Report 2217

MINE–DETECTING CANINES

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This report describes the rationale, protocol, and results of a series of four field tests designed to determine the merits of canines as mine/booby-trap/explosives detection systems. The report begins with a discussion of the factors which led to selection of the dog as the optimum choice for detection service. This is followed by discussion of factors pertinent to an understanding of the results; i.e., the use of the full-reinforcement and partial-reinforcement operant conditioning regimens used to train the animals; the anticipated tactical operational

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environments and the choice of test site analogs to these areas; the nature of the test lanes and of the test protocol. Results are presented in several formats so that every significant finding will be evident to the reader. The report concludes with the general statement that, based upon the most objective test and data analysis possible at this time, canines are the most effective and versatile mine/booby-trap/explosives detection systems available for immediate use in either military or civilian applications.

[redacted]

PREFACE

This report presents a condensation of several thousand data points taken under a variety of conditions by an assortment of recording personnel. The data reduction and data ordering resulted from the efforts of Mrs. B. J. Conley of the MERADCOM Systems Office. Publication of this report was expedited as a result of Mrs. Conley's skills as a mathematician and statistician. Mr. L. Mittelman of the Mine Detection Division assisted in envisioning effective methods for data presentation.

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MINE-DETECTING CANINES

I. INTRODUCTION

1. **Subject.** Research in mine detection has necessarily embraced virtually every discipline of science in the search for effective detection systems. The most recent discipline to receive scientific evaluation is the intricate scientific area grouped under the general heading of "biological systems." At MERADCOM, this field of investigation has embraced research in enzymatic chemistry, conditioned behavior, cerebral electro-stimulus, and olfaction.

This report is concerned with the concept, processes, results, and conclusions of a series of four field tests which were designed to evaluate the overall concept of mine detection via the modality of the in-vivo sensory capabilities of domestic canines.

In order to elucidate the rationale for such research, this report touches upon the general concepts of biological detection and elaborates upon the specific conditioning and training techniques which culminated in the field tests described herein.

It is not the intent of this report to describe in detail the complete selection and training procedures which supplied conditioned canines to the test since these factors are described fully and comprehensively in the reports listed in the bibliography.[1 2 3] Further, this report does not delve deeply into neurobiology, neurophysiology, or psychophysiology. Rather the intent of the brief discussions of these areas is to interest the reader in the overall experimental protocol in the hope that, thus informed, the reader may wish to follow the data in its various presentations in the latter parts of the text.

The authors contend that the results of the four field tests adequately demonstrate that canines are capable of highly satisfactory performance as mine detection systems under a variety of operational situations. While we admit to the (untested) possibility that even highly trained canines subjected to a battlefield

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1 Mitchell, D. S., "Selection of Dogs for Land Mine and Booby Trap Detection Training," Final Technical Report Vol I, Contract DAAK02-73-C-0150, September 1976.

2 Mitchell, D. S., "Training and Employment of Land Mine and Booby Trap Detector Dogs," Final Technical Report Vol II, Contract DAAK02-73-C-0150, September 1976.

3 Mitchell, D. S., "Users Guide: Land Mine and Booby Trap Detector Dogs," Final Technical Report Vol III, Contract DAAK02-73-C-0150, September 1976.

environment could present problems in behavior which could limit their effectiveness, we submit that there is currently no known sensor or system of sensors which can approach the overall detection capabilities of properly trained dogs.

2. **Background.** As noted previously, the continuing efforts in mine detection research at MERADCOM have resulted in intensive investigations covering nearly every discipline of science, and the search continues for techniques, procedures, and devices which will satisfy aspects of the changing mission requirements.

In 1973, MERADCOM began a long-term study of possible explosives detection techniques based upon biological and physiological processes. Several avenues of research were examined for feasibility and priority of treatment. One of these areas, the use of live animals as explosives detection systems, was chosen for immediate in-depth study.

Numerous species and orders of animals were considered, and several types were selected for preliminary tests at Southwest Research Institute (SRI), San Antonio, Texas. Section II describes the process by which the canine was ultimately selected as the optimum candidate for extensive experiments in conditioned behavior which could lead to its use in mine/booby-trap detection service.

After nearly two years of preliminary evaluation and testing, the decision was made to devise and augment an experimental protocol which could allow an objective evaluation of canine detection performance under conditions which approximated the most severe environmental conditions which combat soldiers were likely to encounter. The basic credo of this series of four field tests was that all subjective factors and anecdotal data were to be disallowed in the final data analysis. Obviously, such tests must have constraints which permit only objective testing and data recording. It is not easy to achieve objectivity, since several aspects of human behavior tend to contravene this goal. For example, handlers who have trained with a dog or group of dogs wish to see their team achieve a high test score, and it is not uncommon for impartial observers to notice cueing or guiding on the part of handlers who later deny any conscious attempt to bias the test results.

In order to preclude such incidents, whether they might be intentional or generated by subconscious stimuli, the test was first designed to be of a single-blind format. Since the scorekeeper could also become emotionally involved, a double-blind format was used later where neither handler nor scorekeeper knew the location of any target in advance of a test run.

Accordingly, the test area layouts were developed by use of a pseudo-random computer program (as detailed later in the text). To maintain the integrity of the double-blind format, the data sheets were sealed until the test teams were at the start position where the dog/handler teams were out of voice contact with the data-taker/scorekeeper.

The tests thus were conducted in a scientific manner, the data were essentially free from subjective contamination, and the results should represent an accurate portrayal of the actual performance capabilities of the 15 test animals.

II. INVESTIGATION

3. **Selection of Test Subjects.** The literature contains anecdotal reports of astounding feats of sensory or extra-sensory perception by dogs, but there is little objective data concerning the utility of canines in tactical military operations. It is well documented that canines have accompanied men into battle for centuries, and there are a few documented references to situations where these animals have been called upon to perform tasks which man alone could not accomplish. It is not uncommon to encounter reliable reports describing the ability of dogs in tracking enemy forces or in signaling the presence of intruders. Indeed, similar events are part of the general knowledge of the U.S. population as a result of direct and indirect experience with hunting, tracking, and police dogs.

While the foregoing activities are readily accepted as routine events by most persons, the use of canines in military mine and booby-trap detection service is often greeted with reactions ranging from mild skepticism to open hostility. Accordingly, when it was suggested that canines be formally adopted as a countermeasure to mines and booby traps, there were mixed reactions at all levels of interest. Obviously, in the absence of any reliable "hard data," a scientific test was indicated which could serve to qualify the proponent opinion and to quantify the detection capabilities.

The first consideration to arise in the construction of a test of this nature is "has the proper subject been chosen?" To answer this question, one must first consider the fundamental reasons for selection of any type of animal for detection service:

a. In lieu of information to the contrary, it must be assumed that all explosive devices emit some effluvia which are characteristic of the explosive content and that these effluvia are odorants to some extent. Thus, an olfactory detector of sufficient sensitivity and selectivity should be useful in detecting these devices.

b. Animals, both vertebrate and invertebrate, are thought to possess very high olfactory sensitivities. Indeed, the sensitivity of animals *APPEARS* to exceed that of man in almost every category of odorant, and certain documented cases indicate astonishing sensitivity to specific substances.[4 5 6 7]

c. All animals (from worm to man) can be conditioned to react to stimuli in a predictable and repeatable manner.

Thus, it would seem that some animal might be valuable as an explosives detector. It then remains to decide which to employ.

In spite of their reputed great sensitivity, invertebrate animals (insects) have proved unsatisfactory as detectors of a variety of explosive odorants. This is not surprising since it appears that those odorants to which insects are extremely sensitive are found only in their sex attractants, and the odorant components of these insect pheromones have no common factors with any known explosives. Further, the sensitivity of insects to olfactory stimuli other than pheromones and food is not thought to be extraordinary. In addition, insects are usually short lived, difficult to condition, possess no discernible intelligence, and are incapable of any communication with man. In view of these considerations, insects were not considered to be suitable test subjects.

The host of vetebrate animals available for explosives detection makes the process of elimination more difficult. The following criteria were used in this selection process:

a. The animal must be compatible with man (eliciting neither fear nor repugnance on the part of man or animal).

b. The subject must have sufficient intelligence to initiate some actions which will enhance the detection process, *and* it must be willing to participate in a man/animal interface.

c. The subject should be large enough to travel beside a walking man and not become a victim of the topography. Additionally, the animal must be able to tolerate, without loss of function, the same environment in which man can function effectively.

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4 Schneider, D., "Electrophysologische Untersuchunger von Chemo-und Mechanorezeptoren der Antenne des Seidenspinners Bombyx Mori L.," *Zeitschrift fur Vergleichende Physiologie*, Bd 40, S.8-41, 1957.

5 Schneider, D., et al, "Die Reaktion der Mannlichen Seiderspinner anf Bombykol und Seine Isomeren: Elektroantennogramm und Verhalter," *Zeitschrift fur Vergleichende Physiologie*, Bd 54, S.192-209, 1967.

6 Schneider, D., et al, "Bestimmung der Riechschwelle von Bombyx Mori mit Titrium-markiertem Bombykol," *Naturwissenschaften*, Bd 55, Heft 8, S.395, 1968.

7 Kaissling, K-E, and E. Priesner, "Die Riechenschwelle des Seidenspinners," *Naturwissenschaften*, Bd 57, Heft 1, S.23-28, 1970.

d. The animal must be available in large quantities with all subjects as nearly identical as possible both physiologically and psychologically.

In the initial phases of the vertebrate animal mine detection program, a large selection of potentially acceptable candidates were tested. The animals tested are shown in Table 1. Cats were excluded from the final programs because of their demonstrated refusal to cooperate consistently in joint ventures with man and because of their indifference to rewards in conditioning experiments. Rats were initially excluded on the basis of criteria a and c (above), but later experiments give evidence that they may indeed be useful. (This research effort will be the subject of a later report.)

Table 1. Animals Used in Mine/Explosives Detection Studies

Animal	Number Used	Genus and Species
Badger	1	Taxidea taxus
Coatimundi	2	Nasua nasua
Coyote	4	Canis latrans
Coyote/beagle cross	2	Canis latrans X Canis familiaris
Deer (white tail)	2	Odocoileus virginianus
Domestic Dog	83	Canis familiaris
Ferret	4	Mustela putorius
Fox (Red)	4	Vulpes vulpes
Hog (Red Duroc)	4	Sus scrofa domestica
Javelina	3	Tajacu pecari
Miniature Pig	4	--
Opossum	3	Didelphis virginiana
Raccoon	4	Procyon lotor
Skunk (spotted)	1	Spilogale putorius
Skunk (striped)	2	Mephitis mephitis
Skunk (hog nosed)	1	Conepatus mesoleucus
Timber Wolf	4	Canis lupis

Without exception, the so-called "wild" animals (wolf, coyote, fox, etc.) never fully accepted man as a companion but appeared to view him as a menace to be avoided. These animals may form attachments to one individual, but they invariably fear humans in general. Thus a majority of the vertebrate animals were excluded on the basis of criteria a and b.

The Duroc pig (considered to be a domestic animal) was tested for a brief period in experiments immediately prior to the instant test series. This animal exhibited a remarkable ability to detect all forms of buried explosives and a surprising willingness to work with man. Were it not for the great size of this particular breed (400 lb (182 kg) or more) and its unfortunate social habits, it might have been the ideal choice for detection service. A strain of genetic miniature pigs appeared to manifest the same sensitivity as their large counterparts, but the social stigma were, again, too overwhelming to permit serious consideration of pigs for employment as explosives detectors. Pigs displayed a further undesirable characteristic in their irrepressible desire to root in the soil.[8] Should this behavior occur during a mine search, the results would probably be disasterous for both pig and handler at the moment of detection (assuming no form of animal remote control was used to protect the handler).

Other animals either offered too ludicrous an image (e.g., bovines) or were too stupid (sheep, goats) to warrant serious consideration. Thus, the canine was ultimately selected as the optimal test subject.

It remained at this point only to select the breed of dog most appropriate to the needs of the mine detection program. This choice was simplified by an Army genetic-control breeding program at the Biosensor Research Laboratory at Aberdeen Proving Ground, Maryland. In this unique effort, the Surgeon General had authorized extensive breeding of selected German Shepherd dogs in an attempt to:

a. Minimize or eliminate the affliction known as hip dysplasia which disables a majority of German Shepherds after age 5 to 7 years.

b. Minimize the aggressive tendencies which cause the normal German Shepherd to be somewhat hostile and, hence, dangerous in casual encounters with humans not well known to the animal.

c. Retain sufficient self-confidence to interface with humans. This was an important consideration since, quite often, attempts to breed out aggressiveness have resulted in dogs which appear to fear strangers – an intolerable behavior in the Military dog.

The success of the Surgeon General's program was sufficiently impressive to cause MERADCOM to choose this breed as the prime candidate for field test service. Since it seemed appropriate to try a token quantity of other breeds, we considered the applicable factors of size, weight, emotional stability, and aptitude to a search protocol (hunting ability), and ultimately the choice of a second breed for the tests was the Labrador Retriever. In view of these choices, several of the so-called "Surgeon General's Dogs" were obtained and dispatched to the MERADCOM contractor (SRI)

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[8] For centuries, French farmers have used pigs to locate truffles in their subterranean sites by allowing the pigs to root freely in the soil.

for preliminary screening; at the same time, the contractor obtained several Labrador Retrievers for screening tests.[9]

It is pertinent to note that the 15 animals ultimately chosen survived the rigors of the field tests with no discernible illness, loss of conditioning, or other negative effects. The data show that detection performance appeared to be increasingly better at each test, and we conclude from this that the established selection criteria are adequate for the purpose.

4. **Detection Modality.** The use of animals as explosive detectors leads many observers initially to assume that olfaction is the single sensory modality involved in the detection process. Based upon lengthy and numerous observations during both training and field tests, and after due consideration, we submit that there is no reason to believe that this simplistic premise is entirely correct. Since the test protocol sought only to validate the concept of canine mine detection systems and to quantify efficacy of detection, the experiment was not designed to define exactly those sensory systems used to detect mines and booby traps. Hence, only the most cursory attempts were made to examine the modalities involved. Much more sophisticated experiments will be necessary if these details are to be resolved, but for the present, the reader is cautioned to avoid the assumption that the dog simply "smells" the target substances in a manner similar to the human experience known as smell.

The physiology of the canine is not the exact equivalent of human physiology, and some of the greatest differences are probably those observed in the structure and function of the sensory systems. In the case of the olfactory organs, it is agreed that, on a comparative basis, the olfactory epithelium of the dog is far more extensive than that of humans. Since olfaction is generally held to be the "vacuum of physiology," it is not entirely valid at present to equate this greater area of supposed sensory surface to greater sensitivity. However, the fact that those cortical and subcortical brain areas which can be shown to be part of the olfactory system are far more developed in the canine than in man invariably leads to the conclusion that in all probability the dog has a far more sensitive and selective olfactory system than does man. These observed facts, coupled with the animal's legendary ability as a hunter and tracker, tend to sustain the belief that olfaction is a major factor in the detection process.

If we assume additionally – with no valid basis in fact – that hearing and sight also play a part in the detection process, we are still at a loss to explain how some targets are located so readily. Motion pictures of the various tests described in this

[9] This report cannot approach the subject of the selection of individual canines with sufficient detail to be meaningful; interested readers are urged to examine the volumes by Mitchell listed in the Bibliography.

report indicate that most dogs in the search mode often appear to be trotting casually just in front of the handler when suddenly the dog sits (the detection signal), with none of the precursive actions (such as slowed gait, violent sniffing, agitation, etc.) which one might expect on an olfactory search. This casual attitude has given rise to some speculation that the dog is merely an indicator device for the true detector – the handler. At present, we cannot accept this premise.

As noted previously, the tests were double-blind and conducted by a reputable contractor under the scrutiny of MERADCOM employees; thus there is no reason to suspect that the handlers knew, during a test run, the location of any mine along the route. There is at present no valid reason to assume that humans can locate buried objects; if this ability existed in the average individual, why would the average soldier need any form of mine detection system other than his own senses? Anecdotes which purport to document some detection ability in humans have been investigated and scientific evidence of this ability does not exist.

During the Vietnam conflict, there were reports that certain soldiers had developed the ability to detect mines, booby traps, Punji pits, etc., but interviews with some of these persons suggest that they simply detected anomalies in the environment which suggested recent human presence (bent grass, broken branches, etc.). Such subtle clues enabled these unusually observant soldiers to exercise extreme caution in the area of the anamoly; thereafter, they initiated an increasingly astute search pattern along the path. It should be realized that under these conditions, almost any recently concealed mine can be located in physical environments such as those found in Vietnam. It is equally important to realize that soldiers exhibited no such skills in the mined vegetation-free areas near the Suez Canal (as evidenced by the high casualty rates resulting from land mines). We must assume this failure to be due to the nearly perfect camouflage offered by desert soil and because of the total lack of indicator artifacts.

Based upon this simplistic analysis, it is conceivable that in special environments, the handler may detect signs of mine emplacement and then subconsciously or consciously signal his dog to alert, but the premise that the human is the primary detector in the majority of instances is unacceptable.

It is possible that the dog has sensory capabilities as yet undiscovered, but such conjecture is unwarranted in this report. In summation, the detection performance either indicates a very high olfactory sensitivity (perhaps one part in 10^{16} mol fraction or greater) or the presence of detection factors which defy interpretation by the entire staff in attendance at the test. Perhaps future research in sensory physiology will supply the answer to this enigma.

5. **Conditioning of Subjects.** The procedures devised by the Southwest Research Institute for training the MERADCOM mine-detecting canines are complex, and the interested reader is encouraged to examine volumes on this subject listed in the Bibliography.[10] [11] [12] This report can deal only with the basic philosophy of the conditioning methods used and with the rationale for the choice of these methods.

There are two generally accepted methods for inducing pre-ordained behavioral patterns in experimental subjects. The earliest of these techniques was discovered by Dr. I. Pavlov during his pioneer experiments in digestion, and the method is known today as Classical Conditioning or Pavlovian Conditioning. The second method was developed by the American behavioralist Dr. R. Skinner and is termed Operant Conditioning.

Classical conditioning requires nothing of the experimental subject except its conscious presence, while operant conditioning requires a willful act (an operant) on the part of the subject. While the methods by which any creature amasses learning are still a matter of intense debate,[13] it was sufficient for the purpose of this experiment to accept the basic premises implicit in the techniques of Pavlov and Skinner. Since the canine was required to annuniciate clearly the detection of an explosive substance, operant conditioning was chosen as the proper regimen for the canine experiment, and the experimental conditioning concept, then, was resclved to be as described in the following pages.

Basically, the mine-detecting canine must be taught to identify the presence of military explosives; then the animal must signal the act of detection by some unique method that allows the handler to clearly recognize that detection has occurred. In return for this performance, the animal is taught to expect some reward which is pleasing to at least one aspect of its physical or emotional needs.

The initial training of the MERADCOM mine/booby-trap-detecting canines was determined to be a full-reinforcement operant regimen. This technique demands that each time the animal correctly identifies an explosive target, it is immediately given a food reward whereas failure to detect merely results in no reward being given.

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[10] Mitchell, D. S., "Selection of Dogs for Land Mine and Booby Trap Detection Training," Final Technical Report Vol I, Contract DAAK02-73-C-0150, September 1976.

[11] Mitchell, D. S., "Training and Employment of Land Mine and Booby Trap Detector Dogs," Final Technical Report Vol II, Contract DAAK02-73-C-0150, September 1976.

[12] Mitchell, D. S., "Users Guide: Land Mine and Booby Trap Detector Dogs," Final Technical Report Vol III, Contract DAAK02-73-C-0150, September 1976.

[13] Some psychologists state that much of the human learning experience exemplifies the Classical Conditioning paradigm (exclusive of those experiences which require responses for the process to continue, which cases are often examples of operant conditioning).

Punishment for incorrect behavior is never allowed nor is the trainer permitted to exhibit his displeasure by any nuance of action or vocalization. It is emphasized in the MERADCOM training program that the human hand must never become an object of fear or hatred to the dog but, in fact, it must be viewed as a pleasure source (the dispenser for the food reward or a friendly pat on the head). Thus slapping or rough handling is unallowable even in the case of obstreperous behavior such as fighting, biting, or refusal to search. Even the most aggressive animals soon learn to regard their handler as a trusted ally in the "game" they are learning to play and this is quite important, since the search activity ultimately must be considered as a team action under the present training concept.[14]

Once the animal has become accustomed to the search/reward pattern, the search is made progressively more difficult, first by reducing the quantity of explosive in the targets and finally by reducing the frequency of target occurrence while increasing the number of false targets and distractants. Ultimately, those dogs which are selected as the best performers are taken to a series of test trails where real and practice mines are deployed in simulation of a tactical operation.

The performance of the 15 "best performer" test subjects indicated that their conditioning was effective and that extinguishment due to inactivity of several days duration was not statistically significant. This result was important to continuation of the program, since these periods of no training simulated the effects of troop movements and activities which would preclude any type of reinforcing experience in an actual combat operation.

It was clear to the program personnel that the experimental results to this point demonstrated only that canines could be conditioned to be effective explosives detectors. It was equally clear that this initial training protocol excluded the realities of a true tactical scenario. Thus, when the concept of the large-scale field test was first addressed, it was necessary to modify the conditioning program to accommodate the real-world situation wherein the location of mines was unknown to both handler and dog. Obviously in the practical case, where the validity of the detection signal cannot be evaluated until an explosive ordnance disposal (EOD) team searches the indicated site, the dog should not be rewarded for his annunication of detection. Since the dog has no apparent ability to associate events separated in time, the animal must be made to realize that his search "game" really has two equally possible outcomes -- either he will be rewarded or he will not be.

14 Obviously, the personal safety of the handler could be greatly enhanced if he could remain at some distance from the search area, but early experiments in remote control of explosives-detecting dogs were aborted due to funding limitations long before any statistical result could be obtained and evaluated for assessment of the effects of proximal vs. distal positioning of the handler.

