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UNIVERSITY *of* MICHIGAN RESEARCH INSTITUTE

FINAL REPORT

Model Simulator Studies of the Visibility of Military Targets at Night

CHARLES E. HAMILTON
Vision Research Laboratories

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ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Final Report

MODEL SIMULATOR STUDIES OF THE VISIBILITY OF MILITARY TARGETS AT NIGHT

Charles E. Hamilton

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ERI Project 2699

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This report presents the results of work done under the administration of the Engineering Research Institute, whose name was changed to The University of Michigan Research Institute on July 1, 1958.

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SUMMARY

A program of experiments is reported in which visibility distances for military targets have been assessed using a scale-model simulator. Targets were observed along ground paths under simulated natural and artificial conditions of night-time illumination.

The experiments were concerned with both detection and identification of the targets. The targets were selected to represent different classes of military targets and included a tank, armored personnel carrier, and anti-tank gun and crew. These targets were viewed under starlight, moonlight, and searchlight conditions. They were always located in unconcealed positions and, in different experiments, on relatively uniform and non-uniform terrain. Their visibility under searchlight illumination was studied under a wide range of special conditions relating to searchlight duration, displacement from observer, and flicker.

When the targets were on uniform terrain, detection distances obtained under starlight illumination were about 190 yards for the tank and APC. The anti-tank gun and crew could not be seen at the minimum distance it was possible to use, about 100 yards. Under moonlight illumination, the tank was reasonably detectable at between 900 and 1000 yards; the APC was about as visible or a little more so; 500 yards represents the detection distance for the anti-tank gun and crew. Identification distance under these conditions is estimated at about 600 yards for the tank and APC.

When the tank was located on non-uniform terrain, its detection distance was reduced to about 640 yards which is about the maximum identification range already noted.

With searchlight illumination, the vehicle targets, when on uniform terrain, could be detected at the maximum range of 1500 yards. The anti-tank gun and crew were visible to about 1000 yards under the same conditions.

Targets located on non-uniform terrain and viewed under searchlight illumination were detectable in a complex way as a function of immediate background, duration of searchlight illumination, and searchlight displacement from the observer. The poorest visibility occurred when the targets were against a tree background, for short durations of illumination, and with the searchlight not displaced from the observer. Under these conditions, again, the detection range was about the same as the identification range noted earlier.

Attention was given to determining when possible, the stimulus factors underlying the visibility of the targets. In this regard, photometric data allowed some determination of correspondence of results with predictions from more basic visual detection data. Photometric data were also used to relate the simulator conditions to actual field conditions

in order to evaluate the degree of correspondence. Also, certain of the experiments employed conditions similar to those used in a field study conducted elsewhere, and provide a basis for comparison of performance data.

1. INTRODUCTION

The present report summarizes the experimental studies conducted under Engineering Research Institute Project 2699, established in terms of Subcontract 1-003 with the Human Resources Research Office, George Washington University, Washington, D. C. These studies were part of a program intended to supplement the continuing program of the HumRRO staff of the U.S. Army Armor Human Research Unit, at Fort Knox, Kentucky.

In general terms, the model simulator studies have been concerned with the determination of visibility distances for military targets under certain conditions of night time illumination. The studies are intended to provide, also, a basis for better specifying and understanding the stimulus factors influencing the visibility of targets under such conditions.

Since the specifications of target, terrain, and illumination conditions were intended to relate closely to problems of special interest to the Human Research Unit at Fort Knox, the establishment of these conditions was carried out in close coordination with personnel of that Unit. To achieve this coordination, the writer visited the Human Research Unit at Fort Knox during November 6 and 7, 1957, for the purpose of conferring with Dr. Howard McFann and members of his staff. Extensive discussion was held with Dr. McFann, Dr. Norman Willard, Dr. Nicholas Lewis, Dr. Ed Stark, Dr. Fogel Clark, and Dr. Al Kraemer. The discussion had as its objective to make the stimulus conditions of most direct interest in relation to the studies being conducted at Fort Knox. Agreements (to be listed in detail later) were reached concerning the target, terrain, and illumination conditions for the model simulator studies, as well as the general psychophysical procedures which would be followed.

