therefore, was produced in which the 1, 1, 1- trichlorethane (55%) was diluted with 33% iso-octane. The remaining 12% represents the protein capsule wall. The addition of the aliphatic iso-octane has apparently increased the lifetime of the capsule in water so that it meets the capsule specifications (Section 5. 2. 3).

While the dilution causes a loss of reagent per capsule, the problem of making large capsules has been solved, so that 4 and 5 mm. diameter capsules are easily obtainable. A 4mm. capsule containing a reagent whose density is ~ 1.2 gms/cc would hold between 30 and 40 mgm. of fluid, and since only 50% is useful reagent, there is still 15 to 20 mgms. per capsule.

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Leuco dyes have been dissolved in a vehicle of silicone which should make diffusion losses approach zero, even in the presence of water.

5.3.3 CONCLUSIONS

The physical environment will affect to a marked degree, the behavior and lifetime of capsules and the release time and diffusion of the capsule released agents.

1. Because of their shape and elasticity, preliminary tests indicate that capsules will penetrate fairly dense foliage, but that the canopy will tend to distribute them more widely, so that ground density will be as little as 10% of the density obtained in seeding open area.
2. Oxidization and sunlight do not appear to have any effect on capsules. No brittleness of capsule walls was noticed in exposed capsules, over the several months of the program.
3. Moisture in the environment greater than 20% caused physical deterioration of some capsules, involving a speed up of the natural diffusion losses through the capsule walls. With a loss of the internal phase, these capsules puckered, folded and finally collapsed. It was shown that the disintegration was due to physical forces, not bacterial or enzymatic decay. Methods proposed to combat this effect included:
 - a. a tighter linkage of the gelatin protein,
 - b. the inclusion of hydrophobic materials in the wall structure, and
 - c. the use of highly insoluble vehicles as part of the internal phase.

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Capsules have been made which incorporate the first change (a. above) by substituting gum arabic for the carageenan in phasing out the gelatin (See Appendix A.)

Capsules coated with beeswax were produced as an example of the second method of waterproofing.

The third method was proven feasible by using iso-octane and silicone as reagent diluters.

All three methods have proven to be successful in prolonging the capsule lifetime in the presence of water or soil moisture by at least two orders of magnitude and there is no reason to doubt that capsule life on the exposed ground cannot eventually reach the value of many months.

4. The affects of climatological and micrometeorological as well as terrain features, on released airborne tracers involved considerable library research and several field trips. Aside from the effects of wind velocity, local eddies and turbulence, it was felt that the capping inversion layer, which appears to be an almost daily occurrence over heavily forested areas, will profoundly affect the concentrations of tracers as a function of both time and distance from the release point.

It is recommended that further study be made of tropical inversions and weather conditions as they affect vapor dispersion and travel.

5.4 TASK AREA III - DISSEMINATION

Proper reagents for marking and adequate sensors for detection are of little practical use if the capsules cannot be given useful dissemination in the area to be monitored.

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A useful dissemination system must

1. be mechanically compatible with existing aircraft with little or no modification to the air frame and with no disturbance to the aerodynamic flow,
2. be as completely automated as possible, with all vital information pre-set before flight, leaving the pilot free to maneuver the aircraft.
3. carry a load sufficient to "seed" a reasonably large area, so that large numbers of aircraft are not required to cover a tactical field of interest,
4. be compatible in performance with the aircraft, altitude and speed requirements,
5. be designed so as not to rupture capsules during release, and
6. be able to spread capsules to minimum required densities on the ground. This is a function of capsule release rate, aircraft speed, and the actual mechanical structure of the system.

5.4.1 DISPERSAL CALCULATIONS

Regardless of aircraft speed, regulation of the air intake diameter can set the exit speed of the ram air, thus one can effectively keep a constant effluent velocity in the disseminator airstream.

Assuming that this velocity is kept at 200 mph (300 feet sec.⁻¹), and assuming the hopper releases one pound of capsules per second, since a pound of capsules represents 9×10^4 capsules, then one second's dissemination will put 9×10^4 capsules over 300 linear feet.

If the discharge tube is configured so that, at expected dispersal altitudes, a 100 foot wide path is sown, the density of capsules will be 3 capsules per foot². (See Figure 10). Previous tests have shown a capsule rupture rate of about 20%, for a footstep in a square foot on hard soil. Thus we could expect a footstep to break a maximum of one capsule, releasing 5 mgm. of agent into the air, with a probability of occurrence of 60%.

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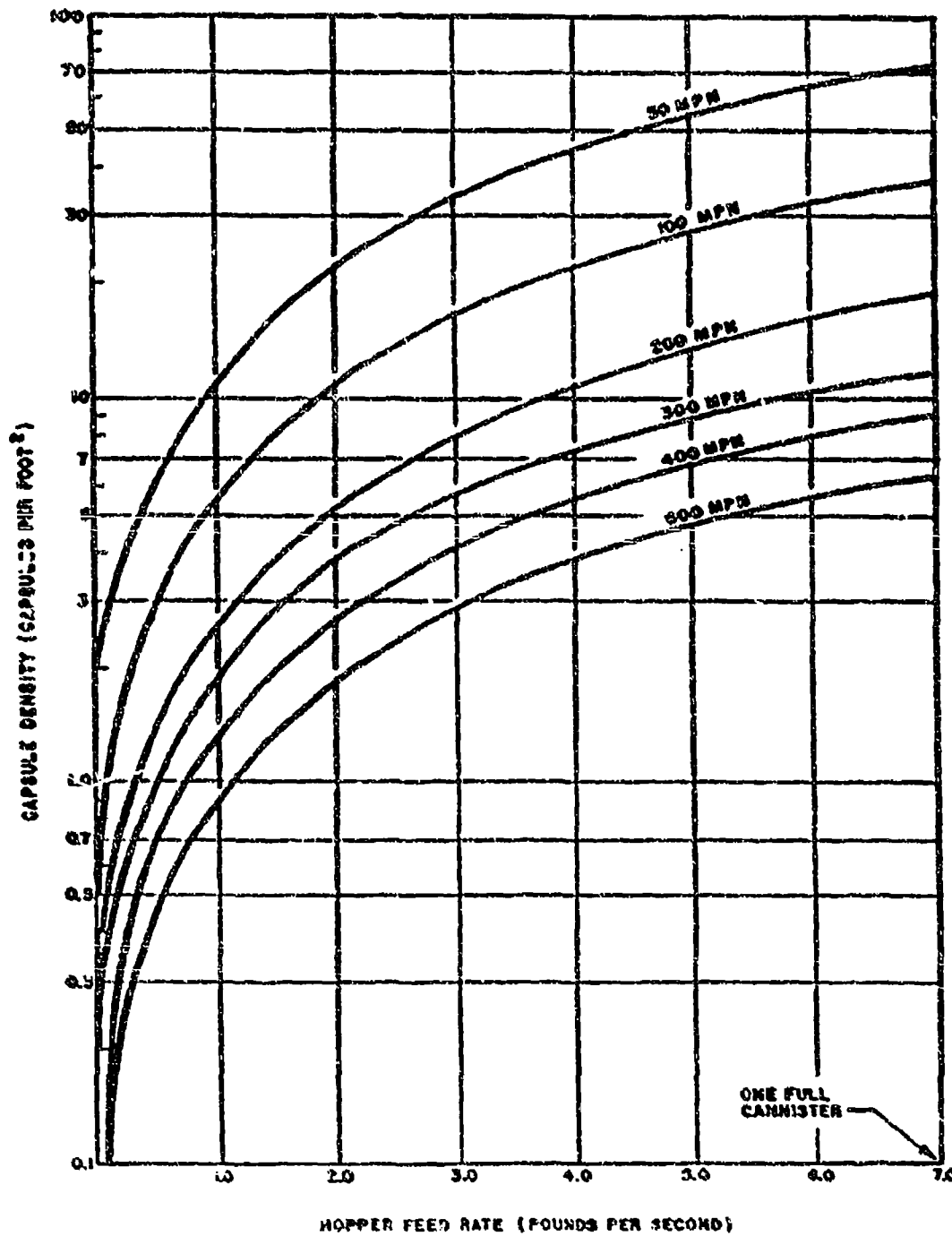


Figure 10
Ground Seeding Density in Capsules / ft²
as a Function of Capsule Feed Rate and Air Flow Rate

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To cover a square mile of territory, the aircraft would have to seed for

$$\frac{36 \times 10^6 \text{ ft}^2}{3 \times 10^4 \text{ ft}^2} = 1200 \text{ seconds, or 20 minutes.}$$

This would cover one square mile or a linear strip 100 feet wide and 60 miles in length.

The required load aboard the plane would be 1200 pounds of capsules. Since the capsules weigh about .001 lb. per cm^3 , this load would occupy about $1.2 \times 10^6 \text{ cm}^3$, or roughly 1 cubic meter.

If the hopper bin contains a stacked vertical array of thin polyethylene canisters, each 3 feet long and 4 inches in diameter, each canister will contain about $7 \times 10^4 \text{ cm}^3$. At $1 \times 10^{-3} \text{ lbs. cm}^{-3}$ this represents 7 pounds. There will be, therefore, about 170 canisters in a load.

An unrealistic assumption being made in all calculations, regards the dispersal of capsules as being relatively uniform. This appeared to be true to a first order of approximation in the simulated dispersal test discussed in Section 5.3.1.1, "Effects of vegetation". This uniformity, however, appeared to be the result of random sorting and distributing by the foliage. The actual dispersal from the aircraft onto open fields, would probably behave more like the results seen in the dispersal study carried on by the U. S. Department of Agriculture - Forestry Service, in re-seeding burnt timberlands with grass seeds, from both helicopters, and Beechcraft planes. See Appendix F.

Since one of the seed types in their study, Tall Fescue, weighs approximately 1.2 mgm. per seed, matching very closely the 1 mm. capsules in weight and since the dispersal rate of Tall Fescue seeds was 2.2 lbs. per acre, or 1400 lbs. per square mile, which almost exactly equals the dispersal rate of a proposed capsule disseminator, it would be interesting to compare the ground density of seeds or capsules per square foot, as a function of lateral distance from the centerline marking the aircraft's path over the ground.

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For capsules, assuming a 200 mph air speed in the disseminator, and 500 foot aircraft altitude, 2 pounds per second release rate, Figure 10 would indicate, over the supposed 100 foot wide swath, a dispersal density of 5 capsules per square foot. This is plotted in Figure 11 with the results of the Forestry Service test for tall fescue seeds.

It is reasonable to assume that in the absence of foliage, the pattern would approach that of the grass seed results. In the presence of a canopy, a curve somewhere between the two in Figure 11 would result.

5.4.2 The Delivery System

Compromises must be made to allow the design of a capsule delivery system which is both versatile and reliable; the first characteristic implies complexity and the second, simplicity.

Crop dusting and rice seeding techniques are not very instructive because these operations are carried out below the stall speed of aircraft like the F-100 and F-105.

Two alternate schemes were derived, each with certain advantages, and both described below.

Scheme I - Vertical Cannisters

Capsules are loaded into thin walled, lightweight, rectangular polyethylene cannisters. The cannister is color coded and labeled so that the contents of the capsules are known. Cannisters are approximately 3.3" x 3.3" in cross sectional area, and 35" in length, and are loaded into the cannister wells in the hopper before the mission. When filled, each cannister should weigh about 7 lbs. As it is rammed home into the well, the thin Mylar film which serves as its end seal is ripped by a blade at the bottom of the well. The released capsules are held in the cannister well by the metallic plate beneath.

If a mission is to deliver several types of capsules to the same area, this is accomplished by the arrangement of the cannisters and the subsequent firing order.

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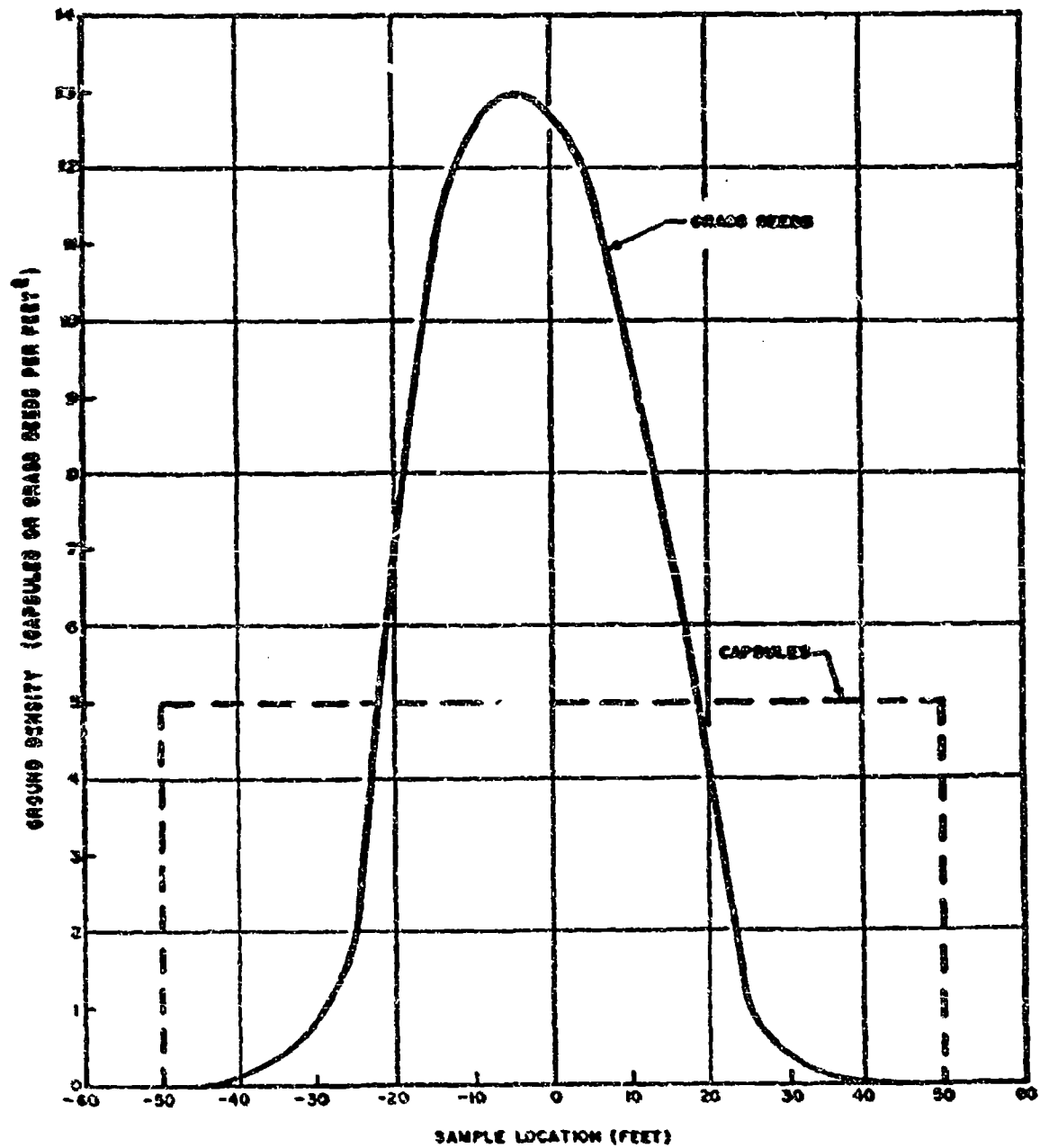


Figure 11. Grass Seed vs. Capsule Ground Distribution

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In the base plate of the hopper are the hinged doors to the cannister wells which are fired open by primers upon electrical impulse from a logic device. This eliminates the need for mechanical linkages and more complex relays. The reliability of the firing mechanism, is therefore enhanced. Figure 12 is a Block Diagram of this Release Mechanism Control.

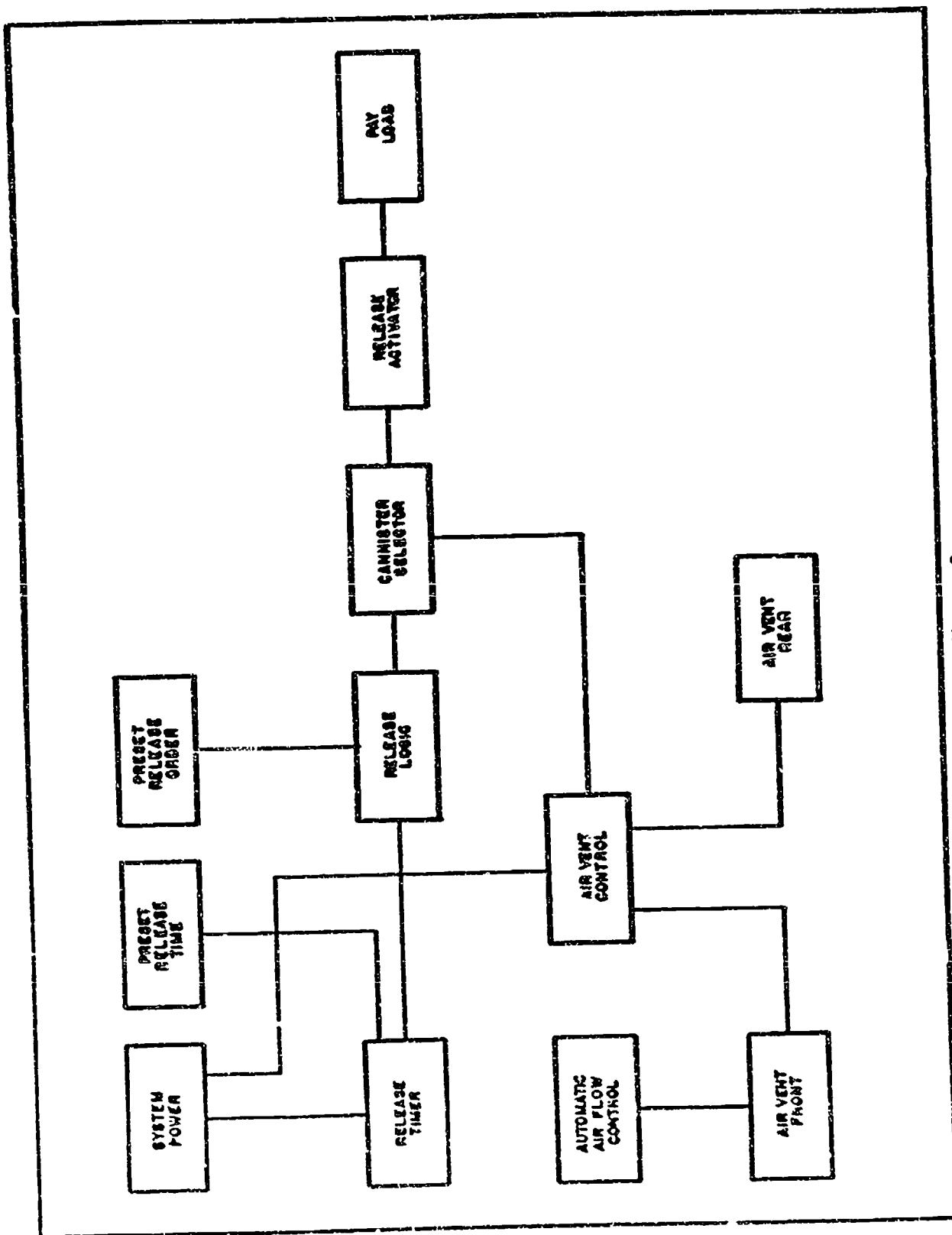
If the total load is to contain 50 cannisters of fluorescent containing materials, for example (No. 1-50), 50 cannisters of leuco-dye containing materials (No. 51-100) and 50 cannisters of chlorinated hydrocarbon (No. 101-150), and the area to be covered is to be seeded equally with all three, the timing mechanism can deliver one pulse per second, and the logic device can send the first pulse to open cannisters No. 1, 51, and 101, and the next pulse to open simultaneously, cannisters No. 2, 52, 102, et cetera until the last cannisters are emptied.

The released capsules drop into the lower section of the hopper and through a neck where a valve determines the rate of feed to the airstream. The valve may be pre-set before the mission, its flow rate dependent on the ground density required, which in turn would depend on the type of terrain to be seeded and the type of mission and potency or detectability of the encapsulated reagents.

The airstream velocity is kept constant (at, for example, 300 feet per second) regardless of aircraft velocity, by use of a valve or diaphragm at the intake scoop. A small velometer in the air tube, positioned before the hopper inlet, reads air velocity in the tube and sends a signal to make corrections in the valve.

In this way, with automatically adjusting airstream speeds, pre-set hopper feed rate, and pre-set programmed capsule release; the pilot is free to fly his mission in regard to location, air speed and altitude without distraction from the weapon system. He need only press the button to activate the system, or an abort button to cut it off at any point if he feels that he must leave the area or alter the mission abruptly due to enemy action or unforeseen mechanical problems.

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Figure 5.
Block Diagram of the Automatic Disseminator Release Mechanism Control

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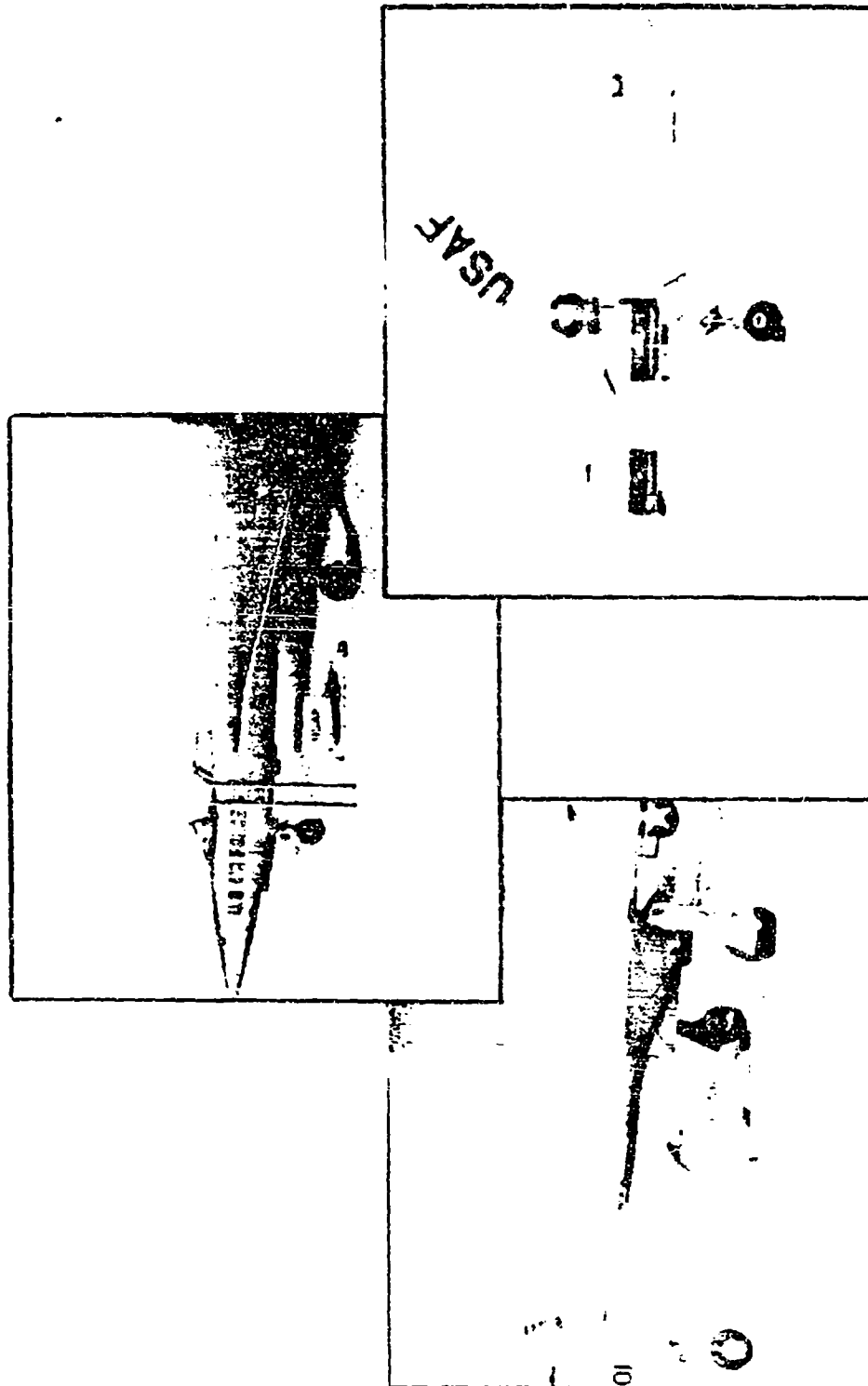


Figure 13
Mock-Up Disseminator Installation

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Scheme I, the Vertical Hopper had to be modified because the maximum vertical displacement available is 48 inches. Since the cannisters alone, are 35" tall, this leaves 13" for a sloping hopper collector, face plate, neck containing a valve, and diameter of the air intake duct.

Thus the following modifications were decided on, as illustrated in Figure 14.

The cannisters release their capsules, after the hatch is blown, into a plenum pan 2" high and 15 feet² in surface area which matches the surface area of the cannister hopper. At the front end, it tapers to a 6" diameter tube which contains the valve mechanism controlling capsule flow rate. This inserts into the air duct below which is a flat duct about 2 inches high and 2 feet wide.

When the capsule flow valve is opened at the moment the pilot activates the system, a second valve opens simultaneously at the front end of the hopper allowing some air from the air intake tube to be shunted to the pan. This creates a small positive pressure and the vacuum created at the capsule release valve by the ram air carries the capsules into the airstream for dissemination. The valve must be carefully configured to allow shut-off without smashing capsules into a wall, possibly a short length of flexible tubing which can be constricted by a collar leaving a streamlined profile.

Because of the dimensions of the available area as gleaned from the aircraft model, Scheme II, the horizontal cannister array, was felt to be too space consuming since air intake and outlet lines had to expand gradually to cover the entire front and rear cross sectional areas of the hopper. Thus, this scheme was rejected as a fuselage-borne piece of gear.

It is amenable, however, with some modification in dimensions, to pod mounting on the wings of a larger aircraft. Pod mounting in wing pylons makes loading and mounting very convenient.