Accordingly, in November 1974, 5 of the group of 15 animals were introduced to a new conditioning regimen known as partial-reinforcement operant conditioning. In the initial protocol, the subjects were required to perform the detection tasks in the same manner as that required in the full-reinforcement regimen, but rewards were withheld on a random basis. As this reconditioning process continued, the rewards became progressively less frequent during each *formal* search program until at length, no rewards were given for correct performance. Note that emphasis was placed upon the *formal* nature of the search and that rewards were withheld *only* during the actual search program. Previous experience had shown that if the practice of withholding rewards is allowed to continue indefinitely, the desired conditioning would ultimately extinguish as a result of (effectively) negative stimuli. To prevent this effect, the animals were taken to a practice area remote from the final test area immediately after each formal test run, and they were allowed to search again. During this "second outcome" effort, each correct annunication was followed immediately by a food reward. This is the essence of the practical technique referred to herein as partial-reinforcement operant conditioning.

In order to examine the effects of the revised conditioning, it was determined that a control group must be selected which would not receive new training but would merely receive maintenance conditioning to determine, if possible, the minimum exposure required to prevent extinction of their full-reinforcement conditioning. To accommodate the various investigations, the 15 dogs were broken into three groups for test purposes. These groups, hereafter referred to as Groups A, B, and C, were held invariant for the remainder of the program.

Group A and Group B animals were trained to expect continuous reinforcement, while those of Group C were retrained to expect partial reinforcement. The latter dogs were guided through repeated runs down test lanes (at the contractor test sites at Camp Bullis, Texas) where each trial resulted in only random rewarding for correct performance (and, of course, no reward for incorrect performance).[15] Thus, in the final procedures, at randomly spaced intervals, the dog received no reward not even the accolade "good dog" – for correct detection performance.[16] Interspersed with this treatment were occasions when the dogs were given a "normal" reward which consisted of a single morsel of dry dog food plus a few congratulatory pats on the head accompanied by profuse verbal praise.

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[15] It was necessary to retrain the handlers to refrain from their nearly reflexive practice of physically rewarding the animal (patting) even when the normal food reward was withheld.

[16] While dogs apparently cannot comprehend complex language, they assuredly can master the meaning of simple phrases although these utterances must be accompanied by adequate vocal emphasis. The accolade "good dog" must always be stated in the same manner or the animal may become confused. Thus even though the dog may not comprehend all the spoken words, it learns to comprehend the mood of the speaker, and the handlers must refrain from verbalization when anger dominates their vocalization. Fear on the part of the handler may also have a negative effect on the dog, but there are no data to substantiate this belief.

In order to attain the maximum data, the three test groups were subjected to two phases of reinforcement as shown in Table 2. Paragraph 9 (Figure 10) presents the results of these permutations. Within two weeks, all test subjects realized the dual nature of the overall training program and were willing to accept the new game rules.

Table 2. Conditioning Protocol for Mine Detecting Dogs

	Conditioning	
Group	Phase I	Phase II
A	Continuous reinforcement	Continuous reinforcement
B	Continuous reinforcement	No reinforcement
C	Partial (random) reinforcement	No reinforcement

The fact that the animals accepted revised training so rapidly was the only surprise in the program, since the effects of partial reinforcement are described abundantly in the literature. Further, it was well established that, while continuous reinforcement is acceptable during initial training, it does not lead to optimum performance even in those situations which permit this practice. This behavioral trait is thought to be due to habituation and anticipation affects where habitual performance rewards dull the anticipation of the reward to the extent that the effectivity of conditioning may suffer severely at extremes of habituation. Thus, the reward ceases to be of sufficient impetus to cause the animal to perform the prescribed search. When the reward is withheld at seemingly unpredictable intervals, the animal has greatly increased anticipation and performs in the manner it thinks will reestablish the reward. Habituation is thus attenuated, and performance remains at initial end-of-first-conditioning levels for periods of many months or, possibly, for years.

After some experiment in allowable reward-to-reward intervals, it was determined that search periods in excess of 2 hours elicited no decline in performance with total withholding of reward. Since this 2-hour period represents possibly the optimum search period before fatigue effects are manifested, it was determined that there would be no extinguishment of conditioning if the search period were followed, at some period during the *same day*, with a "dummy search" where continuous reinforcement was allowed. Dogs appear to be able to accept the fact that when the handler acts in the more formal attitude of the true search program, there will be no reward for correct behavior, but when the "dummy-search" program is in force, a reward will be given for each correct detection. This obviously requires intelligence and an eagerness to please – both of which are evident in those animals which arrive at the final stages of training.

Before moving on to the details and results of the four field tests, it is pertinent to note that the data displayed in Paragraph 9 (Figure 10) represent one of the most significant determinations of the entire canine mine detection program, namely that the performance of dogs will be quite good regardless of the nature of the training regimen. While this observation seems to border on the trivial, the reader is asked to consider the following ramifications of this finding:

a. It is evident that there is no need for precise adherence to any specific training or performance protocol, thus allowing for great variations in trainer and handler capabilities such as would certainly be encountered in a time of intense mobilization of the armed forces.

b. It is evident that rapid retraining is possible with no loss of detection capability. This factor is important if tactical considerations demand operational changes (e.g., remote control operation of canines in areas of extreme hazard).

c. The fact that dogs rapidly accept the new "game rules" (no diminution of performance noted after only 4 weeks of partial and no-reinforcement training) is thus documented.

These observations will hopefully serve to attenuate somewhat the philosophical debates concerning what canines will or will not do in detection service. To reply in advance to arguments that insufficient data were taken to permit such sweeping conclusions, we submit that there are seldom, if ever, experiments where sufficient data are accumulated to satisfy the most critical observer. It is worthy of note that the data obtained from the four tests, when tested by various statistical methods (see Section III), evidence no differences of adequate significance to cast doubt upon the conclusions.

It seems valid, therefore, to conclude that the conditioning as devised for the training of mine-detecting canines is adequate for the operations of global warfare.

6. **Test Sites.** The following test sites were selected.

a. **Winter Site.** Since canines should be available for deployment as mine detectors on a global basis, it was determined that detection performance must be tested in simulated operational situations which would represent the most unfavorable environmental conditions likely to occur. Accordingly, a search for test sites which could satisfy the needs of the experiment was initiated with the provision that funding and time limitations would ultimately preclude the use of more than two geographical locations. The final choice was constrained to include one site which could simulate so-called middle European operations and one which could represent the environment of the mid-East.

Geologist reports indicate that Fort McCoy, Wisconsin, not only has soil conditions analogous to the northern European plain but also has a summer climate which is similar to that of Europe, thus allowing for a mid-range detection test in addition to the planned "extreme limit" regimens. The average winter climate at Fort McCoy is considerably colder than the normal average winter in central Europe, but this factor was not held to be a detriment since, in effect, it allowed the simulation at one site to include extreme northern as well as central Europe. Fort McCoy lies in southwestern Wisconsin in the Wisconsin Driftless Area of the central lowlands. This locale is characterized as a rugged region, varying in elevation of between 183 to 530 meters above sea level. The center has numerous rocky crags, some of which have the appearance of buttes and mesas when viewed from an elevated position. In general, much of the surface is of a rolling or undulating character. Figures 1 and 2 give an overview of the test area.

The Wisconsin Driftless Area, in general, is partly covered with a fine, humus soil, but Fort McCoy is mostly sand to a depth of at least 1.5 meters. The test site was a generally flat, 1.25-square-kilometer area with a slight rise in elevation along the southern border. Trees (scrub oak) were scattered over most of the area with some parts characterized as thickets. Other parts of the area were essentially grass with a few trees. Included in the test area was a flat, sandy area (about 26,000 square meters) which supported no vegetation other than widely scattered clumps of short grass. The specific site for the test was an abandoned small-arms range in an isolated area of the reservation. It was approximately 1.6 kilometers long by 0.8 kilometer wide and was enclosed by a 1.5-meter-high, two-strand barbed wire fence.

The climate in southwestern Wisconsin is characterized by cold winters and hot summers. The average annual temperature is about 6.1° C, varying from an average of -8.3° C during January to 20.6° C in July. Extremes extending to below -17° C in winter and above 30.2° C in summer are not uncommon. The average annual rainfall is about 76 centimeters, and about 20 percent of the total rainfall comes during the growing season (Spring/Summer). This climate is fairly analogous to that found in the northern-European Plain area (i.e., rainfall is similar while the average high and low temperatures are more moderate in central Europe than in Wisconsin).

The winter of 1974/75 was more severe than usual, thus allowing a test with environmental limits nearly as vigorous as some portions of Alaska. Throughout most of the winter test, the average snow cover was about 0.5 meter and the air temperature hovered near -6° C during most of the daylight hours, dropping to -20° C or lower at night. In addition, snowfall and strong winds altered the surface, and hence

Figure 1 Fort McCoy Test Area, February 1975.

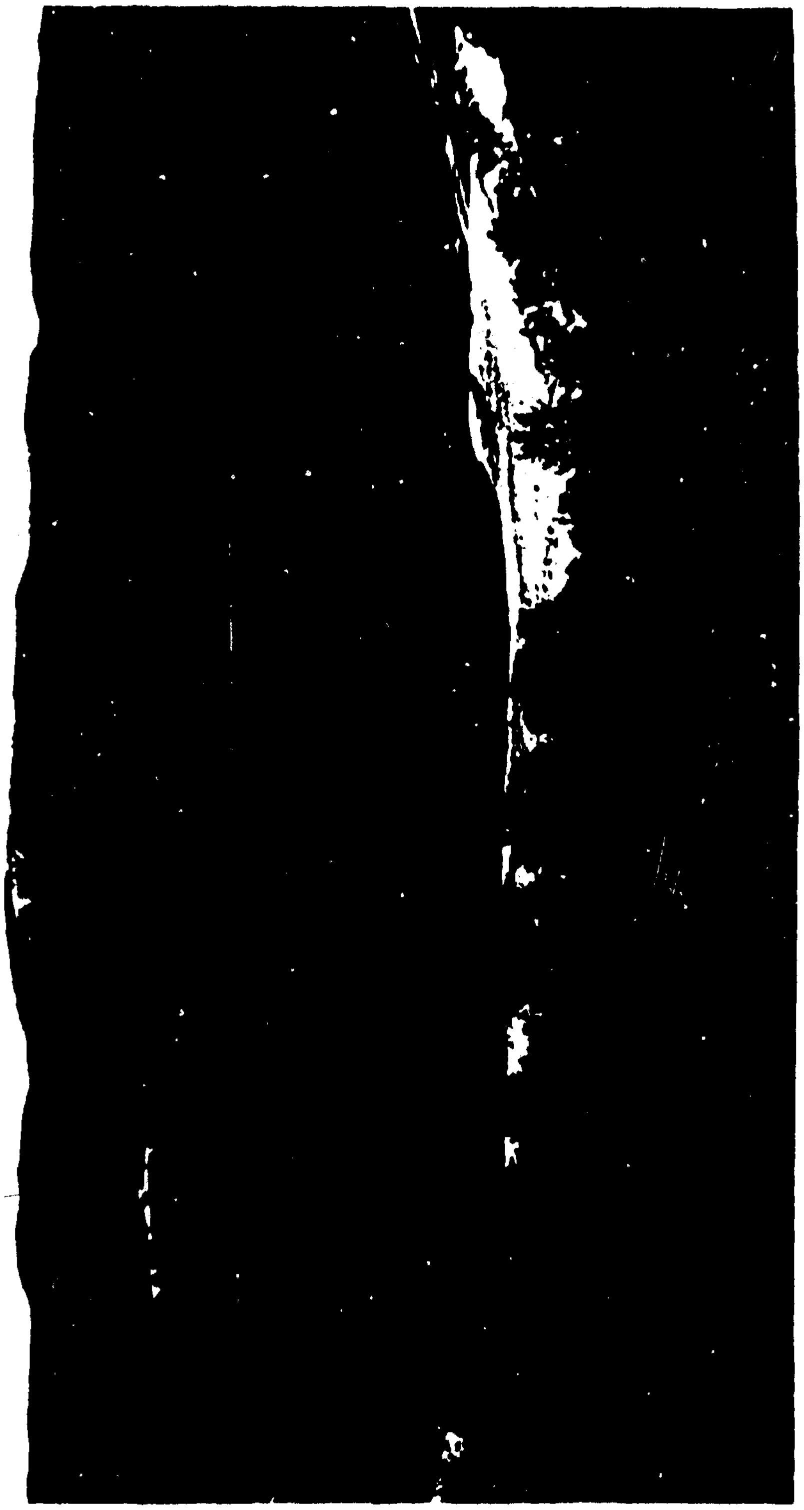

Figure 2 Fort McCoy Test Area, May 1975

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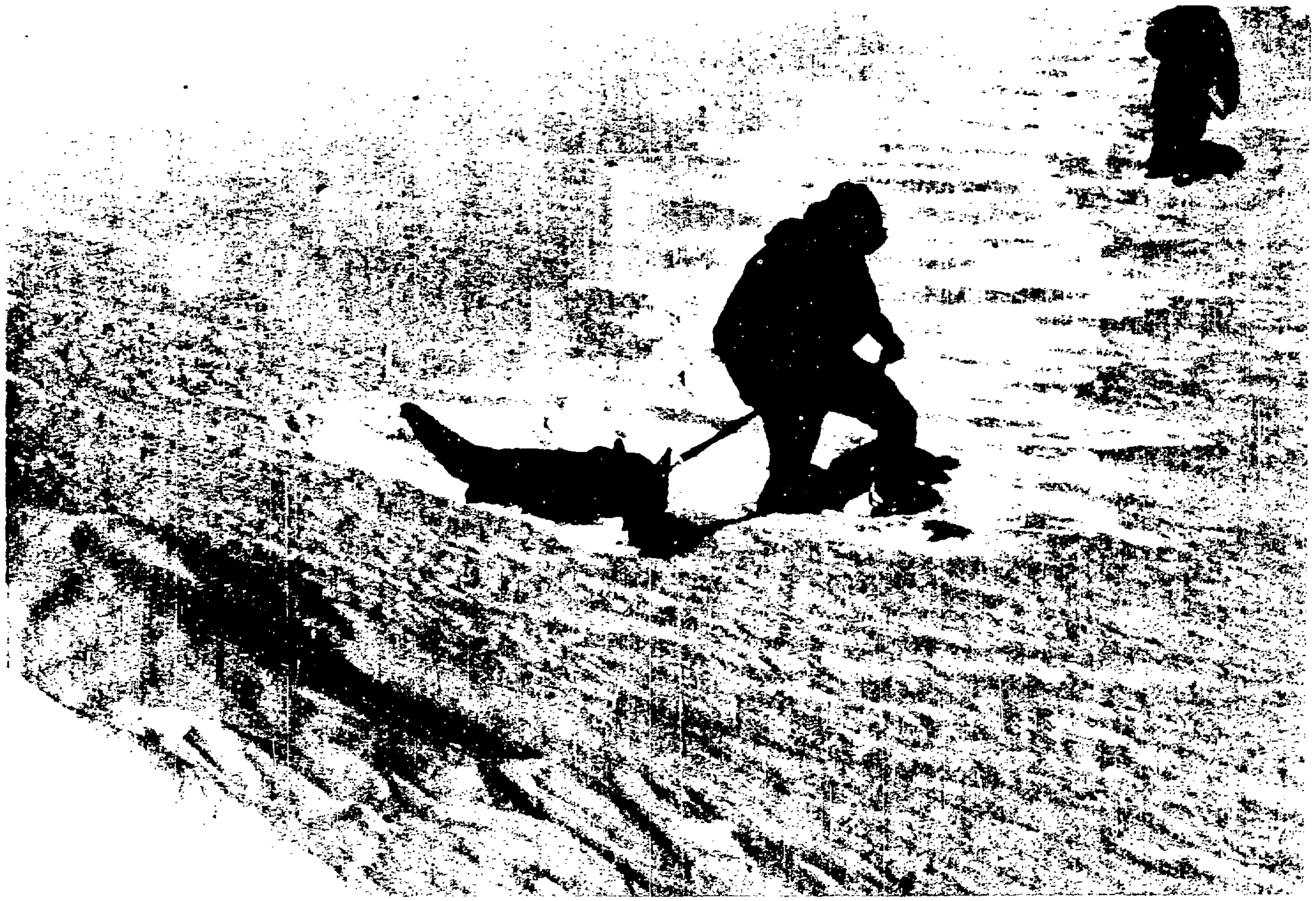

Figure 3 Detection Test Run, Winter Test, Fort McCoy, WI, February 1975

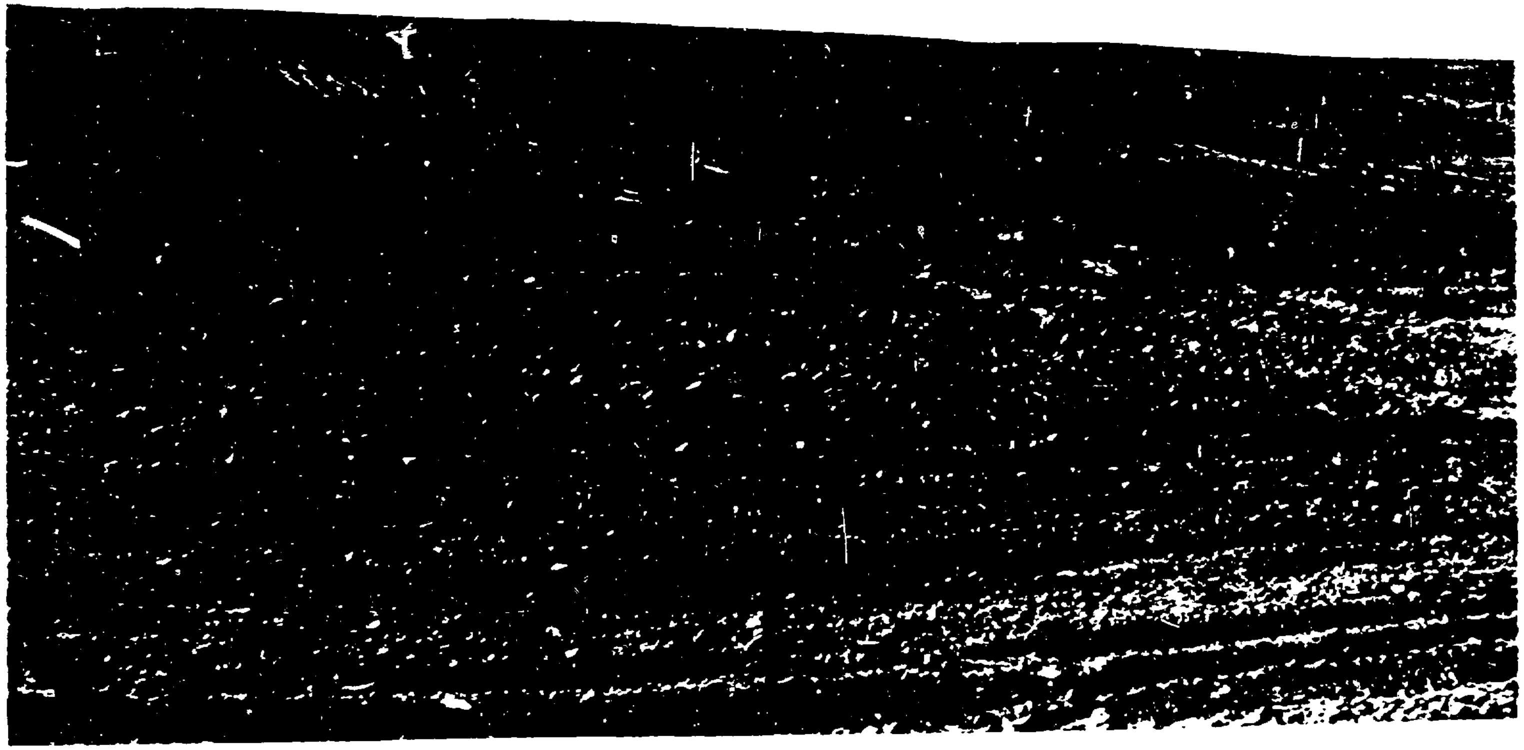

Figure 4. Yuma Test Area, October 1975.

Figure 5 Detection Alert, Yuma Proving Ground, October 1975

visual aspects, of the test site several times during the 2-week test. The winter environment was so severe at Fort McCoy that we must conclude that these weather parameters probably represent the cold weather limit at which canines can function effectively. It is our opinion that attempted operations under similar conditions in a tactical scenario would represent a nearly intolerable situation for both infantry and mechanized forces; thus, the use of mine-detecting dogs would probably never be attempted in such cases. It is doubtful if antipersonnel mines -- normally deployed -- would be detonated in such heavy snow and ice, but antitank mines would probably still be a menace. Figure 3 shows an example of the rigors of the winter test. In the spring 1975 test at Fort McCoy, the weather was unremarkable (average temperature 20° C, moderate skies) and needs no comment here.

b. **Summer (Desert) Site.** The search for a desert site was greatly simplified by the well-documented similarities of Yuma Proving Ground (YPG) to a typical mid-East area (Sinai Desert). Yuma Proving Ground lies in the southwestern corner of Arizona near the California and Mexican borders and is bordered on the west by the Colorado River. It lies in the Sonoran Desert section (locally called the Gila Desert) which occupies over 80,000 square kilometers. The mountain ranges in this section are usually short and rarely greater than 1.2 kilometers above sea level. The basins are wide and mostly flat but are interspersed with shallow dry gulches. These basins are seldom more than 600 meters above sea level. The mountains are comprised primarily of granitic and volcanic material, having practically no soil. The soils in the basins or plains are sandy, gray or buff-colored, and humus-deficient, which is characteristic of arid regions. The sparse vegetation consists principally of cactus, creosote bush (or greasewood), and mesquite. The soil texture differs greatly over small areas with coarse and bouldery materials found at the base of bordering mountins and fine clays in the lower parts of the area.