Subsequently to the conference described above, correspondence between the writer and personnel of the Human Research Unit served to clarify problems and maintain a close relation between the model simulator studies and their counterpart studies at Fort Knox. Visits by Dr. Willard in March and May, 1958, and a visit to Fort Knox by the writer and Mr. Carl Semmelroth to observe the field study, Armornite V, during June, 1958, further aided our objectives.

The target, terrain, and illumination conditions, and psychophysical procedures agreed upon at Fort Knox in November, 1957, will now be outlined. With one exception, noted in the context of the outline, we were able to establish all the required conditions and obtain observations over the wide range shown.

General interest was confined to night time illumination conditions and the observer's task was to be restricted by the following features: (1) The observer has (some) knowledge of the type of target to be detected and its lateral displacement; (2) the target is considered only an "enemy" and determining time for detection is of importance. In addition to item (2) above, recognition responses were to be included in the context of the studies.

The simulated field situation was conceived as that peculiar to the tank platoon. This consideration dictated that the maximum displacement of targets should be restricted to the equivalent of 1200 yards, and, as well, that searchlight angles of illumination and displacement from the observer should be consistent with those typical of the tank platoon under operational conditions.

Consideration was given to the factor of atmosphere in the model simulator situation. Since relatively great interest was expressed in connection with artificial (searchlight) illumination effects, it was evident that a technical problem existed. In simulating the optical effects of the atmosphere in the absorption and scatter of light two possible techniques may be used. The first involves generating artificial atmosphere by means of adding water droplets and opacities to the actual atmosphere surrounding the model. The second utilizes, instead, a "veiling luminance". This is accomplished by placing a partially-silvered mirror before the observer's eyes and reflecting with it an area of uniform luminance superimposed over the observer's view of the model. The later procedure is completely adequate to simulate atmospheric effects occurring between the military target and the observer. However, it does not simulate other effects, such as the appearance of the searchlight beam in passing through the atmosphere.

Consequently, the first procedure outlined appeared to be the only acceptable procedure although its feasibility could not be attested. The use of artificial fog, which would deposit water droplets on the model also, appeared complicated due to the physical dimensions of the experimental room. Previous work had been concerned with simulating dense fog, and the production of relatively light fogs in this manner still remained to be investigated. Since it appeared achieving such conditions posed grave technical problems, it was agreed to conduct the studies initially with no delay for the purpose of introducing scaled atmosphere. If later such conditions could be obtained, they should be added, but, in any event, the results of studies were to be related to atmosphere effects in final interpretation.

The specific conditions to be simulated were agreed upon and are shown below:

A. <u>Targets</u>

The following targets were to be used singly in a given experimental situation:

1. Medium U.S. Tank (M-48)
2. Armored personnel carrier (M-59)
3. An anti-tank gun with crew

These targets were to be positioned head-on to the observer, not dug in or camoflaged. The anti-tank gun and crew were to be arranged in the open as a crew working around the gun, "getting into position".

B. <u>Terrain Background</u>

1. Homogeneous (such as wheat field)
2. Heterogeneous (brush, trees, etc.)

C. <u>Illumination</u>

1. Natural

   a. Dark night, with starlight only
   b. Bright night, with full moonlight

2. Artificial

   a. One or more 18-inch tank mounted searchlights
   b. Flare

It should be noted at this point that due to limitations of time, and the relative importance assigned by the Human Research Unit to item 2 a, searchlight illumination, the studies to be reported did not encompass item 2 b, flare illumination. The conditions for searchlight illumination were listed in more detail than shown above. These special conditions included not only a single searchlight at differing displacements from the observer but also, two searchlights alternately illuminating the target (the latter being under continuous illumination). In addition, intermittent single searchlight illumination was to be included, and the illumination schedules for this and the foregoing condition were indicated.

The general psychophysical procedure agreed upon was to have the observer make observations at a fixed distance of each target positioned on each terrain background under each of the illumination conditions listed. The procedure was intended to lead to frequency-of-seeing data for each experimental condition. The observer's response was to be timed with respect to detection, and, in addition, he was to attempt to make a "class" identification following the detection of a target.