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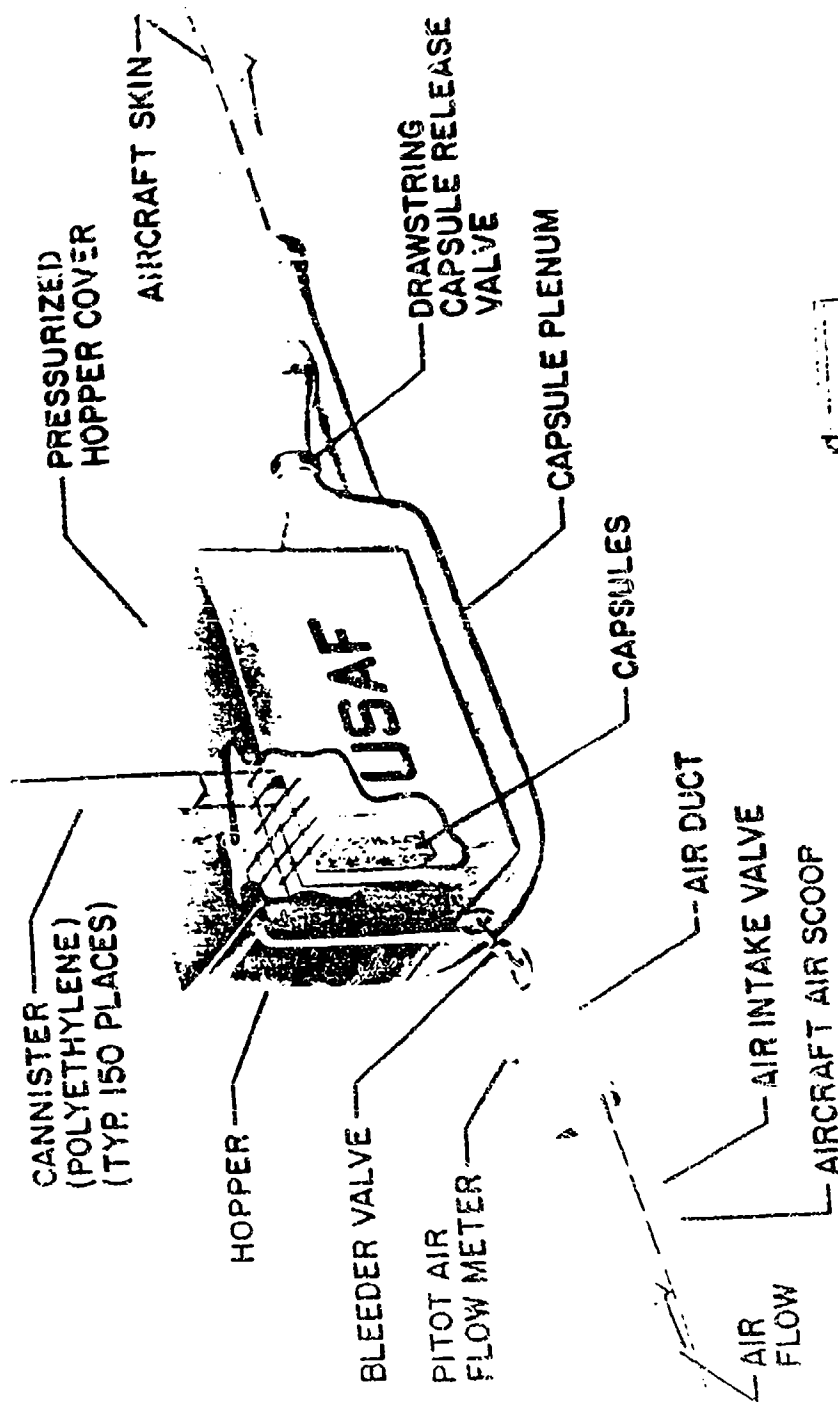


Figure 14
Disseminator

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If the plastic cannisters are now configured 60 inches long, with 2" x 2" cross section, the capsule containing capacity is 240 cubic inches, as compared with 360 cubic inches in the vertical, fuselage mounted cannisters of Figure 14. The number of cannisters in a 2" x 2" cross sectional pylon is 144. Thus 2 pylons contain 288 cannisters each carrying 4.7 pounds. A total load of 1,350 pounds, as compared with 150 vertical cannisters carrying 7 pounds each or 1,050 pounds.

This is shown in Figure 15, an artists' conception of the pod mounted horizontal cannister disseminator. The inset drawing indicates the necessity for maintaining a space between the door which explodes inward and the capsules, restrained by a mesh screen.

5.4.3 Capsule Dissemination Tests

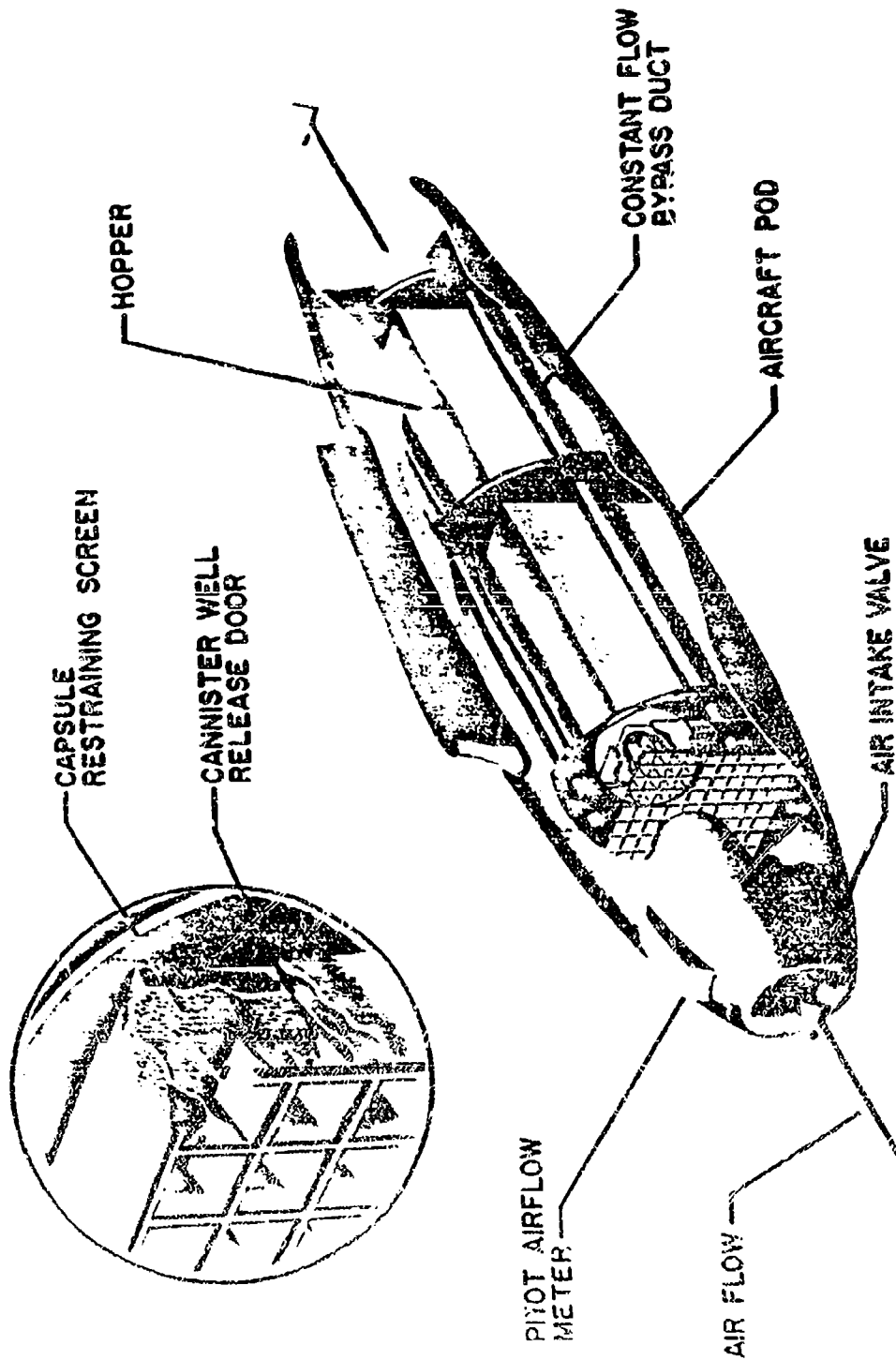
In order to show system feasibility, 1.6 mm. capsules were released through a funnel into a hole in a long 5/8" diameter pipe. Ram air at 45 psi was blown into the front end of the pipe. Capsules were swept into a plastic bag. There appeared (by appearance and odor) to be no breakage at all. Since the pipe area is about 1/3 square inch, the capsules were subjected to 15 pounds.

The test indicated that the basic configuration of a vacuum suction on the hopper due to ram air, is feasible and simple.

It is suggested that a carefully controlled test be conducted in which, through the use of an accurate pressure gauge, the above test be repeated with stronger and stronger air jets until a measurable degree of breakage is detected by an appropriate halogen detector or hydrocarbon detector in an enclosed capsule capture area.

There was some question as to whether or not a capsule at the bottom of a 3 foot column could support the weight of the load above, during aircraft vibration, without rupturing. A glass column of proper dimensions was filled to a height of 3 feet, and then shaken, with no apparent loss of capsules at the bottom, so this does not appear to be a problem.

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Figure 15
Pylon Mounted Disseminator

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5.4.4 Conclusions

Two basic disseminator designs are discussed, one a fuselage-mounted piece of equipment which attaches in line with an air intake and outlet scoop fixed in the body. The basic construction is one of an array of vertical plastic cannisters, each of which, on signal can dump its contents into a plenum pan where vacuum sucks it into the duct and out into the airstream.

The second configuration is one of a horizontal cannister array, pylon-mounted under the wings, and blown out by ram air.

Both systems are compatible with existing aircraft; operate automatically with pre-flight information fed to the control mechanism; carry enough of a load to cover a square mile with from 4 to 6 capsules per square foot expected density; permit easy loading of capsules into cannisters, and cannisters into cannister wells; cannisters are recoverable for re-use; automatic valves control air speed passing through the system and capsule feed rate into the airstream. Complexity is minimum, therefore, reliability should be high.

5.5 TASK AREA IV - AIRBORNE TRACER DETECTION

It was assumed that aggressor activity would cause the release of a volatile tracer from crushed capsules on the ground, and that processes of atmospheric diffusion and upward mixing would result in a more or less stable cloud of tracer at altitudes accessible to low-flying detector-equipped aircraft. Air sampling and analytical instrumentation was known to be commercially available for determining very low concentrations ($\sim 0.01 - 1$ ppm) of many common air pollutants, and devices of very much greater sensitivity were at least theoretically feasible. To evaluate the usefulness of the airborne tracer detection idea, it was necessary to consider existing or theoretical physico-chemical instrumentation for ultra-rapid continuous analysis of extremely low concentrations of airborne gases and vapors. The features of the detection concept, including the design for the laboratory tests (5.5.2) are shown in the Block Diagram of Figure 16.

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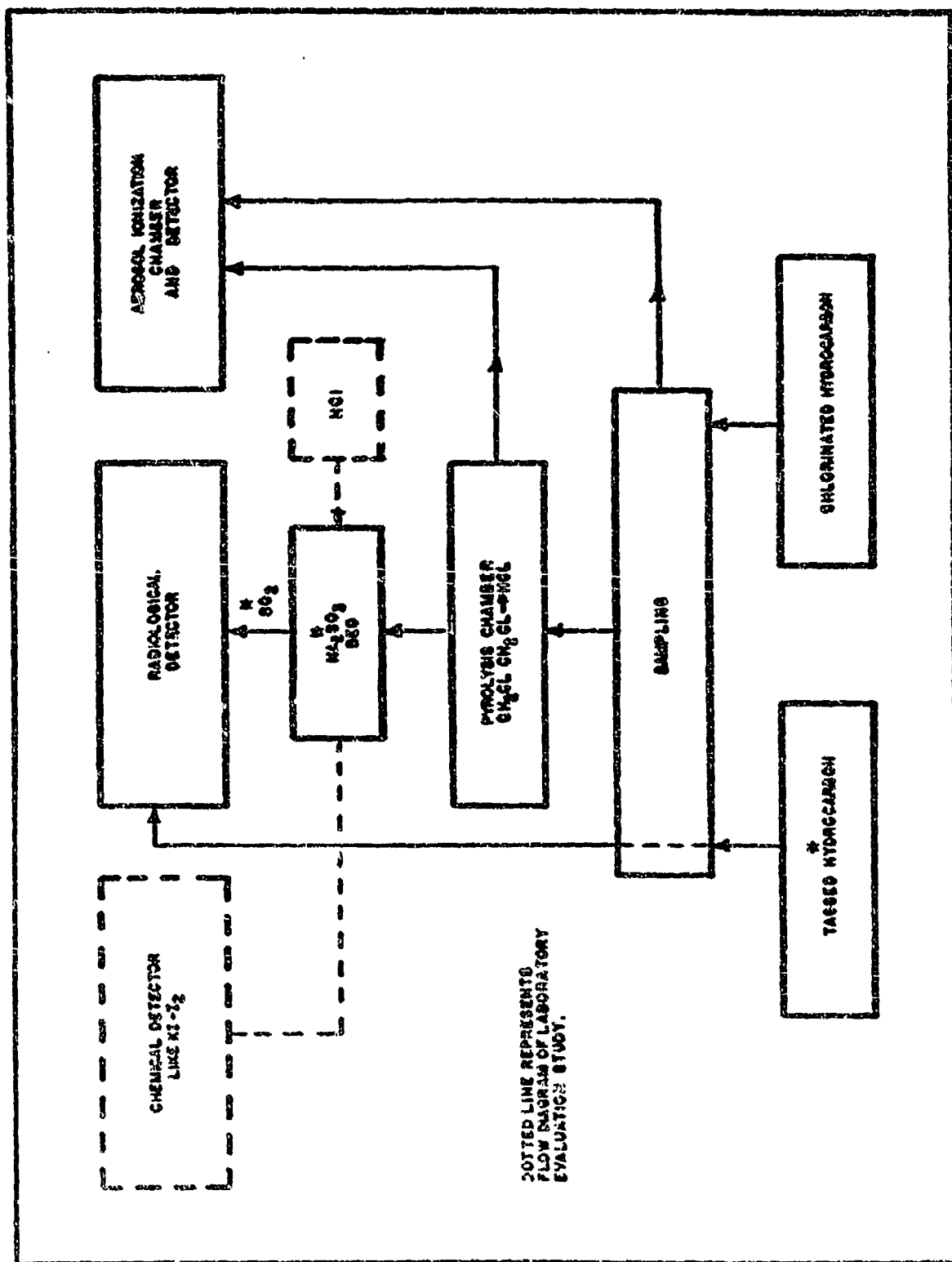


Figure 16. Block Diagram-Schemes for Detection of Airborne Tracers

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5.5.1 Feasible Techniques

5.5.1.1 Radioactive Tracers

The lower limit of sensitivity of presently available air analysis instrumentation of the continuous flow, direct response type, is in the order of parts per billion, ppb (See 5.5.1.3).

For comparison, consider the sensitivity of radiological detection techniques. For this purpose, one can calculate that a 1.0 ppb concentration of HCl, expressed as a weight/volume relationship is given by

$$1.0 = \frac{x \text{ mg/liter} \times 24.5 \times 10^6}{36.5}$$

whence

$$x = 1.5 \times 10^{-6}, \text{ or}$$

the acid

$$\text{concentration} = 1.5 \times 10^{-3} \mu\text{g/l}$$

On the other hand, available radiological monitoring instruments can reliably measure concentrations of radioisotopes of the order of micro-microcuries (10^{-12} c) per liter. As an example, consider the naturally occurring radon isotope Rn^{222} , $t_{1/2} = 3.8$ days, specific activity = 1.55×10^5 curies/gm. A concentration of 25 $\mu\text{c/liter}$ Rn^{222} is readily detectable with a commercially available portable airborne radioactivity monitor of the continuous flow, ionization chamber type. This activity concentration C_a can be expressed as a weight/volume ratio:

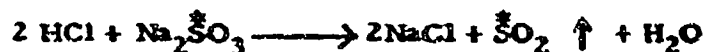
$$\begin{aligned} C_a &= \frac{25 \times 10^{-12} \text{ c/l}}{1.55 \times 10^5 \text{ c/gm}} \text{ gm/l} \\ &= 1.6 \times 10^{-10} \mu\text{g/l} \end{aligned}$$

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It is apparent that direct radiological methods of measurement are, at least theoretically, seven orders of magnitude more sensitive than ordinary physico-chemical methods. Consequently, the use of a tagged tracer agent (for example, a volatile hydrocarbon solvent containing carbon -14 or tritium) immediately suggests itself as the basis of a possible airborne tracer detection technique. However, the problems of public health, safety, and political propaganda inherent in the dissemination of radioactive materials made this investigation unattractive and it was not pursued.

5.5.1.2 Radioisotope Exchange

As a practicable method for exploiting the advantage of the ultimate sensitivity inherent in radiological detection, the concept of the two-stage detection system was advanced by The Bissett-Berman Corporation. In this scheme, the airborne gas or vapor of interest would react with a radioisotope-tagged chemical in an appropriate bed or column to release radioactive gas, which would be monitored by a downstream radiological detector. Several different type reactions were originally proposed, but the one chosen as having the maximum promise was the hydrochloric acid - sodium sulfite reaction:



($\overset{*}{\text{S}}$ = sulfur -35)

The unique advantages of this reaction as a basis for the airborne tracer detector concept included a) the straightforwardness and simplicity of the reaction, which was believed to have a high yield efficiency for SO_2 ; b) the availability of HCl from encapsulable agents such as chlorinated hydrocarbons; and c) the long half-life (88 d.) and energy (0.2 Mev E max) of the S^{35} beta emission, which is easily detected by electron-sensitive scintillation phosphors.

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5.5.1.3 Non-Radiological Techniques

Conventional instrumental analytical devices for the rapid detection and measurement of extremely low concentrations (0.01 - 1 ppb) of airborne contaminants are not suitable for the presently considered tracer concept because either a) they cannot detect in the ultra-low range of interest, or b) they do not respond quickly, i. e., give a detection signal which lags the instant of sample intake by an acceptably small time increment (0.1 - 1 sec.). It is characteristic of the present "state-of-the-art" of (non-radioactive) air pollution analysis that a very high degree of sensitivity is attainable only with a substantial sacrifice in response speed. In general, devices capable of detecting concentrations of less than parts per billion (for example, trace quantities of atmospheric pollutants) accomplish this by collecting very large air volumes over long sampling time periods, and by removing and concentrating the materials of interest in a) appropriate liquid or solid absorbents or adsorbents, b) freeze-out traps, or c) filtration media. For example, Erley (Reference 17) reviewed a technique for measuring 50-100 ppb (0.05 - 0.1 ppm) chlorinated hydrocarbons in air using silica gel adsorption and sampling times of the order of several minutes to extend sensitivity.

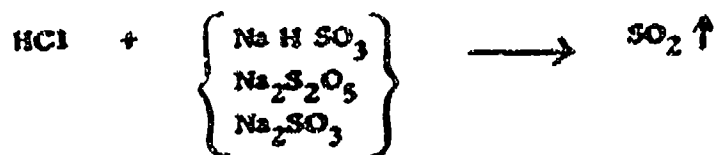
One of the most sensitive commercial devices available, the Mine Safety Appliance Company's "Billionaire" Analyzer, is reportedly capable of measuring concentrations of HCl in air down to a lower limit of 1-2 ppb by reacting the acid with ammonia (from a stored supply) and passing the resultant ammonium chloride aerosol into a sensitive ionization chamber (in contrast, the manufacturer claims a minimum sensitivity for chlorinated hydrocarbons and sulfur dioxide of only ~300 ppb). The instrument's speed of response is reported to be high (1-5 seconds.)

5.5.2 Laboratory Tests

Laboratory tests on the chemistry of the radioisotope exchanger technique were completed during the study period. The reactions

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were carried out with standard laboratory apparatus and methods (See Figure 17) under conditions of known acid concentration and sampling flow rate. In a typical test sequence, a small volume of dry HCl gas was generated in a flask by the reaction of concentrated sulfuric acid on sodium chloride, and was swept into a 20-liter glass carboy for temporary storage. The carboy concentration was determined by acid-base titration of water samples through which known air volumes were drawn in an impinger flask. It was found that this concentration would remain nearly constant over a period of several hours and that three successive 100-ml. air samples could be withdrawn with satisfactorily reproducible titration results.

An acid concentration of 200 ppm (actually calculated 196 ppm) was prepared in the carboy and drawn together with dilution air through a glass column containing 3.5 gm. anhydrous reagent sodium sulfite Na_2SO_3 into a midjet impinger containing a known quantity of starch-iodine reagent, until the color was discharged, by reduction of the iodine to iodide:



The time required for decolorization to be completed was accurately measured. The technique and reagents used were described in Reference 18. The "molecular conversion efficiency" defined as molecules SO_2 produced/molecules HCl available was calculated:

Carboy sampling rate	=	0.050 l/min.
Dilution air flow rate	=	1.01/min.
Normality I_2 solution	=	0.0025
Volume I_2 solution	=	1.0 ml.
No. of m moles I_2	=	0.00250
No. of m moles SO_2		
equiv.	=	0.00125
Molecules SO_2	=	1.25×10^{-3} m mole $\times$ 6×10^{20} molecules/ m mole $= 7.5 \times 10^{17}$

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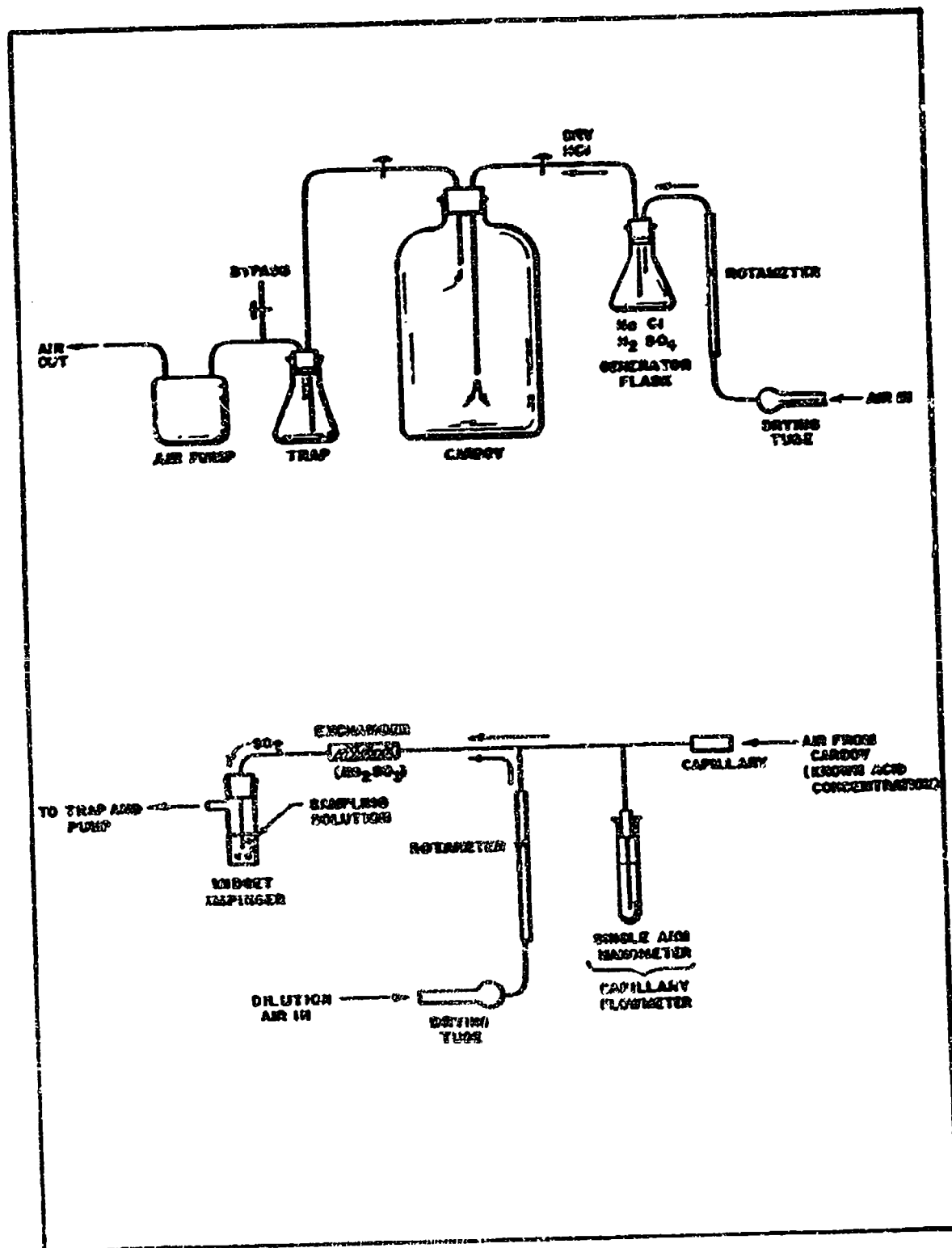


Figure 17
Laboratory Setup HCl/Na₂SO₃ Exchange Experiment
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Time to decolorize I_2	=	8.25 min.
Concentration of HCl in carboy	=	196 ppm = 0.29 mg/l
Concentration of HCl in airstream through exchanger	=	$196/20 \text{ liter} = 9.8 \text{ ppm}$ (or $0.29/20 \text{ liter} =$ 0.015 mg/liter)
Molecules HCl	=	$T_{\text{min}} \times 0.29 \text{ mg/l} \times$ $5 \times 10^{-2} \text{ l/m} \times 6 \times 10^{20}$ <u>molecules/m mole</u> 36.5 mg/m mole $= 1.98 \times 10^{18}$
Molecular conversion efficiency	=	$\frac{\text{molecules } SO_2}{\text{molecules HCl}} = \frac{7.5 \times 10^{17}}{19.8 \times 10^{17}}$ $= 0.378$

In "blank" test runs to prove that the color change (iodine reduction) was a function of the SO_2 concentration only, a) acid-free (room air) was passed successively through the column and the iodine reagent; and b) acid/air mixtures were bubbled through the iodine reagent, bypassing the exchange column altogether. In neither case was a color change in the iodine reagent detectable, indicating that at this acid concentration level (~ 10 ppm in air in contact with the exchange reagent) the concentration of "signal" SO_2 is very much greater than that of "noise" or background SO_2 . The limitations of the chemical test used here to detect SO_2 included a) uncertainty in detection of the earliest stages in the color change (i. e., detection of the sulfur dioxide concentration "front" leaving the exchanger); and b) uncertainty in the visual detection of the reaction end point.