The climate in this region is characterized by: low rainfall (less than 10 cm/yr) with little or no rain falling during the spring months; low humidity (average of less than 35 percent at noon); temperatures that range from an average of 10° C in January to 32° C in July, with extremes of over 40° C in summer; and a range of cloud during daylight from 20 to 30 percent in July to 30 to 40 percent in January. Soils and climate somewhat analogous to this area are found in northern, western, and southern regions of Afghanistan; Southern European Russia; several areas of Spain; and parts of Egypt and Israel.

The site was plowed and denuded of all vegetation in preparation for the tests. The resulting soil was a fine sandy texture, extremely dry (about 1.2 percent moisture content), and easily converted to dust when gusty winds and "dust devils" passed over the area. The final dimensions of the test area were approximately 0.8 kilometer by 0.4 kilometer. Figure 4 shows a portion of the final site after installation of the mine lanes.

At first, it appeared that a single test would provide all the desired data. However, it was necessary to begin the third test at this site in late October 1975 which is not the hottest part of the Yuma climate cycle. This perturbation in the test plan proved to be beneficial since the weather was unusually cool in 1975, and thereby it was possible to amass data in an environment similar to that in certain other desert areas of interest. Figure 5 shows a detection "sit" during the October 1975 test at Yuma Proving Ground.

In view of the unfulfilled need for extreme hot weather data, the test was re-run in June when the conditions were at or beyond the extremes originally anticipated (air temperature +46° C, bright sun, 1 percent humidity). This test was executed exactly in the sequence of the October test, thus allowing for close comparison of data elements. Thus, the two test sites allowed accumulations of four data sets which adequately define canine performance over a range of environments with limits which would represent a severe challenge to humans involved in tactical operations in these areas. Additionally, the variations in soil conditions and types allowed an evaluation of camouflage techniques and the consequent effects on the handler/dog teams.

7. **Test Lanes.** The concept of the canine tests embraced two essential points: The test must be double blind to preclude any conscious or subconscious attempts to influence the results on the part of any participant, and the test area must include targets which are representative of those possibly encountered in tactical operations (thus there should be some distractants which, while unlikely, could conceivably occur).

It was determined that the optimum configuration of a test area for Fort McCoy would consist of 50 lanes each 0.5 mile (800 meters) long and 10 feet (3 meters) wide. The rationale for this choice was based upon the experience of previous contractor tests at Camp Bullis, Texas and at a test site in Montana. From these earlier tests, it appeared that the average dog would function with no loss of interest for periods of up to 2 hours (this was later proven to be an underestimation) and that an area search of about 26000 ft^2 (2430 m^2) would take about 1 hour. Since the lateral space needed to generously accommodate a column of infantry is about 6 feet (2 meters), a 10-foot (3-meter) width seemed to represent the maximum desired width of search. Thus, the length of the test lane became about 2600 feet (800 meters).

Some subjective evidence from previous tests indicated that dogs could easily remember the physical location of targets on practice trails after three or four traverses even if the individual events were separated by a week or more. Regardless of the anecdotal nature of this "memory factor," it was evident that the probability of memory influencing the data was too great to ignore; therefore, the physical layout of the test area was evolved to limit the effects of a possible topographical memory capability. (While some memory factor might have been significant in repeated passages at Fort McCoy, a glance at Figure 5 should suffice to convince the most skeptical that memory could offer little data distortion at YPG.) Aside from a possible topographical memory there remained the distinct possibility that the dog might detect the scent from a previous detection (since there is much local activity when a "sit" occurs) and this accumulation of scents might possibly trigger a detection alert.

Consideration of these potential disturbances led to the determination that at least 50 test lanes were necessary per test site in order to limit the maximum number of searches through any one test lane to two per dog per test. Time and fiscal restraints served to limit the number of lanes to 50, whereas, given unlimited resources, each site would have consisted of at least 100 test lanes, thus permitting a single passage per lane per dog in every instance. To preclude disturbances to the search party, experiments were run at the contractor facility to determine the necessary lateral spacing of the test lanes. It was found that at a 50-foot (15.2-meter) separation (center-to-center), concurrently advancing search parties exhibited no mutual interference. This is not surprising since the dogs used for these tests had never been exposed to any form of attack or tracker training. Even so, during the actual test runs, the parties were never on adjacent lanes, and they were started at staggered, random intervals. It is certain that there was no episode of search distraction due to other test groups during any of the runs in the four tests.

a. **Targets.** After the basic configuration of the test field was determined, it remained to equip each lane with an assortment of targets both true and false. Since U.S. mines were the only devices available in quantity, these were chosen as the majority of live targets. Table 3 shows the complete listing and function of all target substances and devices used at the test sites. The foreign mines were few in number and probably unlikely to be encountered in war, but they were included simply to determine if they were detectable. (They were detected equally as well as U.S. mines.)

For some time there had been a lively debate between two opposing philosophies in the detection community. One group contended that canines were capable only of detecting human scent while the other group contended that it was, in fact, some characteristic of the explosive-filled device which triggered a detection alert. It appeared that this question could be resolved if both explosive-filled and inert-loaded mines of the same type were deployed during the field tests. Thus the available inert correlates of the live, defused mines were also included. Table 4 shows the frequency of target item occurrence at the two sites. It is interesting to note that while there were occasional false alerts attributable to five of the distractants, the sex attractant was totally ignored by all animals in all tests. This may be due to a number of factors, the most probable of which is that the chemical attractant, attained from estrus females, deteriorates rapidly ex-vivo!

Table 3. Target Items

Live Mines			Inert Mines			Distractant
Nomenclature	Function	Country of origin	Nomenclature	Function	Country of Origin	Substance
M14	Antipersonnel, nonmetallic	U.S.	M16A1	Antipersonnel, metallic	U.S.	Oil/gasoline
M15	Antitank, metallic	U.S.	M19	Antitank, nonmetallic	U.S.	Canine sex attractant
M16A1	Antipersonnel, metallic	U.S.	M20	Antitank, metallic	U.S.	Expended shell casings
M18A1	Antipersonnel; plastic case containing steel balls	U.S.	M25	Antipersonnel, nonmetallic	U.S.	Commercial fertilizer
M19	Antitank, nonmetallic	U.S.				Human urine
M0D1951	Antitank, nonmetallic	France				Filled in holes similar to mine implant holes
TMA-3	Antitank, nonmetallic	Yugoslavia				

Table 4. Frequency of Occurrence of Targets at Test Sites

Targets	Fort McCoy (Number)		YPG (Number)
	Lanes 1-40	Lanes 41-47	Lanes 1-50
Live (unfused)			
M14	12	6	16
M15	43	10	44
M16	93	6	33
M18	14	0	20
M19	44	4	38
French	3	0	0
Yugoslovian	1	0	0
Practice (inert)			
M16	25	5	27
M19	10	10	30
M20	48	10	37
M25	23	7	23
Distractants			
Oil/gasoline	38	6	31
Canine sex attractant	34	7	19*
Expended shell casing	33	8	33
Commercial fertilizer	56	9	24
Human urine	15	0	27
Filled hole	212	45	148

* Used only in the October 1975 tests.

b. **Layout.** When the lists of target and distractant items were final, it remained to determine the configuration of item placement. Obviously a truly random selection and placement would leave much to be desired in a universe of only 50 lanes since some lanes would be sparsely populated while others would be too densely populated. Accordingly, the following constraints were imposed:

(1) At least one live mine per lane.
(2) No targets located within the first 12.2 meters (40 feet) of lane.
(3) A minimum target interval of 15.2 meters (50 feet).
(4) Lateral lane separation of 15.2 meters (50 feet) (center-to-center).
(5) Exactly 11 total targets/distractants per lane.
(6) Target lateral position arbitrary within the 3-meter (10-foot) lane width.

Obviously, these constraints reduced the degree of randomness possible to the point that even pseudo-random may be an inappropriate designation for item spacing. In any event, a computer program was devised which would allow the greatest randomness possible in view of the restrictions, and the test site layout was thus generated. Table 5 shows Lane 1 at Yuma Proving Ground as a sample of the pseudo-random layout resulting from the program. Mitchell gives a complete layout of both sites.[17] [18] [19]

Table 5. Location of Targets in Lane 1 at Yuma Proving Ground

Target	Longitudinal Position		Lateral Position	
	(Meters)	(Feet)	(Meters)	(Feet)
Filled hole	12.1	(40)	0.30	(1)
M19 (live)	35.8	(118)	0.91	(3)
Fertilizer	79.7	(263)	2.43	(8)
M19 (live)	107.6	(355)	1.52	(5)
M15 (live)	149.7	(494)	2.12	(7)
M19 (practice)	180.6	(596)	1.52	(5)
M18 (live)	207.6	(685)	0.30	(1)
Sex attractant	244.5	(807)	3.03	(10)
M14 (live)	272.4	(899)	0.30	(1)
M19 (practice	298.2	(984)	1.82	(6)
M15 (live)	331.2	(1093)	1.82	(6)

One final change was made in the initial program after it was recognized that the presence of targets in all lanes left unresolved the question of false alarm performance on a sterile area which purported to be a mined area. Thus, several lanes were not implanted with any item and this fact was concealed from the test parties.[20]

With the determination of the spatial coordinates, the lane layout was complete and implantation was carried out as follows: The targets were buried in accordance with TM9-1345-200, "Land Mines"; M14 and M25 mines were buried flush with the soil surface and covered with a sprinkling of soil; M15, M19 and M20 mines were buried under 3.8 cm of soil; M16 units were buried at 7.6 cm depth; and M18 mines were placed on the surface. At the Fort McCoy site, targets were installed in

[17] Mitchell, D. S., "Selection of Dogs for Land Mine and Booby Trap Detection Training," Final Technical Report Vol I, Contract DAAK02-73-C-0150, September 1976.

[18] Mitchell, D. S., "Training and Employment of Land Mine and Booby Trap Detector Dogs," Final Technical Report Vol II, Contract DAAK02-73-C-0150, September 1976.

[19] Mitchell, D. S., "Users Guide: Land Mine and Booby Trap Detector Dogs," Final Technical Report Vol III, Contract DAAK02-73-C-0150, September 1976.

[20] At Fort McCoy and at YPG the deletion of target items by the MERADCOM installation crew did not preclude the presence of artifacts in these well-used test areas. For example, items discovered by the dogs at Fort McCoy included an unexploded mortar round, numerous ancient shell casings, bits of exploded shells, etc. (It was later learned that the Fort McCoy test area had been an impact zone for an unknown number of National Guard exercises dating back to WW II.)

lanes 1 to 21 in October 1974 and in Lanes 22 to 50 in January 1975. The target emplacements at the YPG site were completed on 11 October 1975.

The site at Fort McCoy was constructed with the test lanes in a north-south direction and with each lane distinguished by a row of wooden distance-marking stakes emplaced 100 feet (30.5 meters) apart. The distance stakes were numbered from "0" to "26" in each lane and were color-coded with surveyors tape to minimize problems in adjacent lane identification. This coding was invaluable during the winter test where deep snow tended to cause extreme disorientation particularly in the wooded areas.

When test runs were being made on these lanes, it was discovered that some of the stakes had been placed more than 30.5 meters apart and some less. Also, some of the lanes had not been surveyed along a straight line. As a consequence, when the site at YPG was prepared, a commercial surveying organization was contracted to survey and mark the test lanes. As at Fort McCoy, lanes were 10 feet (3 meters) wide with a 40-foot (12.2-meter) buffer zone between lanes. Lane marking stakes were placed 50 feet (15.2 meters) apart along the left boundary of each lane and were color-coded with surveyors tape. Stakes were numbered from "0" to "130" in increments of 5 (e.g., 0, 5, 10, 15, - -, 125, 130) in each lane as reference points. This numbering system was used to facilitate recording of distances along the lanes when data were being collected. The distances between stakes were measured in feet and the number on each stake was multiplied by 10 to obtain the distance (in feet) from a given stake to the "0" stake.

8. **Test Protocol.** The participants in a typical test run were a dog, a handler, and an evaluator. Preparatory to beginning a run, the handler and dog took a position at the head of a lane near the "0" stake. When the dog, handler, and evaluator were ready, the evaluator instructed the handler to commence the search. The handler/dog team proceeded down the lane, searching in a serpentine pattern over a 3-meter wide section. The line of wooden stakes bordering the left edge of the lane served as a guide to keep the dog/handler team within bounds. The evaluator took a position approximately 9 meters behind and slightly to the left (in the buffer zone between lanes) of the dog/handler team and maintained this distance as the team progressed down the lane. He also provided guidance to the handler, aiding him in staying within the bounds of the lane.

The handlers were never provided with information about the location of the targets and they were instructed to avoid cueing the dog toward a possible target that appeared to the handler to be visually suspect.

A detection was indicated when the dog sat. The handler then placed a marker flag at this position regardless of whether the sit was motivated by a buried mine or some other object or scent. The evaluator, referring to a data sheet which contained information about target types and their location on the lane being searched and which was given to the evaluator just prior to the beginning of the search, orally indicated to the handler whether or not the marker was on a true target. If a true detection occurred, the extent to which the dog was rewarded by the handler depended upon the dog's prior training and the phase of the test. (See Paragraph 5 on training of dogs in Groups A, B, and C.) At all positions where the dog sat, the evaluator measured and recorded the wind velocity and direction on the data sheet. A sample data sheet is shown in Figure 6. The instructions for filling out the sheet for each run were as follows:

a. Record the following information before going to the test lane:

(1) Evaluation site.

(2) Date.

(3) Dog name, breed, sex.

(4) Lane number.

(5) Handler.

(6) Evaluator.

(7) Group/reinforcement.

b. Measure the soil moisture content at one test site location at a 2-inch depth at the ***start*** of each day. Record time of measurement.

c. Complete immediately prior to the start of test:

(1) Barometric pressure.

(2) Air temperature.

(3) Relative humidity.

(4) Soil characteristics.

(5) Surface conditions (rain, mud, etc.).

d. Record while test is in progress:

(1) Time of day.

(2) Stake number as each stake is passed.

MINE DETECTION DATA SHEET

ETP-76-2
SwRI/USAMERDC

CONTRACT NO. DAAK02-73-C-0150

Evaluation Site: Yuma Proving Ground Date: 6-8-76 Time of Day(start): 1015

Dog: Eve Breed: LR Sex: F Lane No.: 34

Handler: Andy Zuniga Evaluator: E. Benavides Group: A Reinforcement CRF

Soil Moisture: 1.2 % at 0730 (time of day).

Soil Characteristics:

X Gravel/Shale
X Sand
X Clay
Loam
Hardpacked
Other, specify

	START	FINISH
Ground Surface Temp.	81°	86°
Temp. 12" Above Surface	86°	89°
Temp. 36" Above Surface	90°	91°
Relative Humidity	26%	26%
Barometric Pressure	30.11	30.11

Surface Conditions (rain, mud, etc.)

Total Elapsed Search Time 30 Minutes

** Take Wind Reading @ Ground Level Once During Run, Enter In Comment Column.

Start Time (1st half): 1018
Stop Time (1st half): 1030
Elapsed Time (1st half): 22 Min.

FIRST 650 FEET (Stakes 0-65)

Response			Trip Wire E = present	Wind		Stake No.	Comments	Response Reinforced?
Y coordinate	Y overrun (Maximum)	X coordinate		Bearing	MPH			
						0		
59' 6"		o' 9"		330°	7	5	Correct Response (58-2)	X
						10		
						15		
						20		
						25		
						30		
						35		
						40		
						45		
						50		
						55		
613' 0"		9' 0"		300°	6	60	Correct Response (613-9)(M18)	X
							3 mph winds at ground level	
						65		

Figure 6. Sample data sheet (page 1).

Start time (2nd half): 1035
Stop time (2nd half): 1043
Elapsed time (2nd half): 8 Min.

Dog's Name: Eve
Lane No.: 34
Date: 6-8-76

SECOND 650 FEET (Stakes 130 - 65)

Response			Trip Wire E = Present	Wind		Stake No.	Comments	Response Reinforced?
Y coordinate	Y overrun (Maximum)	X coordinate		Bearing	MPH			
						130		
						125		
						120		
				320°	6	115	Passed (1198-8)	
						110		
						105		
						100		
						90		
						85		
						80		
						75		
						70		

Figure 6. Sample data sheet (page 2).

(3) At time of response by dog, write in "correct response" or "false response," whichever is appropriate, in comments column.

(4) Longitudinal ("y") overrun at response position.

(5) Presence of trip wire.

(6) If dog was given reinforcement for response.

(7) Wind speed and direction at each dog response and at each live mine missed by the dog.

(8) Make pertinent comments as necessary (e.g., dog activities which might actuate a fuzed mine; if a dog is given a rest period, indicate the length of the period; general weather conditions; etc.).

e. Complete immediately following end of test:

(1) Enter total elapsed search time in minutes.

(2) Barometric pressure.

(3) Air temperature.

(4) Relative humidity.

(5) Measure x and y coordinates of each response marker placed during test, and record to nearest foot and inch (e.g., if less than 1 foot, record 0 feet and the number of inches).

In order to determine the effects of wind direction on detection, a dual search pattern was employed whereby one half of each lane was searched in one direction and the other half in the opposite direction; thus each search run started at stake "0" and proceeded to the halfway stake. At this point, the dog/handler team moved into the buffer zone to the left of the lane and walked directly to the end of the lane. After a short rest break, the search was resumed, traveling back toward the halfway stake. Upon reaching the halfway stake, the search was terminated, and the search team returned through the buffer zone to the staging area adjacent to the site.

For a given test period, which was usually 10 search days (13 days for the winter tests at Fort McCoy), the handlers and dogs were assigned test lanes on a pseudo-random basis. No handler or dog was assigned to a given lane more than once. (Exception: While conducting the winter tests at Fort McCoy, one dog was assigned the same lane twice within four days but with a different handler.) The daily lane assignments given the dog/handler teams at the Fort McCoy site (winter and spring tests) and at the YPG site (October and June tests) are shown in Tables 6 through 9.

Table 6. Daily Lane Assignments for Dog/Handler Teams, Fort McCoy, Winter 1975

Dog/Handler	February					March							
	24	25	26	27	28	1	2	3	4	5	6	7	8
Angus/Cooper	22	–	34	43	–	11							
Apache/Zuniga	24	–	36	45	–	14							
Eve/Cooper	–	28	40	–	4	–							
Dusky/Zuniga	–	26	38	–	2	–							
Tiger/Cooper	–	30	–	42	7	17							
Val/Zuniga	–	27	–	44	10	20							
Bolo/Cade							3	–	–	–	–	–	–
/Trujillo							–	29	–	–	–	–	–
/Polonis							–	–	–	–	23	–	–
Brandy/Trujillo							6	–	31	–	–	–	–
/Cade							–	–	–	35	–	–	–
/Zuniga							–	–	–	–	–	47	–
Bretta/Cooper							5	–	8	–	25	–	–
Casey/Cade							7	37	18		27	–	35
Duncan/Zuniga							9	39	41	–	–	–	–
/Trujillo							–	–	–	26	–	–	–
/Polonis							–	–	–	–	–	5	–
/Cooper							–	–	–	–	–	–	26
Ernie/Polonis							11	27	–	3	–	–	–
/Cade							–	–	16	–	31	–	36
Marcia/Cooper							14	–	–	5	–	9	–
/Polonis							–	43	33	–	–	–	19
/Zuniga							–	–	–	–	38	–	–
Newton/Zuniga							15	–	–	7	–	–	–
/Trujillo							–	45	12	–	–	–	–
/Cade							–	–	–	–	–	40	–
Quickie/Trujillo							17	–	–	9	–	–	–
/Polonis							–	–	47	–	–	–	–
/Cooper							–	–	–	–	2	–	–
/Zuniga								–	–	–	–	16	42
Rex/Polonis							19	–	–	–	–	–	44
/Zuniga							–		35	–	–	–	–
/Cade							–	–	–	11	–		–
/Cooper							–	–	–	–	–	4	–
Warp/Cade							–	21	–	–	–	–	
/Zuniga							–	–	–	46	–	–	
/Polonis							–	–	–	–	41		
/Cooper							–	–	–	–	–	–	2
Whop/Cooper							–	23	–	–	–	–	
/Polonis							–	–	–	15	–	–	–
/Zuniga							–	–	–	–	43	–	12
Winchester/Zuniga							–	25	–		–	–	
/Cooper							–	–	–	17	–		–
/Polonis							–	–		–	–	20	

Table 7. Daily Lane Assignments for Dog/Handler Teams, Fort McCoy, Spring 1975

Dog/Handler	May						June			
	26	27	28	29	30	31	2	3	4	5
Angus/Cooper	3	32	–	4	30	–	6	27	–	34
Apache/Cade	1	30	–	2	28	–	4	29	–	40
Bretta/Mouton	17	–	33	18	–	7	16	–	5	24
Casey/Cade	11	–	39	12	–	1	14	–	3	28
Duncan/Mouton	7	36	–	8	24	–	10	23	–	32
Dusky/Zuniga	–	28	21		32/35	19	–	31	9	
Ernie/Cooper	40	22	27	–	38	13	–	37	19	–
Eve/Zuniga	19	–	31	20	–	9	2	–	11	22
Quickie/Marcinko	–	24	25/14	–	36	15	–	35	7	–
Rex/Zuniga	9	38	–	10	22	–	20	21	–	36
Tiger/Cooper	13	–	37	14	–	3	12	–	33	26
Val/Cade	–	20/2	29	–	40	11	–	39	17	
Warp/Marcinko	5	34	–	6	26	–	8	25	–	30
Whop/Marcinko	15	–	35	16	–	5	18	–	13	38
Winchester/Mouton	–	26	23	–	34	17/37	–	33	15	–

9. **Test Results.** The results are presented graphically in Figures 7 through 21. During preliminary data analysis, in preparation for graphical presentation, an acceptable detection radius was determined. The dogs alerted on the mines at random locations around the mines (see Figure 21) and calculations were made to determine the distribution of these alerts within incremental radii from the center of the mines as a percentage of the total distribution (alerts out to 3 meters). The initial computation was made for a radius of 0.3 meter with subsequent computations made for radii increased by 0.3-meter increments out to 3 meters. These calculated values were then plotted and curves were drawn as shown in Figure 7.