In the studies reported in the following sections we attempted to adhere as closely as possible to the agreed upon conditions. In addition, in connection with other phases of the subcontract, we attempted to relate our conditions as closely as possible to actual field conditions. Information concerning such interrelationship with field conditions will be given later in this report. And, finally, within the framework of the foregoing specific conditions, we attempted to utilize the advantages of the model simulator situation (repeatability of particular conditions, etc.) to gain as much insight as possible into the observer's task, effects of practice, and stimulus factors of importance in a general sense as well as determining the particularized target visibility distances for the specific conditions studied.

To present our findings as simply as possible, the material has been organized into three sections which follow. Section II contains a description of the special equipment and general experimental conditions used. Section III contains the results for the series of experiments conducted within the framework outlined in the present section. In section III attention will be given primarily to presenting the particular findings for each condition of observation described. In section IV the results of the different experiments will be interrelated in a more general manner and attention will be given to exploring more fully factors underlying the form of the results.

II. GENERAL EXPERIMENTAL CONDITIONS

The model studies were conducted using a three-dimensional terrain model, at a scale of 108:1, measuring approximately 20 feet by 20 feet. This model represents a sample of actual terrain with hills, meadow land, highways, a river, and a town. The model is complete with surface detail. Figure 1 shows an over-all view of the terrain model. The terrain model was developed initially under sponsorship of a tri-service contract administered by The Signal Corps (Project MICHIGAN), for use in earlier studies relating to the visibility of military targets along ground paths. The model, as well as certain other equipment, was used by permission of Project MICHIGAN for the present studies.

The terrain model was located at one end of a room approximately 60 feet long by 30 feet wide, and 20 feet high. The walls and ceiling of the room were painted black to reduce stray interreflection of light. The room itself was made highly light-tight to afford good control over the low levels of illumination intended. All personnel taking part in the experiments and all equipment used were in this single room. Blackout conditions were maintained during sessions except for the special illumination introduced.

To isolate the observer from the activities of the experimenter, he was seated on a theatre chair in an enclosed observing booth mounted on castors. When the booth door was closed, the observer's vision was restricted to viewing the terrain model through a cutout window 30 inches wide by 20 inches high centered 20 inches in front of him. A shelf immediately in front of the observer supported a chin cup and forehead rest assembly which was intended to make for consistent head positioning. The observer's eyes were 46 inches above the floor. The shelf also held an intercom unit and a pushbutton box which the observer used to signal his detection responses. The use of this equipment will be described later. Because the observer's booth was positioned at varied distances from the terrain model, several different black cardboard cutouts were available to fasten over the window of the booth so that in each case the observer saw only the terrain model. The model was seen approximately from its left to right extremities, and seen in the vertical dimention only from the lower edge of black curtain below the model to a point in the "sky" just below the ceiling. With these restrictions, the observer was prevented from seeing any of the sources of illumination or the activities at the experimenter's desk on the left side of the room near the model.

Figure 2 shows the experimental room in most of its details. At the right is shown the side of the observer's booth facing toward the terrain model in the background. At the left, against the wall, is the experimenter's desk containing the master intercom unit and a one-hundredth second electric clock timer associated by a special circuit with the observer's response box. The experimenter's desk was illuminated by a shielded red lamp, which under dark-adapted conditions was adequate for the activities required. (It should be added that during sessions, the experimenter used only a red filtered flashlight to guide his way to and from the model itself to reduce the possibility of accidentally affecting the observer's state of dark adaptation.)

Certain other features seen in Figure 2 are of interest. First, the long white line seen on the floor parallel with the edge of the booth is a guide line for positioning the observer. An indicator, seen projecting from the lower left edge of the booth, was at the same distance from the target as the observer's eyes and by appropriate positioning the booth indicator at distances marked on the guide line, any desired distance from a given target position could be obtained. It may be seen that the booth faced the terrain model from an angle of about thirty degrees. This was necessary because the model itself was lowest in its center front and sloped upwards in all directions from this point. By positioning the booth as was done, the observer viewed the expanse of the left side without obstructions in the foreground. This portion of the terrain sloped gently upward going away from him, and terminated in trees at the skyline on the left leading to the hills on the right. For part of the sessions, the main part of this area was uniform (as may be seen in Figure 1) and for the remaining sessions it was made non-uniform with bushes and trees (as may be seen in Figure 2). The details of the terrain surrounding a target will be found in the next section.