Tests carried out on the usefulness of $NaHSO_3$ (sodium bisulfite) and $Na_2S_2O_5$ (sodium metabisulfite) as exchange reagents showed that they yielded high concentrations of SO_2 when acid-free air was passed through them. The "background" concentration levels were of the order of magnitude expected from acid/air exchange tests. Only the normal salt, sodium sulfite, was found suitable as the packing for the exchange column.

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We can, for illustrative purposes only, assign arbitrary (but reasonable) values to some of the operations parameters. For example, a reasonable speed for the search aircraft would be 200 knots (230 m/h; 338 f/s). The ambient air must therefore be sampled at this time (linear) rate, and the resultant volume flow rate will be fixed by the intake duct diameter. Since it is desirable to have a maximum volume flow consistent with minimum velocity through the components, a small duct leading to a large diameter detection system is predicated.

Intake duct area	0.1 cm^2
Intake velocity	10^4 cm/sec.
Intake sampling rate	$10^3 \text{ cm}^3/\text{sec.}$
System Cross-Section Area	0.1 ft^2
Velocity of sample through Detector	21 f/m

∴ Detection
System draws a
1.0 liter sample in
traversing 338 feet
(in 1 sec.)

While there is no way of reasonably predicting the available tracer (i. e., chlorinated hydrocarbon) concentration, it is conservative to assume a value of 0.01 ppb (10^{-5} ppm). Taking into account large losses in the pyrolysis and exchange steps, this may be converted with a net overall efficiency of 0.01 to SO_2 , yielding a "usable" SO_2 concentration of 10^{-7} ppm, or 2.6×10^{-10} mg/l, since, from the volumetric formula (5.5.1.1);

$$\text{ppm} = 10^{-7} = \frac{2.6 \times 10^{-10} \text{ mg/l} \times 24,500}{64}$$

The specific activity of S^{35} is $4.34 \times 10^{10} \text{ } \mu\text{c/g}$ and the specific activity of S^{35}O_2 is therefore $2.17 \times 10^7 \text{ } \mu\text{c/mg}$.

This is equivalent, in terms of specific radioactive decay rate, to

$$\begin{aligned} & 2.17 \times 10^7 \text{ } \mu\text{c/mg} \times 3.7 \times 10^4 \text{ dis/sec. } \mu\text{c} \\ & = 8.05 \times 10^{11} \text{ dis/sec. mg.} \end{aligned}$$

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We have therefore

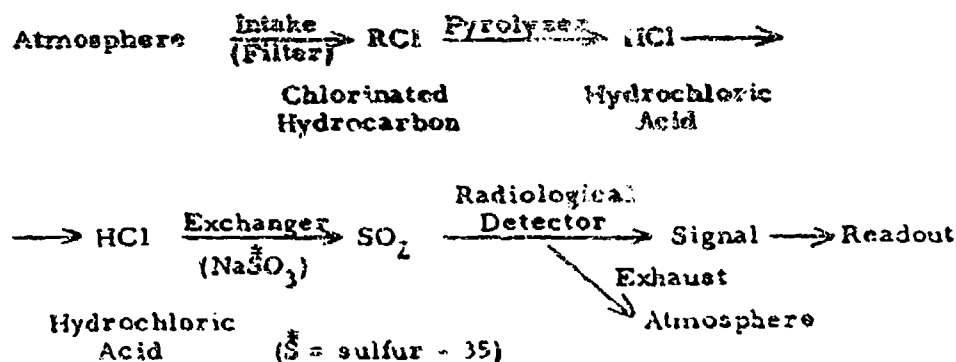
$$8.05 \times 10^{11} \text{ dis/sec. mg} \times 2.6 \times 10^{-10} \text{ mg/l} \\ = 210 \text{ dis/sec. l.}$$

If the scintillation detector sensitive volume is of the order of 1.0 liter, it will have available to it 210 dis/sec./sec. It is expected that this level should exceed the background activity by some unknown value, approaching one to two orders of magnitude.

It is instructive to compare the sensitivities of radiological and non-radiological detection systems. It has been shown that one of the most sensitive, fast-responding commercially available analytical instruments can detect as little as 1.0 ppb ($\approx 10^{-3} \mu\text{g/l}$) HCl in air and that a typical radiological detector could "see" as little as $10^{-10} \mu\text{g/l}$ of a radioactive isotope. It appears that a very large advantage in sensitivity is to be gained by the incorporation of a radiation detection step in the proposed concept. The actual (i. e., practicably attainable) magnitude of this advantage lies in the estimated loss in conversion of tracer agent to the tagged final product.

5.5.3 Discussion

An instrumental concept was developed on the basis of existing techniques, the experimental data, and some theoretical considerations. Figure 18 shows the generalized configuration of the detection system components. The overall process may be summarized as follows:



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The pyrolysis of chlorinated hydrocarbons to hydrochloric acid (among other products) by contact with silica or platinum at $\sim 100^{\circ}\text{C}$. is a commonly used procedure. (Reference 19) The conversion of the acid to the radioisotope-tagged sulfur dioxide is expected to supply sufficient radioactivity for the downstream detector to yield a usable signal. Anthracene or sodium iodide β -scintillation phosphors and associated circuitry are available which may reasonably be expected to respond to the tagged gas rapidly and efficiently. The air pump is required to provide constant and uniform air flow through the filter and exchange elements.

It is difficult to specify the sampling rate and instrumentation dimension and performance parameters with any degree of precision in view of the large uncertainties in available tracer concentrations and in component characteristics (i.e., efficiency of exchange at high flow rates). One factor which bears significantly on this concept is that the desired response is qualitative "go-no go" rather than a quantitative concentration estimate. The detector system is required only to give a positive response in the presence of airborne tracer, and concentration of which is greater than some arbitrarily selected level, and to remain passive the rest of the time.

5.5.4 Conclusions

From these studies on airborne tracer detection, the following general conclusions are reached:

1. Chlorinated hydrocarbon vapors are potentially suitable airborne tracers because they offer promise of being detectable at very low concentrations after being released to the atmosphere from broken or crushed capsules on the ground.
2. A generalized airborne detection system for the dispersed tracer can be predicated on the basis of present conventional technology and straightforward theoretical considerations.

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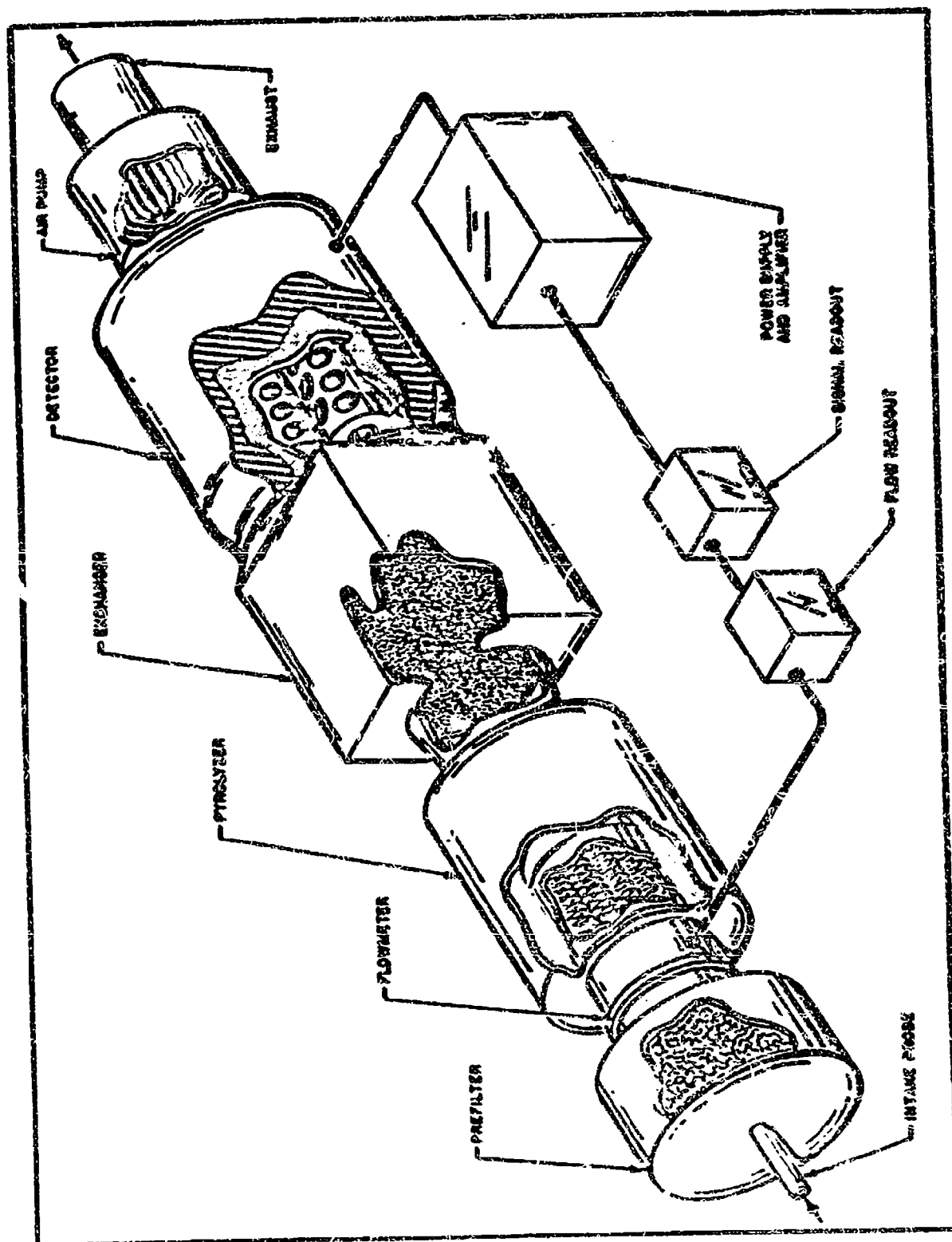


Figure 14
Air-borne Tracer Detector Instrumental Concept

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3. In order to support the design of practical hardware, further information is needed:
 - a. The actual attainable conversion efficiencies for $\text{RCL} \rightarrow \text{HCL} \rightarrow \text{SO}_2$ at high rates of flow through components of varying configuration; and
 - b. the performance characteristics of radiological (scintillation) detectors.

5.6 TASK AREA V - LONG RANGE OPTICAL DETECTION OF AIRBORNE TRACERS

The previous section dealt with the detection of tracer materials put into the air and detected by aircraft through a sampling technique.

It would be very desirable to possess the ability to detect the presence of tracer materials in the atmosphere without the need for sampling. For one thing, the task of constructing an adequate and efficient sampling system would be alleviated. For another, the aircraft is then free to search at a distance; it need not have to run into a cloud of tracer material to find it.

The ultimate long range system, as mentioned in Section 5.1.2 would be an automatic scanning device which scanned until detection occurred and then automatically locked on with an electronic notification to the pilot who then would either mark the area on his map or take whatever action was necessary to fulfill his particular mission.

5.6.1 Theory

The optimum method of long range detection, appears to be optical; that is, the detection of electromagnetic radiation and changes in this radiation in the long wave ultraviolet, the visible or the short wave infrared regions of the spectrum. These radiations, encompassing light frequencies from about 5×10^{13} cycles per second, to 1.5×10^{15} cycles per second can be handled by standard optical techniques of reflection, refraction, dispersion, scattering and absorption.

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5.6.1.1 Colored Gases

One such technique would be the release from the capsules of reagents which appear colored; that is which possess absorption lines in the visible region of the spectrum. The pilot or the sensor would see what appeared to be a colored cloud hanging over the canopy. Covertness is sacrificed.

A more attractive possibility is the release of a reagent gas or vapor which is colorless, but which on oxidation in the air, or in the presence of high energy photons from sunlight, becomes colored. Thus the enemy is unaware that he has released a reagent, unless he looks up through the tree tops and sees the colored cloud forming.

5.6.1.2 Cloud Formers

A variation of this technique would employ a material which when released, oxidizes, or reacts with the water vapor in the air to form clouds not necessarily colored. The process, in this case, is the formation of a scattering aerosol of particulate size, rather than absorption.

Calcium carbide powder for example, if it could be encapsulated; would, after capsule rupture, react strongly with moisture on the ground and in the atmosphere to give rise to acetylene gas. The strong odor of this gas, however, makes it too easily detectable by ground forces.

A more interesting variation would entail a double encapsulation (either a capsule within a capsule, or two capsules attached); one portion containing a strong oxidizer like methylethyl ketone peroxide and the other, containing cobalt naphthenate. A delayed catalyzed auto oxidation reaction occurs which is exothermic. After the double capsule is ruptured, the reagents mix slowly, emitting more and more heat. Finally, a critical temperature is attained, and the reaction goes off with a small explosion creating a white cloud which rises slowly. By the time this occurs the guerrilla agent whose footsteps broke the capsules, has passed many yards down the trail.

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5.6.1.3 Spectroscopic Analysis

Spectral analysis of either absorption lines or fluorescent lines of a vapor, is a well established technique for determining the presence of small quantities of material.

A spectroscopic absorption technique requires

1. An adequate source of radiation.
2. A sufficient quantity of the gas or vapor to be detected. This in turn requires a sufficient concentration, sufficient path length and substantial absorption coefficient.
3. A means for isolating the appropriate spectral bandwidth.
4. A detector sensitive to change in the spectral bandwidth of interest.

5.6.2 Calculations and Discussion

5.6.2.1 Colored Gases and Cloud Formers

It was decided that the spectral absorption techniques would probably provide maximum feasibility, and therefore, no detailed study was made of the cloud formers and colored gases.

Many of the conclusions reached in next section 5.6.2.2 concerning absorption lines in the visible regions, apply to the study of colored gases.

5.6.2.2 Spectroscopic Analysis

Passive and Active Detection in the Visible Spectrum

Early calculations performed indicated that the density of vapor molecules released from the capsules by a small troop movement might be of the order of 2×10^{16} molecules per square centimeter as viewed from the aircraft. Another calculation indicated that the absorption cross section σ^2 , is given approximately by the equation

$$\sigma^2 = \frac{2\pi e^2 \lambda^2}{mc^2 d\lambda}$$

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where λ is the wavelength of the absorbed radiation and $d\lambda$ is the width of the absorption band. Using a value for λ of 5000 Å which is in the middle of the visible spectrum one obtains a value

$$\sigma^2 = 4.5 \times 10^{-13} \text{ cm}^2/\text{molecule}$$

The product of this number and the density of molecules given above is much larger than one, indicating very heavy absorption of the radiation passing through the vapor cloud.

Although the experimental and theoretical feasibility studies indicate that the simple theory presented in the proposal is substantially correct, it was found that there are serious practical difficulties in implementing the system as described. The principal problem being lack of available molecules having absorption bands in the visible which are also stable and amenable to capsule dissemination.

Inorganic Vapors

There are very few inorganic gases or vapors which have absorption bands in the visible. Those which have been found which might be suitable are the halogens and certain nitrogen compounds. Among the halogens, chlorine, bromine, and iodine all form vapors by means of homonuclear, diatomic molecules such as Cl_2 , Br_2 , and I_2 . Although each of these absorbs in the visible, the symmetry of the molecule does not allow electric dipole absorption so that the formula presented above for σ^2 is not correct for these molecules. The absorption cross-section would have to be reduced by at least a factor,

$$\frac{2\pi e^2}{hc} \rightarrow \frac{1}{137}.$$

Nitrogen chloride (NCl_3), nitrosyl chloride (NOCl), and nitrogen dioxide (NO_2) all decompose in light, absorbing energy in the visible portion of the spectrum. In these cases the light is absorbed over the region 4100-4700 Å and in the last case the absorption is over almost all of the visible spectrum in bands which are more or less periodic.

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Nitrogen dioxide (NO_2) would have to be produced at the crushing of the capsule, a process which adds additional complications. Nitrogen chloride, however, is a yellow, oily liquid which evaporates rapidly and is soluble in benzene and insoluble in water being a good material for encapsulation. It is highly unstable, however, and might be dangerous to work with in large quantities.

Other inorganic vapors which absorb in the visible have been looked for in the literature but none have been found which do not result in the decomposition of the molecule by the action of the light.

Organic Vapors

Similar problems are encountered when examining organic molecules for absorption in the visible. An additional difficulty arises, however, in that most organic molecules are of a high molecular weight. Consequently, if they vaporize at all, their molecular weight keeps them low to the ground and would not allow for their diffusion up through the jungle canopy. It is therefore necessary to confine our intention to rather simple organic molecules.

Light absorption in organic molecules takes place in one or two more or less distinct ways. Either the bond between an atom and the rest of the molecule or a small group of atoms and the rest of the molecule will resonate at the absorbing frequency or the entire molecule can resonate between two states with electrons shifting over a relatively large area. The latter case is the mechanism by which organic dyes absorb light very intensely in the visible spectrum. This phenomenon is pronounced only when the molecule (and its molecular weight) is sufficiently large so that good coupling is obtained to the electromagnetic field with correspondingly large wavelengths of the visible spectrum.

The feasibility to obtain absorption in the visible with resonance at a single bond between the molecule and one of its groups (called a chromophoric group) can be determined by examination of Table 3.

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Table 3
Chromophoric Groups

Group	Example	λ_{max} , $\text{\AA}$	Intensity, E
$\text{C}=\text{C}$	Ethylene	1930	10,000
$\text{C}\equiv\text{C}$	Acetylene	1730	6,000
$\text{C}=\text{N}$	Acetonitrile	1900	5,000
$\text{C}\equiv\text{N}$	Acetonitrile	1600	
$\text{C}=\text{O}$	Acetone	2706	15.8
CHO	Acetaldehyde	2934	11.8
CO_2H	Acetic acid	2040	40
CONH ₂	Acetamide	2080	
$\text{N}=\text{N}$	Diazomethane	4100	1,200
$\text{N}=\text{O}$	Nitrosobutane	3000	
		6650	100,20
NO_2	Nitromethane	2710	18.6
ONO	Octyl nitrite	2300	
		3700	2,200,55
ONO ₂	Ethyl nitrate	2700	12

From this table it will be seen that there are only two groups which fall into the visible spectrum, the diazo group and the nitroso group. Of these the simplest molecules having these groups are diazo methane (CH_2N_2) which is decomposed by light at the absorption frequency and nitroso butane ($\text{C}_4\text{H}_9\text{NO}$), which on the other hand, is so heavy a molecule that it would not diffuse vertically over any significant distance. A similar objection can be made to the use of octyl nitrite.

The group CHO was thought to hold some promise because in its simplest molecule, glyoxal, (CHOCHO) it was found to have a slightly yellow color with absorption at 4555 $\text{\AA}$. Experiments were conducted with

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glyoxal to measure the absorption bands but were completely unsuccessful the reason being that glyoxal cannot be obtained in its pure form since it spontaneously polymerizes into long-chain molecules which do not vaporize. It can only be obtained in a 30% water solution which did not have sufficient vapor pressure to produce a vapor of sufficient density to result in laboratory detection of the absorption bands. For this reason it would not be suitable for the TREAD application.

An examination of Table 3 indicates that all other chromophoric groups have absorption bands which lie below 2850 Å. Since the ozone layer of the atmosphere absorbs radiation below 2850 Å there are no other groups which can be used passively.

The possibility of ultraviolet absorption in the region from 2850 Å to 4000 Å was discussed in the paragraphs above. A brief examination of the feasibility of using induced fluorescence in the ultraviolet was also conducted with similar negative results. All fluorescent materials which could be found had relatively high molecular weights and did not readily produce vapors which would diffuse vertically to a region where they could be observed from an aircraft.

The possibility remains of utilizing a light source on the aircraft to illuminate the vapor released from the capsules. The vapor could reveal its presence by the absorption of the light beam reflected from the canopy or by induced fluorescence from the light beam. In either case a very powerful light source is required because of the long ranges involved. Calculations indicate that the technique is not feasible unless the light beam has a wavelength shorter than the solar radiation or else fluctuations in the background due to sunlight will completely mask the reflected signal. This requires a light source of wavelength shorter than 2850 Å. A high intensity light source of this wavelength or shorter does not presently exist. Either a carbon arc or a mercury vapor lamp are all that are presently available and neither will produce sufficiently intense illumination for the system described. It is possible that a laser can be developed which will radiate below 2850 Å, however, such a device does not presently exist. Thus, it can be generally stated that the visible region of the spectrum holds little potential value in the system concept outlined.

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Infra-Red Spectral Analysis

The spectroscope in almost all of its applications has sufficient illumination, because the gas to be studied has been captured in a sample bottle, and the desired illumination is supplied.

In this case, however, the sample is free, mixed in the atmosphere, and observed from a distance. The only illumination available is the ambient sunlight, scattered in the atmosphere, or reflected from clouds or from the earth.

The first task, therefore, is to determine if this source of radiant energy is adequate for the task.

Figure 19 indicates the irradiance at the receiver optics from Rayleigh scattered sunlight versus wavelength. The peak of the curve falls below the 5000 Å wavelength which marks the peak of a 6000° K light source like the solar disc.

If a vapor like toluene or benzene is released into the atmosphere, it appears that both of these hydrocarbons have a narrow absorption band at 1.16μ.

At this wavelength, according to Figure 19, there are 4×10^{-5} watts $\text{cm}^{-2} \mu^{-1} \text{sterad}^{-1}$.

If we assume the use of an interference filter of the type called 13-A Infra Red, by The Optics Technology, Incorporated and if we assume a telescope collector with an 8 inch diameter, and a photomultiplier tube with a near infra-red sensitive surface, it is possible to determine the adequacy of the illumination.

$$J = I A_{\text{coll}} \Delta \lambda T_o T_F T_A \omega^2$$

where

J	=	radiation at the cell
I	=	background radiance = 4×10^{-5} watts $\text{cm}^{-2} \mu^{-1} \text{sterad}^{-1}$
A_{coll}	=	$3 \times 10^2 \text{ cm}^2$
T_o	=	optical transmission = 0.7
T_F	=	peak filter transmission = 0.35
T_A	=	atmospheric transmission = 0.7

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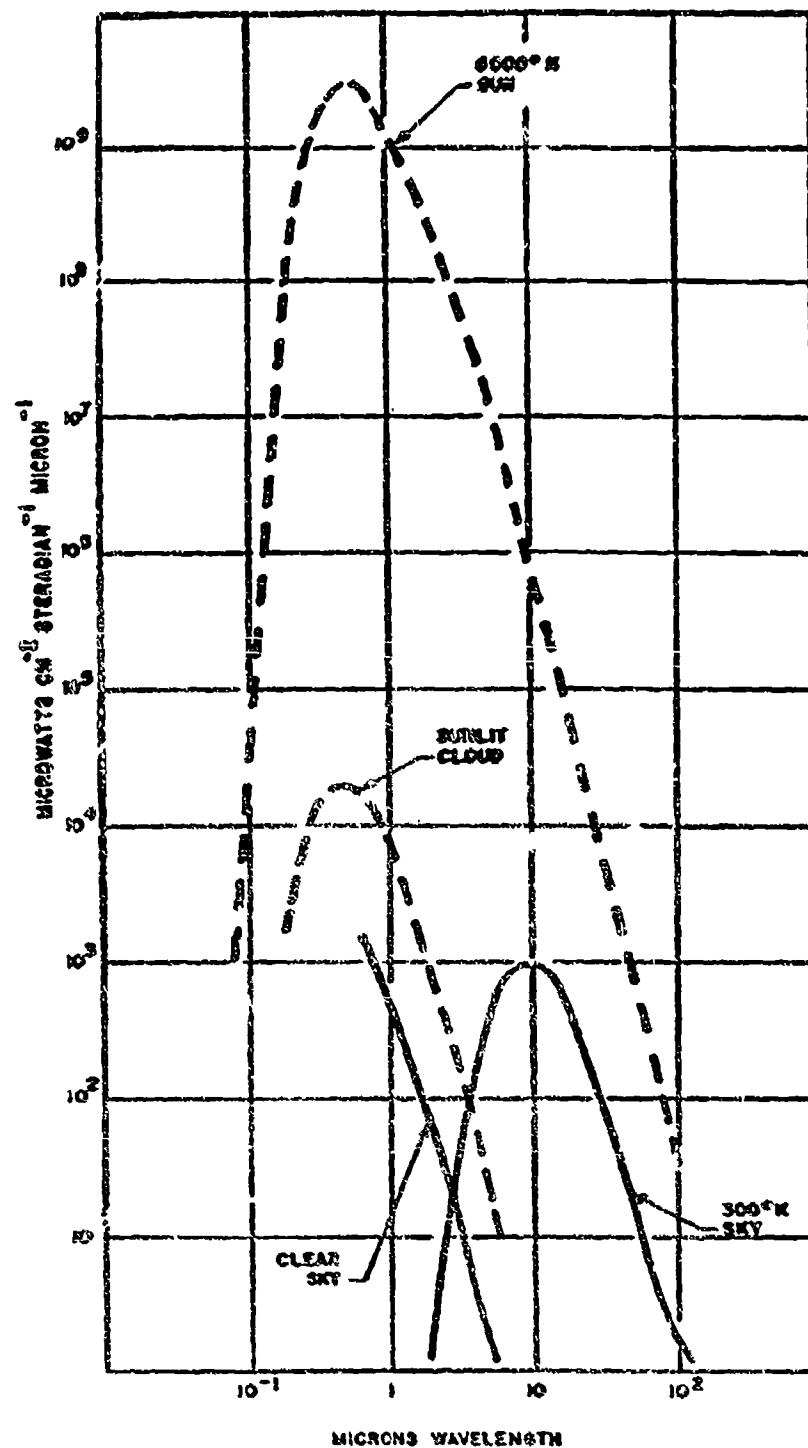


Figure 19
Spectral Energy Available from Sunlight and Scattered Sunlight
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$\Delta\lambda$ or half width, according to Optics Technology, Incorporated specifications is 3% of the central wavelength, or $.03\mu$. The band pass wavelength is $0.10\mu \pm 0.05\mu$.

If we consider a very fast system, like F-2, the focal length is therefore 2 x the diameter, or 16". Assuming, the cell area is 1 cm^2 , the field of view, $\omega = .025$ and the solid angle is 6.25×10^{-4} steradians.

$\therefore J = 4 \times 10^{-8}$ watts which is easily detectable by a cell with a N.E.P. of about 10^{-11} .

The next major question is this; is the absorption band intense enough to be easily detected.

The amount of absorption by an atom or a molecule in the visible or near infrared portion of the spectrum can be calculated to a first order using classical or quantum mechanical expressions for the absorption of an oscillating dipole. Both classical and quantum mechanical analysis yield the following equation:

$$S = 2\pi^2 \frac{e^2}{mc} I_0(\nu_0)$$

where

$S =$ the absorbed energy per second by a molecule.