There were few alerts beyond 3 meters and a curve was plotted for each of the four tests. It is observed that about 90 percent of the alerts fall within a radius of 1.5 meters. Therefore this radius was used in scoring the detection performance of the dogs. Since dogs Bolo, Brandy, Marcia, and Newton were used only during the first test period (February-March 1975 at Fort McCoy), their performance data were not included in the test results. Figure 8 shows the detection performance in percent of live mine targets detected (i.e., the number of live mine targets detected divided by the total number of mine targets that were possible to detect) by each dog during each of the four test periods (indicated by 1, 2, 3, and 4 in Figure 8). The circle indicates the percent of live mine targets detected by each dog during all test periods.

Table 8. Daily Lane Assignments for Dog/Handler Teams, YPG, October 1975

Dog/Handler	October									
	14	15	16	17	18	20	21	22	23	24
Angus/Trujillo		2	17	43	11		26		4	29
Apache/Cade	5	26	37		14	30		24	28	
Bretta/Cooper		6	22	48		50			9	44
/Cade							31			
Casey/Cade	50			33			16	42		19
/Zuniga			7			40				
Duncan/Trujillo	15	36		16	24	6		12	38	
Dusky/Zuniga	45		14	38		1	21	32		24
Ernie/Cooper	20	41	12					17	43	
/Cade					29	45				
Eve/Cade				18			2			
/Zuniga	30		47		39			27		5
Quickie/Cooper	40			28	49		11	37		14
/Cade			3							
Rex/Zuniga	10	31		4	19			3	33	
/Trujillo						34				
Tiger/Cooper	1	21	42		5	25	46		23	
Val/Trujillo	35	8		23	44		7	47		10
Warp/Cooper				13	34					
/Cade	25	46						22		
/Zuniga									48	49
Whop/Zuniga		16			9				18	
/Trujillo			32			20	41			34
Winchester/Cooper						15				
/Cade		11	27	8					13	39
/Zuniga							36			

Table 9. Daily Lane Assignments for Dog/Handler Teams, YPG, June 1976

Dog/Handler	June									
	8	9	10	11	12	14	15	16	17	18
Angus/Trujillo		7	16	46	49		47		3	34
Apache/Cade	9	27	43		15	48		7	46	
Brett/Cooper		1	21	26		43			11	45
/Cade							33			
Casey/Cade	45			35			17	44		18
/Zuniga			6			31				
Duncan/Trujillo	19	37		8	27	9		13	30	
Dusky/Zunigo	49		11	40		4	23	50		29
Ernie/Cooper	22	42	18					19	35	
/Cade					36	25				
Eve/Cade				13			1			
/Zuniga	34		48		41			36		10
Quickie/Cooper	44			30	29		12	41		23
/Cade			2							
Rex/Zuniga	14	32		3	22			2	26	
/Trujillo						38				
Tiger/Cooper	4	24	38		10	34	28		16	
Val/Trujillo	39	15		25	45		6	31		5
Warp/Cooper				20	32					
/Cade	29	47						24		
/Zuniga									39	38
Whop/Zuniga		17			5				8	
/Trujillo			33			21	42			48
Winchester/Cooper						14				
/Cade		12	28	50					20	40
/Zuniga							37			

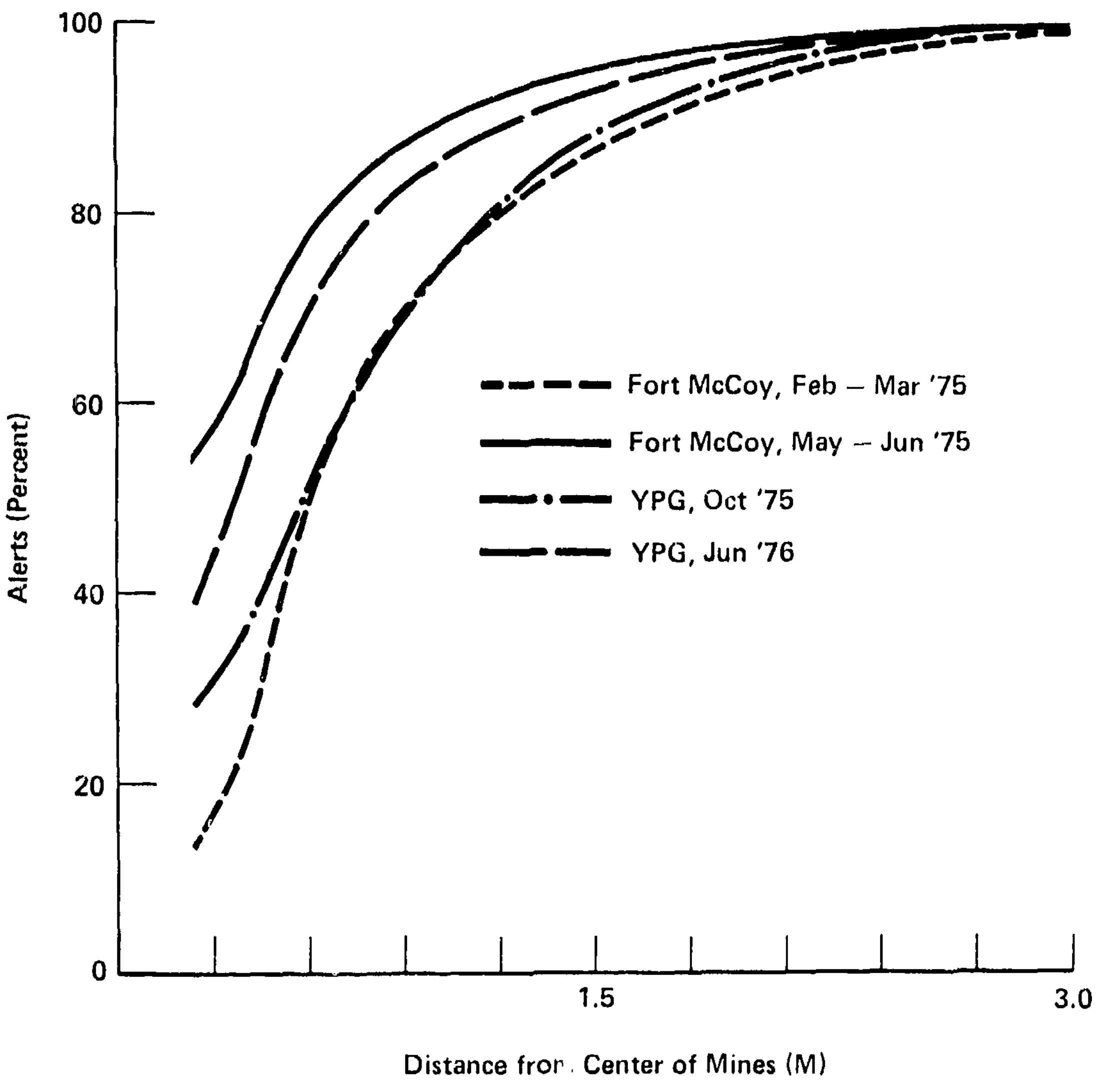

Figure 7. Density of dog alerts as a function of "sit" distance from center of mines.

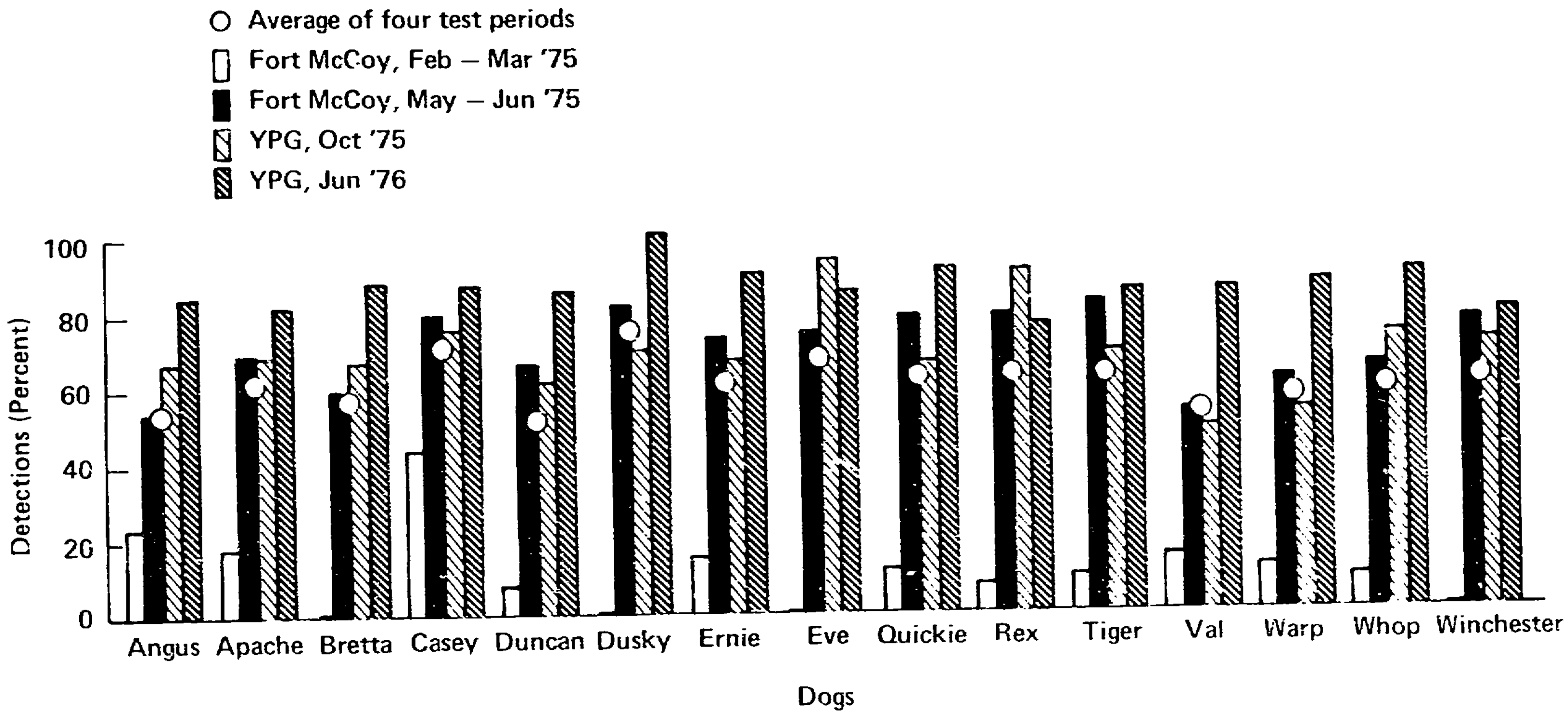

Figure 8. Detection performance of dogs.

Test periods 1 and 2 were at Fort McCoy, and periods 3 and 4 were at YPG. In Figure 9, morning detection performances are compared with afternoon performances for the four test periods. In Figure 10, the performances of dog groups are compared. As explained in Paragraph 5, there were three groups of dogs (A, B, and C), and each group was comprised of five dogs. Groups A and B were trained on continuous reinforcement and Group C, on partial reinforcement. Group A worked during phase 1 (the first half of each test) and phase 2 (the latter half of each test) under continuous reinforcement. Group B worked during phase 1 under continuous reinforcement and during phase 2 under no reinforcement. Group C worked during phase 1 under partial reinforcement and during phase 2 under no reinforcement. Figure 11 shows the percentage of each type of mine that was detected by all dogs during each test period (1, 2, 3, and 4) and during all periods (indicated by circles). Figure 12 shows the performance of dogs grouped by handlers. Three handlers (Cade, Cooper, and Zuniga) worked dogs during all four test periods; Trujillo, during test periods 1, 3, and 4; Marcinko and Moulton, during period 2; and Polonis, during period 1. Figure 13 shows the percentage detection of (A) live mines and (B) practice mines and distractants by all dogs for each test period. Figure 14 shows the total number of alerts by all dogs during each test period on (A) live mines, (B) practice mines and distractants, and (C) unidentified targets. Figure 15 shows the number of false responses per kilometer (for a 3-meter width search path) by each dog for each test period (1, 2, 3, and 4) and all test periods (indicated by circles). The false responses were alerts on practice mines, distractants, or unidentified targets. Figure 16 shows area search rate (square meters/minute) for each dog for each test period indicated by 1, 2, 3, and 4) and all search periods (indicated by circle). In Figures 17 through 20 the location of the alerts about mines were plotted to determine whether or not wind direction had an effect on alert position. Each figure represents a different search condition that is characterized by different wind and search directions for the four test periods. A composite of all alerts was plotted (Figure 21) to show their cluster about the mines. The magnitude of the alerts at locations on or near the mines is indicated by the height of the vertical lines. The climatic conditions that prevailed during each day of each test period are shown in Tables 10 through 13.

III. DISCUSSION

10. **Evaluation of Test Results.** The detection performance of the dogs (Figure 8) during the first test period (February-March 1975 at Fort McCoy) was poor (11 percent detection) due primarily to the severe weather conditions that prevailed. The weather (see Table 10) varied from clear to cloudy with periods of heavy snow and there was light rain one day. Most of the days were generally clear. Winds varied in velocity from 0 to gusts of about 30 knots, but mostly wind velocities ranged between

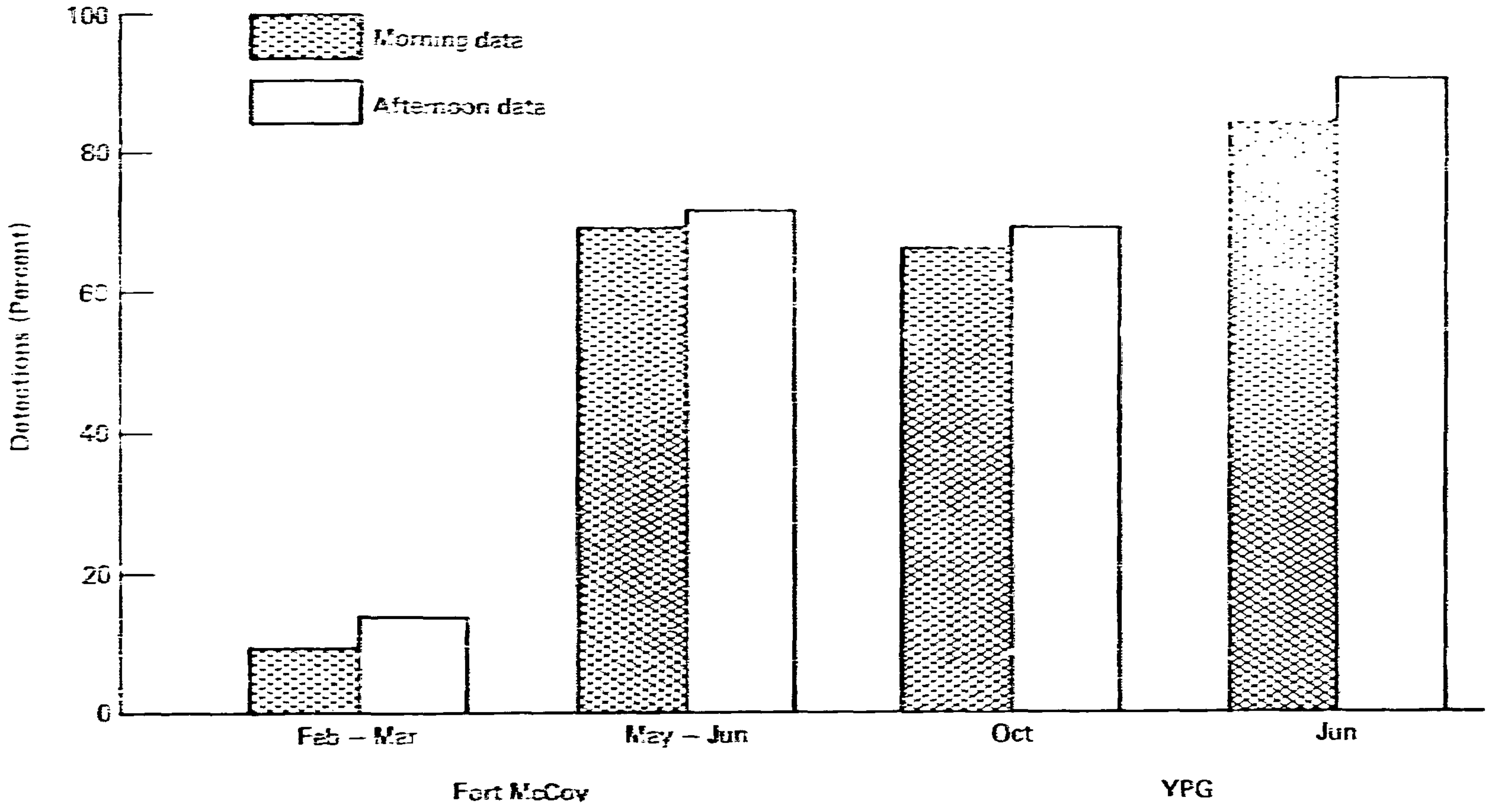

Figure 9. Detection performance by time of day.

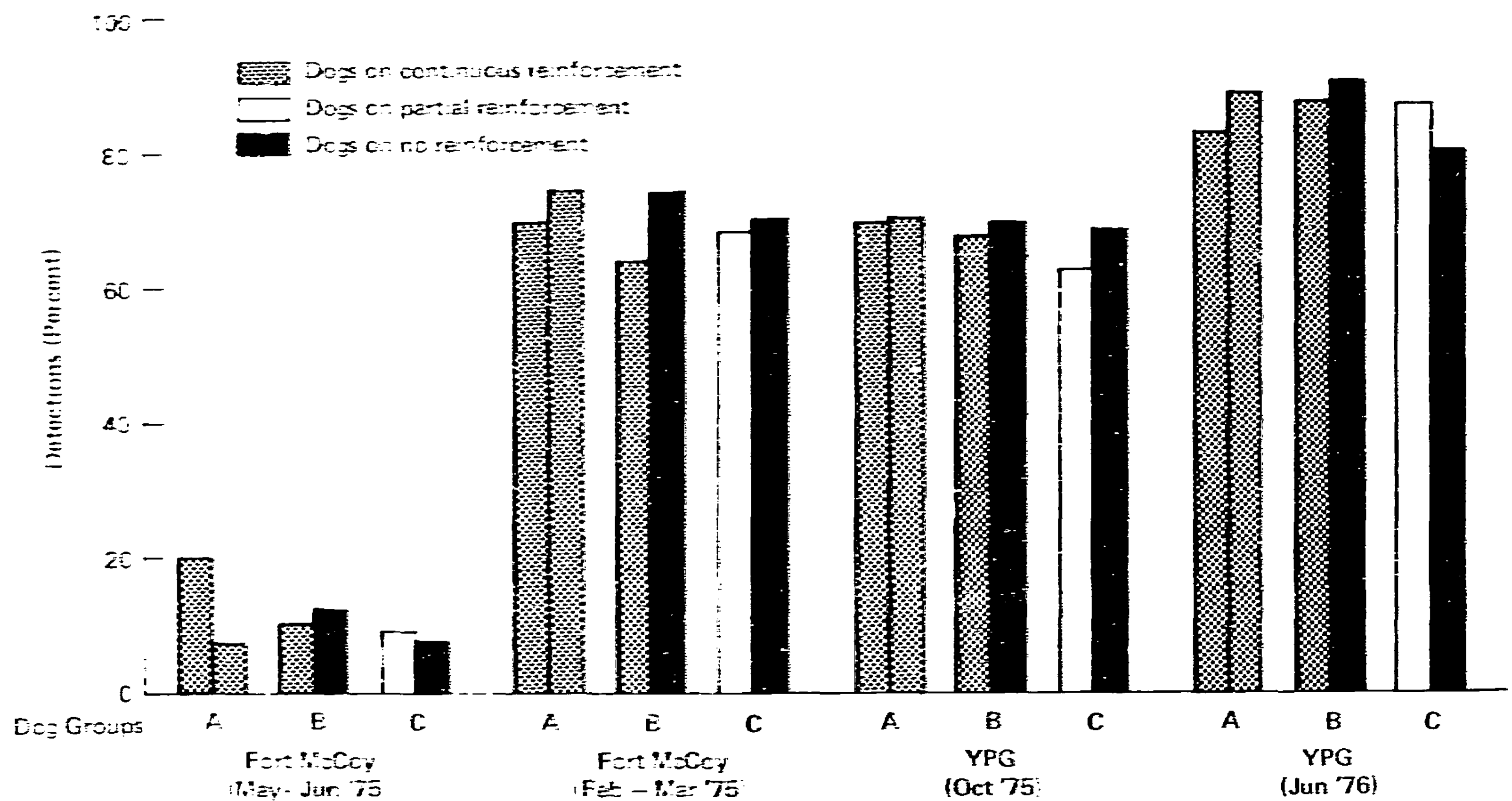

Figure 10. Detection performance of dog groups.