Attention should be called to the special equipment also seen in Figure 2. On the left in the foreground, on its tripod, is a special photoelectric telephotometer used in these studies. The use of this instrument, developed by Mr. Benjamin S. Pritchard, will be described later. Between the telephotometer and the observer's booth is seen one of the projectors used to simulate searchlight illumination on the terrain. This is seen with its light shield cover off. Its arrangement and use will be described later, also.

In the remainder of this section details will be given concerning the target models, sources of illumination, photometry, observers, and, experimental procedures used.

Target Models: The three targets specified earlier were constructed to scale (108:1) and are shown in detail in Figures 3, 4, and 5. The M-48 tank was modified in detail from a commercially produced scale model (Authenticast) based on photographs and dimensions provided from the Human Research Unit. The M-59 armored personnel carrier was constructed in its entirety from this information since no commercially made model was available. The anti-tank gun and crew, consisting of six men, was assembled as an integral unit. The two vehicles posed an interesting problem with respect to their color. Since what is termed "O.D." color ranges over about fourteen Munsell notations, it was considered imperative that our target models correspond as exactly as possible to the field tanks at Fort Knox. A sample of paint forwarded from Fort Knox by Dr. Willard was used to secure this control. The actual "O.D." resulting can be described in Munsell notation as 2.5 yellow, 2 value, and 2 chroma. (This is in distinction to the unmodified authenticast color which can be described as 10.0 yellow, 5 value, and 2 chroma.) The original tank paint is a semi-gloss paint but it apparently abrades on exposure to dirt and air and the vehicles in the field are essentially "matte" in appearance and quite dark. Accordingly, our models were spray-painted to meet these color specifications. The anti-tank gun and crew were painted with similar paint for the O.D. portions. The faces of the crew were approximately flesh color although in combat probably they would be blackened. In general, it was felt that detail of the targets should be made as accurate as possible even though under the intended viewing conditions an observer's acuity for such detail would be poor.

Sources of Illumination. First will be described the means of simulating natural field illumination, i.e., starlight, and moonlight. Ideally, to simulate starlight, a sky dome would be required. This would provide the diffuse illumination of the ground typical of the clear night sky. By reason of practical considerations a sky dome was only approximated by providing highly diffuse illumination from the ceiling area over the terrain model. This was accomplished by partially covering the cement ceiling beams with matte white paper. The beams were about six inches wide and eleven inches deep from the ceiling. They were spaced about two feet apart. Since the uncovered portions of the ceiling were painted black, about ten percent of the ceiling area was responsible for reflecting light directed upon it from two louvres, one at each side of the model. Each louvre contained a single one candle, six volt, lamp. The lamps were shielded so that they illuminated only the ceiling area. In turn, the model was illuminated by the light reflected from the whole ceiling area, and to some small extent by re-reflected light from the walls. A 36 inch wide white plastic curtain was hung from the ceiling in front of the model. This may be seen along the ceiling in Figure 2. This served to add to the reflected light at the front of the model. The lamps were powered from a Variac and transformer connected to an A.C. outlet.

To achieve the lowest level of illumination, for starlight, neutral filters of nominal density 1 were positioned within the louvres. When moonlight levels were intended, the filters were removed to allow a greater contribution of scattered light to the illumination. Although the procedure described did not provide quite enough illumination from the front and sides to an object on the terrain, it seemed quite adequate in that no discernable shadows were created and objects appear uniformly illuminated. Under starlight illumination the luminance of the uniform ground in the target area (as measured along the observer's line of sight, photoelectrically) was about 10^{-5} foot lamberts.