$I_0(\nu_0) d\nu$ is the incident energy per cm^2 per second, and $d\nu$ is the bandwidth of the absorption line. Also, e and m are the charge and mass of the electron and c is the velocity of light.

The absorption cross section, σ^2 , is given by

$$\sigma^2 = \frac{S}{I_0(\nu_0) d\nu} \text{ cm}^2$$

This yields

$$\sigma^2 = \frac{2\pi e^2}{mc d\nu} = \frac{2\pi e^2 \lambda^2}{mc^2 d\lambda}$$

where

$\lambda =$ the wavelength of the absorption line
 $d\lambda =$ the line width

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Assuming a value of 1.1μ for λ (1.1×10^{-4} cm) and a line width approximating the filter pass band half width, or 3×10^{-6} cm, then

$$\sigma^2 \approx 7 \times 10^{-15} \text{ cm}^2 \text{ per molecule.}$$

Taking into consideration, the correction factor of

$$\frac{2\pi\sigma^2}{hc} = \frac{1}{137}$$

$$\sigma^2 \text{ becomes } 5 \times 10^{-17}$$

To determine the number of absorbers in a typical problem, we will assume that 1 gram of material is released in an area of $1 \times 10^5 \text{ ft}^2$, providing a vapor concentration (c) of approximately $0.01 \mu\text{gm per cm}^2$ as viewed from above. Since benzene has a molecular weight (MW) of 78, this presents to the observer a density of vapor molecules of $N = \frac{AN \times c}{MW}$

where

$$AN = \text{Avogadro's number} = 6 \times 10^{23} \text{ molecule/mole}$$

$$\therefore N = 7.7 \times 10^{13} \text{ molecules}$$

Since the ratio of non-absorbed energy I_o is related to the incident energy I_{in} by the Lambert-Beer relationship

$$I_o = I_{in} e^{-N \sigma^2 x}$$

it is possible to determine the absorption in the spectral line for various path lengths (X). See Table 4.

Table 4

Path Length (X cm)	Absorption (I_o/I_{in})
1 mm	~ 1.0
1 cm	~ 1.0
10 cm	.965
100 cm	.680
1000 cm (330')	.020
10000 cm (3,300')	10^{-15}

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According to these optimistic calculations, even small clouds should demonstrate a measurable energy loss through absorption. It must be remembered that the assumption was made that the filter half width equaled approximately the line width, where as in fact the line width might prove to be as much as 2 orders of magnitude less broad than the half width of 300 Å.

5.6.3 Laboratory Tests

5.6.3.1 Colored Gases and Visible Absorption

Experimental measurements were made in the laboratory on various halogen vapors and it was found that the absorption is indeed lower than the theoretical value calculated without taking into account the loss factor of $\frac{2\pi e^2}{hc}$ or about $\frac{1}{137}$.

Measurements were made on nitrogen dioxide (NO_2) in sufficiently small quantity to confirm that the absorption intensity is of the order indicated by the calculations. Nitrogen dioxide, however, like nitrogen chloride (NCl_3) and nitrosyl chloride (NOCl) suffer from the same operational problems in that they absorb light by decomposing the molecule into colorless constituents and thus the absorbing vapor persists only from seconds to minutes which would allow insufficient time for detection.

5.6.3.2 Cloud Formers

Time did not permit a study of the delayed reaction cloud forming reagents. One such combination felt to be most promising was the methyl-ethyl ketone peroxide and cobalt naphthenate auto oxidation reaction, but no attempt was made to acquire and test these reagents.

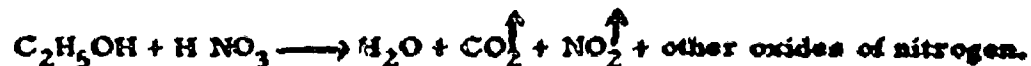
Instead, in order to get some idea as to the magnitude of cloud size with small quantities of reagent, the following test was conducted.

Two grams of ethyl alcohol were poured into a glass beaker, swished about and poured out. 3cc of concentrated nitric acid, was then added to

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the beaker whose walls were coated with the alcohol. After a 30 second delay, an explosion took place, sending up a visible reddish brown cloud of nitrogen dioxide.



The cloud attained a height of about 4 feet and an approximated volume of 20 cubic feet, lasted from 10 to 15 seconds, and finally dissipated through diffusion, dilution and downwind motion by a slight breeze.

It is difficult to evaluate this type of performance. Should a series of dense opaque clouds appear against a dark brown or green field, visible recognition from reasonable distances might be a possibility. Should cloud formers be broken under a tree canopy, it is very unlikely that they would remain in tact long enough or in concentration sufficient to penetrate the canopy and still exist as opaque or colored clouds. Detection would be highly unlikely.

5.6.3.3 Infra Red Spectral Analysis

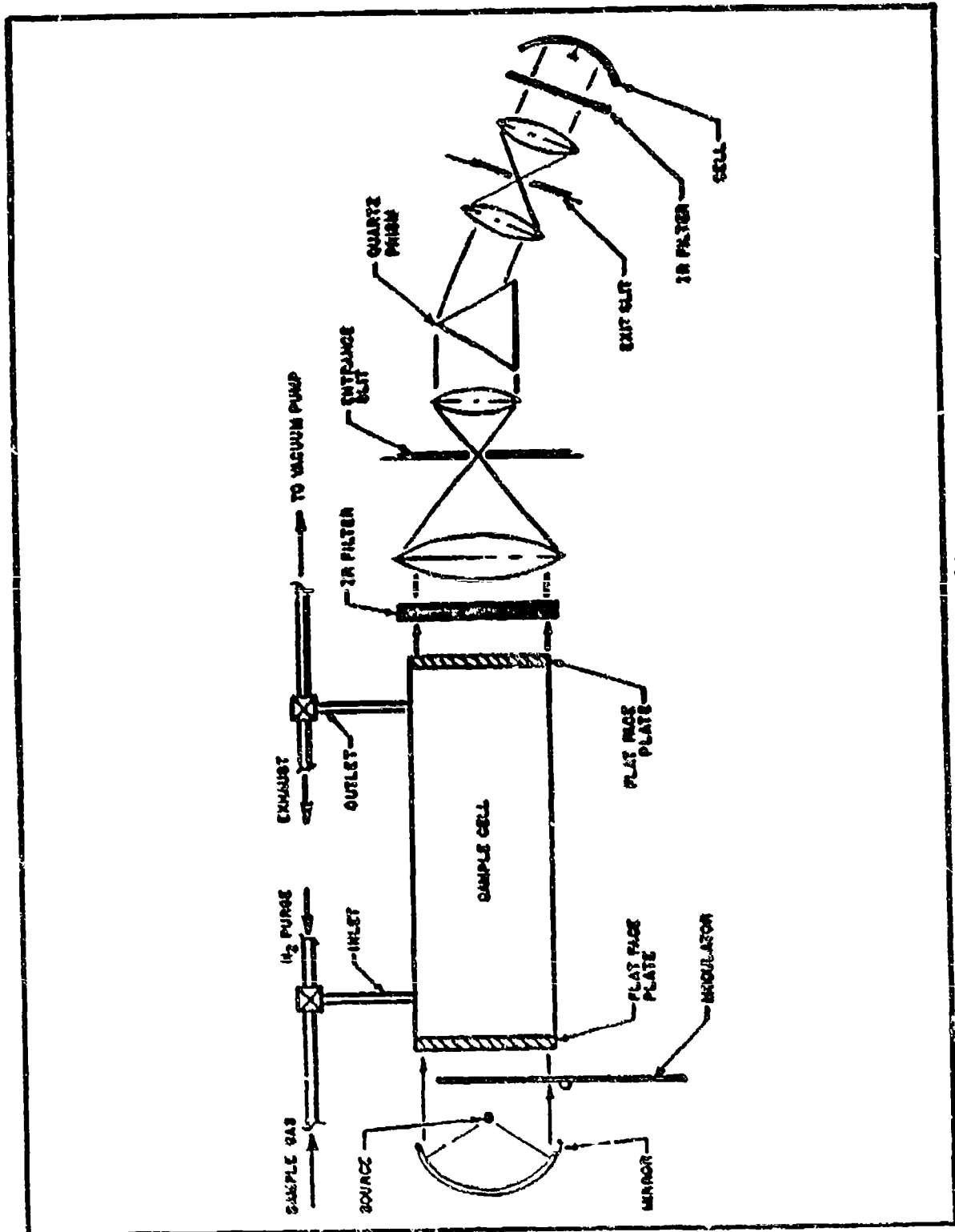
In order to show the feasibility, once the encouraging calculations indicated that infrared absorption bands proved attractive, a laboratory test was arranged using the Hilger-Watts quartz prism spectrometer. See Figure 20.

The Light Source is 275 watt 3000°K tungsten lamp with hemispherical reflector. Assume a full 50% is directed onto the face of the spectrometer, or 137 watts. The 87 C. Infrared Wratten filter removes all energy below .8μ or 15% leaving 115 watts, falling in a circle of 12 cm. diameter or 115 cm². Since the spectrometer slit is only 2 cm. long and 5 x 10⁻² cm. wide, its area is 1 x 10⁻¹ cm². Therefore, it intercepts only 8.7 x 10⁻⁴ of the energy directed at the spectrometer, or 1 x 10⁻¹ watts. About half of this is lost in traversing the mirrors and quartz prism of the spectrometer and only 5 x 10⁻² total watts remain. The spectral loss, due to bandwidth which covers the spectral region from 1.13μ to 1.23μ permits transit of only 6% of the 3000°K. source, thus, the output is 3 x 10⁻³ watts.

This is more than sufficient energy to perform the tests, using an uncooled lead sulfide cell as the detector. Readout was obtained on a vacuum tube voltmeter.

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Figure 20
Laboratory Setup for Spectral Absorption Studies

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Test 1

Procedure

The apparatus was arranged as in Figure 20. The slit width opening of .25mm. in the 1μ wavelength region has a dispersion of .045 μ . With no sample in the tube, a S/N value of 3 was obtained at 1.18 μ .

Table 5 lists the relative spectral intensity curve of a 3000° K Black Body, the relative spectral response of an uncooled lead sulfide photoconductive cell, the relative spectral transmittance of the No. 87 C Wratten filter, the product of all three factors, the S/N values obtained experimentally, and finally, the S/N values divided by the product of the three spectral factors, to present the behavior of benzene absorption alone.

Table 5

Wavelength	Relative Spectral Response			Measured S/N	S/N *
	Radiance 3000°K.	PbS Cell	Filter		
0.80 μ	.920	.150	.570	1.17	15.0
0.875 μ	.980	.160	.810	1.66	13.1
1.00 μ	.995	.200	.930	3.08	17.1
1.05 μ	.980	.230	.950	3.40	15.9
1.07 μ	.960	.240	.950	3.50	16.0
1.18 μ	.910	.280	.950	2.84	11.7
1.26 μ	.810	.310	.950	3.18	13.2
1.37 μ	.760	.360	.950	2.84	10.9
1.45 μ	.710	.400	.950	2.90	10.8
1.535 μ	.650	.450	.950	2.33	8.35
1.63 μ	.580	.500	.950	3.18	12.00

* Represents S/N divided by the product of the Source, cell, and filter response.

The last column is plotted in Figure 21 versus wavelength. Note the correlation between these findings and the data given by the Matheson-Coleman and Bell Chemical Company.

The concentration of the source gas is high (.5 grams per liter.)

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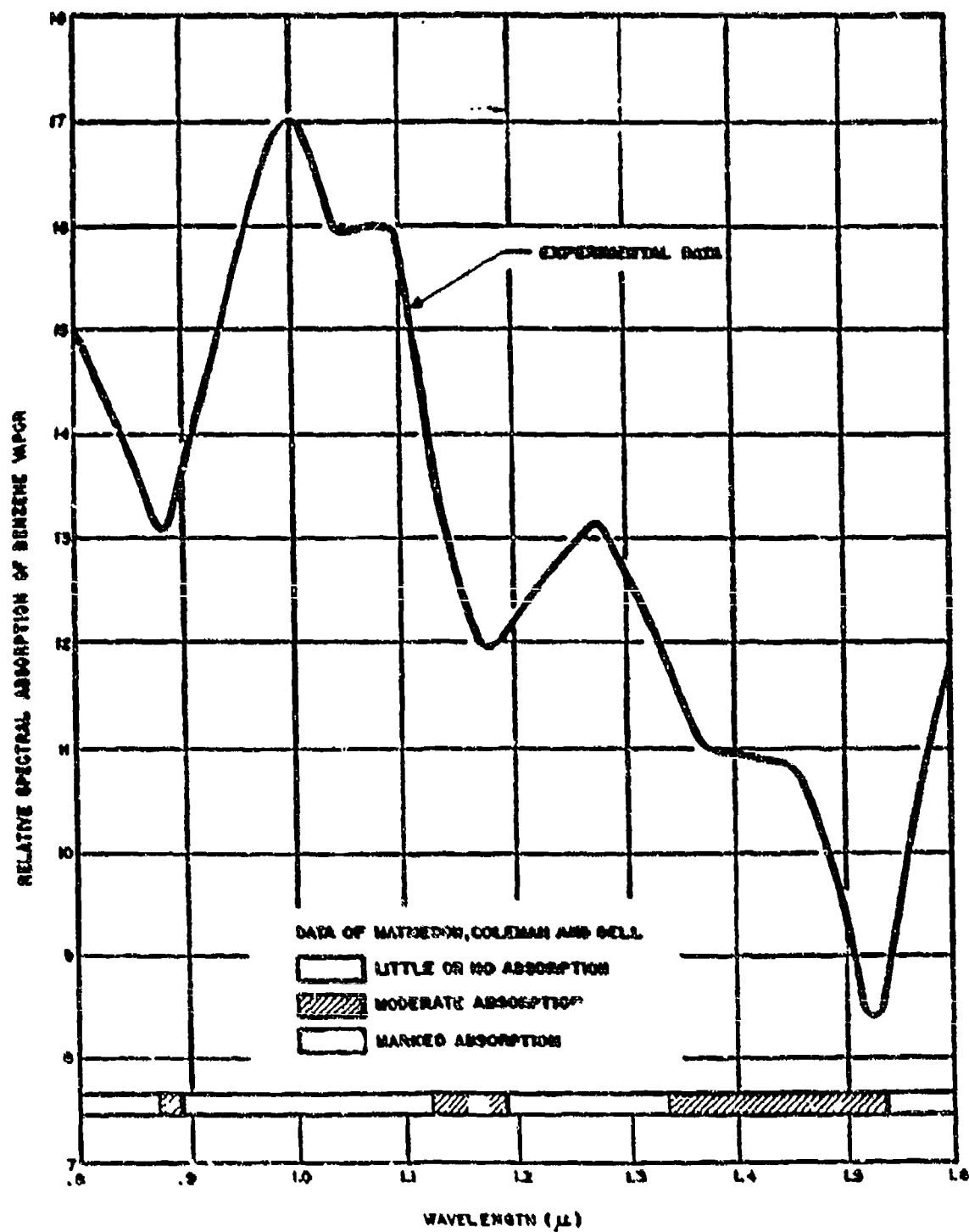


Figure 21
Relative Spectral Absorption of Benzene in Air
500 mgm/Liter Versus Wavelength

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Test 2

Procedure

The test was repeated after the cell had been thoroughly washed with water, hydrocarbon solvent and purged with dry nitrogen gas. The sample release on a second test was one broken toluene capsule, or approximately 3 mg. This concentration, 1.5 mgm per liter represents about 200 ppm and was still detectable at 1.18 μ . (See Figure 22.)

Figure 23 represents an artists' conception of the scanning long range optical detector. There are two sensors, each pod mounted on the wings, each sweeping a 60° field of view, from straight ahead to 60° to the side, giving a total azimuthal coverage of 120°.

Mechanical scanning is achieved by pivoting about a vertical axis.

The package consists of a lightweight aluminum housing, a parabolic reflector 8 inches in diameter, a 16 inch focal length, folded by a 45° prism flat reflecting secondary. The prism is mounted on a transparent window, and the focused beam, after passing through the narrow band interference filter, falls on the face of a sensitive photomultiplier tube.

A second scanning concept was considered, one in which a rotary scan was achieved with a fixed telescope, by means of nutation of a wedge element at the focus of the beam. Because of the small mass of the quartz wedge, mechanical torque problems will be very much simplified.

5.6.4 Conclusions

1. Radiant energy in the form of scattered sunlight, from molecular Rayleigh scattered blue sky light, scattered sunlight from clouds and from canopy top, should provide adequate illumination for a proposed spectral absorption airborne detector. In fact, there appears to be sufficient energy out to 3 μ , by at least an order of magnitude when coupled to a large (8" diameter) collector and high sensitivity (photomultiplier) detector.

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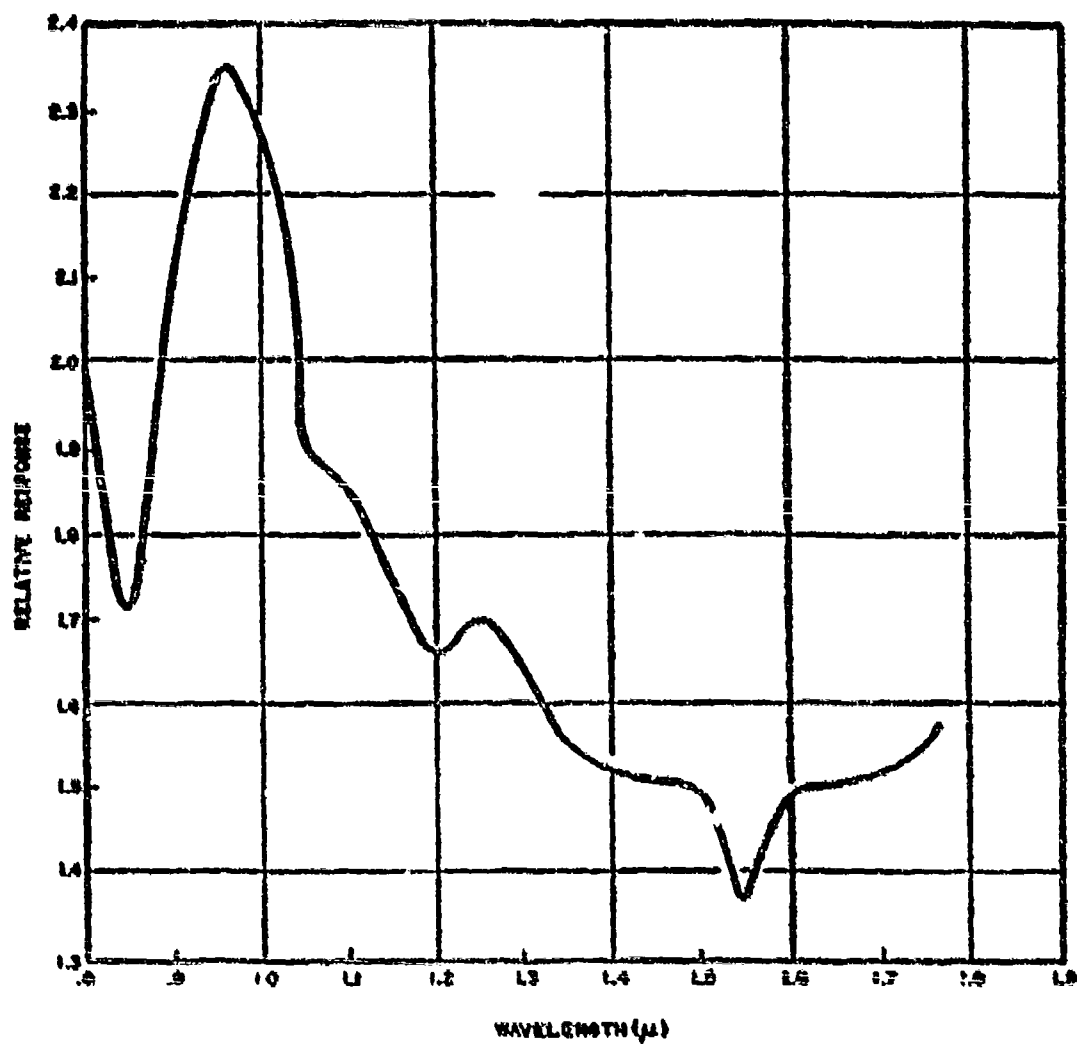


Figure 22
Relative Spectral Absorption of Toluene in Air
1.5 mgm/Liter Versus Wavelength

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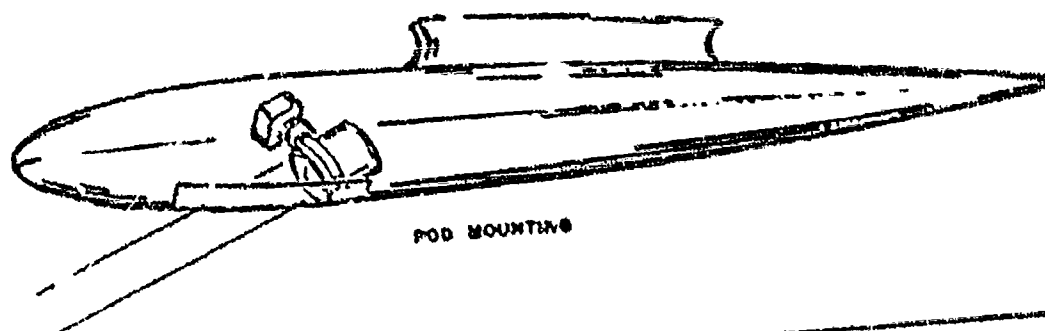
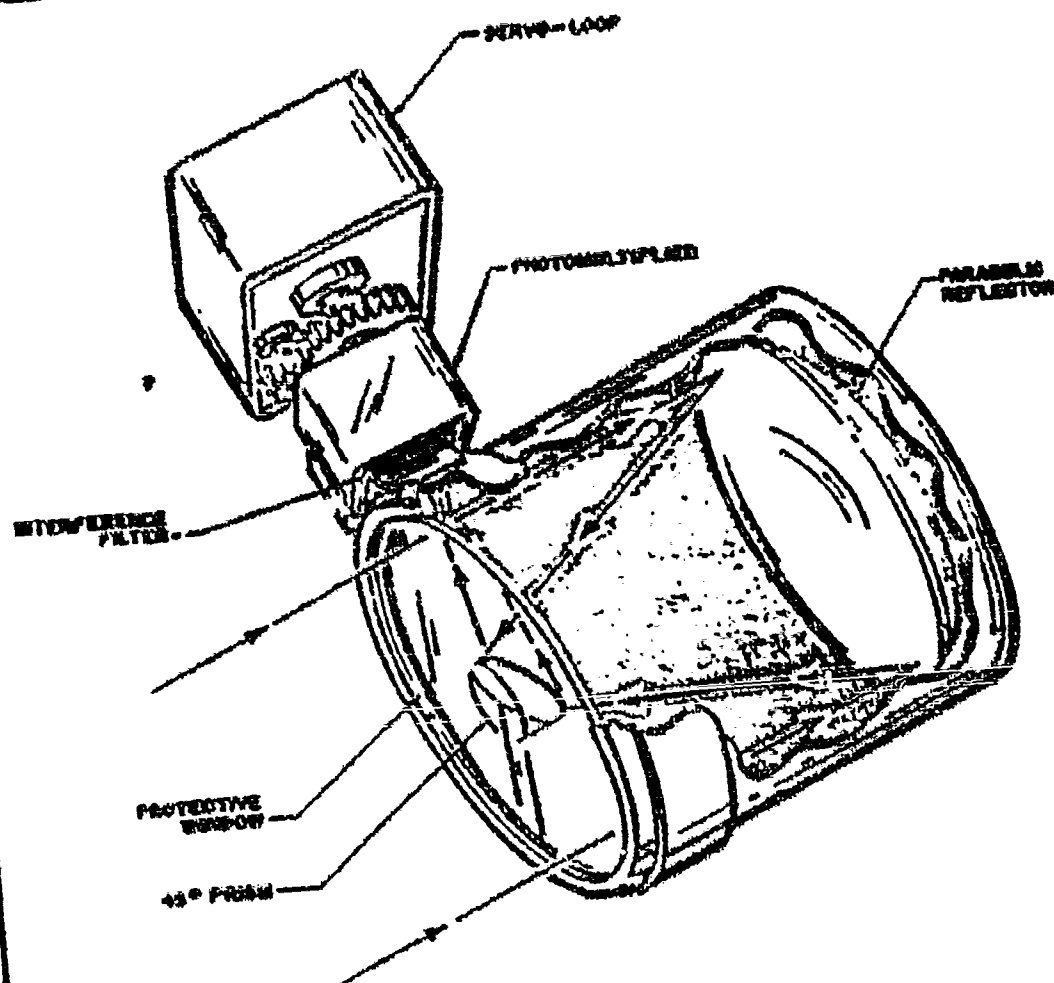


Figure 23
Instrumental Concept - Pylon Mounted
Long Range Optical Detector
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2. Absorption lines in the visible spectrum do not lend themselves to this program, because those materials which exhibit such lines are too reactive, and therefore combine chemically with other materials found in nature, or explode or in some other manner alter their chemical nature within a short period of time.
3. Molecular rotational and vibrational lines of hydrocarbons in the near infrared portion of the spectrum were found in laboratory tests, demonstrating a degree of feasibility.
4. A scanning telescopic-photomultiplier detector for long range absorption detection has been sketched, utilizing an interference type of filter for absorption line isolation.
5. Cloud forming agents were studied but did not appear to be very attractive.

5.7 TASK AREA VI - GROUND MARKER TECHNIQUES

5.7.1 Theory

Tracer reagents already discussed were those which diffused into the atmosphere and were either sampled and detected in an aircraft, or observed as a cloud from afar.

Another technique related to the latter principal, that is, detection at a distance, involves marking the ground with reagents which, by standing out in some manner from their background, are detectable from the air.

5.7.2 Materials - Technique

Dyes and stains released from ruptured capsules would theoretically mark spots on the clay, soil, leaf, wood or stone against which they are broken. It seems however, that the task of finding such spots against an earth background would be extremely difficult to implement.

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An interesting approach might be the release from ruptured capsules of reagents which generate vapors that on rising, stain or kill the foliage. Stains would affect the underside of the canopy far more than the upper surfaces. Defoliants have been employed extensively for some time. What is being suggested here, is a chemical which in killing or damaging the leaf discolors it to such an extent that a large patch would be obvious to an airborne observer. Unfortunately, most plant killers work too slowly to be useful in TREAD applications.