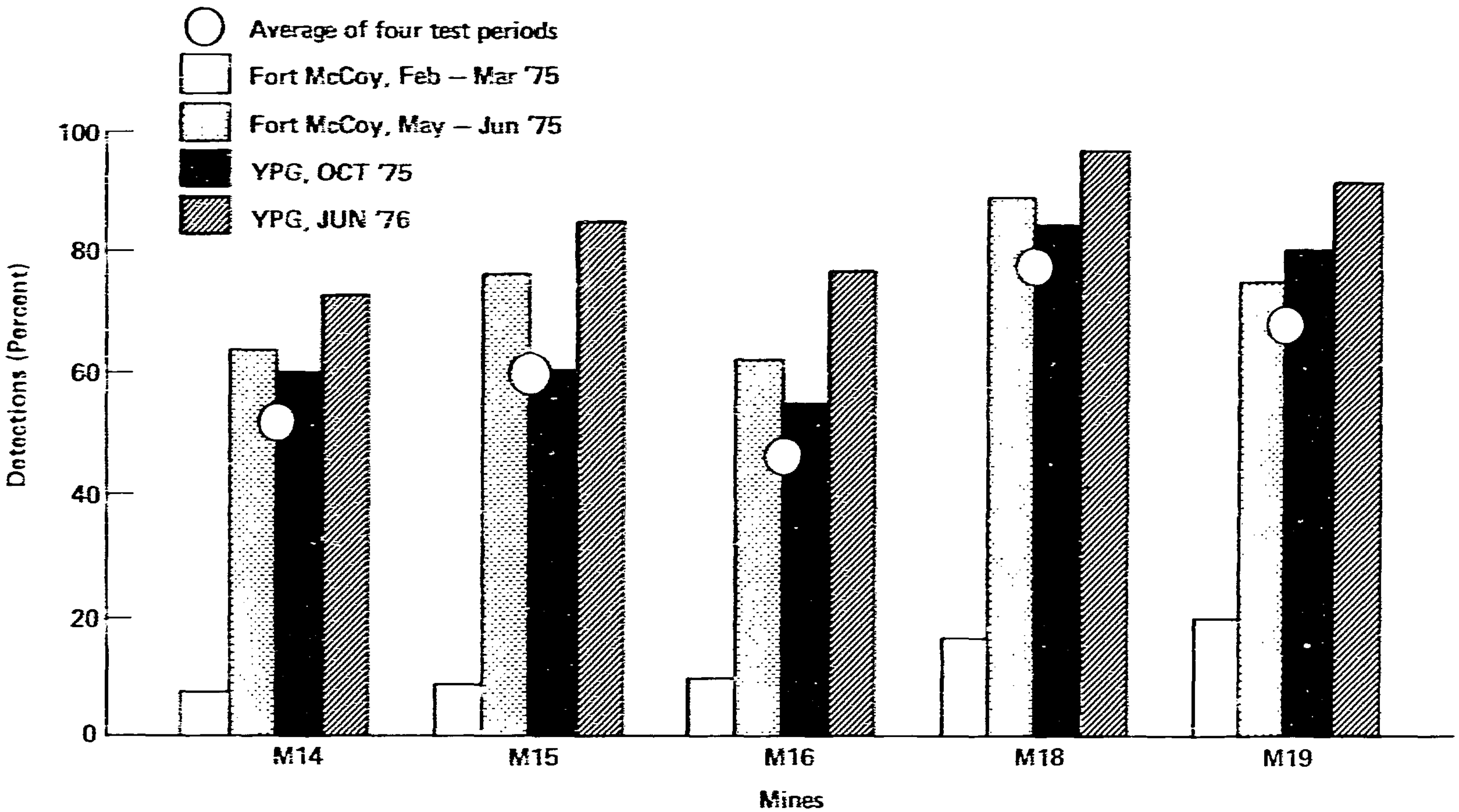

Figure 11. Mines detected by type of mine.

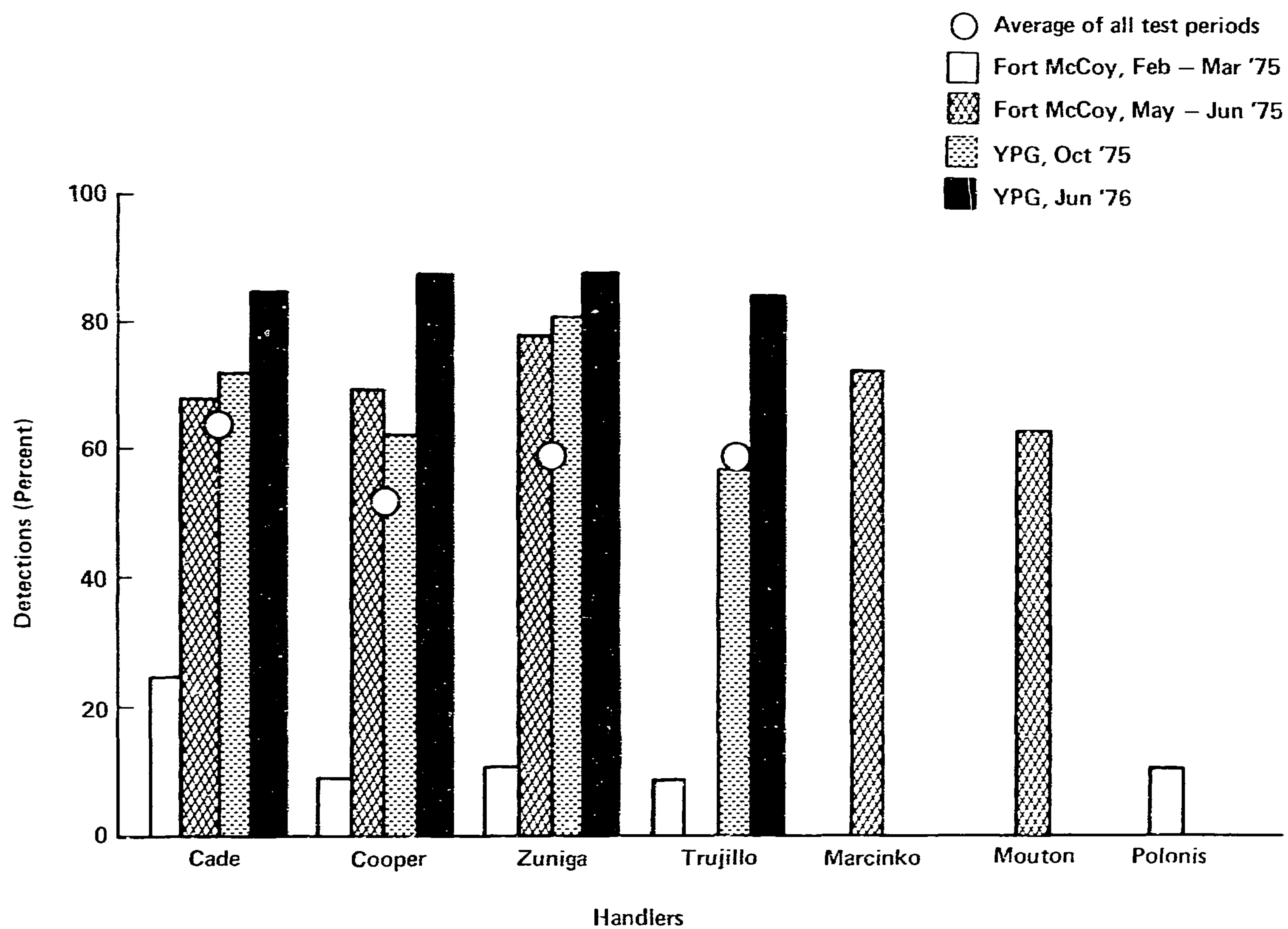

Figure 12. Detection performance, grouped by handlers.

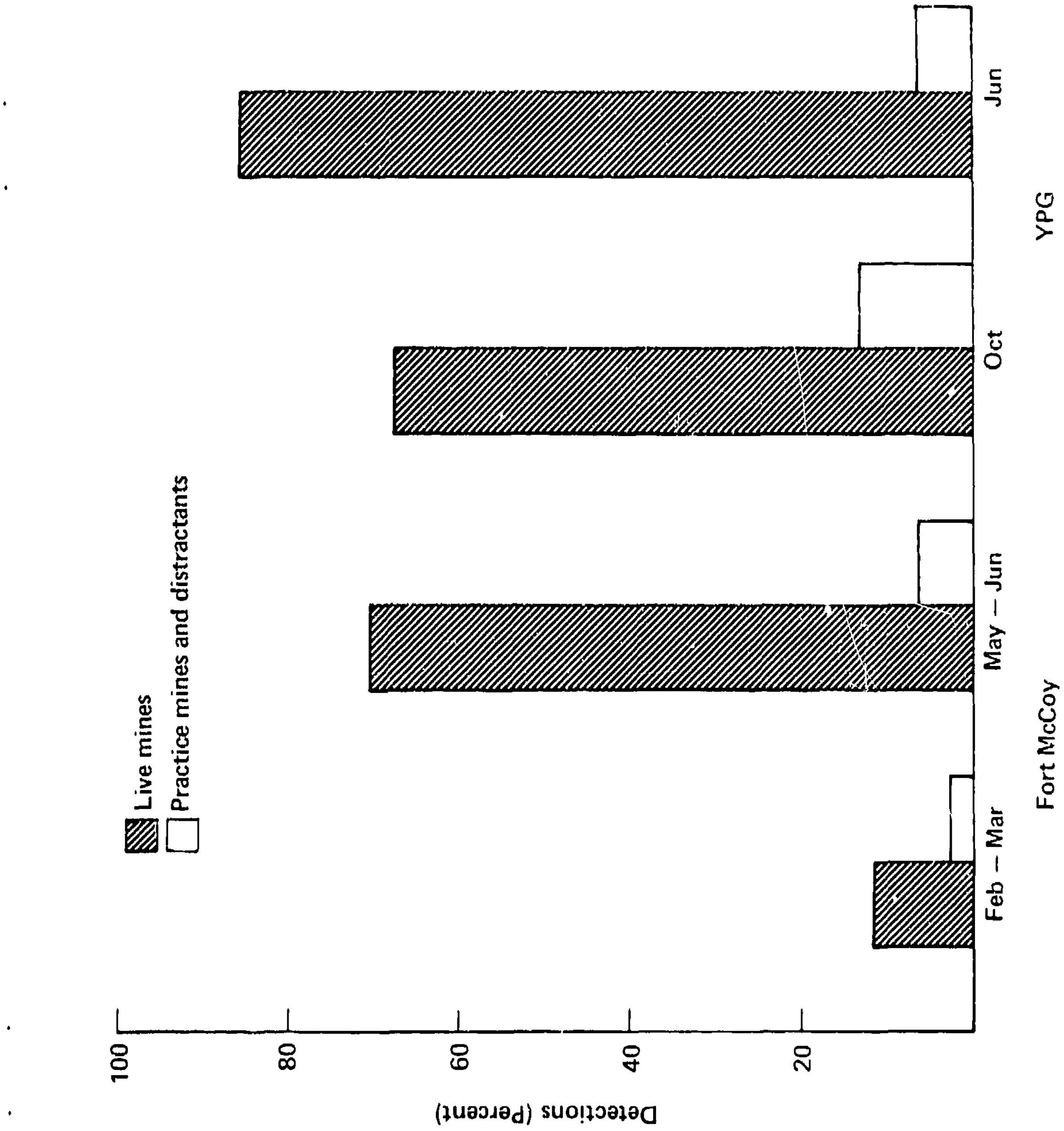

Figure 13. Dog alerts on mines and distractants.

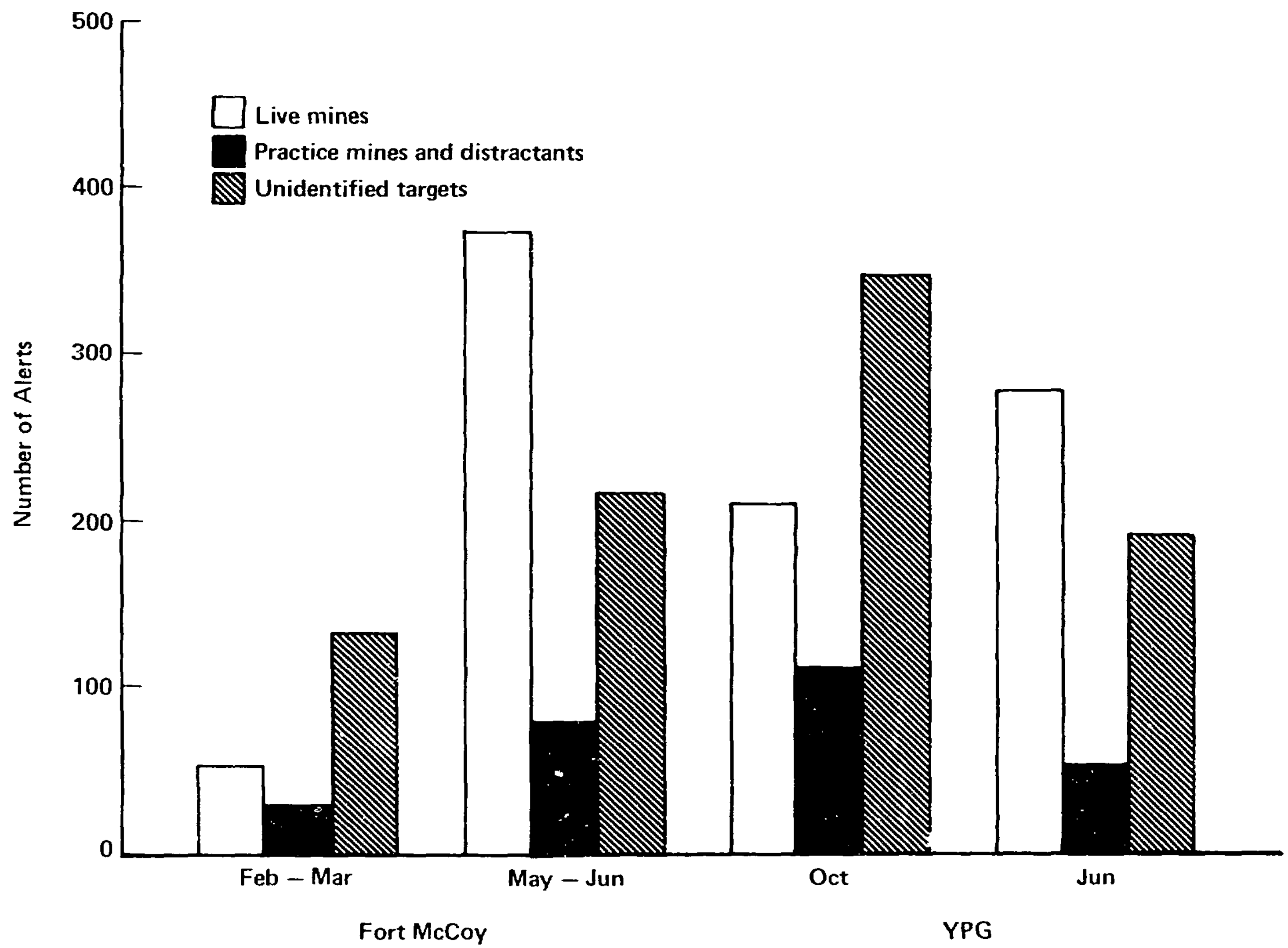

Figure 14. Distribution of all dog alerts.

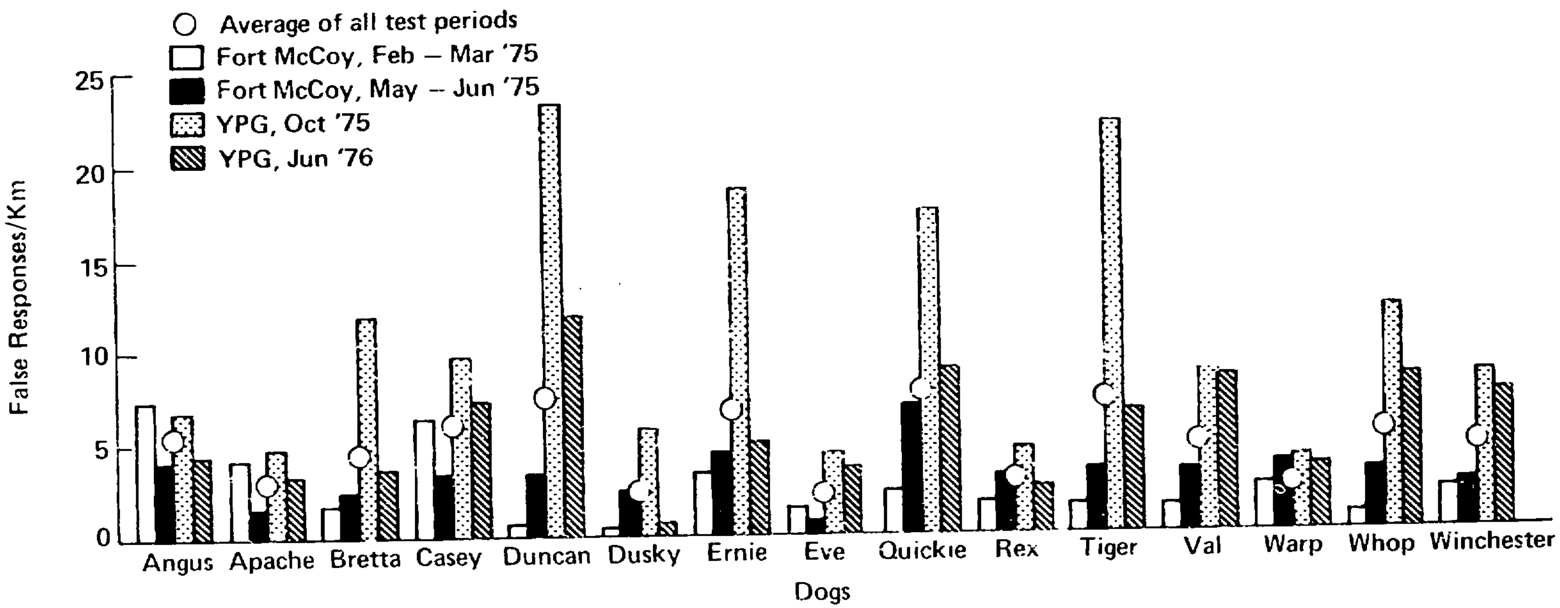

Figure 15. Dog alerts on practice mines, distractants, or unidentified targets.

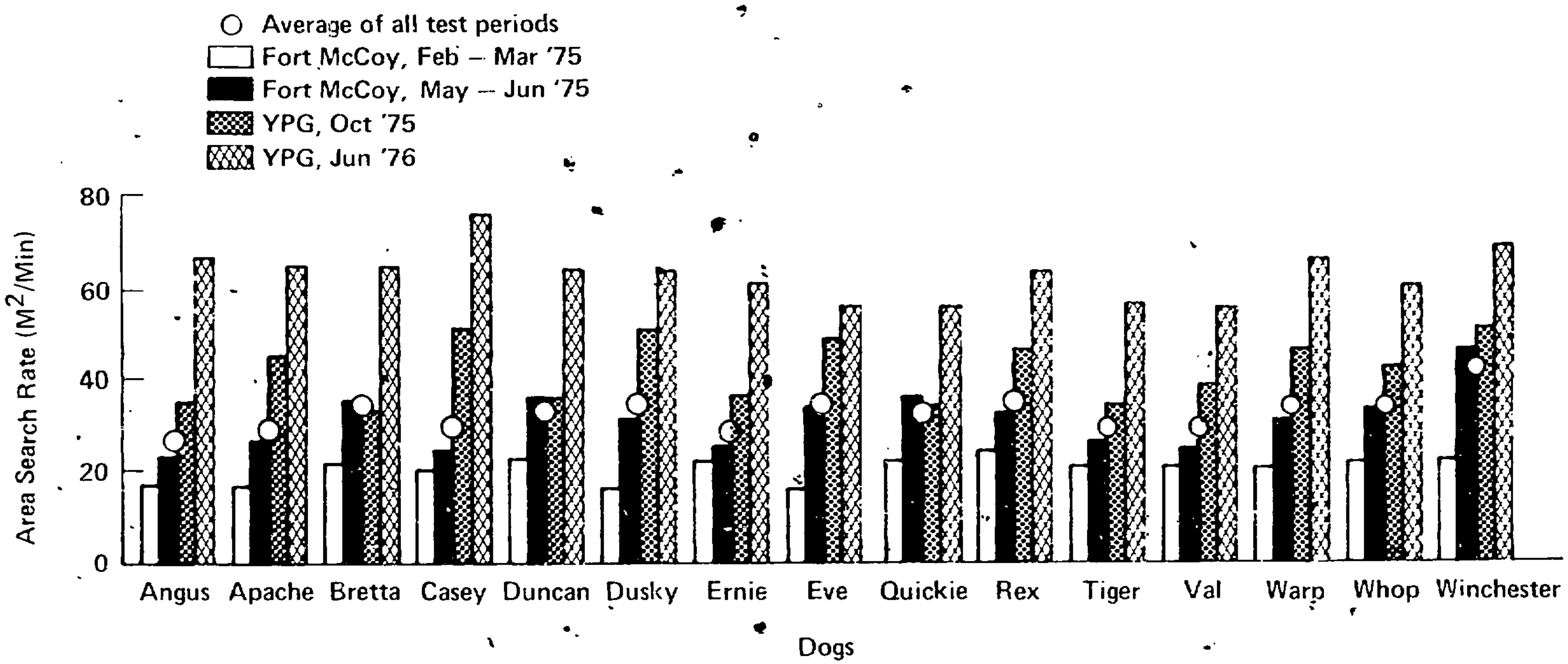

Figure 16. Area search rate of dogs.