Moonlight, in distinction to starlight, is highly directional in character. To achieve this feature, a light louvre was mounted on a scaffolding near the rear of the experimental room. The louvre enclosed a 300 watt projector lamp. The light from the lamp illuminated the model from an elevation of sixteen feet and at a distance of approximately 35 feet. Two filters were used to achieve the desired level of illumination. A Wratten 78 filter altered the spectral composition of the light to achieve the visual equivalent of approximately 5000 degrees color temperature, and an appropriate neutral density filter further reduced the over-all level of illumination on the model. A mask in front of the filters adjusted the light pattern so that it illuminated only the terrain model directly. In use, some light was reflected from parts of the model to the walls and re-reflected to the model. In addition, as noted above, the "starlight" louvres were operated without additional filters so as to add to the diffuse light when "moonlight" simulation was intended. The direct light from the moonlight louvre illuminated the terrain in the target area at a vertical angle of about 20 degrees, and at an angle separated from the observer (to his left) of about 45 degrees. Two features should be noted regarding the moonlight illumination. First, the over-all level yielded a luminance for the ground, as seen from the observer's position, of approximately 10^{-3} foot lamberts. This level is quite satisfactory for the intended simulation (Ref. 1). Secondly, however, the ratio of direct to scattered light was too great in the direction of the direct source. The desired ratio would be about 2:1. Our ratio was, in fact, 840:1. This made for more sharply delimited shadows and possibly greater contrasts under moonlight conditions than would be the case ordinarily. It was not possible, however, to achieve a better balance between the direct and scattered light for this case within the time available.

For searchlight illumination we simulated the 18-inch tank-mounted searchlight which uses a 2500 watt lamp of new design. This lamp has a four million peak candlepower and an 8-degree horizontal beam spread when used in the tank mounted reflector housing. Working from candlepower distribution data provided by the Human Research Unit, corrector slides were made on thirty five millimeter film slides which provided the desired characteristics of beam spread from Argus slide projectors. The candlepower distribution attained is shown in Figure 32. The illumination was scaled according to principles stated in Reference 2. To determine requirements concerning peak candlepower of the simulated source, the peak value for the 2500 watt lamp (4,000,000 candles) was divided by the square of the scale factor (108^2), yielding approximately 400 candles for the simulation source peak. The objective lens of the slide projector used as a source was stopped down until the peak reading of light projected through the corrector slide measured the requisite level in candles. With the foregoing scaling of illumination and adjustment given by the corrector slide, the illumination of the model terrain afforded by such a projector simulated realistically searchlight illumination.

The Argus projectors were mounted on small stands. In front of each projector, there was a solonoid operated flag shutter which could be opened remotely by closing a switch at the experimenter's desk. The switch was a double throw type and could be alternated in its two positions to allow two such projectors to serially illuminate the target. If single searchlight illumination was required, the timing of illumination was controlled in a similar manner. The projectors were enclosed by boxes, except for an opening in front of the lens and shutter, to prevent stray light from altering the general illumination levels.

In simulating the proper separation of a searchlight source from the observer, a problem arose in connection with the scaling of our distances. In keeping the searchlight at the same distance from the target as the observer, it was not possible to place it closer than about twenty inches to his side (due to the presence of the observing booth). Thus an equivalent separation of seventy-five yards could be achieved directly but smaller separations could not. Since placing a searchlight simulation projector in front of the booth displaced it about thirty inches forward of the observer (equivalent in scale factor terms to 90 yards) it was necessary to employ an indirect means of achieving "on beam" and small separations. This was done by setting the projector at right angles to the front of the booth and positioning a front-surfaced mirror at 45 degrees inclination about two feet in front of the objective lens. The mirror reflected the light along the desired forward path. In this way, the searchlight beam could be made to nearly coincide with the observer's line of sight, or to project along other desired paths. Since some light was lost due to the mirror, the actual distance from the source to the target was reduced slightly to compensate when this manner of operation was employed. Since the searchlight beam originated 44 inches from the floor of the room, the observer's line of sight was a little higher than the searchlight beam itself as would be the case for an observer looking from a position on top of a tank turret. The appearance of various targets under these different illumination conditions is illustrated photographically in a number of figures to be introduced in a later section.

Photometry: Throughout the sessions the establishment and control over levels of illumination, and the measurement of values of luminance for selected portions of terrain and targets was accomplished by use of the photoelectric telephotometer developed in these laboratories by Mr. Benjamin S. Pritchard under sponsorship of the Illuminating Engineering Research Institute. It was necessary to use such a device because direct visual photometry for such low levels of illumination would not be accurate or even possible in some instances. The instrument consisted of two units, the photoelectric sensing unit and its associated optics, and the registering meter containing the power source (dry cell batteries). The instrument allowed its user to view through the optical system and see directly that which was to be measured photoelectrically. A reticle indicated the portion of the field which would be effective at the photomultiplier depending on the aperture used as a field stop. A Wratten 106 filter was effective in correcting the spectral sensitivity characteristics of the photomultiplier to approximate the photopic visual curve. It was possible to position the telephotometer at the observer's location, the equivalent of 1000 yards, for example, and register selected parts of a target such as the upper turret of a model tank.