While color staining agents on the ground would be almost impossible to spot from the air, capsules containing a highly reflecting material like small pieces of broken glass mirror, might easily be spotted by the glitter of reflected sunlight. Unfortunately, covertness would be lost. Guerrillas walking along a trail could see the glittering spots with relative ease.

The same objection is true for chemicals which, on release from the capsules and in the presence of moisture, stimulate crystal growth which can act as diffuse reflectors if they are white or near-white in color.

The one technique which in this category of ground markers is felt to be of great value, is the use of fluorescent markers which can be stimulated from the air by the appropriate radiant energy and detected with the aid of optical filters.

While, in theory this should provide a detection system which can operate in daylight, practical considerations like the unavailability of extremely narrow band filters to cancel out scattered sunlight, limit this application.

Night time application, however, should provide adequate ranges to make this technique very useful. In fact, this is the only method which provides a positive night capability. Since much of the guerrilla activity and movement takes place in the dark, and since the fluorescent spots will not dissipate in a short period of time as will the airborne tracers, detection of activity which had occurred some length of time previously, will still be attainable. See Figure 24.

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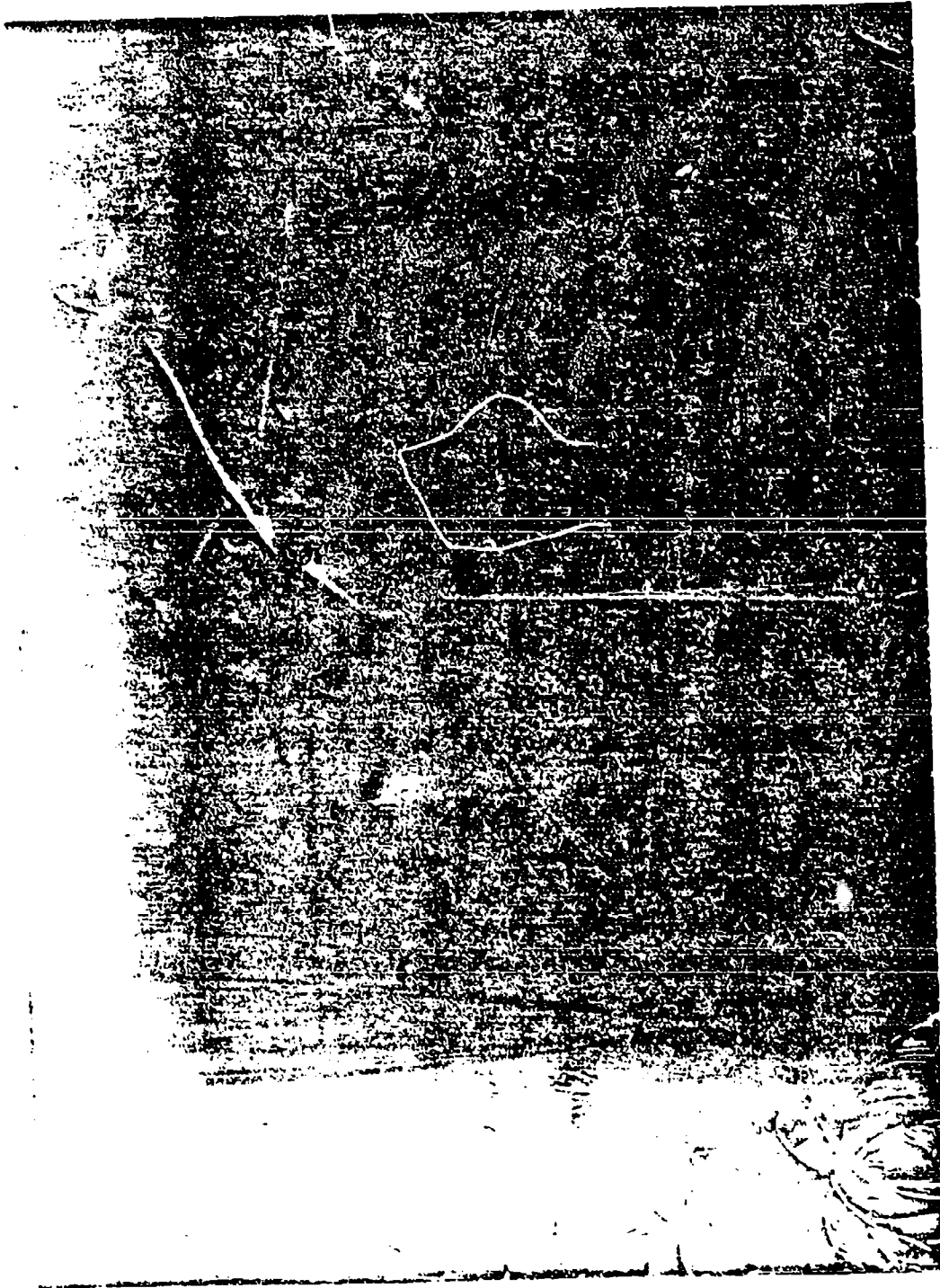


Figure 23
Night Airborne Detection of Fluorescent Ground Tracers

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5.7.3 Laboratory Tests

The original concept as described in the proposal involved stimulating fluorescent powders or liquids with ultra-violet radiation. This would require the use of a high pressure mercury lamp whose efficiency at the appropriate wavelength is low.

Since detection may be accomplished from low flying aircraft like the F-100 and F-105, covertness would be compromised to some degree and visible light suitably filtered may be used instead of U. V. This offers the advantage of dealing with less exotic, less expensive, more reliable lamps with no special power source problems.

In the laboratory, we were able to stimulate aqueous solutions of sodium fluorescein (uranine) with light from a 28 Volt - 40 Watt tungsten aircraft lamp whose energy was filtered through a crystal violet filter. The filter was made by dissolving 2 mgms. of crystal violet powder in 200 cc. of dissolved gelatine. The hot gel was then poured between two plates of boro-silicate crown glass and allowed to cool.

The lamp was fixed at the focal plane of a 4" diameter F/75 spherical mirror, thus collimating the beam.

A small glass vial of Sodium Fluorescein, diluted in ethyl alcohol to a concentration of 1×10^{-4} was positioned at the other end of the laboratory, 20 feet away, in the beam of the collimator.

The back scattered, fluorescent yellow-green light was observed from a distance of 20 feet (along side of the lamp source) through a green Eastman Kodak Wratten Filter No. 74. This filter reduces the yellow-green intensity of fluorescent light by 2/3 but reduces the purple background to zero intensity.

Figure 25 displays the transmissivity of a crystal violet filter. The chief absorption band of uranine is indicated.

Figure 26 indicates the relative energy output of a 3000°K. tungsten filament and a 6500°K. Xenon Flash Lamp.

Figure 27 indicates the structure of uranine, its absorption and emission lines.

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Figure 28 indicates the spectral characteristics of the Wratten No. 74 filter, indicating the emission line of uranine.

It was then possible to reduce the intensity of the source radiation until the threshold level was obtained (positive identification of the glowing fluorescein as seen through the Wratten No. 74 filter.)

One could then calculate the sensitivity of the detector, in this case the N.E.P. of the human eye. If these results compared favorably with long established physiological values, then it could be said with some confidence that we had been able to account for all radiation losses.

The human eye, when fully dark adapted, after 60 minutes, can detect a flash of 0.2 seconds duration, in which approximately 100 photons arrive at the cornea. Only 5 to 10 quanta are transmitted by the ocular media and absorbed into the photo-pigment, rhodopsin.

Thus, the threshold level under optimum conditions, must be at least 500 photons sec.^{-1} at the cornea. Assuming 1000 photons sec.^{-1} as an average value, and since each photon of green light (5100 Å) represents $h\nu$ watts where

$$\begin{aligned} h &= \text{Plank's constant} = 6.625 \times 10^{-34} \text{ watts sec.}^2 \\ \nu &= \frac{c}{\lambda} = \frac{3 \times 10^{10} \text{ cm sec.}^{-1}}{5.1 \times 10^{-5} \text{ cm}} = 0.59 \times 10^{15} \text{ cycles/sec.} \\ \therefore h\nu &= 3.9 \times 10^{-19} \text{ watts per photon} \end{aligned}$$

The threshold level is therefore $3.9 \times 10^{-19} \times 1 \times 10^3 = 4 \times 10^{-16}$ watts. Davison (Reference 20) quotes the classic measurement of Kohlrausch to show that, after 17 minutes in the dark, the eyes are 10 x as insensitive as they are in 60 minutes. At 10 minutes, the threshold is 100 x higher, at 7 minutes it is 1000 x higher, at 3 minutes, 5000 x.

The test conducted in the laboratory was conducted after 5 minutes in the dark. The threshold value, or N.E.P. should, then, be about $3000 \times 4 \times 10^{-16}$ or 1.2×10^{-12} watts. Our finding of 6×10^{-13} is in error by a factor of 2 which is close enough to lend validity to the measurements.

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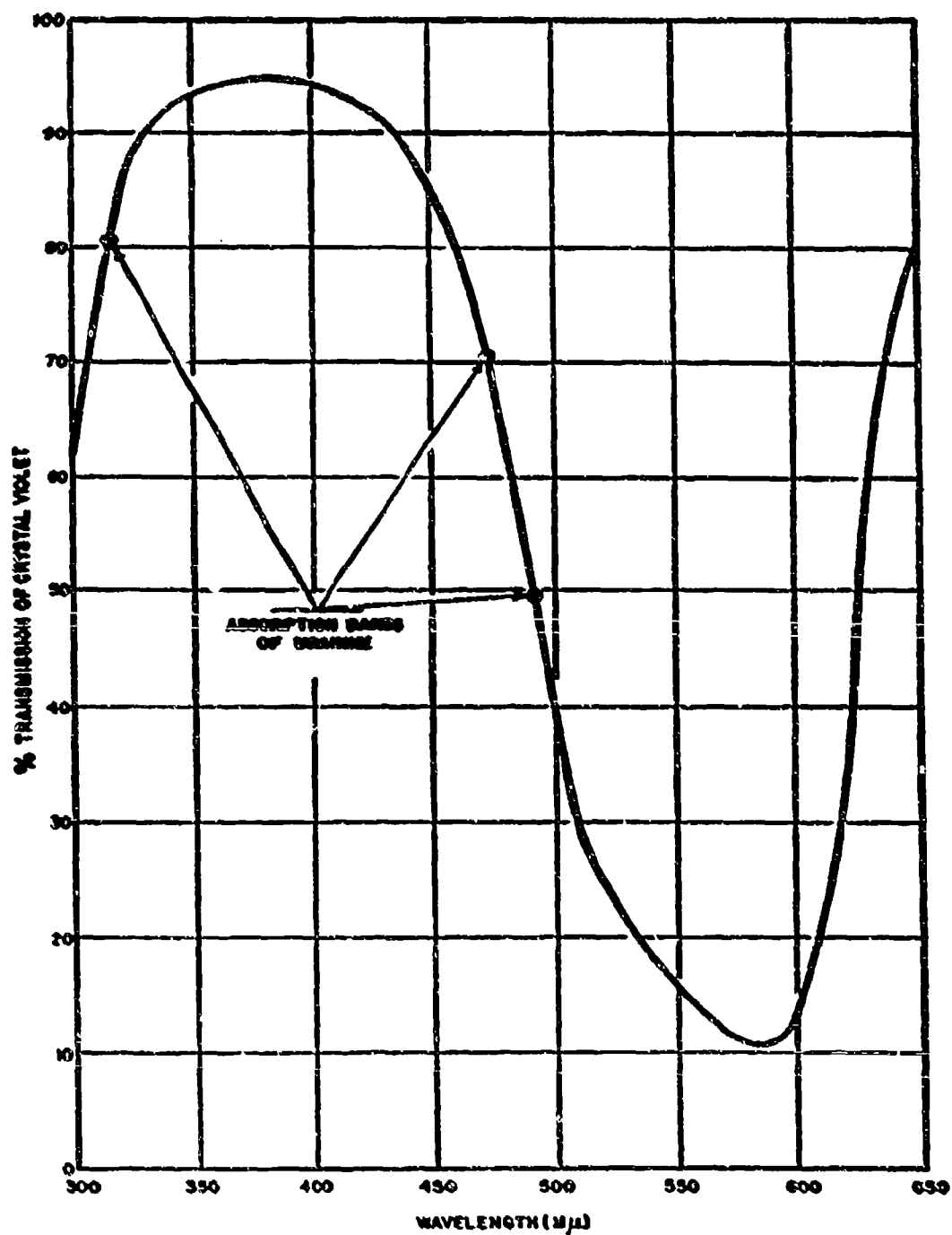


Figure 25
Spectral Transmission Curve
of a Crystal Violet Filter

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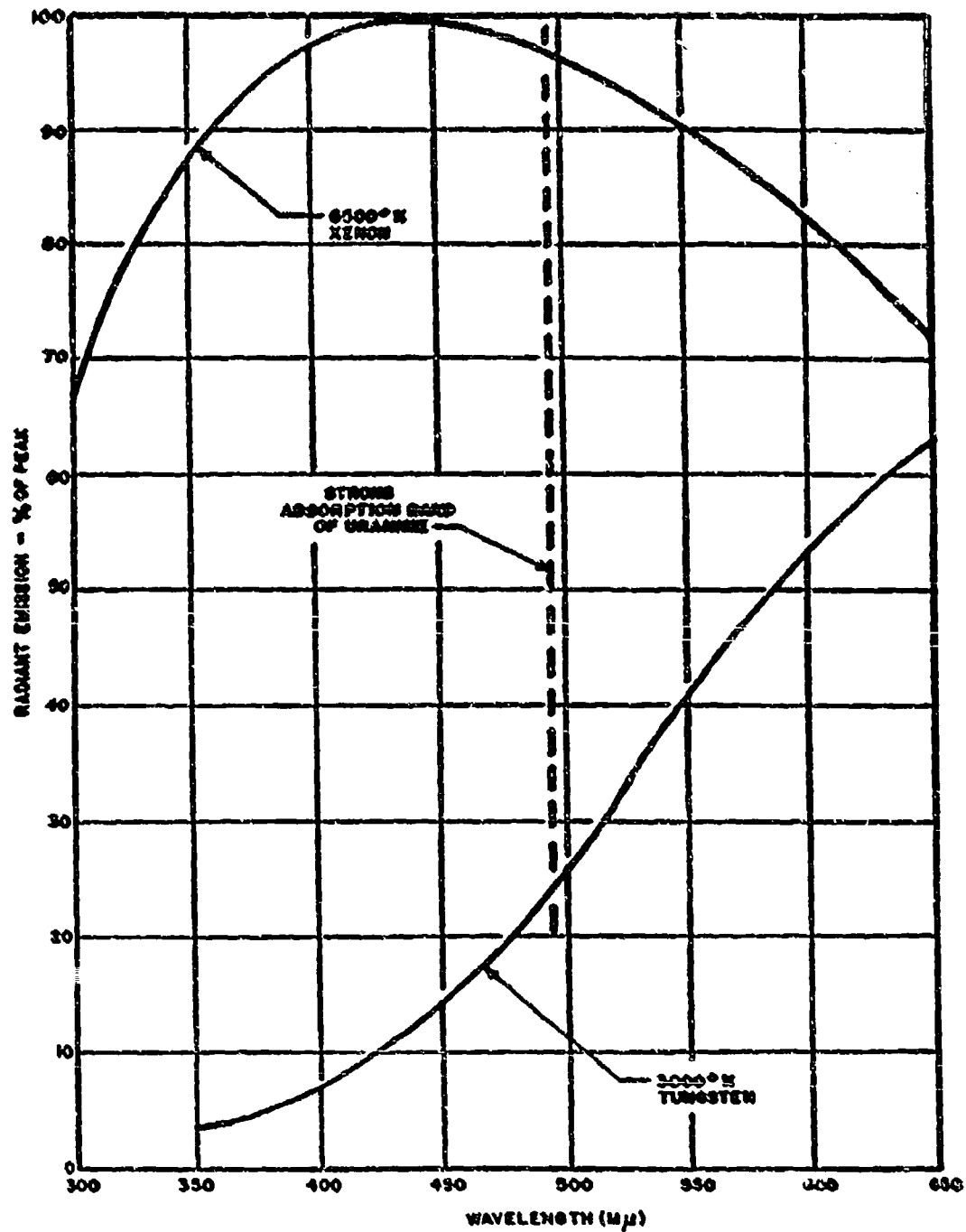
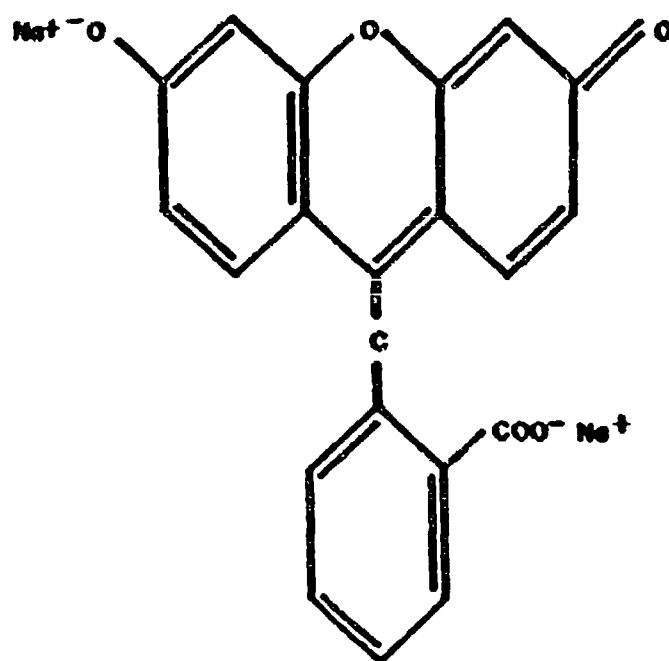


Figure 26
Relative Radiant Energy Output of
Tungsten and Xenon Light Sources

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ABSORPTION AT 3125 Å
STRONG ABSORPTION AT 4950 Å
DIMER ABSORPTION AT HIGH CONCENTRATION AT 4710 Å
ALL ABSORBED RADIATION—RE-EMITTED AT 5420 Å

Figure 27
Uranine - Structure and Photo-Characteristics

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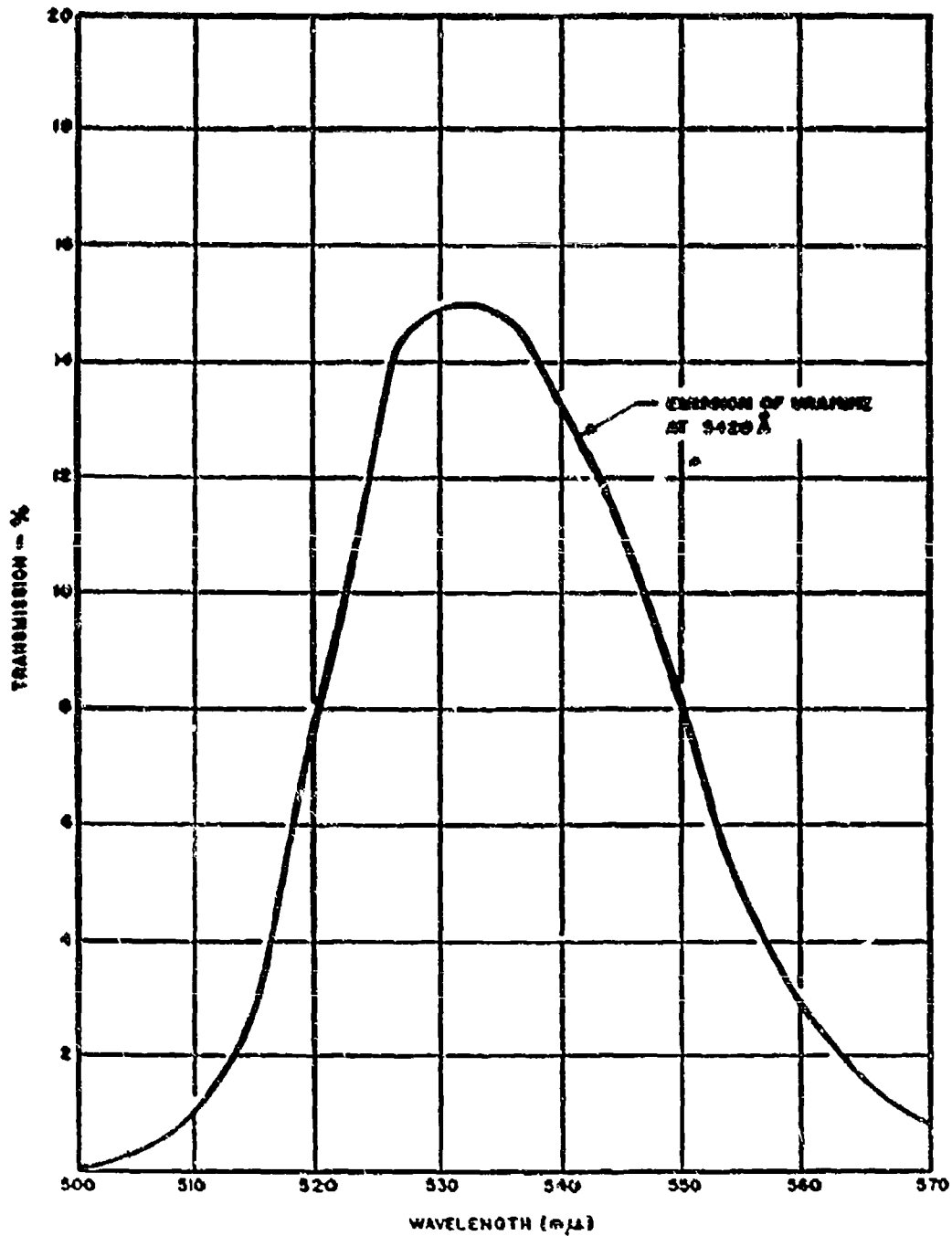


Figure 28

Spectral Transmission Curve of Wratten Filter No. 74

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A second test was conducted after 10 minutes dark adaptation. The threshold was achieved with the lamp input at 7 volts and 0.6 amperes or 4.2 watts. This should reduce the N. E. P. by a factor

$$\frac{4.2}{7.7} = .55, \text{ which}$$

would mean an N. E. P. of 3.3×10^{-13} , compared with 4×10^{-14} . Here we are in error by an order of magnitude.

A third test was conducted at a range of 30' instead of 20'. After 5 minutes of dark adaptation, the lamp had to be set at 18 watts. Since the range had increased $\frac{30}{20} = 1.5 \times$, the input energy needed to be increased $(1.5)^2$ or $2.25 \times$. In the first test, 7.7 watts was the power output. $7.7 \times 2.25 = 17.4$ watts, compared with the 18 watts actually found in testing. Again this lent a degree of validity to the measurements.

The method for determining these values is indicated below in the use of formula #1

$$\text{The Noise Equivalent Power (N. E. P.)} = \frac{I_{\Delta \lambda_{cv}} T_o A_T \alpha A_{coll} T_{\Delta \lambda_{74}}}{S/N R^2 r^2 \pi^3} \quad (1)$$

where

I	=	intensity of source = $11 \text{ v} \times 0.7 \text{ amperes} = 7.7 \text{ watts}$
$\Delta \lambda_{cv}$	=	spectral transmittance of the crystal violet filter Integration of the curve in Figure 25 indicated that 3.1% of all visible radiation is transmitted. Since visible radiation represents only 7% of the energy radiated by a 2900° K tungsten filament $\Delta \lambda_{cv} = 2.2 \times 10^{-3}$
T_o	=	transmission of optics = 0.7
A_T	=	area of fluorescent target = 6 cm^2
α	=	conversion efficiency of uranine = 1.00
A_{coll}	=	area of collector (pupil of the eye) = $1.5 \times 10^{-1} \text{ cm}^2$
$T_{\Delta \lambda_{74}}$	=	spectral transmittance of Wratten filter No. 74 = 3.4×10^{-2}

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S/N = signal-to-noise ratio = 1.00 at N. E. P. level
R = range = 20 feet = 6×10^2 cm
f = focal length of the collimator = 7.5 cm
 $\therefore$ NEP = 6×10^{-13} watts

The next determination to make is this: can we utilize this detection method in a practical system? Can we detect small spots of fluorescence at night from aircraft at reasonable altitudes?

5.7.4 Discussion

5.7.4.1 System Considerations

The light source can be increased from a 40 watt lamp to 250 watts. The area of the fluorescent target is decreased considerably from 6 cm^2 to the size of a spot produced in rupturing a capsule. Figure 29 indicates size of spots obtained from encapsulated benzene, in capsules of varying size. If we use a capsule of diameter = 2.5 mm, the spot size will have an area of 130 mm^2 .

The final major change is the nature of the detector. One would ideally desire an automatic scanning device with high sensitivity in the visible region. Use of human, dark adapted observers is not practical, nor is the time constant of the eye sufficient at aircraft speeds at low altitudes.