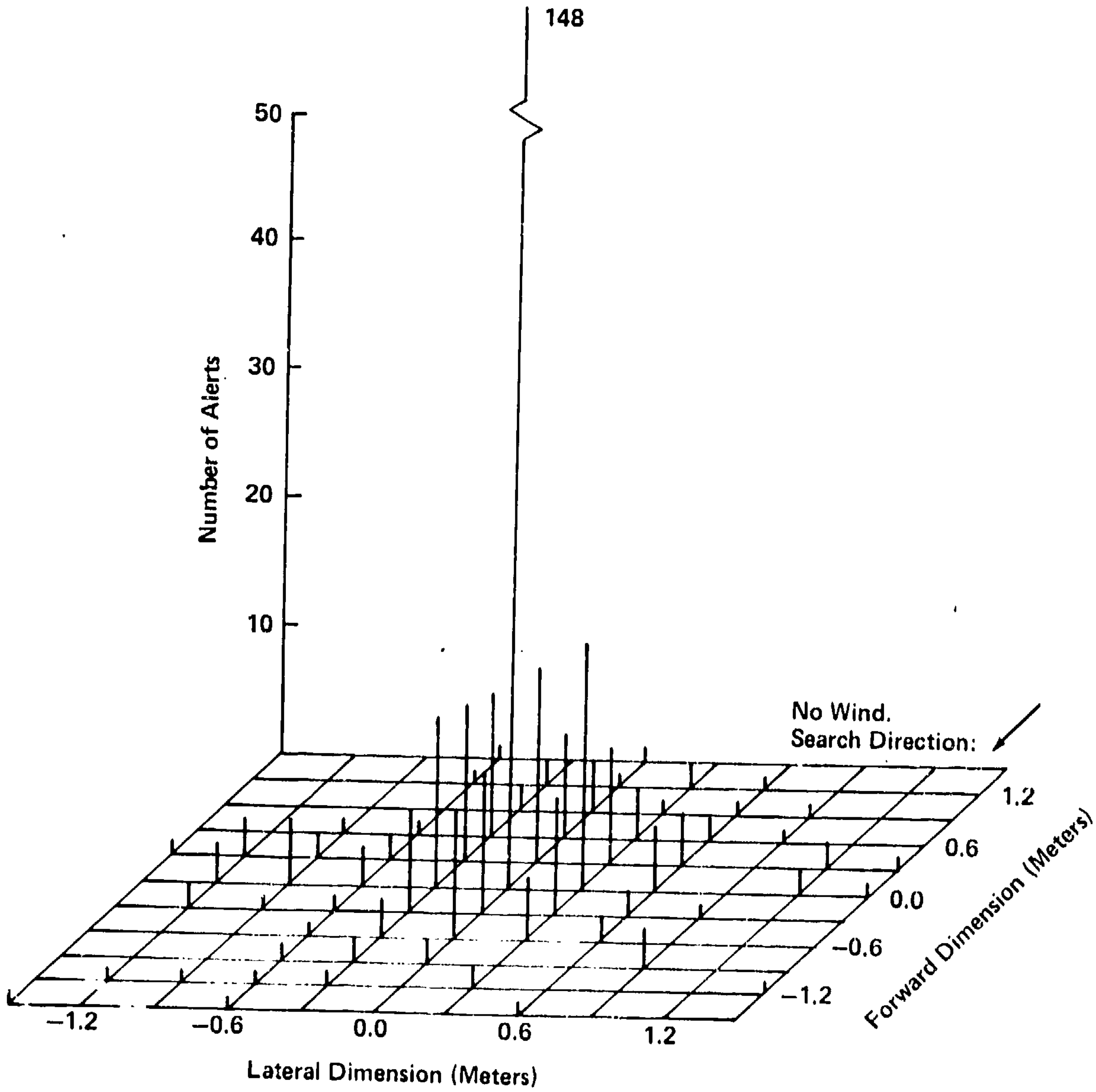

Figure 17. Location of alerts about mines.

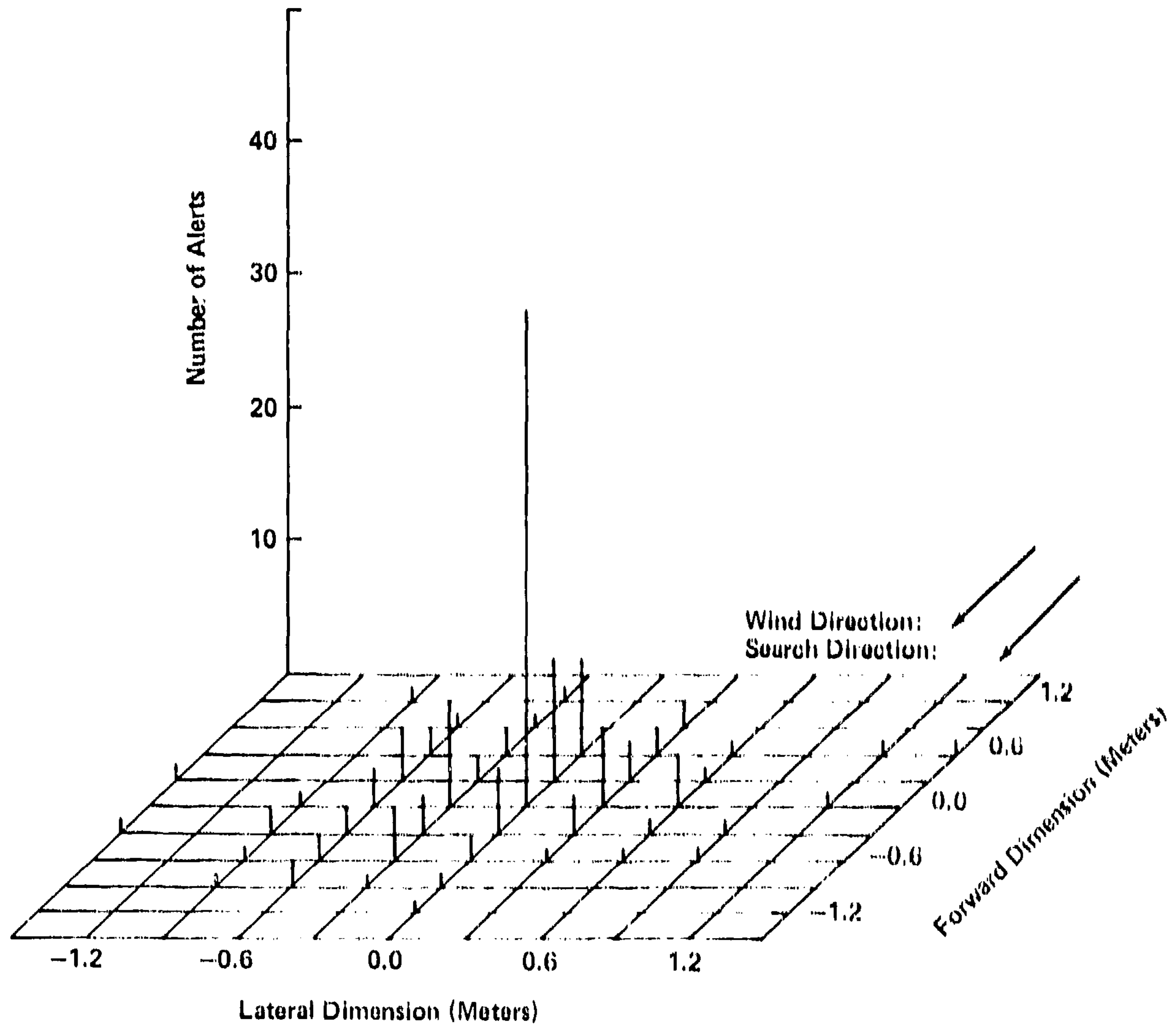

Figure 18. Location of alerts about mines.

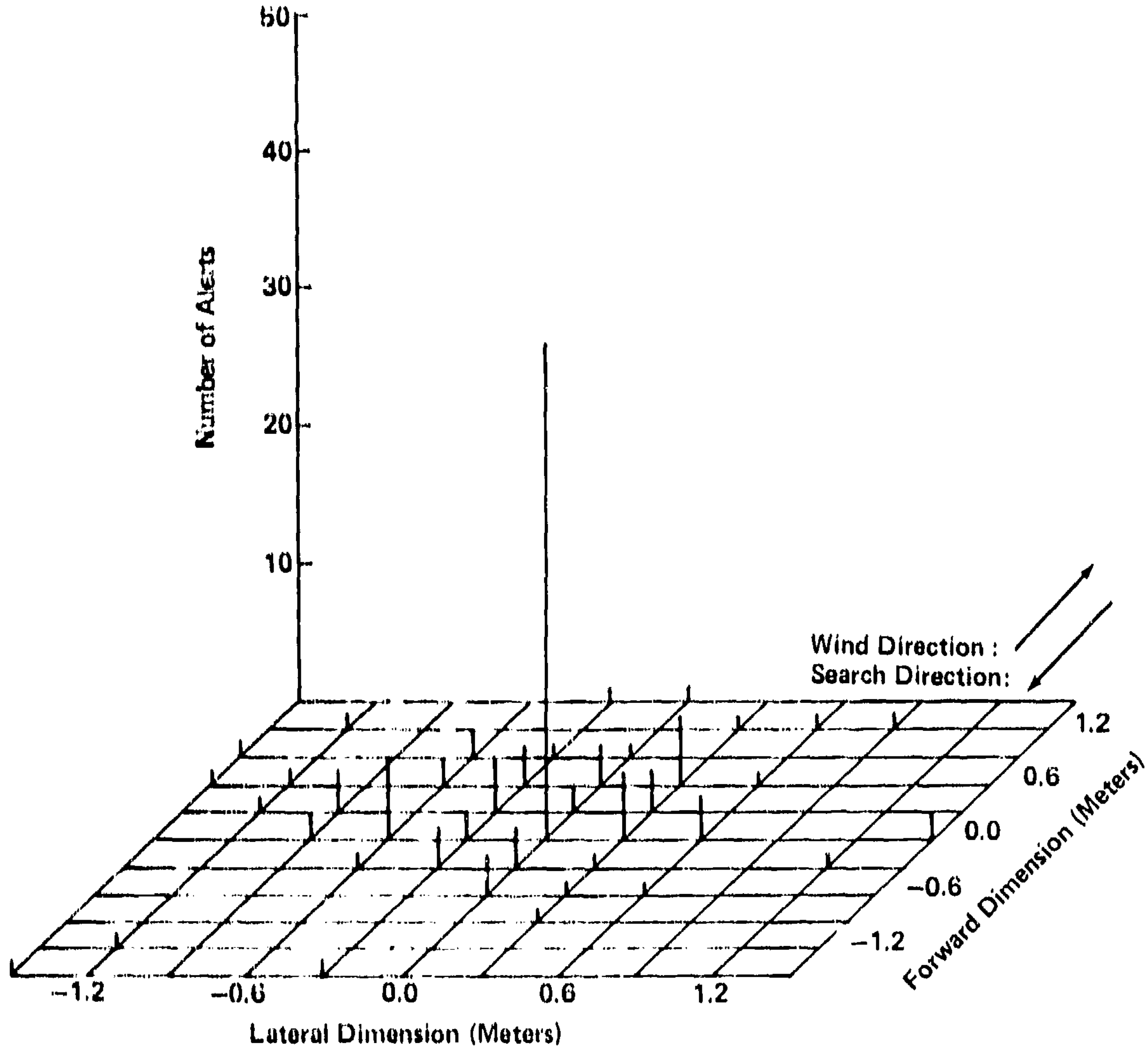

Figure 19. Location of alerts about mines.

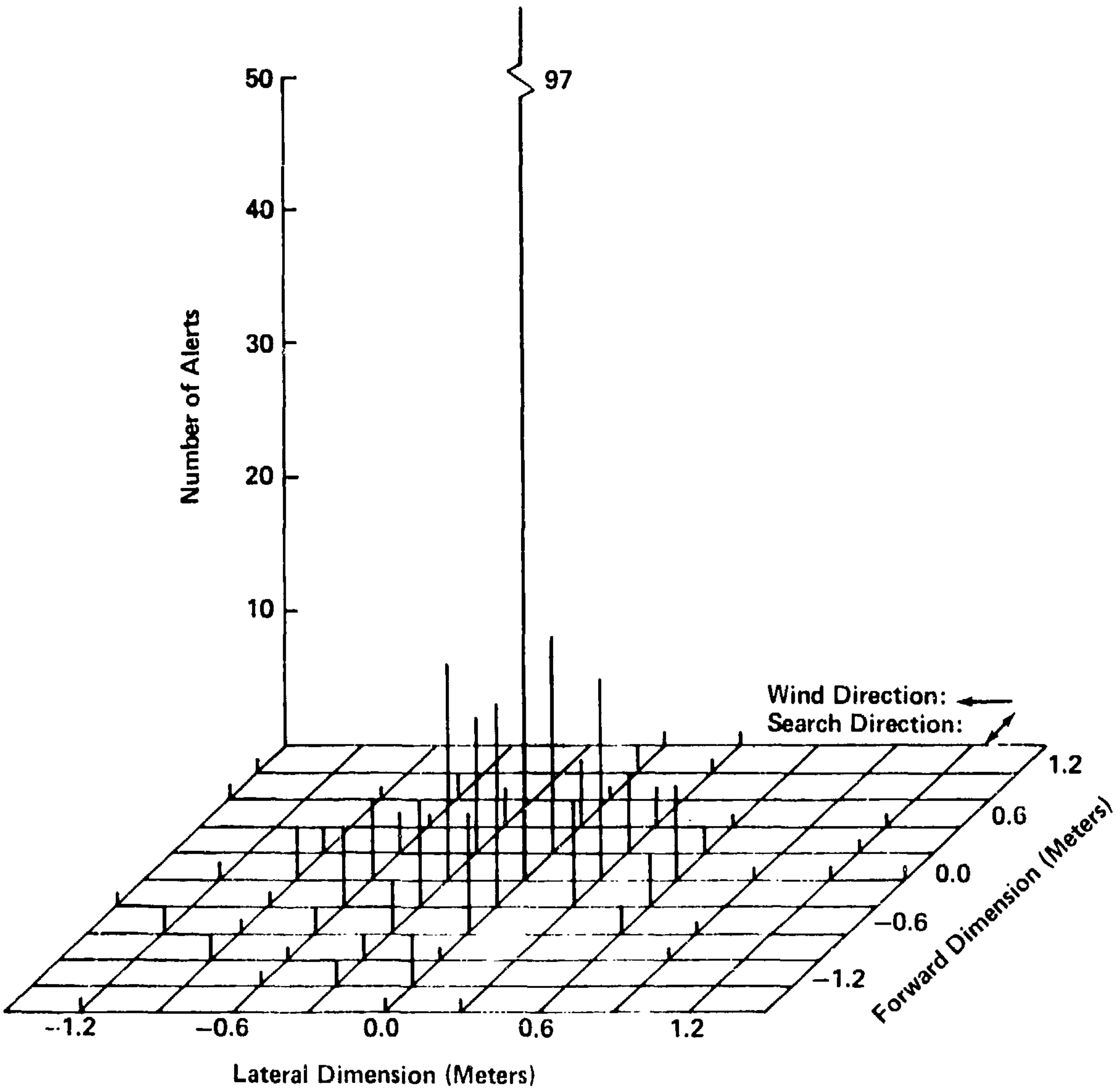

Figure 20. Location of alerts about mines.

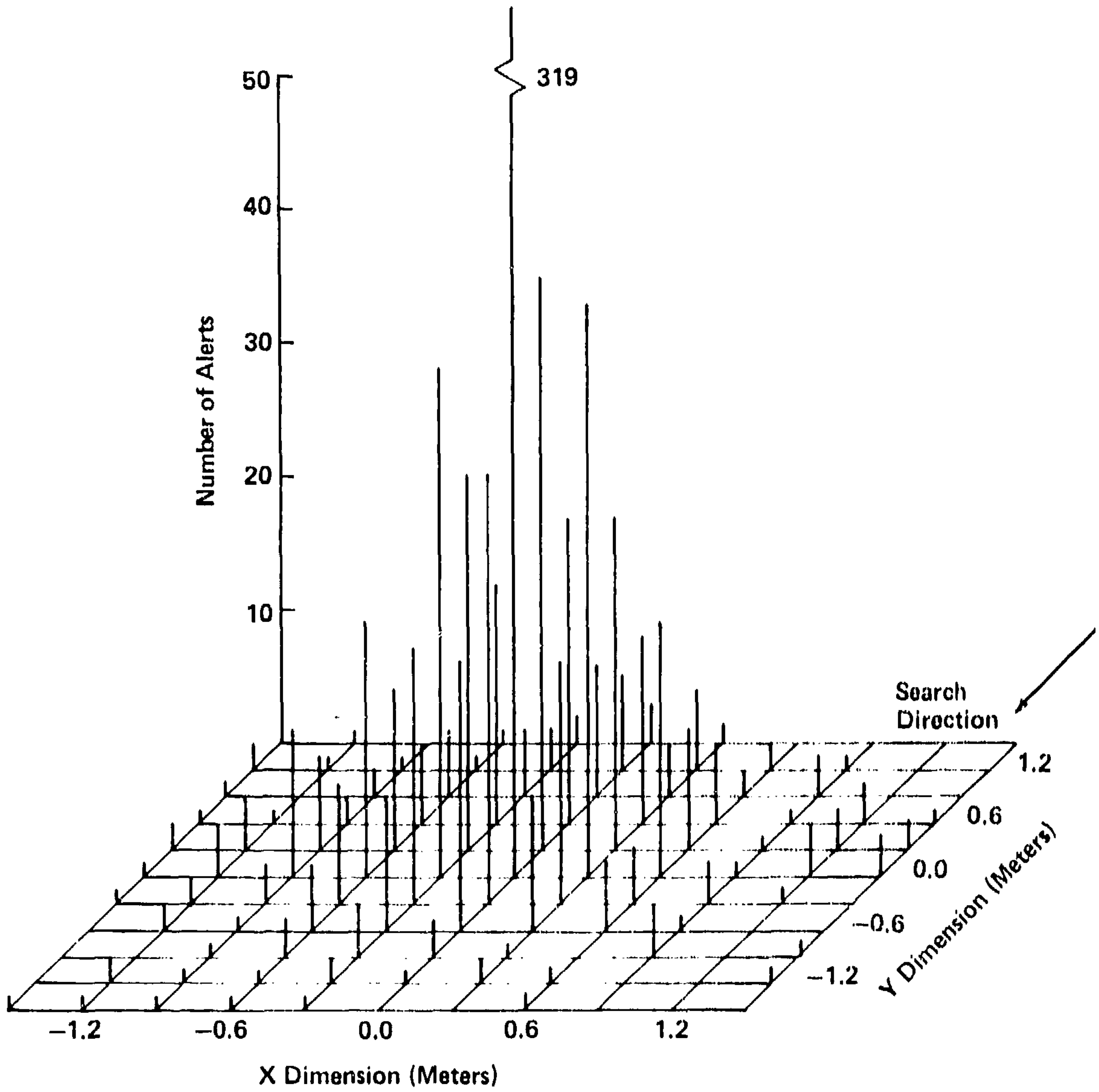

Figure 21. Composite of all alerts about mines.

Table 10. Climatic Conditions During Test (Average Values)
Fort McCoy, February-March 1975

Date	Ambient Temperatures (°C)		Relative Humidity (%)		Atmospheric Conditions		Wind Direction and Velocity (kn)	
	AM[1]	PM[2]	AM[1]	PM[2]	AM[1]	PM[2]	AM[1]	PM[2]
Feb 24	No data	-1.1	No data	84	snow	rain	No data	N4
25	-2.8	-2.8	72	74	snow	clear	W12	W12
26	-5.0	-6.1[3]	60	42	cloudy	clear	W10	W6
27	-5.8	-2.5	37	64	clear	cloudy	0	S4
28	-3.9	-1.7	70	60	clear	clear	WNW5	NW8
Mar 1	-13.6	-8.9	45	43	clear	clear	W3	WNW5
2	-13.6	-5.3	32	32	clear	partly cloudy	0	NW6
3	-11.1	-6.1	31	32	clear	clear	0	W5
4	-16.5	-6.1	37	35	clear	partly cloudy	0	WNW6
5	-3.9	-2.2	70	70	snow	snow	SW3	SSW4
6	-2.8	1.7	70	58	cloudy	partly cloudy	SW2	SW3
7	0	0.6	45	72	partly cloudy	clear	NW4	NW6
8	-5.8	0	32	35	clear	clear	WNW4	WNW4

[1] 0800-1100 hours
[2] 1300-1600 hours
[3] 1800-2100 hours

Table 11. Climatic Conditions During Test (Average Values)
Fort McCoy, May–June 1975

Date	Ambient Temperature (°C)		Relative Humidity (Percent)		Atmospheric Conditions		Wind Direction and Velocity (kn)		Soil Moisture (Percent)
	AM	PM	AM	PM	AM	PM	AM	PM	
May 26	[illegible]	[illegible]	[illegible]	54	rain	partly cloudy	W3	NW3	18.0
27	[illegible]	[illegible]	[illegible]	45	clear	clear	NW2	W4	11.0
28	[illegible]	[illegible]	55	53	partly cloudy	partly cloudy	0	E3	6.0
29	[illegible]	[illegible]	[illegible]	—	drizzle	cloudy	E3	0	12.0
30	[illegible]	[illegible]	[illegible]	—	cloudy	rain	0	0	11.0
31	[illegible]	[illegible]	[illegible]	55	clear	clear	0	WNW4	11.0
June 2	[illegible]	[illegible]	[illegible]	[illegible]	clear	partly cloudy	0	0	9.5
3	[illegible]	[illegible]	[illegible]	53	clear	clear	WSW5	W4	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	rain	partly cloudy	0	W3	19.0
5	[illegible]	[illegible]	[illegible]	51	clear	clear	W4	W[illegible]	[illegible]

[illegible]–1030 hour
[illegible] 1300–1530 hour

Table 12. Climatic Conditions During Test (Average Values)
YPG, October 1975

Date	Ambient Temperature (°C)		Relative Humidity (%)		Atmospheric Conditions		Wind Direction and Velocity (kt)		Soil Moisture (%)
	AM[1]	PM[2]	AM[1]	PM[2]	AM[1]	PM[2]	AM[1]	PM[2]	
Oct 14	22.6	26.5	34	2[illegible]	clear	clear	NNW[illegible]	NNW10	1.2
15	18.3	30.0	34	17	clear	clear	NNW5	NW9	1.5
16	17.8	33.0	31	2[illegible]	clear	clear	0	W4	1.8
17[3]	16.3	34.4	27	25	clear	clear	0	0	1.4
18	14.4	33.5	26	2[illegible]	partly cloudy	partly cloudy	0	S4	1.2
20	16.3	2[illegible].7	[illegible]	34	clear	clear	SE	SE6	1.2
21	15.0	2[illegible].4	[illegible]	40	clear	clear	0	SSW4	1.2
22	20.6	31.7	52	42	clear	clear	E7	SW11	1.4
23	17.8	2[illegible].6	36	30	clear	clear	NW12	NNW10	1.0
24	15.6	No data	32	No data	clear	No data	NNW5	No data	1.2

[1] 0730–0830 hours
[2] 1300–1530 hours
[3] Ground surface temperature [illegible] °C at 1325 hours

Table 15. Climatic Conditions During Test (Average Values)
YPG, June 1976

Date	Ambient Temperature (°C)		Relative Humidity (%)		Atmospheric Conditions		Wind Direction and Velocity (km)		Soil Moisture (%)
	AM[1]	PM[2]	AM[1]	PM[2]	AM[1]	PM[2]	AM[1]	PM[2]	
June 8	29.4	No data	26	No data	clear	No data	S6	No data	1.2
9	27.8	35.6	37	34	clear	clear	E5	SW13	1.5
10	24.4	28.3	36	39	clear	clear	W10	W15	1.0
11	22.2	29.4	46	36	clear	clear	NW4	SW6	1.2
12	25.6	33.3	44	34	clear	clear	SW3	SW8	1.0
14	32.8	38.9	30	23	clear	clear	NNW10	N14	1.2
15	33.3	38.9	22	23	clear	clear	NNW13	N7	1.2
16	33.9	42.2	26	23	clear	clear	NNW4	SSW13	0.8
17	30.6	38.3	27	23	clear	clear	SE4	SW14	0.8
18	35.0	No data	28	No data	clear	No data	SW3	No data	1.0

[1] 0730-1130 hours
[2] 1230-1445 hours

0 and 10 knots. Ambient temperatures varied from about -20° C (night temperature) to 1.7° C (day temperature), with most temperatures ranging below 0° C.