The photomultiplier unit itself could be removed from its housing and placed on a terrain area to measure incident light falling on the area. The complete instrument contained a radium-phosphor internal standard which could be used at any time to repeat a sensitivity setting and allow the meter scale readings to be interpreted in physical unit terms. The instrument could not give information for the worst conditions (lowest light levels, small target areas) but could cover a sufficient range that these conditions can be fairly well understood in any event.

Observers: Three observers served during the experimental sessions. The writer (C.H.), Mr. Carl Semmelroth (C.S.), and Mr. William Dickerman (W.D.). The writer observed in every observation condition reported although, for reasons indicated later, the data obtained for some conditions are not utilized. In any event, the writer has a basis in direct personal knowledge of each observer task posed by the many conditions of the experiments described in the following section. This experience was highly desirable to afford continuity between conditions where different additional observers might be used, and to provide a meaningful basis for relating phenomenal aspects of the observer's tasks to the varied particular situations. Mr. Semmelroth observed under most conditions, and, in the beginning provided a basis for assessing the effects of practice. Prior to this work he had not had experience as an observer. In addition, he visited during the field tests at Fort Knox, along with the writer. His role included being the experimenter when the writer was observer, and he had complete knowledge at all times of our procedures and objectives. Mr. Dickerman supplemented as observer and assisted the experimentation when not observing. His knowledge of the task was not as complete, but sufficiently so to ensure objectivity during observing. Mr. Dickerman's beginning observation sessions also afforded an indication of the effects of practice since he, too, was initially naive as an observer.

The visual capabilities of the observers were checked. For C.H., right eye only, far acuity was 20/18. No measurable central acuity exists for C.H.'s left eye, as explained below. For C.S., binocular far acuity was 20/22. For W.D., binocular far acuity was 20/18. These measures for C.H. and C.S. were with glasses normally worn, and worn during all experimental sessions. W.D. did not require corrective lenses for distant vision. During all sessions binocular vision was employed restricted only by the window of the observer's booth, described earlier. No unusual visual defects are noted for observers C.S. and W.D. For the writer, however, the left eye central 20-degree field is lost due to an old scotoma. The peripheral field in the left eye is fairly normal. In the writer's right eye visual field, a small scotoma exists in the lower right quadrant. This scotoma lies about ten degrees from the field center and its presence is phenomenally available to the writer, hence observations can be made with confidence that the scotoma is not interfering. Because of these visual defects, foveal vision is monocular but peripheral vision is binocular for the writer. In spite of such defects, the writer felt capable of obtaining satisfactory data, and similar data obtained from additional observers served as a check in this regard.

It should be noted that in the experiments to follow, that our approach was that of classical psychophysics. By this is meant that we, as observers, had complete knowledge of the task and attempted to achieve complete objectivity in making responses. Conditions, to be described shortly, were arranged to provide maximum objectivity, and it is felt that such an objective was closely approached. Some comments relative to the foregoing point will be made later when describing the experimental procedures.

<u>Experimental Procedure</u>: In deciding upon our general experimental procedure, only one previous model simulator study had any direct relevance. This study, by Gordon (Ref. 3) differed in several important respects from the dictates of our earlier conference agreements as to procedure. Gordon, studying the relative visibility of military targets along ground paths, had the observer moved continuously closer to the terrain model until he could distinguish the targets along a line or lines of sight afforded by visible markers at the model edge. This procedure would not be satisfactory since we were to obtain frequency of seeing data. Gordon's targets were sideways rather than head-on to the observer. Illumination was from a single source located in varied elevations and azimuths to the observer; the illumination was similar to that from a flare, but fixed in position. Certain of Gordon's findings will be related to our results later, but it should be noted that our experiments called for rather different procedures, and, as well, for a closer relation to specified field conditions.