Assume an aircraft altitude of 500 feet, or 1.5×10^5 mm. Since the spot diameter is 13 mm, the angular subtense is therefore

$$\frac{13}{1.5 \times 10^5} = 8.7 \times 10^{-5} \text{ rad.}$$

If the aircraft is flying at 300 mph or 450 ft sec^{-1} , this represents an angular rate of $\frac{450}{500} = .9 \text{ rad. sec}^{-1}$

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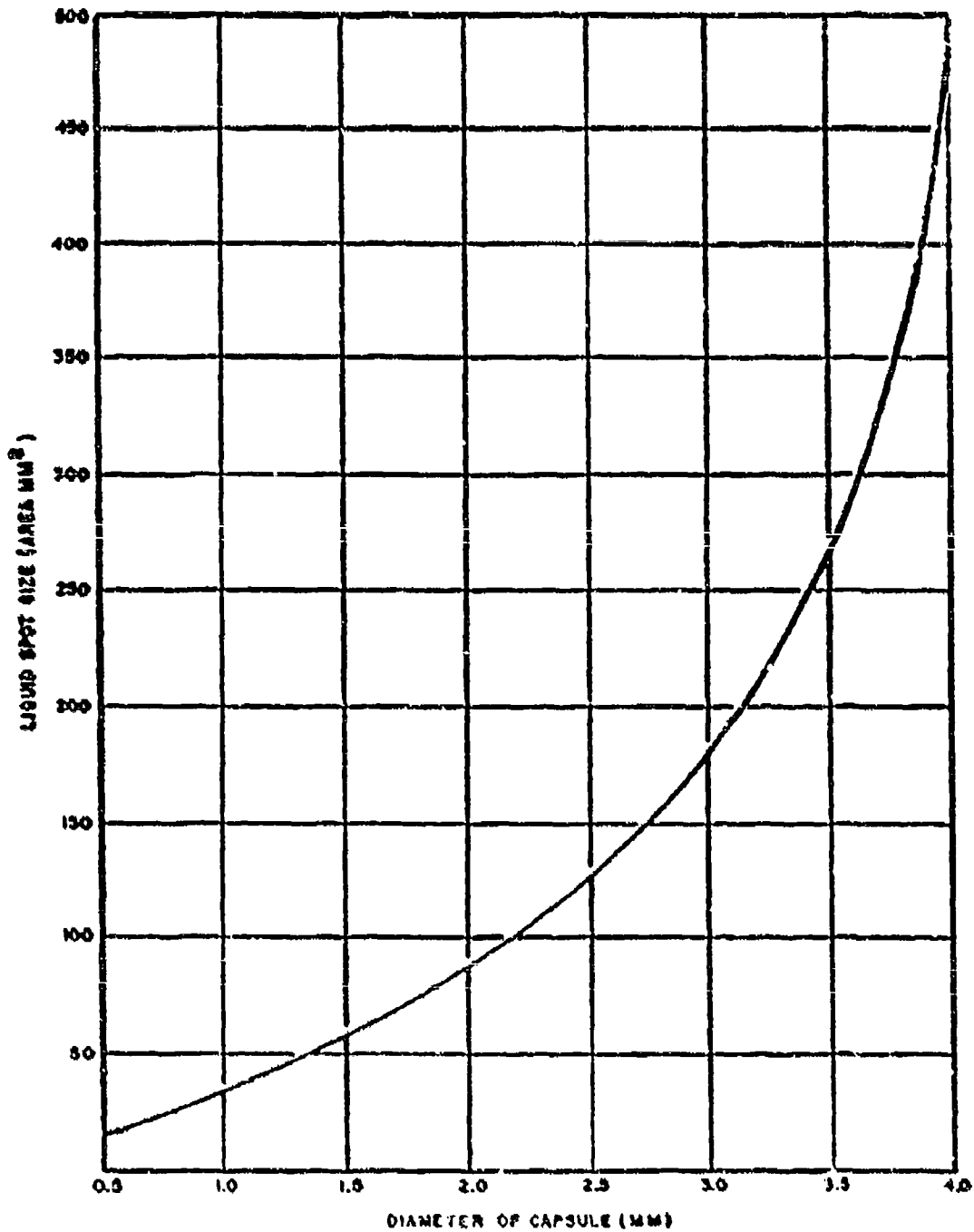


Figure 29
Liquid Spot Size Versus Capsule Diameter

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The dwell time on the detector $\tau = \frac{\text{Field of View}}{\text{Angular Rate}} = \frac{8.7 \times 10^{-5} \text{ rad}}{.9 \text{ rad/sec}}$

$\therefore \tau = 9.7 \times 10^{-5} \text{ sec or } 97 \mu\text{sec.}$

The electrical bandwidth of the system $\Delta f = \frac{1}{\tau}$

$\therefore \Delta f = \frac{1}{.97 \times 10^{-4}} = 20,000 \text{ cycles.}$

The N.E.P. of a detector is degraded by the square root of its bandwidth.

Consider a sensitive photomultiplier like the RCA Tube 7029, with a No. 17 spectral response which peaks at 5000 Å.

It has an NEP of 1×10^{-11} lumens. Since it is rated at 125 $\mu\text{A} = \text{Lumen}^{-1}$, the dark current is $1.25 \times 10^{-4} \times 10^{-11} = 1.25 \times 10^{-15}$ amps.

At the peak sensitivity (5000 Å), the spectral sensitivity is given as 0.085 ampe/watt.

This indicates an NEP for 1 cycle bandwidth of $\frac{1.25 \times 10^{-15}}{.95 \times 10^{-1}} = 1.47 \times 10^{-14}$ watts.

The sensitivity of our proposed receiver is $\frac{1.47 \times 10^{-14}}{(2 \times 10^4)^{1/2}} = 1 \times 10^{-12}$ watts.

If this detector is mounted behind a telescope, one can now calculate the size of the collector needed to detect at 500 feet. In using formula No. 1, it is found that the collector area need be

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only 21 cm^2 or a diameter of 5.2 cm (2").

If one utilizes a 6" collector, the range can be increased to 1400 feet.

From a practical consideration, this system is severely limited by the size of the spot on the ground directed from the light source. Even with excellent intelligence of the location of capsule dissemination by the pilot, the use of such a narrow beam would constitute a very difficult search pattern problem.

Scanning is not a satisfactory solution because of the rapid speed of the aircraft.

A possible solution is to project on the ground, a long narrow fan beam of radiant energy at right angles to the path of the aircraft.

If a cylindrical convex lens or a spherocylindrical (Toric) lens is utilized to project a spot as a long narrow, astigmatic streak, two problems are created:

1. The proportion of line length to range height is in ratio to the projection lens diameter to the focal length. Thus, a very small diameter lens or long focal length lens is needed to project a line 100 feet at an altitude of 1000 feet. This means the use of large f number lens, like F40. Such a lens utilizes a small fraction of the incident light. One tenth of a radian, squared equals .01 steradians, which is only 8×10^{-4} of the 4π steradians being emitted.
2. The energy now reaching the ground is spread out over an area of 100 feet by 10 feet instead of concentrated in the small 6" diameter circle, thus the 1 cm^2 spot of fluorescent material is receiving and returning only 1.1×10^{-6} of the energy on the ground.

Even at 500 feet, the energy incident on the receiver will be reduced to 10^{-14} watts or 2 orders of magnitude below threshold response.

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Another technique is the use of a long filament and a spherical projection lens. Here, the filament length and diameter are projected on the ground magnified in the ratio of range to focal length and the same two problems arise.

A very attractive solution is offered by the use of a Xenon flash tube. These have the added advantage of approximating black body sources of 6500° K temperature. Thus, the spectral radiant output peak occurs at $\lambda = 0.45\mu$, or very near the absorption peak of uranine. (See Figure 26)

The E, Q, and Q₁ flash lamps, for example, can be obtained in dimensions of several sizes from 5 x 1 mm to 30 x 2 inches.

Considering a flight speed of 300 mph or 13.5×10^2 cm per second, if the projecting optical system consists of a 6" (15cm) diameter lens of focal length = 37.5 cm, making this an F/2.5 system; and assuming an arc dimension of FX-1 type lamp (3 inches long by 1/2 cm diameter), the projected spot on the ground from a height of 400 feet is 100 feet x 7 feet.

Since the width of the bar is 7 feet or about 210 cm, and the craft flies at 13.5×10^2 cm/sec., the number of pulses per second need be only $\frac{13.5 \times 10^3}{2.1 \times 10^2} = 60$

Since the tube can handle 5 joules (watt - sec.) of energy, if the duration of the flashes is limited to 20 μ sec. (12 μ sec is the limit of this particular tube), the peak power achievable is $\frac{5}{20 \times 10^{-6}} = 250,000$ watts.

The average input power required is 7 watts, and the lamp can operate from a 28 volt DC aircraft supply.

The lamp requires a large bank of capacitors, but this is a small price to pay for feasibility. Another serious problem with such a strong peak pulse, is the need to provide severe shielding to the photomultiplier.

Applying formula (1) where I is now 2.5×10^5 watts, and the light is spread over a 100 by 7 foot bar on the ground, the range is

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500 feet, one finds that the N. E. I. $\approx 3 \times 10^{-12}$ watts, which approaches the detectable threshold.

Due to the difficulty of encapsulating sodium fluorescein, and because in its non-polar form, uranine loses much of its fluorescent efficiency, other fluorescent materials had to be investigated.

Among the most efficient fluorescing oil soluble materials are the polynuclear hydrocarbons. Samples of several of these materials were obtained for evaluation. Care was taken in the handling of them since they are known to be somewhat carcinogenic. They are listed below with their maximum emission wavelengths.

Hydrocarbon	Emission Maxima (mμ)			
	A	B	C	D
Anthracene	400	398	401	406
Perylene	440	438	---	443
Coronene	447	450	---	447
Fluoranthene	462	464	468	467

These all appeared to be relatively inefficient fluorescing agents compared with uranine when stimulated by the tungsten light source through the crystal violet filter, or the blue cobalt filter. Perylene was the best of the group.

Under the mercury arc lamp, however, the 3650 Å line, caused a high degree of absorption in all materials, dilute perylene again demonstrating maximum fluorescent intensity on emission (the dilution being on the order of a few parts per million by weight in xylene solution). While under tungsten radiation of 3000° K ($\lambda_{\text{max}} = 10,000 \text{ Å}$) perylene does not achieve the high degree of fluorescence that uranine provides, it would probably increase its efficiency under the xenon flash lamp radiation ($\lambda_{\text{max}} = 4500 \text{ Å}$).

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Under the long wave mercury Arc ($\lambda = 3650 \text{ \AA}$), it appears to surpass uranine.

The feasibility of perylene, Fluorol OB and Velva Glo dye brighteners as emitters caused us to re-evaluate mercury sources as airborne stimulators. General Electric produces a 1000 watt, high pressure mercury vapor tube which yields about 7% or 70 watts of its output radiation in the $3650 \text{ \AA}$ line.

If a F-1.0 optical system, utilizing a sphero-cylindrical convex quartz lens, is used to image a 100 foot by 10 foot band on the ground, its collection efficiency approaches 5%, thus 3.5 watts are spread over the ground area of $9.0 \times 10^5 \text{ cm}^2$. The broken capsule spot of about 2 cm^2 , returns 2.2×10^{-6} of this energy or 7.7×10^{-6} watts. This assumes a 100% fluorescent efficiency. For a 66% efficiency, 5×10^{-6} watts are emitted.

The spot now acts as a point source radiating into a hemisphere. It is detected by the airborne photomultiplier with a previously calculated system sensitivity of 10^{-12} watts.

It is then possible to calculate the useful range of the system since:

$$R_s = \left(\frac{I A_{\text{coll}} T_o T_A T_{\text{ch}}}{\pi \text{ NEP } S/N} \right)^{1/2}$$

R_s	=	system range
I	=	source intensity = 5×10^{-6} watts
A_{coll}	=	collector area for 8" mirror $\approx 314 \text{ cm}^2$
T_o	=	transmission of optics = 0.7
T_A	=	transmission of atmosphere = 1.0 at short ranges
T_{ch}	=	"chopper" efficiency = 0.5
NEP	=	10^{-12}
S/N	=	1

Therefore:

$$R_s = 1.75 \times 10^4 \text{ cm} = 440 \text{ feet}$$

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Figure 30 indicates the artist's concept of the ground marker detection system which consists of a transmitter module and a receiver module.

The light source of the transmitter module is an arc lamp like a xenon flash tube, but could as well be a mercury high pressure arc. An astigmatic mirror directs the linear beam on the ground as described in Section 5.7.4. The window through which the energy passes is coated with a Wratten type filter, centered at 4500 Å in the case of a xenon source, at 3650 Å if the mercury lamp is used.

The receiver module is basically a telescopic collector. A parabolic front silvered mirror primary and a folded Newtonian flat secondary focus the beam through an optical filter on to the front of a photomultiplier cell. The filter does not match the filter in the transmitter, but centers on the emission line of the fluorescent material. The problem of background radiation from fluorescence of decaying vegetation is still an unknown quantity. Chlorophyll is fluorescent at the longer (red) wavelengths and should be totally removed by the choice of appropriate filters with steep cut on and cut off characteristics.

It is suggested that floral fluorescence characteristics should be studied under the illumination of the 3650 Å light source.

5.7.5 Conclusions

1. Ground marking agents like colored dye spots or reflecting particles appear unattractive because of low detection probability.
2. Fluorescent materials can be encapsulated. Feasibility has been demonstrated by the encapsulation of perylene, anthracene, Fluorol-OB brighteners and Velva-Glo orange dye brightner. Capsules as large as 4 to 5 mm diameter have been produced and opaques and when broken, leave an oily spot of more than 2 cm² area, emitting with high fluorescent efficiency.

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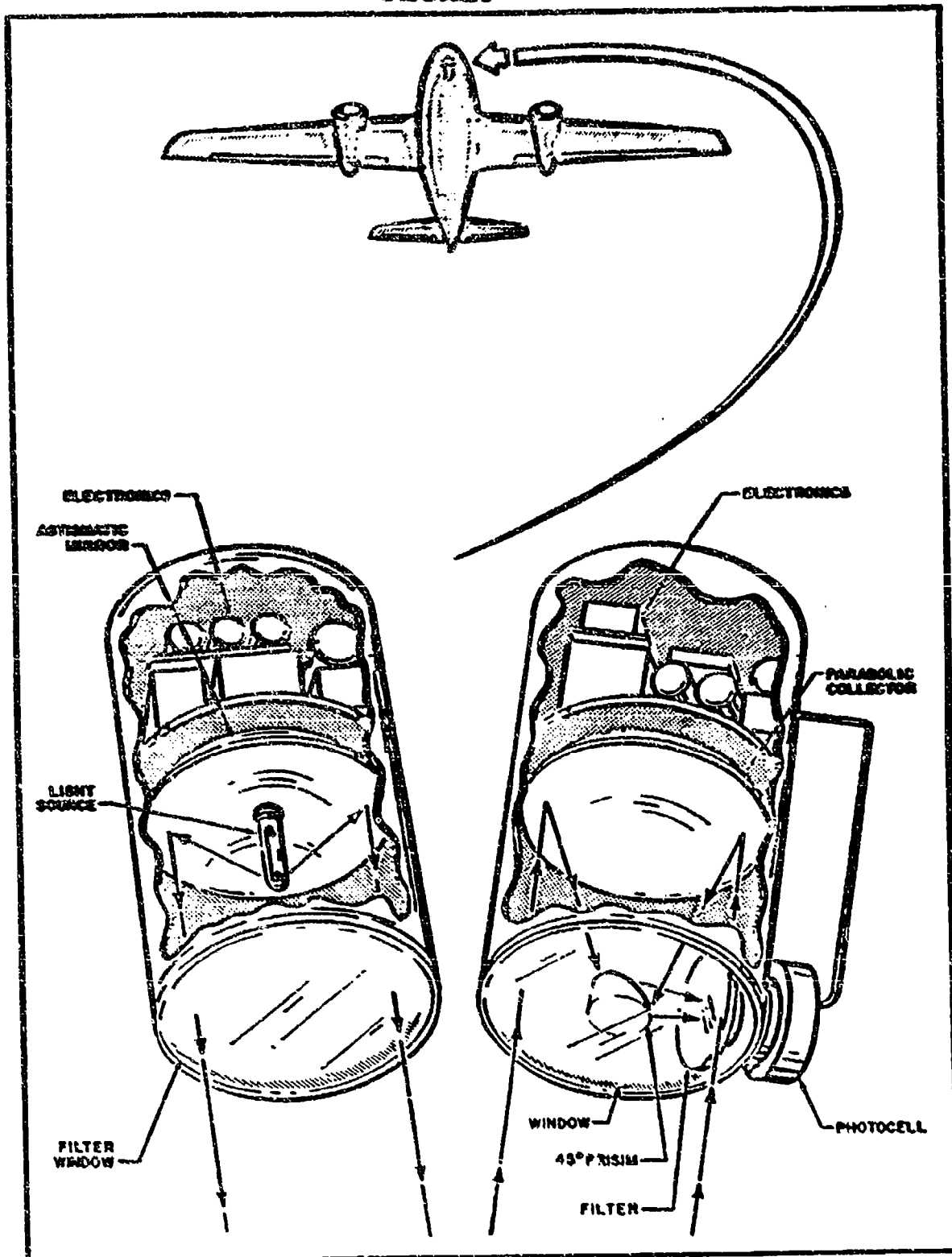


Figure 30
System Concept - Fluorescent
Ground Marking Detection

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3. Calculations and laboratory tests indicate that by use of a large enough collector and an intense enough source (within state of the art boundaries) detection of a small fluorescent spot is feasible from low altitude (under 500 feet) high speed (up to 400 knots) aircraft at night.

4. Background fluorescence of naturally decaying flora and fauna do not appear to be a serious background problem.

5.8 PERSONNEL MARKING TECHNIQUES

5.8.1 Theory

Previous sections have dealt with various methods for putting tracer elements into the air or on to the ground, both indicating activity by insurgent forces. In these situations, the reagent is disseminated from the air and detection also is carried on from the air.

The methods of personnel markings to be discussed in this section allow for airborne dissemination of the marking agents, but do not lend themselves to practicable methods of airborne detection.

They do, however, fulfill a definite need to the overall tactical problem of locating and marking indigenous personnel operating for or with the insurgent forces. Ground detection of activity by individuals and small bands is essential for the security of friendly personnel, materials, and weapons. Military aircraft, airfields, supply depots and other installations must be secured from infiltration, sabotage, and surprise attack. Friendly force personnel must be appraised of the loyalty of local peoples providing the labor force at these installations. Trails and paths between installations, fortified hamlets, et cetera must be secured from ambush.

In the light of these problems, the ability to single out those

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indigenous personnel who have been marked, and thereby identified as having been in an "off limits" area, or in an area where recent guerrilla activity is known to have occurred, gives us a useful psychological as well as tactical weapon.

5.8.2 Marking Agents

5.8.2.1 Skin Dyes

Capsules containing dyes which are color-fast, when crushed underfoot, will stain the foot or sandal. If any equipment is being dragged about or set down, these too will be marked. Such dyes as eosin, crystal violet, safranin et cetera, are very difficult to remove without abrading the outer layers of skin. Acid solutions can remove them, but large supplies of acids are not readily available to the insurgents. A dye like crystal violet would probably remain for several days to a few weeks depending on the wear given to the skin or leather which is stained. The bright purple color is not something which could be acquired by any natural jungle area stains. A quick inspection of the soles of a man's sandals or feet will indicate the presence or absence of the stain.

5.8.2.2 Leuco Dyes

Unfortunately, the stain is an obvious one to the man who is marked. Not only does he know he is marked, but might quickly determine how it was done. One solution to this problem is the use of leuco dyes, that is, dyes which in their leuco or un-oxidized forms are colorless, and gradually in the presence of oxygen, transform to the oxidized colored configuration. Methylene blue, for example, appears under special pH conditions in a leuco form. Colorless indoxyl transforms to indigo a strong bluish purple dye. A man so marked would not have a visible stain for a period of time and probably would not associate the color when it did appear with his walk along a certain path or area.

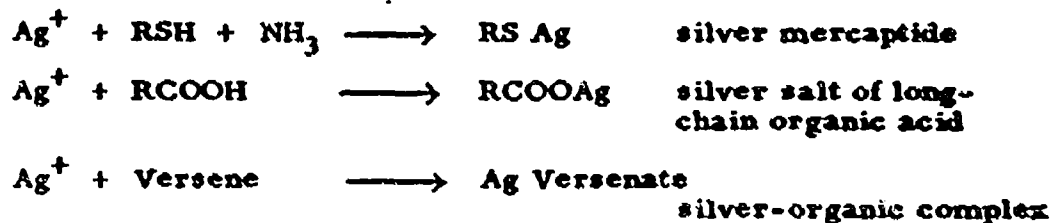
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We have tried to encapsulate indoxyl, but found that the conversion from the leuco to the indigo dye form requires more rapid oxidation than that provided by the air. The presence of a strong oxidizing agent appears to be required at ordinary temperature.

5.8.2.3 Silver-Salt Reactions

Many silver salts are reacted on in the presence of sunlight so that free silver is reduced as in the photographic process. If large silver organic molecules are encapsulable (which is a theoretical possibility) in opaque capsules and then are pressure released onto the foot of an individual, rapid oxidation-reduction should lead to the depositing of small black stippled spots of free silver on the skin not easily removed without a little gouging. Suggested silver-organic molecules to be investigated are:



5.8.2.4 Tanning Agents

The same is true for the tanning agents like those now employed in acquiring artificial tan purchased in bottles at drug stores everywhere in this country. The active ingredient is a white powder called dihydroxyacetone which has been used for years as a tanning agent for hides and as a wood preservative. The manner in which it tans human skin is still something of a mystery, but it is known that it affects only the keratin protein of the outer skin layer. You cannot wash it out, but the color will fade in a week or so with gradual sloughing off of the old skin.

A rice farmer with a tan on the bottoms of his feet would

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certainly be suspect of having wandered deliberately or accidentally into an area seeded with dihydroxyacetone capsules.

5.8.2.5 **Fluorescent Agents**

Fluorescent dyes can be put into media which will cling to skin or sandal leather or straw, and fluoresce intensely under a small hand held portable U. V. lamp like the gem hunter's "mineralite". The same fluorescent materials discussed in Section 5.7.4.1 are equally applicable here. The same portable U. V. lamp can be used by ground patrols for following "luminous" footprints where the material has served as a ground marker, and then as a detector of personnel markers.

5.8.2.6 **Ineradicable Stenches**

Another broad classification of markers, are the olfactory agents which apply a distinguishing odor to the individual. The human nose is highly sensitive to certain odors like

1.	methyl mercaptan	4×10^{-8} mgm/liter
2.	artificial musk	4×10^{-5} mgm/liter
3.	propyl mercaptan	6×10^{-3} mgm/liter
4.	butyric acid	9×10^{-3} mgm/liter

These odors are pervasive, difficult to mask, and hard to get rid of. Most important, they are characteristic. If there is nothing in the area which produces a similar odor or stench, the individual is "tagged".

Again, the quality of covertness is compromised. A guerrilla stepping down and then smelling the strong obnoxious odor of methyl mercaptan will search the trail and find the source, small broken capsules still reeking of reagent. This may, however, create a new situation to our advantage. If an area is known to the enemy to be seeded, he cannot go in and neutralize or collect all of the capsules the way he might neutralize a known mine field. He may avoid the area rather than take the chance of being identified. This will allow a large measure of area denial

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which provides strategic or tactical advantage.

5.8.2.7 Time Delayed Odors

The feature of covertness would again be introduced to the system if an odor was used as a tag which only appeared after a time lag.

It has long been known in the industrial hygiene field, that tellurium (Te) compounds, when injected or inhaled in extremely small quantities (~micrograms) by human beings and many animals, confers a pronounced and long lasting garlic odor upon the breath and body fluids. The effect was first reported in 1824 and was extensively written up in the literature of industrial toxicology in the 1940's and 1950's. Compounds of the element selenium (Se), a close chemical relative of tellurium, exert a similar but less pronounced effect. In the amounts in which they produce the garlic odor syndrome, tellurium compounds are relatively harmless; no serious symptom of physiological disturbance, aside from nausea and/or loss of appetite, have been reported.

The odor of the breath and sweat of the exposed individual is often so marked as to be strongly distasteful to others, and some experiences amounting to social ostracism have been reported in the literature. In all cases, the effect is a prolonged one and may last from a few hours to months, depending on the individual and the dosage. The odor is stated by most authorities to be due to dimethyl telluride $(CH_3)_2Te$, the product formed by the body's detoxification mechanism, the extreme slowness of which accounts for the unusual persistence of the symptom.

Reisert (21) observed in 1884 that 0.5 μ gm of $Te O_2$ (tellurium dioxide) taken orally by humans produced, within one hour and fifteen minutes, garlic breath which lasted for 30 hours. In a 1947 study on ascorbic acid therapy for tellurium intoxication, De Meio (22) found that orally administered doses of 1-50 micrograms of sodium tellurite in solution induced garlic breath in 20-30

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minutes in a test involving 13 men and 7 women. Elemental tellurium as powdered metal was found to be much less effective. In the same paper, De Meio reported that massive or repeated doses of ascorbic acid were effective in suppressing or eliminating the odor in workers occupationally exposed to tellurium dust, but he did not discuss the treatment for single acute dosages of Te compounds. A single inhaled or swallowed dose of 100 micrograms would almost certainly produce a definite garlic odor on the breath, but the time of onset and persistence of the symptoms are difficult to predict. De Meio believed that the differences in human response to the agent were unrelated to sex, body weight, or diet.

If a large group or column of men broke a number of capsules and kicked up some of their contents with the dust, it is conceivable that enough material would become airborne so that some of the men immediately following those who did the capsule breaking would inhale enough tellurium to develop within a matter of hours a persistent garlic odor of the breath, sweat, urine, feces, and saliva.

5.6.3 Discussion and Conclusions

To the degree that these agents are not noticeable to the insurgent, and to the degree in which they persist, all of these personnel marking agents are useful. Unfortunately, none lend themselves to airborne detection.

In the last stages of the program, the problem of being able to produce large capsules without compromising capsule wall integrity was solved. Having at our disposal capsules of 3, 4, or 5 mm diameter permits us now to contemplate new and intriguing ideas to enhance the TREAD concept.

For example, it would not be unreasonable to think of loading a capsule with a fine fluorescent powder and a material which, when exposed to air or moisture on capsule rupture, explodes and sprays an aerosol or a dust cloud several feet into the air so that fluorescent or dye particles spray all over a man's

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body, clothing, hair, and equipment. It is even conceivable that this material could then be detected from a low flying aircraft.

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6.0 SUMMARY AND CONCLUSIONS

In a four month program which spanned the period 25 June to 24 October involving more than 2000 man hours of library research, calculations, laboratory tests and experimentation, and field trips, the TREAD concept was given intensive study. As a result of this study, feasibility for certain portions of the program was demonstrated, nonfeasibility for other portions was determined; several areas, not receiving sufficient study, were left indeterminate. Only those areas, however, which did not appear attractive were included in the category of insufficient study. Study in certain areas of investigation led to new problems which could not be encompassed in the present program. These are discussed in Section 7.0.

The following statements incorporate a summary of findings and the major conclusions and deductions drawn from them.

1. Tracers A list of various reagents to be used as air tracers, ground tracers, and personnel tracers was drawn up and encapsulation of these reagents attempted.

A. As an airborne contaminant or tracer, it was decided to encapsulate a low molecular weight hydrocarbon which could, by a transfer method, have tagged (radioactive) carbon substitute for the nonradioactive carbon atoms. Benzene and toluene as well as the heavier diethylbenzene were all successfully encapsulated. No attempt was made in this study to carry on radioactive transfer.

B. Since the airborne vapor detector scheme involving exchange of tagged atoms in an airborne exchange bed required HCl vapor, the encapsulated material of choice had to be a chlorinated hydrocarbon. Several reagents were rejected because their low boiling points made them incompatible with the encapsulation technique. Cis -1,2- dichlorethylene was encapsulated but the

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internal phase was lost during drying operations. Finally 1,1,1-trichloroethane diluted with toluene or isooctane was successfully encapsulated.