The major factor impacting on this test was the snow, which ranged in depth from about 30 to 60 cm. In addition to the fatiguing effect on the handlers, the snow made it difficult for the dogs to perform effectively; at times they had to struggle simply to move through the snow. In addition to the impairment of movement the snow provided additional cover for the explosive odorant to penetrate, thereby providing less odorant for the dogs to scent.[21] A day or two after a fresh snowfall, the snow surface became crusty. This surface would partially support the dog, but when he would shift his weight, his paws would fall through into the snow and ice below. As a result, in a number of cases, the dogs foot pads were cut seriously enough to cause profuse bleeding. This condition was common among the dogs that arrived at Fort McCoy in February just prior to the beginning of the test period, but a group of dogs that had been at Fort McCoy since January did not have this problem to any great extent. However, one of the early arrival dogs did occasionally get ice in his paws which disturbed him, and another dog suffered some loss of skin from his foot pads due to adhesion to the cold metal floor in the truck in which he was riding from the housing area to the test site. Possibly as a result of these adverse physical conditions, the dogs frequently appeared not to be working (i.e., they were simply walking back and forth across the lane with the handler urging the dog on or, in some few cases, partially dragging him along).

A night run made during this test period with two handler/dog teams was started at 1830 hours but was discontinued before half completed due to difficulties in staying within the confines of the lane being searched, the adverse climatic conditions (snow and cold), and the poor search attitude of the dogs. No other night runs were attempted.

Detection performance improved considerably during the remaining three tests (see Figure 13) where the average detection performance was 70.1 percent for the May-June (Fort McCoy) period, 67.3 percent for the October (YPG) period, and 85.7 percent for the June (YPG) period. The weather conditions during these periods were vastly improved over the winter conditions experienced during the first test. At Fort McCoy in May-June, the cloud cover varied from clear to cloudy with light rain (see Table 11). Half of the days were cloudy and winds varied in velocity from 0 to about 9 knots. The ambient temperature varied from about 14° C to 24° C during test operations, and the soil moisture varied from about 6 to 19 percent. The trees were in full leaf and grass abounded over the test site except in the sand area and in thickets.

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21 Please refer to the discussion of detection modality in Paragraph 4.

At YPG in October 1975, the weather was mostly clear (see Table 12). Ambient temperatures ranged from 15° C to 34.4° C during the test operations. When the ambient air temperature reached 34.4° C, the ground temperature was found to be 49° C. During the morning hours, the relative humidity was often about 65 percent, while in the afternoon, it was in the 30 percent range. The soil moisture averaged about 1.3 percent on all occasions.

Even at the most extreme high temperatures, the dogs never appeared to become extremely uncomfortable. However, after working a run on these hot days, which required about 40 minutes, they appeared to be quite thirsty. The omnipresent dust in the area did not appear to affect the detection performance of the dogs adversely, which is somewhat surprising, especially if one accepts the premise that olfaction is the major sensory modality.

At YPG in June 1976, the days were clear and the ambient temperatures varied from a low of about 21° C in the mornings to a high of about 41° C in the afternoons (Table 13). The relative humidity varied from 22 to 46 percent in the mornings and 23 to 39 percent in the afternoons, the wind velocity varied from 0 to 20 knots, and the soil moisture averaged about 1.1 percent. The performance of the dogs is seen to be best during this test period (see Figure 13).

The October 1975 tests were run less than two weeks after mine implantation, and it is possible that numerous distracting scents resulting from implantation tended to confuse the animals. (For example, mines might have been briefly in contact with the ground near the site of implant during digging operations.) Eight months later (in June 1976) these artifacts were probably non-existent due to ground surface displacement resulting from wind and rain. It is also possible that the effluvia from the mines had permeated the soil above the target to a greater extent by June.

The performance varies from one test period to another (Figure 8), and the performance of each animal differs from the others. A statistical analysis of these variations was made using analysis of variance methods. For the data presented in the figure, the analysis of variance is given in the following list (see Appendix):

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square
Among rows (dogs)	1,587	14	113
Within rows (dogs) (error)	52,127	45	1158
TOTAL	53,714	59	

$$F = \frac{113}{1158} = 0.098$$

For 14 and 45 degrees of freedom, F would have to be as large as 1.91 (the 0.05 probability point for the distribution of F) for there to be any significant difference between dogs. If the effect of differences among test periods, which are highly significant (F = 174.8, and for 3 and 42 degrees of freedom, F = 4.29 for the 0.01 probability point), is excluded from the error term as in the following list:

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square
Among rows (dogs)	1,587	14	113
Among test periods	48,247	3	16,082
Residual (error)	3,880	42	92
TOTAL	53,714	59	–

then, for dogs, $F = \frac{113}{92} = 1.23$, which for 14 and 42 degrees of freedom is still not significant, since the probability is greater than 0.05 that the ratio 1.23 could have occurred by chance. Although the F test indicates over-all homogeneity among dogs, the difference between two dogs (Casey and Val) appears to be possibly significant. However, a t test applied to the data on these two dogs shows that there is no significant difference between them ($t = 1.59$). This value for t is much smaller than the value (> 2.44) required for significance. The absence of significance is attributable to the large variance in the data from one test period to another.

A comparison of morning detection performances with afternoon performances (Figure 9) indicates that although the afternoon performances were somewhat better, this difference is not significant. For $t = 0.155$ with 6 degrees of freedom, $P > 0.80$. The weather conditions were somewhat different in the afternoons than in the mornings; the ambient temperatures were higher and the relative humidities lower. The wind conditions were not very different. The temperature differences are statistically significant; the humidity and wind differences were not. Evidently the morning-afternoon temperature differences were not great enough to cause significant variance in performance. The data show that in severe cold conditions with considerable snow, the performance was poor as is patently obvious in Figures 9 through 15. (It is not known what the performance would be in severe cold conditions with no snow.) The high-temperature environmental conditions that would adversely affect performance were not realized, and the maximum temperature at which canine performance would start deteriorating was not determined. Further, it cannot be estimated, although one would expect physiological limits to become significant at temperatures not much above those encountered in June 1976.

The speed at which a dog is worked and extended continuous periods of work are factors that would have to be considered in addition to environmental factors in determining the limit of endurance.

The data presented in Figure 10 show that differences in dog groups trained and worked under the conditions specified are without significant effect on detection performance. Removing the effects of test periods, $F = 2.5$, and with 2 and 14 degrees of freedom, $P > 0.05$. These results indicate that once a dog has been thoroughly trained to work on a particular scent, he performs equally well during a search with or without reinforcement. The dogs were maintained in an optimumly conditioned state either by temporarily interrupting the search and allowing the dog to respond to a surrogate target or by conducting reinforced practice sessions after the search to counteract potential extinction effects resulting from inadequate reinforcement during the tests. The dogs were never worked more than one search period (Morning or Afternoon Search) without being reinforced in some way.

Some types of mines were detected more often than others (Figure 11). The M18 was detected most readily, followed by the M19, M15, M14 and M16, in that order. These data show that when the effects of test periods are removed, $F = 13.6$, and for 4 and 12 degrees of freedom, $P < 0.01$, which indicates a significant difference in the dogs' detection performances for different types of mines. The dogs were expected to score better on the M18 because these mines were placed on top of the soil surface and in most cases, a trip wire was attached. However, the snow provided a cover for the M18s and thus the M19s were detected more often during the Feb-Mar 75 test period at Fort McCoy. The plastic-cased M19 was detected more often than the metal-cased M15, possibly because the explosive vapor escapes more readily from a plastic case than from a metal case. The M16 mines were detected less often than any of the other types. This was due possibly to relatively small size of the M16 (smaller than M15 and M19 but larger than M14), its metal casing, and the fact that it was buried deeper (7.5-cm soil overlay) than the other mines.

Just as there are some psychological differences between dogs (although their detection performances are not significantly different), there are differences between handlers, and although the dog and handler work as a team, it would be beneficial from the standpoint of developing criteria for the selection of handlers to know the extent of the differences (if any) between handlers. An analysis of the data for the three handlers (Cade, Cooper, and Zuniga) who participated in all four test periods) shows that there is no significant difference between handlers ($F = 1.24$, and for 2 and 6 degrees of freedom, $P > 0.05$). The effects of the dogs are not removed, however, in determining the F value. Also, in analyzing the data for dog performance, the effects of handlers were not removed. Some data were collected in a manner that would permit evaluating the dog-handler relationship but they were inadequate for the purpose.

The detection performance data obtained for the dog/handler combinations from the YPG tests are presented in Table 14. Data from Fort McCoy tests were not included in this table because a low-performance score obtained in winter by an X-dog/X-handler team would be compared with a high-performance score obtained under better conditions by an X-dog/Y-handler team, and during the May-June test, each handler worked his group of dogs only (i.e., no two handlers worked the same dog).

There are insufficient data in Table 14 to make a meaningful analysis. Some data spaces are not filled, and there are not enough data points for the spaces that are filled. If the data table were complete, the effects of dogs could be removed when applying the F test to the analysis of handler variance and vice versa. This type of analysis would provide a better insight into the relationship between dog and handler. The data available in Table 14 give some support to the F test results showing no significant differences between handlers. The Cooper-Bretta and Cooper-Ernie performances are somewhat better than the Cade-Bretta and Cade-Ernie performances; the Cade-Casey and Cade-Eve performances are better than those of Zuniga-Casey and Zuniga-Eve; the Zuniga-Warp and Zuniga-Winchester performances are much better than those of Cade-Warp, Cade-Winchester, Cooper-Warp, and Cooper-Winchester. The Cooper-Winchester performance is very poor, but as mentioned earlier, there are too little data in this statistic to give it significant weight.

Trujillo worked only two dogs (Rex and Whop) that were worked by another handler (Zuniga). Trujillo's performance was only slightly worse than Zuniga's. Figure 12 shows that Trujillo performed better than Cooper, equal to Zuniga, and worse than Cade for the test periods, but this is caused by the smaller number of runs made by Trujillo during the first test period compared to the other handlers, resulting in the third and fourth period data being weighted more heavily for Trujillo. Actually Cooper's performance for the third and fourth periods were slightly better than Trujillo's and about the same during the first. However, since Cooper made more runs than Trujillo during the first period, the data for all test periods are weighted in Trujillo's favor.

Figure 13 shows that the dogs alerted on a small percentage of the practice mines and distractants but alerted on a significant percentage of live mines. This difference is highly significant and tends to support a common belief that the dogs are alerting on the explosive vapors emanating from mines. There were 1144 false alarms (i.e., alerts) on practice mines and distractants, with 903 alerts on live mines (Figure 14); of the false alarms, 879 were unidentified targets, which may possibly be artifacts from tests of explosive devices carried out in the test areas in previous years. In two of the four tests (February-March at Fort McCoy and October at YPG), the dogs alerted on a greater number of unidentified targets than on live mines. The severe winter conditions in February-March promoted this type of performance. As noted

Table 14. Detection Performance of Dog/Handler Teams

Dogs	Handlers											
	Cade			Cooper			Zuniga			Trujillo		
	Possible	Actual No.	%	Possible	Actual No.	%	Possible	Actual No.	%	Possible	Actual No.	%
Angus										31	23	74.2
Apache	43	32	74.7									
Bretta	4	3	75.0	44	34	[77.3]						
Casey	25	21	[84.0]				13	10	76.9			
Duncan										45	31	68.9
Dusky							44	36	81.8			
Ernie	13	9	69.2	29	23	[79.3]						
Eve	13	12	[92.3]				26	22	84.6			
Quickie	6	5	[83.3]	38	29	76.3						
Rex							31	26	[83.9]	9	7	77.8
Tiger				48	37	77.1						
Val										47	32	68.1
Warp	17	10	58.8	11	6	54.5	15	14	[93.3]			
Whop							14	11	[78.6]	22	16	72.7
Winchester	33	29	87.9	6	1	16.7	7	7	[100.0]			

NOTE: Blanks indicate no data.

For the dogs who worked with more than one handler, the best performance is the blocked figure.

earlier in this report, the snow cover was 30 cm to 60 cm deep, a condition which would make the escape of the explosive vapor to the surface more difficult. It is obvious that the dogs alerted infrequently in deep snow operations and the total number of alerts is so small that valid comparison with the later three tests is difficult.

The large number of alerts on unidentified targets during the October test period at YPG may have been caused by the presence of odorants incident to the mine implantation activities as noted earlier. Although the dogs were trained not to alert on human odor, explosive odors from live mines being buried may have been deposited on all distractants including inert mines during the implantation period. Figure 14 shows a greater number of alerts on the practice mines (109) during the October period than during any other test period. Note that for the June period at YPG, which was several months after mine implantation activities had been completed, the number of alerts on live mines increased and the number of alerts on practice mines, attractants, and unidentified targets decreased when compared with the October data.

The relationship between alerts on live mines, practice mines, distractants, and unidentified targets for the May-June Fort McCoy period are similar to those for the June YPG period. However, the number of alerts on practice mines, distractants, and unidentified targets (which averaged about 5/km for all tests), were greater at YPG than at Fort McCoy (see Figure 15). Both of these sites were located in areas where explosive materials had been detonated in the past. It may be that YPG contained more residue from this past activity than Fort McCoy, thereby misleading the dogs more often. There is no adequate instrumentation to check this premise, but the concept appears to be valid to the experienced personnel involved in the four tests.

The data for alerts on practice mines, distractants, and unidentified targets per kilometer by each dog were analyzed and for a comparison of test periods, $F = 18.0$ and for 3 and 42 degrees of freedom, $P < 0.01$ which indicates a significant difference. For a comparison of dogs, $F = 1.93$ and for 14 and 42 degrees of freedom, $P = 0.05$ which is not significant. Possible reasons for the difference in alerts for different test periods were discussed above.

The average area search rate for the dogs was 38 m^2/min (Figure 16). An analysis of variance F test was applied to these data. For a comparison of dogs, $F = 1.95$ and for 14 and 42 degrees of freedom, $P > 0.05$ which is not significant. For test periods, $F = 198.4$ and for 3 and 42 degrees of freedom, $P < 0.01$ which is highly significant. The slowest search rate occurred during the February-March period at Fort McCoy, and this was obviously caused by the presence of deep snow. The search rate during the May-June period at Fort McCoy was faster than during the preceding period (due to the absence of snow) but slower than during both tests at YPG. This is also logical since the YPG site contained no vegetation, whereas the Fort McCoy site contained some areas of dense growth which required more time and effort for the dog-handler team to traverse. The improved search rate during the June 1976 tests at YPG over the preceding October test without working the dogs to the limit of their endurance indicates that dogs may be worked at high search rates (m^2/min) as long as the environmental conditions are favorable to the dog.

Based upon an evaluation of the plotted data, it appears that wind variations did not alter significantly the alert positions relative to the buried mines. Over one-third (34.7 percent) of all alerts were made at points where mines were buried (Figure 21). The remainder of the alerts were scattered in a near-normal distribution about the center out to 1.5 meters, with 20.7 percent of all alerts appearing on the approach side to the mines, 16.8 percent on the right side, 14.3 percent on the left side, and 13.5 percent beyond the mines. For the "no wind" condition (Figure 17), 39.9 percent of the alerts were in the center, 18.3 percent on the approach side, 13.2 percent on the right side, 14.0 percent on the left side, and 14.6 percent beyond the mines. When leeward (wind from back) searches were made (Figure 18), 26.8 percent of the alerts were in the center, 21.7 percent on the approach side, 20.3 percent on the right side, 15.2 percent on the left side, and 16.0 percent beyond the mines. When windward searches were made (Figure 19), 31.6 percent of the alerts were in the center, 24.5 percent on the approach side, 20.2 percent on the right side, 12.3 on the left side, and 11.4 beyond the mines. When the wind was blowing from the left of the search direction (Figure 20), 32.9 percent of the alerts were in the center, 15.3 percent were on the approach side, 19.3 percent on the right side, 14.2 percent on the left side, and 18.3 percent beyond the mines.

From these data, it is seen that, for the leeward search condition, slightly more of the off-center alerts were on the approach side to the mines rather than on the leeward side, a condition not to be expected if winds were effective in blowing the explosive scent downwind. On the other hand, when the search was windward, slightly more off-center alerts were downwind as would be expected; and when there was a lateral wind, slightly more off-center alerts were downwind as would be expected. However, for the "no wind" condition and a composite of all search conditions, slightly more off-center alerts were on the approach side. Therefore, since there is so little variation in the scatter of alerts around the center under different wind conditions and the patterns are not consistent, *it can be concluded only that there was a slight tendency for the animals to alert on the approach side of the mines and that wind direction had no significant effect on where the dogs alerted.*

It must be remembered that the wind velocity was measured at a height of about 1.5 meters above the ground surface. A more realistic height would be from 10 to about 25 cm, a height at which a dog has its nose while searching. It is probable that the wind speed near the surface would be lower than at the 1.5-meter height, but it is not known what direction it might take. Possibly, a more meaningful estimate of the effects of wind on the movement of the explosive scent from the buried mine could have been made if near-surface wind velocities had been measured.

11. Comparison of Canines with Other Detection Systems. In an attempt to determine the relative merit of mine-detection dogs, their performance was compared with the performance of the AN/PSS-11 (a type-classified production model detector of metal mines) when used by experienced operators. Performance data for both the dogs and the AN/PSS-11 were obtained during the same periods at Fort McCoy and are presented graphically in Figures 22 and 23.

Figure 23 shows the detection performance, by type of mine, of the dogs and the AN/PSS-11 during the February-March and May-June tests at Fort McCoy. During the February-March period the AN/PSS-11 performed much better than the dogs in detecting M15 (72.0 percent vs 8.0 percent) and M16 mines (68.3 percent vs 9.8 percent), and somewhat better in detecting M18 mines (40.0 percent vs 16.0 percent), the AN/PSS-11 was not effective in detecting M14 (0 vs 6.9 percent) and M19 vs 19.8 percent) mines.

During the May-June period, the detection performance of the AN/PSS-11 for M15, M16, and M18 mines was somewhat better than that of the dog (87.1 percent vs 76.4 percent, 77.0 percent vs 62.6 percent, and 100 percent vs 89.2 percent, respectively) but not as good for the M14 and M19 mines (50 percent vs 63.6 percent and 44.2 percent vs 75.9 percent, respectively).

For all mines the performance of the AN/PSS-11 during the February-March period was 48 percent compared to 12 percent for the dogs, and during the May-June period, it was 72 percent vs 70 percent. The February-March statistics are a fair indication of the better performance of the AN/PSS-11 during a severe winter with heavy snow conditions. However, the May-June statistics are misleading in that the AN/PSS-11 would not normally detect M14 and M19 mines. Some of these nonmetallic mines were detected during the May-June period because the metal safety clips had not been removed. (During normal deployment these clips must be removed to activate the mines.) None of the M14 or M19 mines were detected during the February-March period because of the heavy snow cover which necessitated keeping the detecting head of the AN/PSS-11 30 to 60 cm above the mines, a distance at which the metal clip would not be detected.