Initially the problem of determining whether an observer reporting the presence of a target was correct led to a procedure shown to be erroneous by exploratory experiments. In view of the paucity of experiments of the present type, the exploratory work will be described and the reasons for its rejection mentioned. In this context, our final method may be better justified as the most suitable for these studies.

Our initial attempt was restricted to the moonlight condition with uniform terrain surrounding the target. At that time the present large uniform area of the lower left side of the model was divided into two equal sections differing in ground cover. Figure 6 illustrates this earlier arrangement. Five target positions and paired alternate positions were located in the original area. These are shown in Figure 6. The five positions varied in distance from a given position of the observer's booth by fixed amounts. In selecting these target positions, care was taken to select positions such that uniform ground would surround the target for at least twice its own dimensions in any direction. The positions chosen met this criterion, and in fact were the only locations which would allow for the experimenter to rapidly place the target on the terrain for each observation. The experimenter's task was complicated by attachments to the target to be described shortly.

During a session, after appropriate time for dark adaptation, the observer was instructed via the intercom to close his eyes. The experimenter then placed the target at one of the five distances according to a randomized schedule. On signal, the observer opened his eyes and tried to detect at which point in the field there was a target. Concurrently with the verbal signal to begin observing, the experimenter closed a switch which started the interval timer. When the observer thought he detected a target, he depressed the response button on the box at his hand in the booth. This stopped the timer and simultaneously closed a circuit to allow a charged condenser to "fire" a small neon lamp briefly. The lamp was mounted under the target on the terrain. This was connected by fine wires to the control circuit. The observer could tell by the flash of the neon lamp whether his response was correct (to a target) or wrong (to some other visual stimulus in the field).

The procedure seemed effective and fairly consistent results were obtained for the tank as target over several sessions. Examination of our data showed that a distance could be chosen for the observer from the nearest target position at which he nearly always detected the target. Performance was progressively poorer for the succeedingly more remote target locations. Further, in the most remote location, the target was essentially invisible to the observer.

Two difficulties led to abandoning this procedure. First, the possible target locations were readily learned in relation to visible terrain features (mainly skyline characteristics). It then was easy to imagine seeing a target in a more remote position when it was not visible in a nearer position, (proven by data from blank trials). More seriously, considering the angular size of the target, it should have been visible at greater distances than our data indicated. Accordingly, check experiments were conducted in which the observer-to-target distance was the same as for the earlier sessions with reference to the most remote target position, but the target itself was in the most forward location. This check showed that the target was now almost perfectly detectable and that its earlier loss of detectability in the more remote position probably was due to its relatively greater proximity to non-uniform skyline (as seen by the observer). It appeared that under these conditions, we had a mixed case in which some targets were in a fairly uniform surround and others essentially in a non-uniform surround. How much separation of the target from discriminable non-uniformities would be required for a target to be considered as in a uniform surround was clearly impossible to predict in advance. Our preliminary work showed that we simply had not provided sufficient uniformity in the immediate background for some of the targets.

To correct the foregoing situation, the terrain was modified to provide a greater uniformity of target surround. The grass cover to the right of the original target field was removed and the entire area between the road in the center to the trees on the left hand edge was made uniform as shown in Figure 7. A new single target position, designated as the "mid-field" position was chosen such that at any intended distance of the observer's booth, the observer saw no obvious lack of uniformity in the surround for distances up to several times the dimensions of the target. Because of this change, the experimenter had to position the target well into an interior portion of the model and it was impossible to do so easily if the neon lamp were attached to the target. Also, some further exploratory observation showed that inconsistent data would result if the distance between observer and target were varied by altering the target position, hence the single target position was dictated. In view of this latter finding, the use of the neon flasher indicating the target position was eliminated and our final experimental procedure was developed.

The final procedure adopted was used throughout all the sessions from which data and observations are reported. In this procedure, for a given condition of illumination, the target occupied a single position on the terrain model. For a given series of observations, the observer's booth was located at a fixed distance, and for this series he attempted to report the presence or absence of the target for each discrete observation. After the series was completed, the booth was moved to a new distance from the target position and another series was run.