C. As a material needed to demonstrate absorption bands in the near infra-red region of the spectrum for long range optical detection, benzene and toluene, already encapsulated, were chosen.

D. As a fluorescent ground marker, sodium fluorescein was selected because of its high efficiency and absorption of energy from tungsten or xenon sources. When it was found too difficult to encapsulate, it was rejected in favor of the polynuclear hydrocarbons. Both anthracene and perylene in xylene were encapsulated. Fluorol-OB dye brightener was also successfully encapsulated in a cotton seed oil substrate.

E. While a large number of dyes, leuco dyes, stains, and olfactory markers were studied, only a few were encapsulated to show feasibility. Velva-Glo dye brightener - orange in a substrate of silicone oil proved highly successful. Velva-Glo dyes can be obtained in nine different colors. Black enamel paint was also encapsulated as was cinnamaldehyde, a staining agent.

2. Capsules were given a multitude of tests to determine their shear strength, elasticity, water impermeability, ability to withstand temperature and pressure extremes et cetera. With the exception of poor water impermeability of some batches of capsules, they met all of the other requirements. Laboratory tests proved that the collapse of some capsules in water with subsequent loss of reagent was of a physical nature involving hydration of the protein wall rather than biolytic activity like bacterial digestion or enzyme lysis.

Several steps taken to prevent this occurrence included the use of hydrophobic materials in or on the walls, the use of substrates or diluents with little or no water solubility, the tightening of the polypeptide linkage during capsule wall formation. Each method individually or in combination with the others seems

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to have eliminated the problem.

3. Environmental conditions which might alter the dispersal behavior of air dropped capsules, or affect their life on the ground, or which influenced the released tracer after liberation from the ruptured capsule, were studied.

A. Dense foliage appears to spread the capsule distribution causing a lower ground density than that found in open areas by as much as a factor of 10.

B. Capsule life time in the absence of pressure rupture is dependent on the gradual diffusion loss of reagent which should take many months, unless waterproofing has not been adequate, in which case, lifetimes of days to weeks is probable.

C. Larger capsules (2-4 mm diameter) are easily ruptured by an adults footstep when he is wearing shoes, on clay soils, grass and firm soils.

D. Micrometeorological factors such as local inversions and lapses, wind velocities, terrain features causing eddies and turbulence, all affect markedly, the distribution of released gases in the air. Dye dispersion experiments and field trips to forested areas where cloud forming agents were released indicate that these are a complex set of factors which require more study. Afternoon inversions, for example, will tend to hold down released gases which would have to be sampled before the late afternoon rains and accompanying lapse rate conditions with high winds and turbulence set in.

4. Two disseminating systems were derived, one fuselage mounted, the other pylon mounted. They are essentially similar in that capsules contained in polyethylene cannisters set into pigeon hole wells are released, one cannister at a time, by an automatic firing mechanism which is pre-set before the mission. Air velocity flow through the system is kept constant by automatic feedback from a pitot velometer to a variable

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opening valve.

Ground concentration in capsules per square foot is determined by the aircraft altitude, air velocity through the disseminator, capsule release rate in pounds per second, and configuration of air outlet duct.

5. Airborne Sampling Tracer Detection Laboratory tests indicate that the exchange bed concept for use in the air contaminant sampling sensor is feasible. Chemical detection means were utilized. Calculations indicate that, theoretically, seven orders of magnitude more sensitivity might be expected from a radiological exchange. From practical considerations such as exchange efficiency and pyrolysis efficiency, the realizable sensitivity increase over chemical detection methods is more like two orders of magnitude. Efficiency of exchange in the laboratory was determined to be 0.37 as compared with the theoretical 0.50. Whether this high level of efficiency can be maintained in the airborne instrumental concept with very high flow rates remains to be determined.

6. Long Range Optical Detection of Airborne Tracers

A. A study of various means for long range optical detection indicated that the release of colored gases from capsules is unlikely from theoretical considerations. Cloud forming agents, especially with delayed reactions appear attractive but insufficient evidence was gathered to show feasibility. Other markers seen from a distance suffer from lack of covertness as in the case of reflecting particles, or poor detectability as in the case of colored ground stains.

B. Airborne vapor detection by spectral analysis of absorption and/or fluorescent lines in the visible spectrum proved to be unfeasible. The same was true of the ultraviolet spectrum.

C. The near infra-red spectrum containing absorption lines due to molecular rotations and vibrations appeared attractive. Encapsulable hydrocarbons like benzene and toluene have several absorption lines between 0.8μ and 1.5μ .

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Laboratory tests utilizing these vapors in a long path cell and a Hilger-Watts quartz prism spectrometer proved the feasibility of detection.

D. Scattered sunlight from clouds, blue sky and even the green canopy appears, in calculation, to be sufficient when coupled with a large aperture telescopic collector and a highly sensitive photomultiplier tube, to locate clouds of these vapors if they are of sufficient concentration.

7. Ground marking reagents appear unattractive in daylight operation although they should not be ruled out entirely. Fluorescent markers appear in calculations to be detectable from aircraft at altitudes under 500 feet at night. A system design is suggested in which a xenon or mercury arc source in a stimulator module is directed in a fan beam at the earth. Fluorescent spots emitting radiation from broken capsules serve as the source which is sensed by a detector module consisting of a telescopic collector, filter, and photomultiplier.

8. Personnel markers including dyes, leuco dyes, tanning agents, silver stains, fluorescent dyes, and olfactory markers were studied. Encapsulation of Velva-Glo dye brightener-orange in silicone oil provided a colored dye which also fluoresces strongly under mercury light ($3650 \text{ \AA}$). While these agents do not lend themselves to detection from the air (primarily staining the feet and shoes), one can conceive of new uses for larger capsules so that explosives send a cloud of marking agent into the air covering the man, his clothing and equipment. This staining or fluorescent material might then prove to be detectable from the air.

As a general statement of summary, one can conclude that the TREAD concept through the use of multiple tracers in the air, on the ground, and on the insurgent, provides a feasible means for marking and detecting troops. The use of capsules provides a unique and successful method for disseminating these reagents

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so that they remain inactive on the ground until activated by troop movement.

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7.0 RECOMMENDATIONS

The 16-week program was sufficient to develop the major features of the system concept. Several reagents, techniques and programs could not be included because of the time restriction, and a number of task areas of the study were not explored to the depth that was perhaps warranted. Enough data and information have been collected to permit definition of the specific problem areas, and the following recommendations are made:

1. In the area of encapsulation, those reagents found to offer promise as useful tracers but not as yet encapsulated should be encapsulated, if this is feasible, and tested for stability and release characteristics.
2. Study should be devoted to producing double capsules (i. e. capsules within capsules), or tandem (joined) capsules to permit a more versatile use of mixed reagent.
3. The problem of "scaling up" the encapsulation process to large batch production requires further investigation and development. The successful synthesis of one-pint batches does not necessarily guarantee successful production of eight-gallon batches by the mere scaling up of ingredients and equipment by a factor of 64.
4. There are gaps in our understanding of the environmental factors affecting the diffusion of tracers in the atmosphere. Data from Dugway Proving Ground studies and Bissett-Berman Corporation investigations make it apparent that a more detailed study of inversion conditions in the atmospheres of heavily forested tropical areas is essential. Other environmental tests which should be carried out include the release of large numbers of capsules through a real forest canopy for the purpose of studying distribution, and release of cloud-forming materials in a representative tropical environment in order to study concentration and dilution problems. Background samples of tropical air should be collected and analyzed

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to determine whether trace quantities of hydrocarbons and chlorinated hydrocarbons exist to produce a background level of any consequence.

5. The disseminator should be fabricated and aircraft-mounted for testing.

6. Capsule breakage and agent release characteristics should be tested under controlled simulated field conditions, and laboratory experiments should be carried out to prove the operational feasibility of the radioisotope exchange detection system.

7. The feasibility of using absorption lines of hydrocarbons in the near infra-red spectrum should be given further investigation using a photomultiplier as the detector, and a narrow band interference filter (instead of a spectrometer prism) to isolate the absorption line. The development of the prototype hardware for a scanning long-range optical detector would follow these tests.

8. Prototype hardware for the fluorescent ground marker detector should be developed and tested.

9. Experimentation should be carried out to develop capsules which will burst under foot with sufficient violence to spray their contents upon nearby men and equipment.

10. The development of reagent-filled capsules which rupture in predictable time intervals should be pursued.

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8.0 REFERENCES

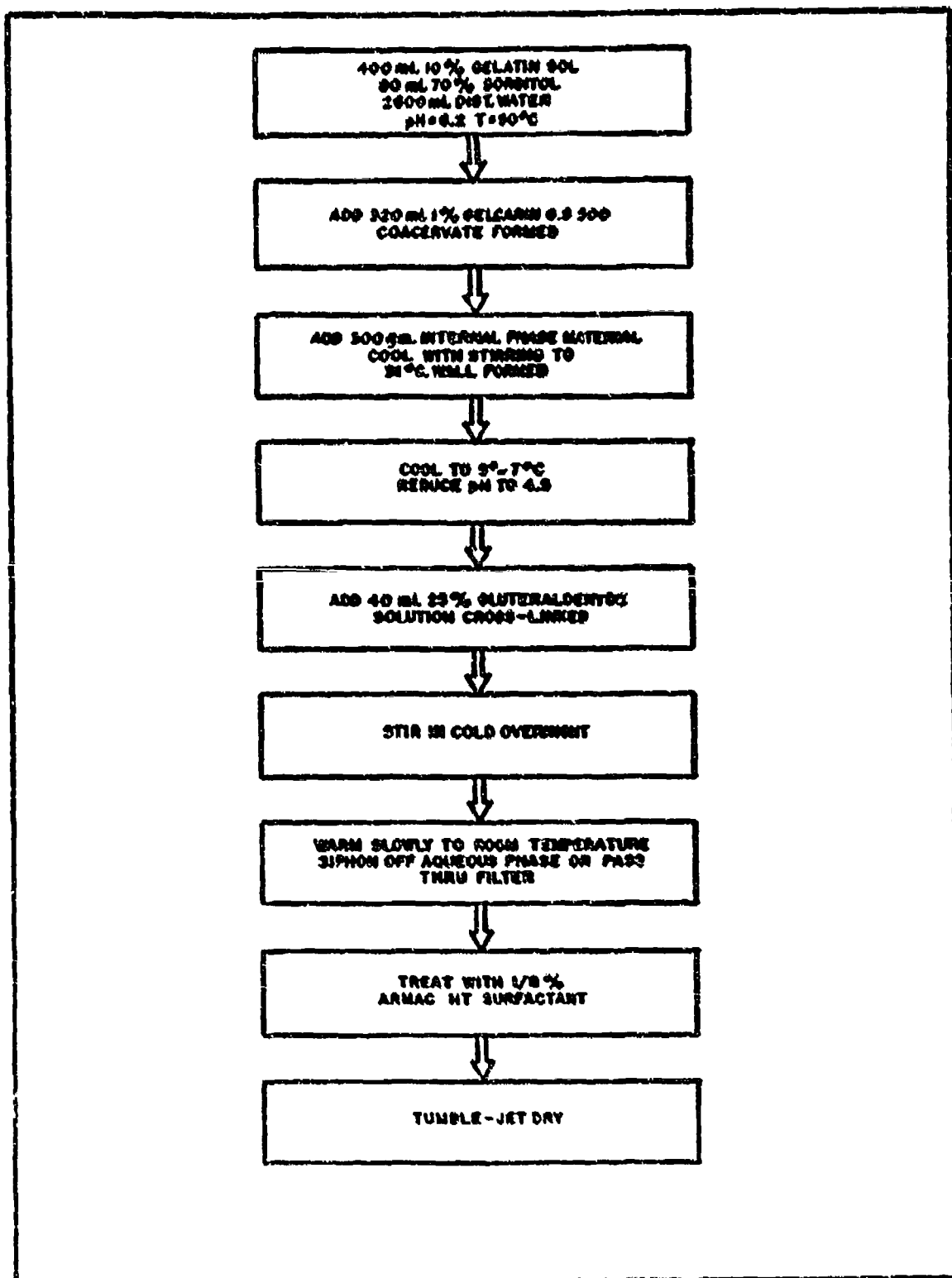
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APPENDIX A



Flow Diagram of Capsule Manufacture
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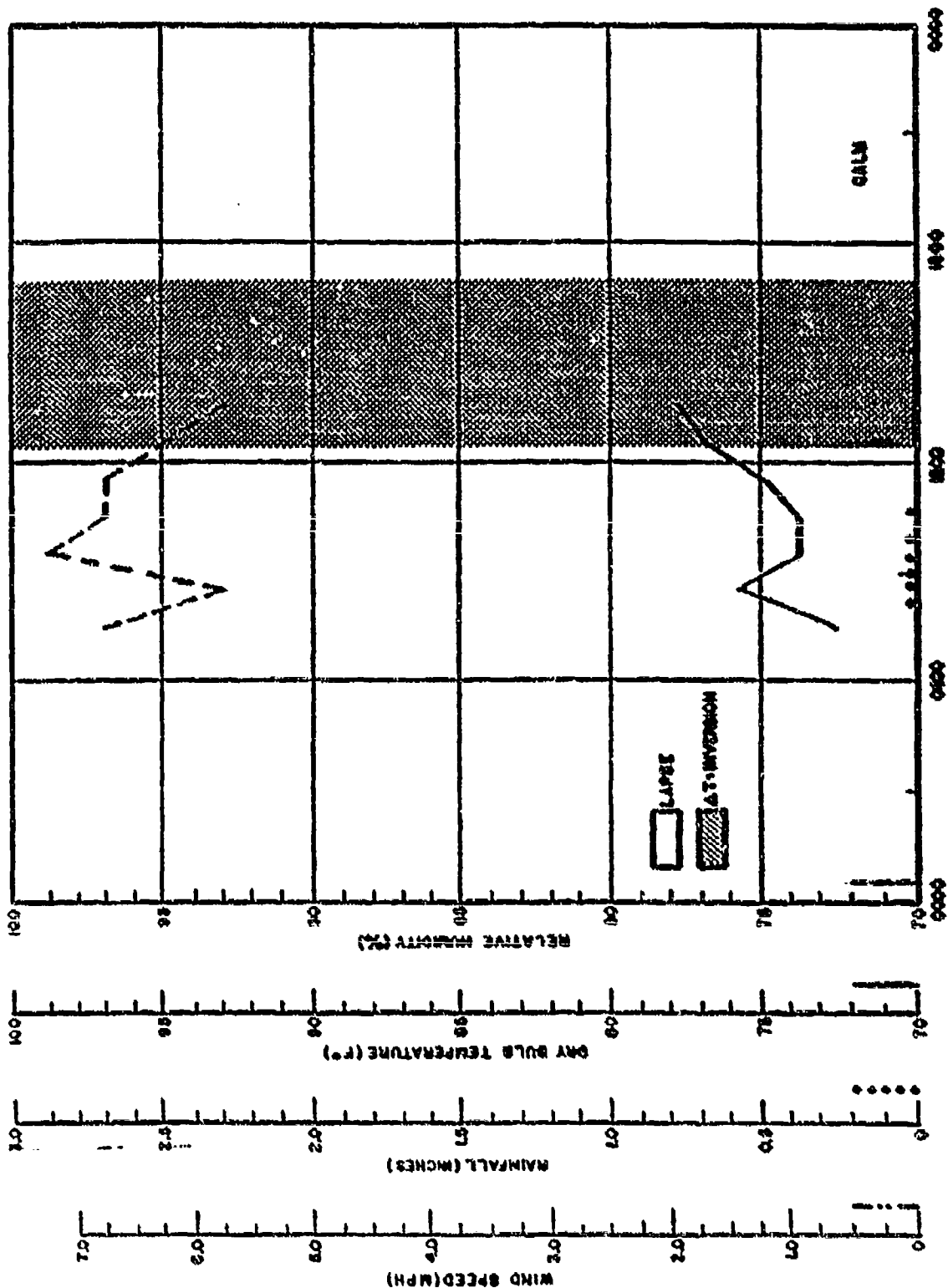
APPENDIX I.

TROPICAL WET SEASON WEATHER

Tables B-1 to B-7 summarize the weather recorded at seven locations in the Darien Jungle of Panama during the high sun rainy period. The data were taken during the period 30 August to 29 September 1961 and observed by Bissett-Berman personnel. This information together with text material from some of the other references is the basis for the summary table presented in Section 5.3.1.1.

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TABLE B3



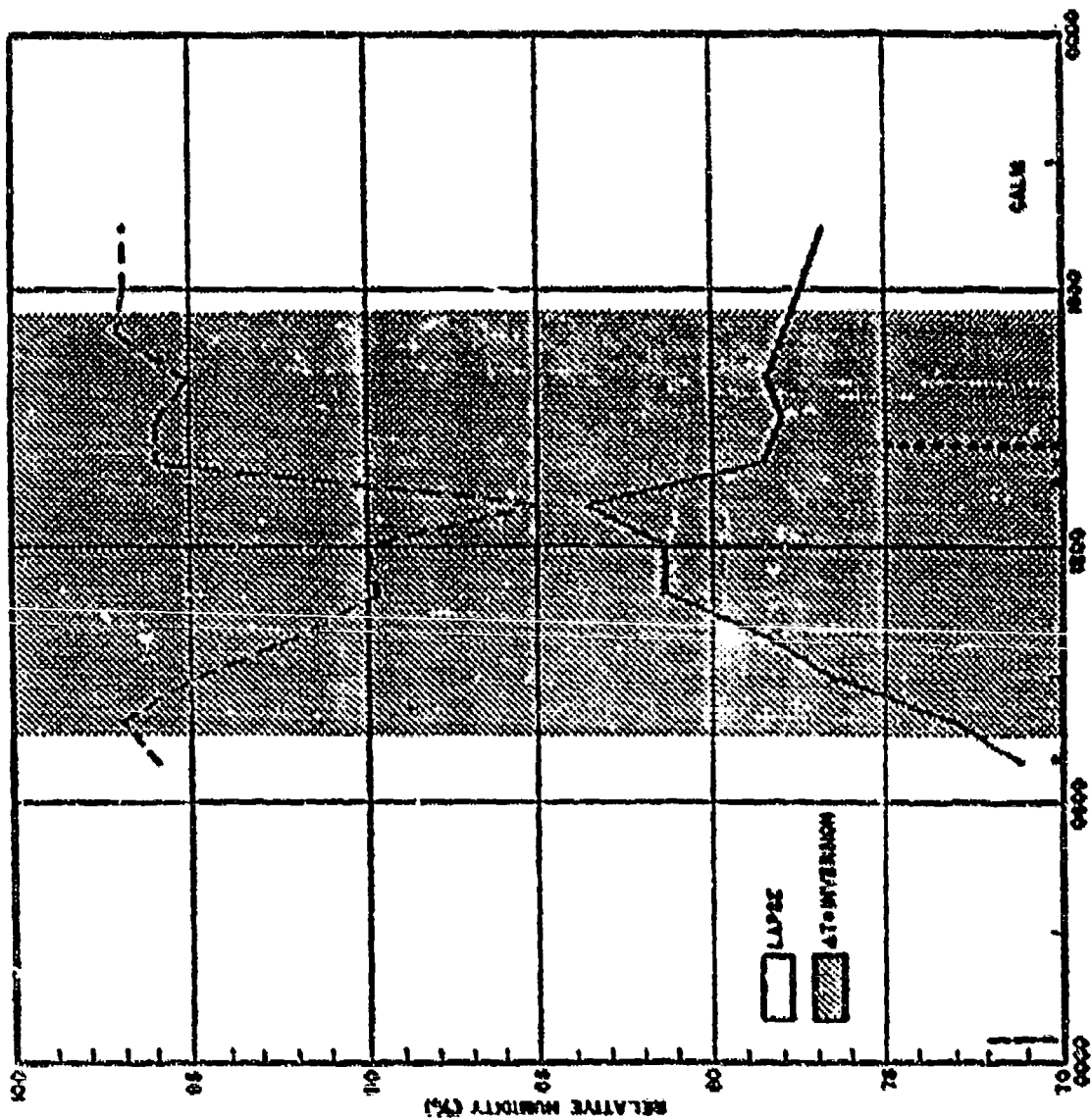
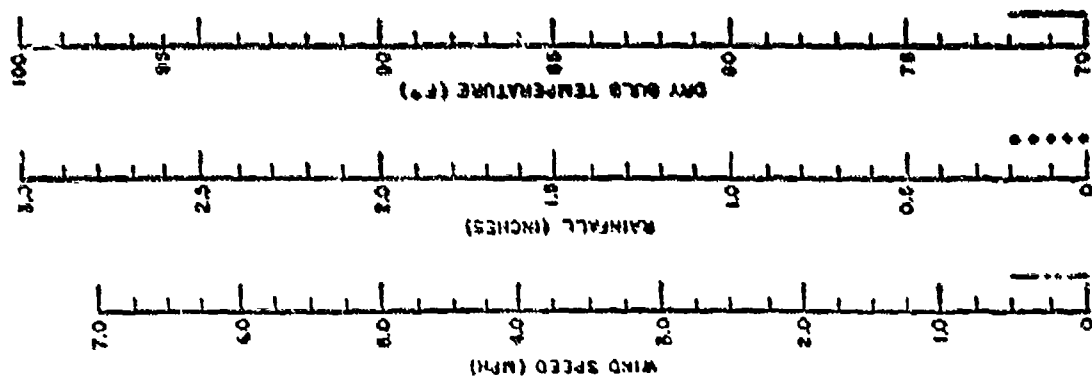


TABLE 23



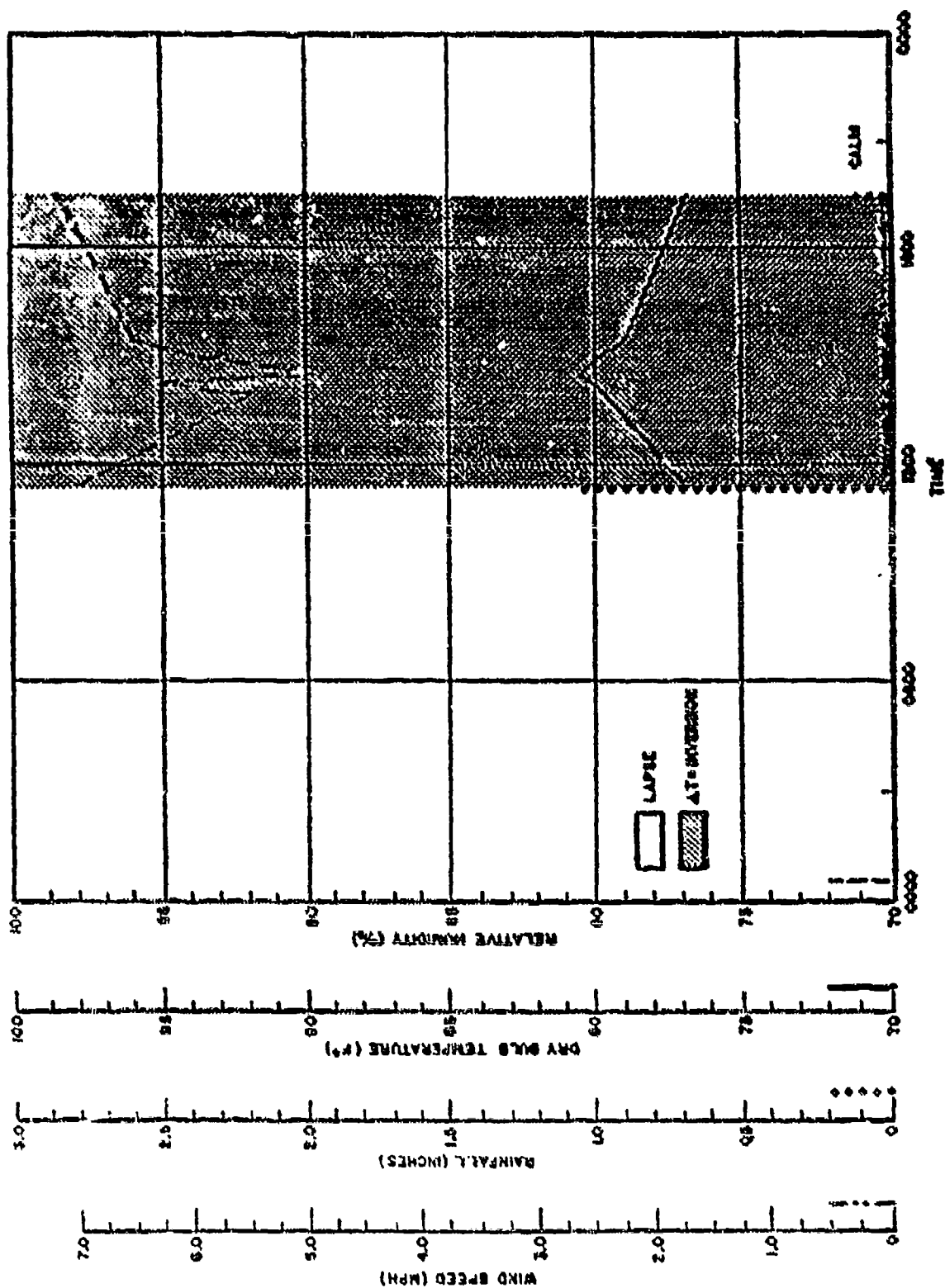
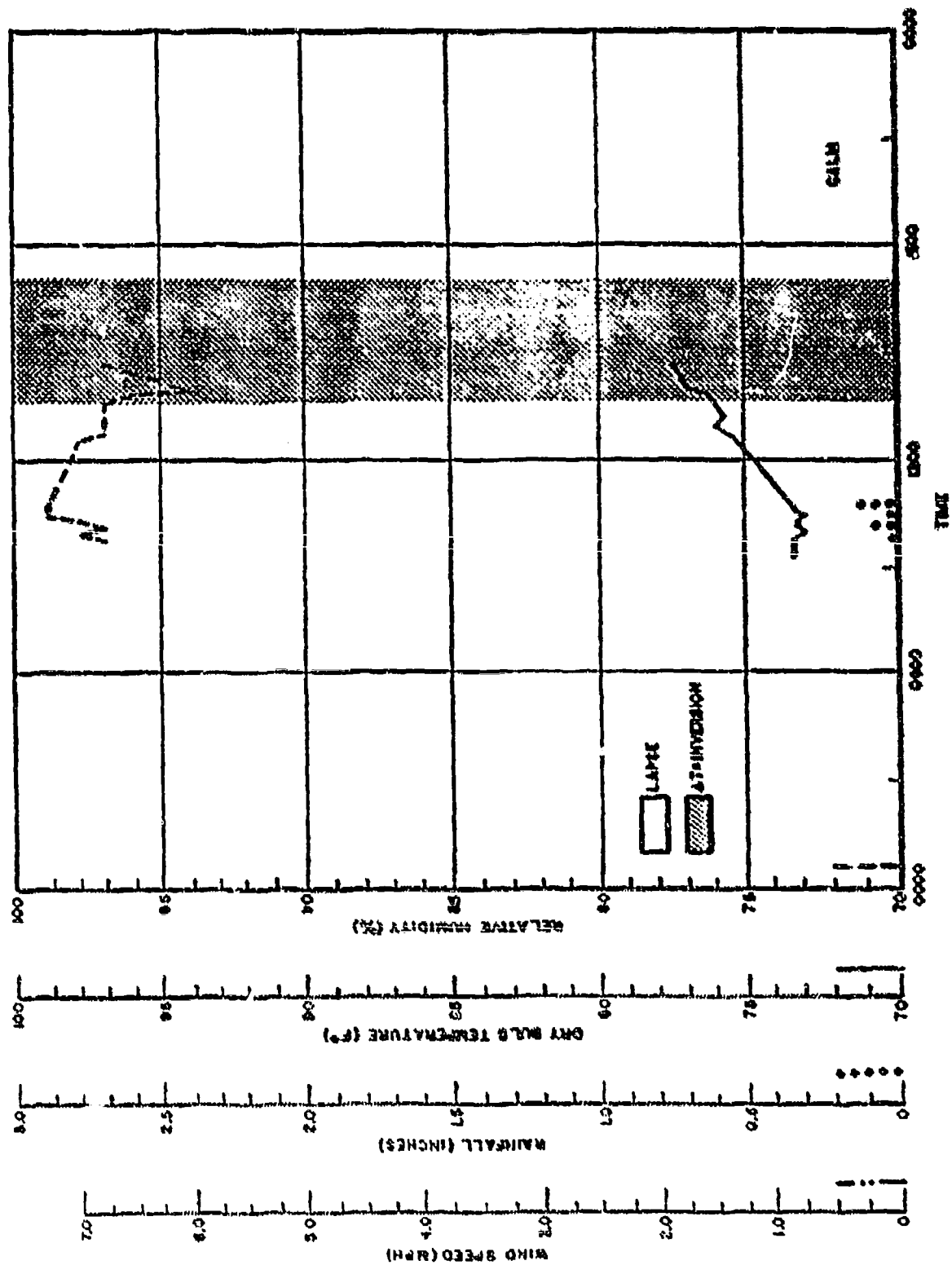