If it is assumed that these mines would not normally have been detected by the AN/PSS-11 during the May-June period, its performance for all mines would have

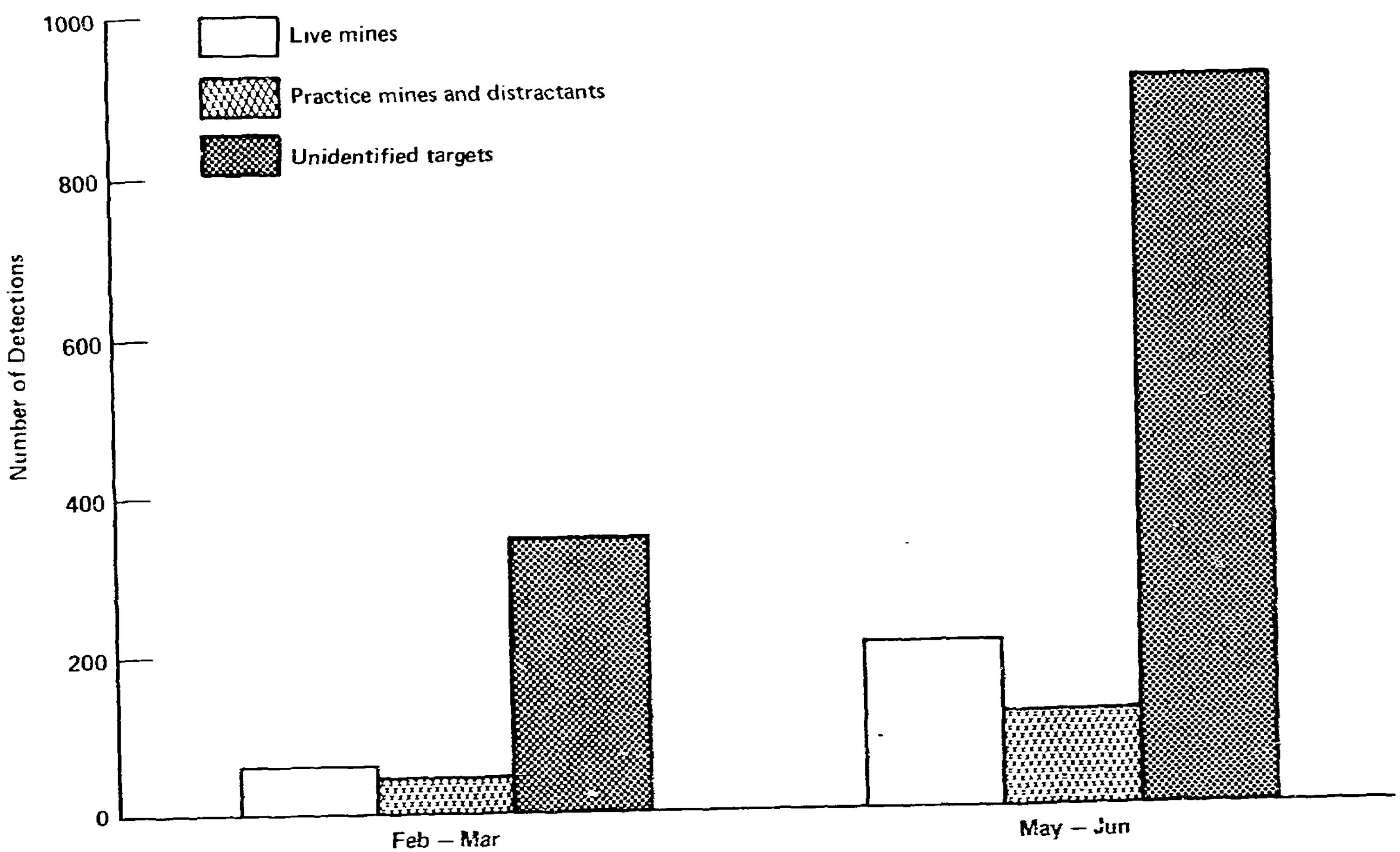

Figure 22. AN/PSS-11 detections at Fort McCoy.

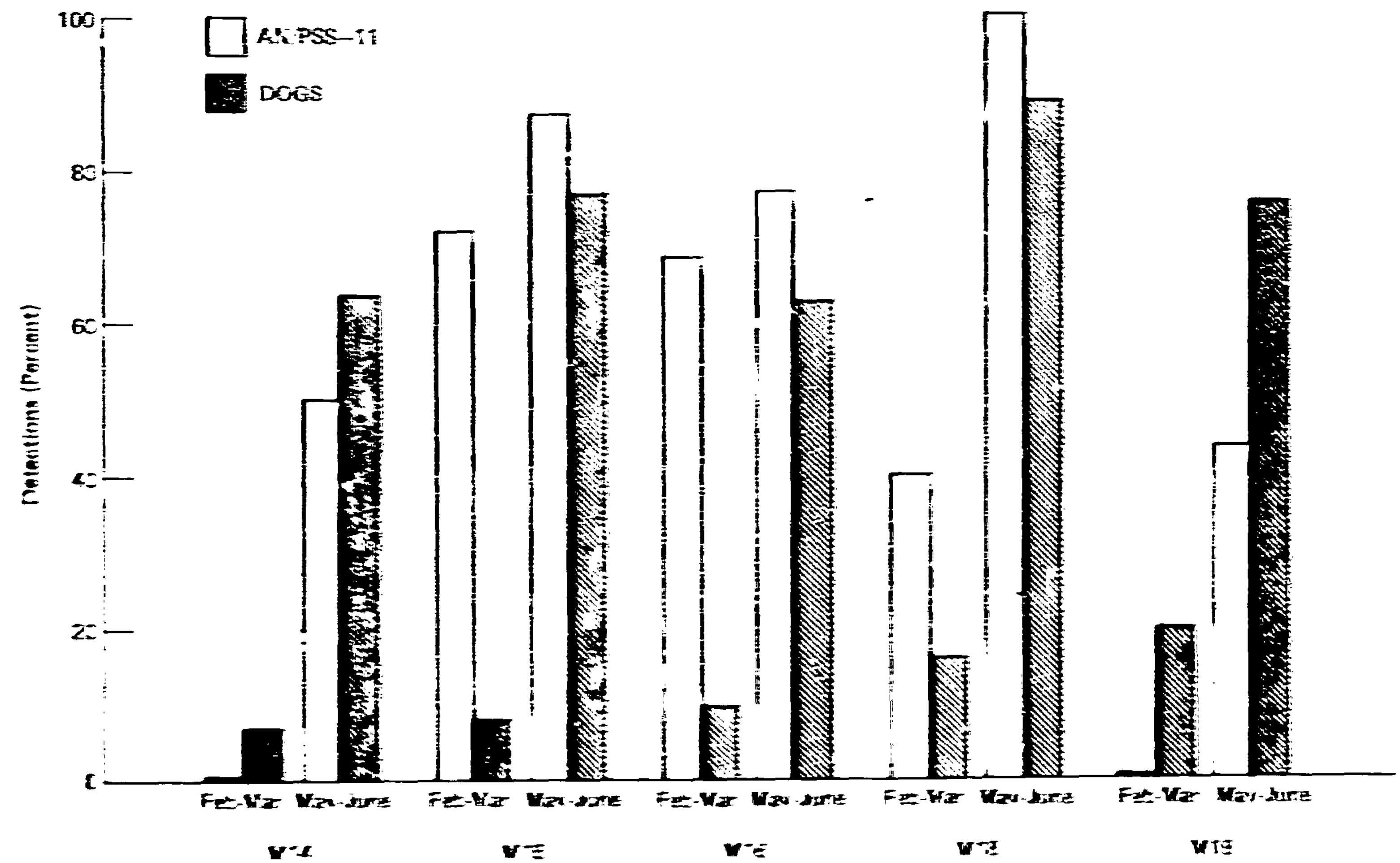

Figure [illegible]. Mines detected by type of mine.

been 59 percent compared to 70 percent for the dogs. For metal mines, the AN/PSS-11 is generally a somewhat better detector than the dog, but it has a false alarm rate much greater than that for the dogs (compare results in Figure 22 with those in Figure 14).

Observe in Figure 23 that the M18 was the only type of mine that was detected 100 percent of the time in the May-June test by the AN/PSS-11. This accomplishment was probably due to the fact that these mines were visible to the operator since the M18 is surface deployed. The M18 mines were also visible to the dog handlers, but in ~~this test,~~ a detection was scored only if the dog alerted. Evidently the dogs did not alert on these mines on every pass through those test lanes containing M18 mines.

Although the M15 mines (which were detected most frequently with the AN/PSS-11) were buried with only about 4 cm of soil cover, they were not detected 100 percent of the time by this unit. Misses were possibly due to the scanning procedure followed by the operator which left parts of the area unscanned; i.e., the operator swung the detector head laterally from left to right as he proceeded down the lanes at about a 4-km per hour rate, thereby leaving unscanned gaps in the area. This inefficiency on the part of the operator causes one to speculate upon the reasons for the less-than-perfect performance of the dogs. It is possible that the explosive scent (or whatever the detectable aura may be) is present around all mines, but that the dogs do not approach closely enough to some mines, because of their scanning procedure, to detect the scent. Or it is possible that the dogs simply ignore the scent in some cases. Only a very advanced research program could answer these pertinent questions.

IV. CONCLUSION

12. Conclusion. Analysis of the data presented in this report plus those personal observations of the Test Personnel obtained from the field experience lead to the conclusion that the canine can be trained routinely to function extremely well as a Mine Detection "System" which is capable of operating in a vast expanse of climatic and topographical environments.

The phrase "extremely well" is ambiguous and subjective, however, and one might wish for a more quantitative evaluation. An attempt at truly objective comparison of canines with other mine detection systems leads to immediate complications similar to those encountered in comparing any animal, including man, with a machine of similar function. As an example, consider the case of the metal-detecting AN/PSS-11 as noted previously. While it is likely that the alarm/false alarm ratio for this existing metal detector may exceed the performance of canines in a "clean" area, one must observe that mine detectors must be used where many types of human activity have usually left the search area vastly populated with metal artifacts. And, of course, the hostile forces may not oblige the friendly forces by using metallic mines.

Considering only effective target range, the two systems are apparently of similar capability; whereas, if the number of types of detectable explosive items is also considered, the canine is far superior to the AN/PSS-11. Both will operate in hostile climatic environments and are capable of approximately equal area coverage per unit time and the dog is equal or superior to the AN/PSS-11 in false-alarm performance.

Overall, then, the canine is superior to the AN/PSS-11 as a general-purpose mine/booby-trap/explosive detector.

The observed performance of the AN/PRS-7 can only be subjectively compared to canines at this time, but available AN/PRS-7 Performance Reports indicate that the dog would outperform this unit in both detection probability and in false-alarm count per unit area searched.

Currently, it is not possible to compare canines with other systems on the basis of sensitivity alone since we cannot state with any degree of confidence exactly what the dog is responding to when it alerts to a target. The obvious suspect substance is some effluence emitted by the explosive device, but the nature of this substance (or, possibly, substances) is unknown at present. Current research at MERADCOM is being directed to analysis of the effluvia from all U.S. mines; when definitive results are achieved in this area, it may be possible to initiate tests with trained dogs to determine the actual "target" substance.

While arguments implying canine extra-sensory perception are not scientifically valid at present, it is equally specious to argue that vision, hearing, and olfaction are the sole modalities of detection. It is valid only to state that some subsurface anomaly unique to explosives devices is readily sensed by the trained canines. It would be highly beneficial to future detection programs if ongoing mine effluvia investigations are carried to fruition in this area of research, since then the existing canine training protocol can be modified to address the specific mechanism of detection instead of the rather broad-spectrum treatment currently necessary.

A major factor in determination of the relative merits of canines as mine/booby-trap/explosives detection systems concerns the operational topographical environment~~s—which~~ The detector can tolerate and still function in a near-normal fashion. In this area of consideration, the canine has absolutely no peer. There is presently no single physical system which can function normally in locations such as on and near metal bridges, in and around buildings (containing virtually any substance in addition to the explosive target substance), amid any population, in and around vehicles of all descriptions, along railroad tracks, on both deserted and active metropolitan streets, in the rubble of collapsed structures, in scrap metal areas, and so on and on. The dog has repeatedly demonstrated (during the MERADCOM tests and in countless other scenarios) its ability to operate nearly normally in adverse searches such as in crowded airports, in deserted fields, in aircraft, in civilian automobiles and military vehicles, along jungle trails, in deep snow, in desert heat, under enemy fire, and in a variety of other environments.

This great adaptability to the environmental features of the search area allow the canine explosives detector to replace a series of elaborate physical instruments and their redundant verification systems. As an example, if one wished to achieve a high explosives detection probability in an urban area, the detection system could require, as a minimum, an effective trace gas subsystem (none now exist), an EM subsystem, and possibly an enzymatic subsystem (under development). This collection of equipment would be bulky even when reduced to "Spacecraft" dimensions by long and expensive development programs. Further, this collection of apparatus probably would not operate in true real time but might require several seconds (up to 30) to achieve detection. Worst of all, the predicted field service date for such a system is probably 1990 or later. The canine can presently accomplish the task in real time with no further development.

Just as there is the foregoing list of search protocols which are ideal for the use of canines, there are certain search situations where canines would be acceptable only as a verification system. One such example is the case where wide area searches of uncluttered terrain such as roads and open fields need to be carried out in minimum time. Here, systems such as the MERADCOM RIMD System (Road Interdiction Mine Detector) are capable of greater speed per unit of search area, but there is a potential use for canines even in the case of systems such as RIMD. Here the dog could be a passenger in the vehicle dedicated to this microwave system and the animal could be useful as a verification device in instances where detection by RIMD was suspect. The utility of the dog in this service must be postulated until the effects of battlefield environments on trained dogs are more fully understood.

It is perhaps unlikely that canines would be fully effective in the midst of active combat where the activity and noise could possibly lead to confusion or frank terror on the part of the dog. There are no objective data which either confirm or refute this possibility, and if future canine program efforts are undertaken, they should be directed toward detection testing under the most rigorous simulated battlefield conditions prior to eliminating the canine from consideration in this milieu.

In addition to possible use as a verifier system for wide-area search systems such as RIMD, the dog has a potential value as a back-up verifier system for other

MERADCOM developmental items such as the enzymatic detection system or a Nuclear Resonance System. Further, it is reasonable to conceive of using the dog in concert with the type-classified hand-held units (AN/PRS-7 and AN/PSS-11).

The full potential of the canine as a mine detection system has yet to be realized, since the developmental efforts were halted by the lack of funds. In order to achieve the maximum user utility, several concepts should be developed for future canine mine/booby trap/explosives detectors. These developmental areas are:

a. Remote Control (off leash).
b. Combat Simulation.
c. Physiological Instrumentation.

The first area, remote control, is so obviously necessary as to be considered the top priority item in future canine detector system development. Clearly, at the present level of development, the handler is exposed to totally unnecessary risks due to accidental target detonation or due to hostile fire. These hazards exist under the required operating procedures since the animal cannot be controlled readily in all environments by means of hand or voice signals when operated off-leash.

Very brief experiments performed during training (between field tests) demonstrated a remarkable ability on the part of the dogs to adapt to a hastily assembled remote control system (a modified model aircraft radio-control unit). In the interest of handler safety, this crude effort deserves an early follow-up.

Once remote control techniques have been perfected, the combat simulation alluded to earlier warrants investigation for inclusion into the "basic training" of the detector dogs. Should the present fears concerning the adaptability of dogs to full combat be determined to be groundless, then the animals, in a remote-control mode, could become extremely useful for numerous explosives detection missions.

Finally, certain investigations with lower order animals indicate that there is possible merit in brain electro-stimulation both as an "ultimate-stimulus" conditioning technique and as a method for minimizing the effects of the battlefield environment on canine detection performance. This work is highly experimental at present and will be monitored for its possible utility in canine service.

In brief summary, we submit that the mine/booby-trap/explosives-detecting canine in its present state of development represents a highly adaptable, high-sensitivity, high-specificity detection system which is relatively inexpensive, reasonably durable, readily reproducible, and immediately available!

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APPENDIX

ANALYSIS OF VARIANCE (SEVERAL MEANS)

Statistical variance of a small sample of data is defined as

$$\sigma^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}$$

where the divisor represents the number of degrees of freedom for an estimate of variance (i.e., the number of independent deviations from the mean which went into the sum of the square of deviations from the mean). n is the number of terms in the sample.

Analysis of variance involves determining the significance of the difference of means for several columns or rows of either uncorrelated or correlated data.

The procedure in analysis of variance is summarized in the following:

Source of Variation	Sum of Square	Degree of Freedom	Mean Square
Between k rows	$\Sigma (\bar{x}_R - \bar{x})^2$	k - 1	$\frac{\Sigma (\bar{x}_R - x)^2}{k - 1}$
Within k rows	$\Sigma (x - \bar{x}_R)^2$	n - k	$\frac{\Sigma (x - \bar{x}_R)^2}{n - k}$
Total	$\Sigma (x - \bar{x})^2$	n - 1	$\frac{\Sigma (x - \bar{x})^2}{n - 1}$

For convenience in computation, the sums of squares terms are expanded in the following forms:

$$\Sigma (\bar{x}_R - \bar{x})^2 = \Sigma \bar{x}_R^2 - \frac{(\Sigma x)^2}{n}$$

$$\Sigma (x - \bar{x}_R)^2 = \Sigma x^2 - \Sigma \bar{x}_R^2$$

$$\Sigma (x - \bar{x})^2 = \Sigma x^2 - \frac{(\Sigma x)^2}{n}$$

where

$$\Sigma x_R^2 = \frac{(\Sigma x_1)^2}{n_1} + \frac{(\Sigma x_2)^2}{n_2} + \ldots \frac{(\Sigma x_n)^2}{n_k} .$$

For the data shown in Table 15:

Table 15. Detection Performance of Dogs
(Percent of Available Targets)

	Test Periods			
	Fort McCoy		YPG	
Dogs	Feb-Mar 75	May-Jun 75	Oct 75	Jun 76
Angus	22.7	53.6	66.7	84.6
Apache	17.6	69.0	68.2	81.0
Bretta	0	59.0	66.7	87.5
Casey	42.9	79.2	75.0	86.4
Duncan	6.9	65.7	56.0	85.0
Dusky	0	81.1	69.2	100.0
Ernie	14.8	72.5	66.7	88.9
Eve	0	73.5	92.3	84.6
Quickie	11.1	78.0	65.2	90.5
Rex	7.4	78.0	89.5	76.2
Tiger	8.7	81.5	68.2	84.6
Val	13.6	52.6	47.6	84.6
Warp	11.8	60.6	52.4	84.6
Whop	8.3	75.8	72.2	77.8
Winchester	0	64.3	70.0	88.5

$$\Sigma \bar{x}_R^2 = 208{,}411$$

$$\frac{(\Sigma x)^2}{n} = 206{,}824$$

$$\Sigma x^2 = 260{,}538$$

$$\Sigma (\bar{x}_R - \bar{x})^2 = 208{,}411 - 206{,}824 = 1{,}587$$

$$\Sigma (x - \bar{x}_R)^2 = 260{,}538 - 208{,}411 = 52{,}127$$

$$\Sigma (x - \bar{x})^2 = 260{,}538 - 206{,}824 = 53{,}714.$$

and for these data, the analysis of variance is summarized as follows:

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square
Between rows (dogs)	1,587	14	113
Within rows (error)	52,127	45	1,158
Total	53,714	59	

$F = \frac{113}{1158} = 0.098$ which for 14 and 45 degrees of freedom is not significant because the F value (in the standard F tables) at the 5 percent point is 2.30. F (variance ratio) is the symbol representing the ratio of two independent estimates of the variance of the same normal population. The distribution function for F involves the number of degrees of freedom for each of the two variances in the ratio. Tables of 0.05 and 0.01 probability points for the distribution of F have been calculated for degrees of freedom values increased incrementally from 1 to infinity. When values of F obtained from sample data are less than the 0.05 probability values shown in the tables, this indicates no significant difference between the sample variances.

In other words, if the calculated F value is the same or less than the F value at the 0.05 probability point in the tables, the probability is 0.05 or greater that this ratio could have occurred by chance in sampling from normal population of identical means and variances, and it is concluded that any differences between the variances are not significant. If the calculated F value is greater than the one at the 0.05 probability point, the probability is less than 0.05 that the ratio could have occurred by chance, and it is concluded that the difference between variances are significant.

If it is desired to remove the effects of variations between columns, the analysis of variance procedure is as follows:

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square
Between k rows	$\Sigma (\bar{\bar{x}}_R - \bar{\bar{x}})^2$	$k - 1$	$\frac{\Sigma (\bar{\bar{x}}_R - \bar{\bar{x}})^2}{k - 1}$
Between j columns	$\Sigma (\bar{\bar{x}}_c - \bar{\bar{x}})^2$	$j - 1$	$\frac{\Sigma (\bar{\bar{x}}_c - \bar{\bar{x}})^2}{j - 1}$
Residual (error)	Remainder	$n - k - j + 1$	$\frac{\text{Remainder}}{n - k - j + 1}$
Total	$\Sigma (x - \bar{\bar{x}})^2$	$n - 1$	

Using the same data given in Table 18:

$\Sigma \bar{\bar{x}}_R^2 = 208{,}411$

$\Sigma \bar{\bar{x}}_c^2 = 255{,}071$

$\frac{(\Sigma x)^2}{n} = 206{,}824$

$\Sigma x^2 = 260{,}538$

$\Sigma (\bar{\bar{x}}_R - \bar{\bar{x}})^2 = 208{,}411 - 206{,}824 = 1{,}587$

$\Sigma (\bar{\bar{x}}_c - \bar{\bar{x}})^2 = 255{,}071 - 206{,}824 = 48{,}247$

$\Sigma (x - \bar{\bar{x}})^2 = 260{,}538 - 206{,}824 = 53{,}714$

For these data, the analysis of variance is summarized as follows:

Source of Variation	Sum of Square	Degrees of Freedom	Mean Square
Between rows (dogs)	1,587	14	113
Between columns (periods)	48,247	3	16,082
Residual (error)	3,880	42	92
Total	53,714	59	

$F = \frac{113}{92} = 1.23$ which for 14 and 42 degrees of freedom is not significant.

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