TABLE B4



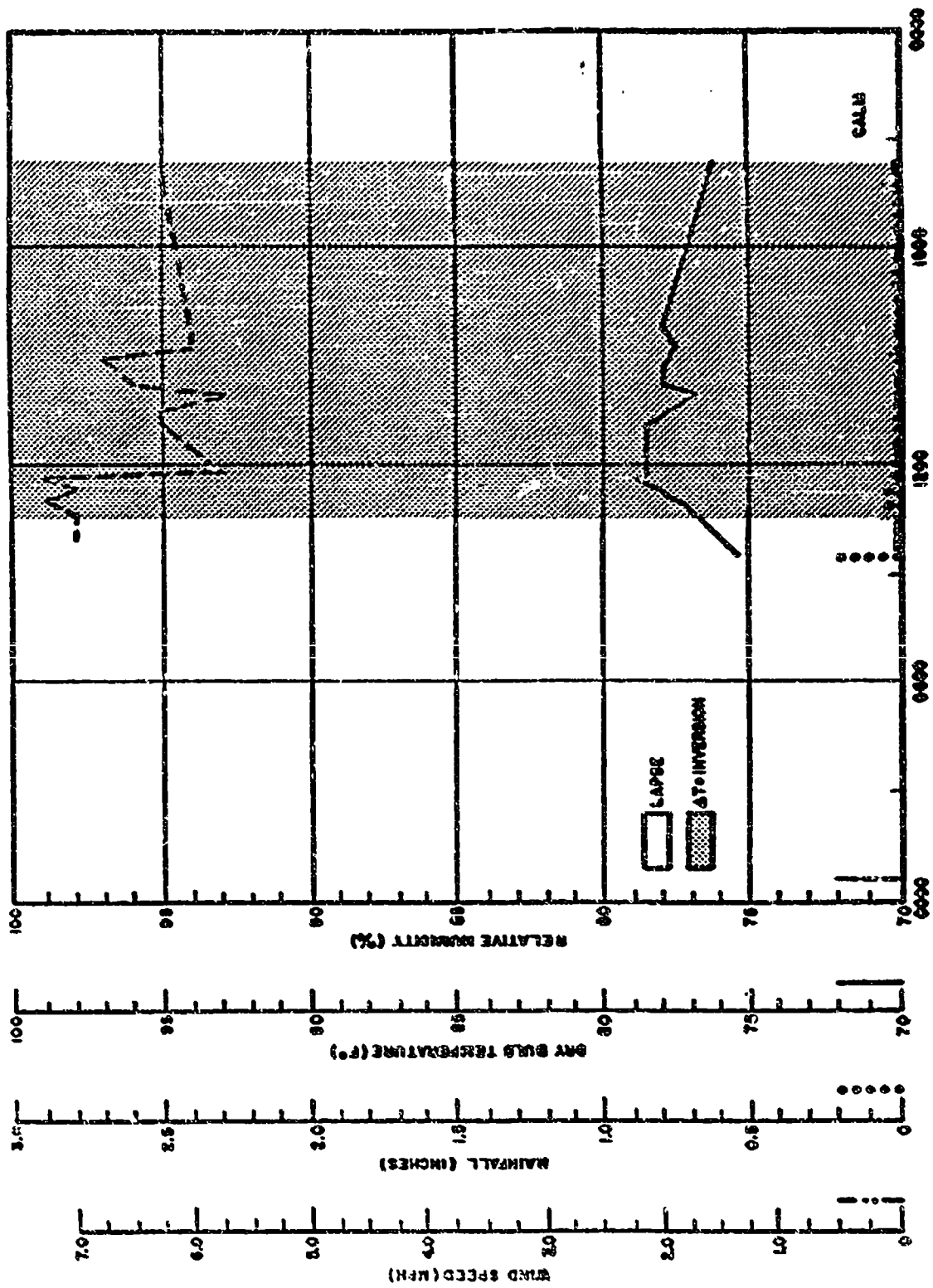
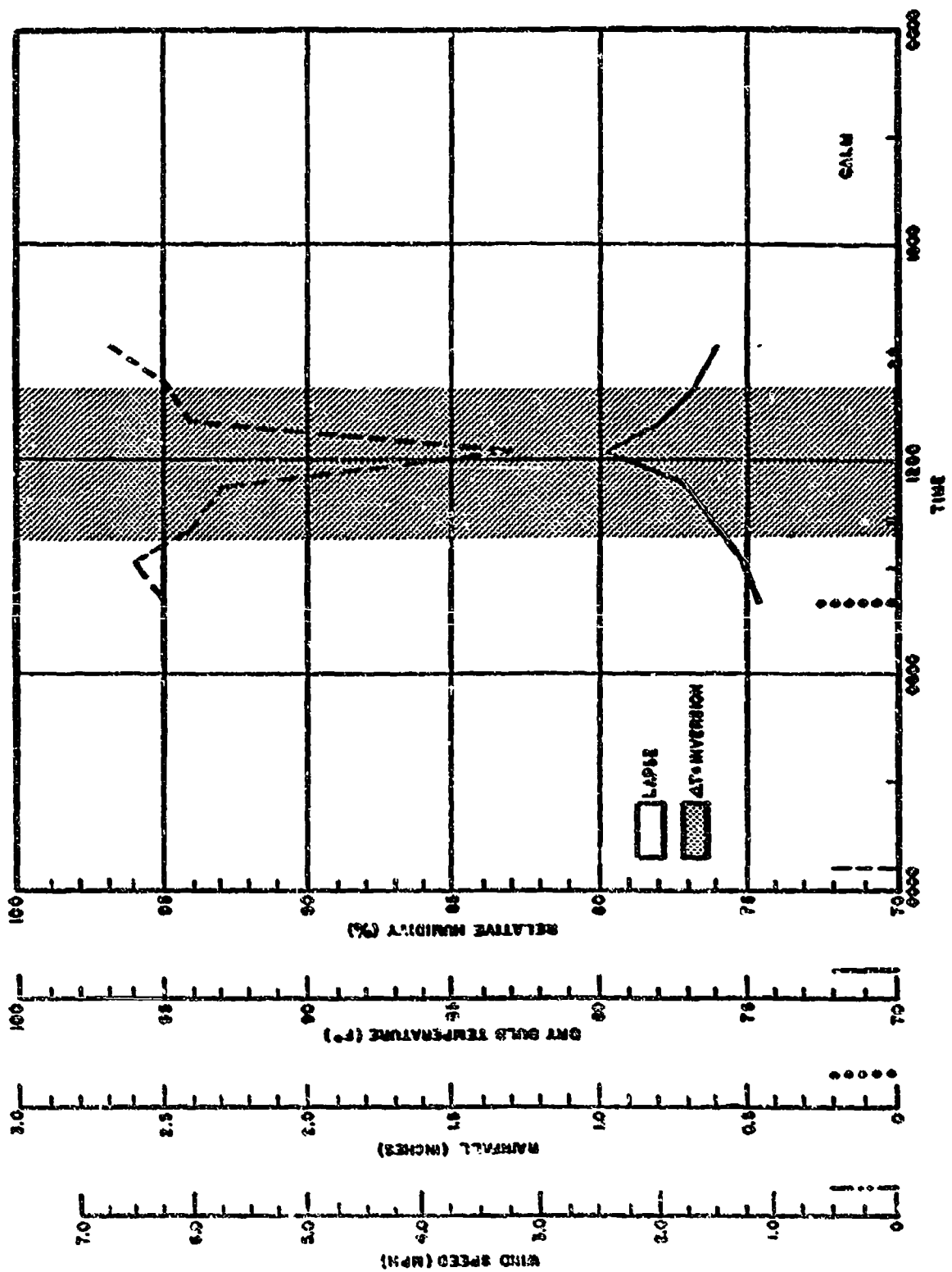


TABLE B6



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APPENDIX C

The following information is presented here as a basis for analysis of tropical environmental conditions classified according to Köppen (Reference 7).

A: Tropical rainy climates, temperature of the coolest month above 64.4° (18°C.). With monthly temperatures lower than 64.4° certain sensitive tropical plants do not thrive. This is the realm of plants known as megatherms which need continuously high temperatures and relatively abundant precipitation. Within the A group of climates two main types are recognized, one in which there is adequate precipitation throughout the year, while the other contains a distinctly dry season which affects vegetation adversely.

Af: tropical wet climate f: rainfall of the driest month is at least 2.4 in. (6 cm.). Within this climate there is a minimum of seasonal variation in temperature and precipitation, both remaining high throughout the year.

Aw: tropical wet and dry climate; w: distinct dry season in low-sun period or winter. A marked seasonal rhythm of rainfall characterizes Aw climates; at least one month must have less than 2.4 in. (6 cm.). Temperature is similar to that in Af.

Other small letters used with A climates are as follows:

m(monsoon) : short dry season, but with total rainfall so great that ground remains sufficiently wet throughout the year to support rainforest. Am is intermediate between Af and Aw, resembling Af in amount of precipitation and Aw in seasonal distribution. In both Aw and Am the rainfall of

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the driest month is below 2.4 inc. (6 cm.).

Whether it is Aw or Am depends upon the total amount of rainfall and the amount occurring in the driest month. For example, when the total annual rainfall is 50 in. the boundary between Aw and Am is 1.94 in. for the driest month; less than this is Aw; more than this, but less than 2.4 in. , is Am. At 60 in. annual total the Am/Aw boundary is 1.55; at 70 in. 1.15; at 90 in. 0.34. The boundary between Am and Aw is expressed by the formula $\underline{a} = 3.94 - r/25$, where r is the annual rainfall in inches and $\underline{a}$ the rainfall during the driest month. If with a given annual rainfall the rainfall of the driest month is greater than the value of $\underline{a}$ as obtained by the preceding formula, the climate is Am; if smaller than $\underline{a}$, it is Aw.

- w^o: rainfall maximum in autumn.
- w^u: two distinct rainfall maxima separated by two dry season.
- s: dry season during high-sun period (rare).
- i: range of temperature between warmest and coldest months less than 9° (5°C.).
- g: Ganges-type of annual march of temperature; hottest month comes before the solstice and the summer rainy season.

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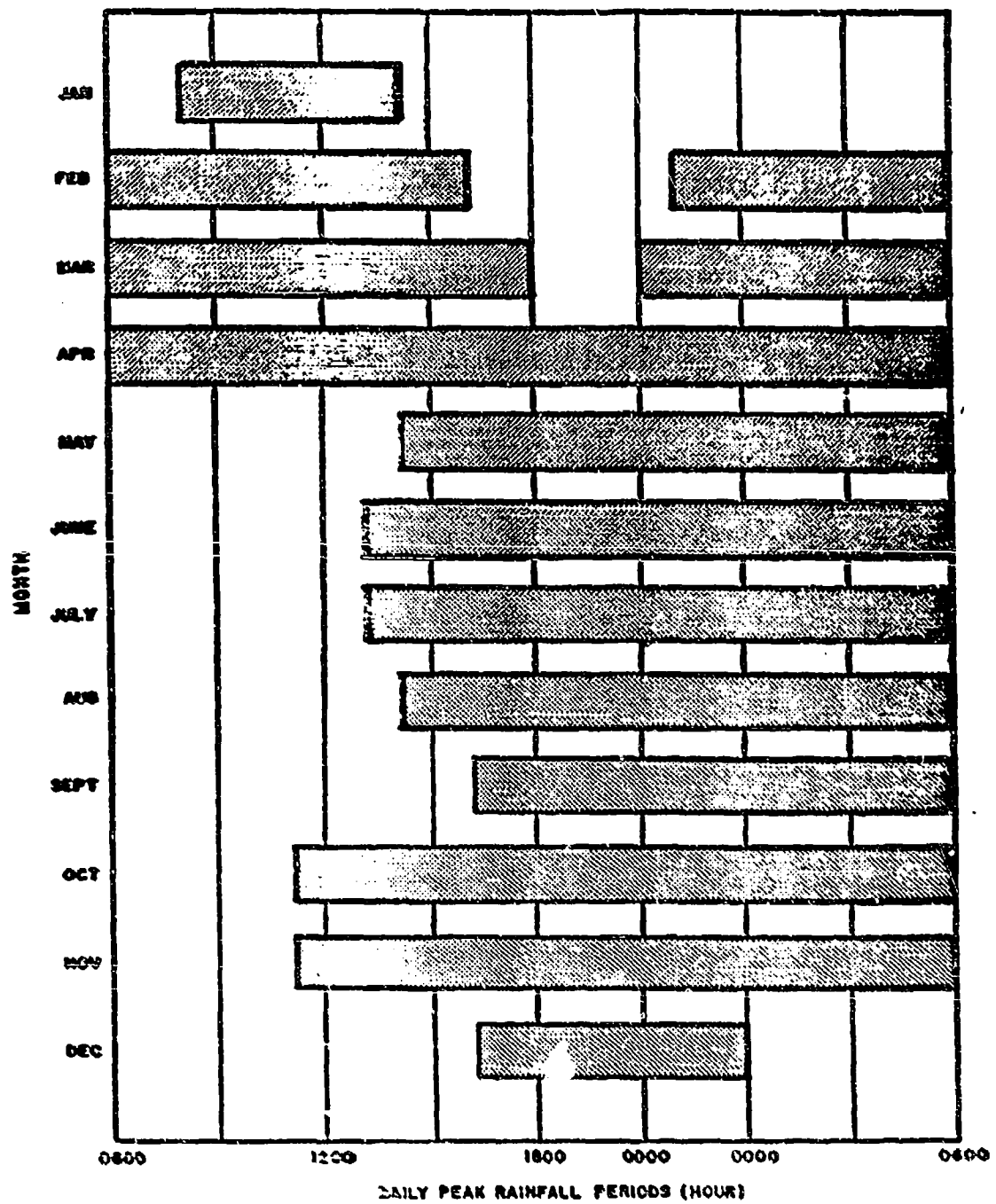
APPENDIX D

DAILY RAINFALL PATTERNS

The hours in which the greatest rainfall occurs throughout the year in Bangkok, Thailand (Am climate) are summarized in Table C-1. The table shows, for example, that in January most of the precipitation falls during the hours from 0800 to 1400 and in August, during the hours from 1400 to 1011.

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Rainfall In Bangkok-Thailand (Am Climate) 1

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APPENDIX E

Table 1

Pan No.	1	2	3	4	5	6	7	8	9	10
Pan Weight (gms)	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45
Soil Weight (gms)	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Water Weight (gms)	8.00	8.00	6.00	6.00	4.00	4.00	2.00	2.00	0	0
Soil Moisture (%)	100	100	75	75	50	50	25	25	0	0
Capsule Count:	8	8	9	12	29	12	10	10	11	11
14 Aug. 0900	8	8	9	12	29	12	10	10	11	11
1200	8	8	9	12	29	12	10	10	11	11
1500	8	8	9	12	29	12	10	10	11	11
1800	8	8	9	12	29	12	10	10	11	11
2100	8	8	9	12	29	12	10	10	11	11
15 Aug. 0800	8	8	9	12	29	12	10	10	11	11
1200	8	8	9	12	29	12	10	10	11	11
1500	8	8	9	12	29	12	10	10	11	11
1900	8	8	9	12	29	12	10	10	11	11
2100	8	8	9	12	29	12	10	10	11	11
16 Aug. 0800	8	8	9	12	29	12	10	10	11	11
1500	8	8	9	12	29	12	10	10	11	11
1700	8	8	9	12	29	12	10	10	11	11
2100	8	8	9	12	29	12	10	10	11	11
17 Aug. 1230	8	8	9	12	29	12	10	10	11	11
18 Aug. 1345	8	8	9	12	29	12	10	10	11	11
19 Aug. 0800	*7	8	1	1	15	6	10	10	11	11
Soil Moisture (%)	25	25	3	5	0	0	0	0	0	0
1200	7	8	1	1	15	6	10	10	11	11
1500	7	8	1	1	15	6	10	10	11	11
1800	7	8	1	1	15	6	10	10	11	11
20 Aug. 0700	7	8	1	1	15	6	10	10	11	11
0900	5	5	1	1	15	6	10	10	11	11
Soil Moisture (%)	6	4	0	0	0	0	0	0	0	0
1100	5	5	1	1	15	5	10	10	11	11
1500	5	5	1	1	15	5	10	10	11	11
1600	5	5	1	1	15	5	10	10	11	11
Final Count	5	5	1	1	15	5	10	10	11	11
Soil Moisture (%)	<1	<1	0	0	0	0	0	0	0	0

Soil Moisture: Capsule Test, Experiment 1

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Table 2

	1	2	3	4	5	6	7	8	9	10
Pan Weight (gms)										
Soil Weight (gms)										
Water Weight (gms)										
Soil Moisture (%)	100	100	75	75	53	57	25	25	0	0
Capsule Count	10	10	10	10	10	10	10	10	10	10
2000 20 Aug.	10	10	10	10	10	10	10	10	10	10
0900 21 Aug.	10	10	10	10	10	10	10	10	10	10
1200 21 Aug.	10	10	10	10	10	10	10	10	10	10
1500 21 Aug.	10	10	10	10	10	10	10	10	10	10
1800 21 Aug.	10	10	10	10	10	10	10	10	10	10
2100 21 Aug.	10	10	10	10	10	10	10	10	10	10
Soil Moisture	80	80	57	58	37	38	7	7	0	<1
0900 22 Aug.	10	10	10	10	10	10	10	10	10	10
1100 22 Aug.	10	10	10	10	10	10	10	10	10	10
1500 22 Aug.	10	10	10	10	10	10	10	10	10	10
0800 23 Aug.	10	10	10	10	10	10	10	10	10	10
1130 23 Aug.	10	10	10	10	10	10	10	10	10	10
1330 23 Aug.	10	10	10	10	8	8	10	10	10	10
Soil Moisture	55	55	36	36	14	16	2	2	0	<1
1530 23 Aug.	10	10	10	10	8	6	10	10	10	10
1630 23 Aug.	10	10	10	10	7	5	10	10	10	10
2100 23 Aug.	10	9	10	10	6	4	10	10	10	10
Soil Moisture	50	50	29	29	9	9	2	2	0	<1
0800 24 Aug.	10	8	10	10	5	3	10	10	10	10
1000 24 Aug.	10	8	10	10	5	3	10	10	10	10
1245 24 Aug.	10	8	9	10	5	3	10	10	10	10
Soil Moisture	39	40	20	20	3	3	<1	<1	0	0
1315 24 Aug.	10	8	9	8	5	3	10	10	10	10
1345 24 Aug.	9	8	9	7	5	3	10	10	10	10
1400 24 Aug.	9	8	9	7	5	2	10	10	10	10
1500 24 Aug.	8	6	9	7	5	2	10	10	10	10
1800 24 Aug.	7	6	8	7	5	2	10	10	10	10
Soil Moisture	34	34	15	15	3	3	0	0	0	0
0745 25 Aug.	7	6	2	2	5	2	10	10	10	10
Soil Moisture	26	28	7	7	2	2	0	0	0	0
1230 25 Aug.	7	6	2	2	5	2	10	10	10	10
1330 25 Aug.	7	6	1	1	5	2	10	10	10	10
Soil Moisture	21	22	4	4	2	2	0	0	0	0
1345 25 Aug.	6	5	1	1	5	2	10	10	10	10
1430 25 Aug.	5	4	1	1	5	2	10	10	10	10
1500 25 Aug.	4	4	1	1	5	2	10	10	10	10
1800 25 Aug.	3	4	1	1	5	2	10	10	10	10
2300 25 Aug.	1	1	1	1	5	2	10	10	10	10
Soil Moisture	13	15	2	2	2	2	0	0	0	0
0730 26 Aug.	0	0	0	1	5	2	10	10	10	10
Soil Moisture	7	9	1	1	0	0	0	0	0	0
FINAL COUNT	0	0	0	1	5	2	10	10	10	10

Capsule Test, Experiment 1:2

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APPENDIX F

DISTRIBUTION OF SEEDS - HELICOPTER SOWN

The following tables summarize work carried on by the U.S. Department of Agriculture, Forestry Service, in reseeding burnt out timberlands from low flying helicopters using centrifugal seed hoppers.

Table 1 demonstrates the influence of wind speed and direction on ground distribution of various types of seed.

Table 2 indicates the effects of sowing rate in pounds per acre on ground distribution for various types of seed.

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Table 1 -- Distribution of total seed in helicopter - sown swath, as affected by addition of rice hulls and by wind speed and direction

Seed mix or species, and rice hull addition	Wind Speed	Direction	sample locations											
			Feet West						Feet East					
			50	40	30	20	10	line	10	20	30	40	50	
			<u>Number of seed per square foot^{1/}</u>											
			<u>Mi./hr.</u>											
Perennial No. 1 No hulls With hulls	2-5	ENE	0	37	90	114	118	98	66	6	0	0	0	
	0-2	SSW	0	0	0	24	60	114	209	76	38	0	0	
Perennial No. 2 No hulls With hulls	0-3	E	0	2	11	62	111	79	73	40	3	0	0	
	0-3	S	0	0	0	10	52	65	69	74	17	0	0	
Perennial-annual No hulls With hulls	1-3	ENE	0	2	24	81	132	122	64	8	8	8	8	
	0-2	S	0	0	0	2	29	64	98	152	42	20	2	
Ryegrass-Blando No hulls	3-4	NE	0	2	21	42	83	87	62	32	0	0	0	
Ryegrass No hulls	4-6	ENE	0	11	41	108	113	104	44	0	0	0	0	
Blando brome	0-3	SSW	0	0	2	9	18	32	85	50	25	7	0	
Mustard No hulls	2-3	ENE	2	14	32	62	73	70	57	27	2	0	0	

^{1/} Average of 4 sample stations

Table 2 -- Distribution of seed in helicopter-sown swath, by species and sowing rate

Species	Average rate of sowing ^{1/}	Sample location 2/ Feet									
		45	35	25	15	5	5	15	25	35	45
	Lbs./acre	Number of seeds per square foot 3/									
Ryegrass	20.2	0	0	11	41	108	113	104	44	0	0
	12.0	0	2	9	25	61	64	45	23	0	0
	6.4	0	0	1	15	24	26	25	4	1	0
	0.8	0	0	1	3	3	5	3	1	0	0
Blando brome	9.7	2	9	18	32	85	50	23	7	0	0
	3.0	0	0	11	16	20	23	16	9	0	0
	0.8	0	0	1	4	5	5	5	2	0	0
Big bluegrass	1.7	0	2	11	28	43	28	26	10	0	0
Orchard grass	4.3	0	1	9	28	39	59	51	11	7	1
	1.6	0	1	3	11	20	15	14	4	0	0
Smilo	1.7	0	2	5	16	28	26	15	4	0	0
Hardinggrass	5.1	0	0	9	27	38	52	27	13	0	0
Wheatgrasses	9.6	0	0	2	11	18	19	16	5	0	0
	8.6	0	0	3	10	24	23	9	3	0	0
	6.8	0	0	4	9	15	18	11	1	0	0
Tall fescues	2.2	0	0	2	11	13	12	7	1	0	0
	1.6	0	0	0	4	7	7	5	2	0	0
Mustard	15.4	2	14	32	62	73	70	57	27	2	0

- ^{1/} Calculated from total seed caught for each mixture in each swath trial, based on counts of seed per pound.
- ^{2/} Number of feet west and east of the center of each swath rather than from the center line of the flying course.
- ^{3/} Average of 4 to 24 sample stations.

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report		
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14. KEY WORDS	Line A		Line B		Line C	
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[REDACTED] (Op-4)

ATL-TR-57-27 (Continued)

area is desirable, practical implementation seems to be within state-of-the-art disciplines. 6. Fluorescent tracers on the ground appear to be detectable from low flying aircraft at night, thereby providing a night-time capability in detection. 7. Personnel marking by employing encapsulated chemicals is feasible for the detection of insurgent personnel by ground forces.

[REDACTED]