With this procedure, the problem arose regarding the proportion of trials in a series which should be blank. It seemed evident that one could not arbitrarily say, regarding the type of errors an observer might make, whether a false alarm (or false positive) or a miss would be more serious under actual field conditions. Hence it seemed desirable to arrange the stimulus series to avoid predisposing the observer in either direction (aside from his inherent non-randomness). This dictated that during half the trials of a series, the target should be present and half should be blank. Further, it was felt by each observer that he could dissociate his memory of a previous response better if on any given trial the probability of a target being present was the same as being absent. Accordingly, for each experimental series, the particular target was present for half the trials following a randomized schedule.

The procedure for each observation was similar to the procedure earlier. To begin, the experimenter instructed the observer via the intercom to close his eyes. The experimenter then went <u>in every instance</u> to the model and physically touched the target position. When he left the model, the target was either present or absent according to his schedule. He then gave the verbal signal, "ready", over the intercom, at which time the observer opened his eyes and looked to the right of the model (out of the target area). When the observer indicated that he was ready, the experimenter gave the signal, "begin", and started the interval timer. The observer then attempted to detect the target if it was present. When the observer reached a decision concerning the presence or absence of the target, he pressed the response button stopping the timer, and indicated his decision by saying "yes" or "no" over the intercom. After recording the response and its latency, the experimenter proceeded in the same manner to arrange the next trial in the series. During a series, the observer was not told the correctness of his individual responses. At the end of a series, it was common to record phenomenal observations of interest, and ordinarily the observer was informed of his over-all performance at this time.

In general, for a particular target and condition of illumination, we made an initial guess as to how far away the observer could be and still have some expectation of seeing the target. The observer then ran a series of observations at this distance and if performance was reasonably good, the distance was increased and a second series run. This was continued until the distance was sufficiently great that, for a series, the observer's responses were degraded to chance (being "wrong" as often as "right"). Our data then show, for a set of varied observational distances, the relative reduction in frequency of correct judgments ("yes", target present or "no", target absent) in proportion to wrong judgments ("yes", target absent and "no", target present).

Some remarks were made earlier concerning our effort to give completely objective observations. Under these conditions an observer could, of course, keep track of the number of each of his two categories of response and equate their frequency. We did not do so. During a series we might be aware that we had exceeded a fifty percent level of "yes" or "no" responses, but felt definitely that each instance of observation demanded its own unique judgment regardless of preceding responses which might be recalled. Also, we encountered some conditions in which false positives were likely to occur and some others in which they seldom would occur (misses being the rule, instead). We simply let the situation dictate each response as completely as possible and tried to gain the best possible understanding of it. During a given session, if the observer felt that anything was forestalling the desired objectivity he could (and did in some instances) call off further observations at the time.

A final comment relates to the measurement of response latency. During all sessions except those employing searchlight illumination, the observer was allowed as much time as he required for each judgment. For the searchlight conditions, the observer was not given unrestricted time. Instead, each series featured a predetermined fixed time during which the searchlight or searchlights illuminated the target position. Reasons for this procedural change are discussed in the context of the specific experiments.

III. EXPERIMENTAL RESULTS

The experimental sessions may be most conveniently organized for reporting in terms of, first, terrain background, and, second, mode of illumination. With this organization, comparisons may be made readily among the results for the different target types and from the different observers.

In presenting the results from our experiments, the main data are shown in tabular form. For each condition, in the order introduced in the text, a table shows the frequency of response data and, except for the searchlight conditions, the time for response (latency) data. In analysing these data for discussion, a statistic is derived (also shown in each data table) which is used for illustrating the change in target detectability under the particular experimental conditions employed.

Since the statistic referred to, above, was developed for the purpose of these experiments, some discussion must be given to its rationale before proceeding.

We may begin by considering the results of one group of sessions by way of illustration. These sessions, shown in Table I A are for the M-48 tank in a uniform background under starlight only. The responses fall into four catagories: (1) "yes", target present; (2) "no", target absent; (3) "yes", target absent; (4) "no", target present. The first two catagories are correct responses; the second two are wrong. It may be seen from the table that at the scaled distance equivalent to 135 yards, the observer (C.S.) made no incorrect responses. As he was moved successively further from the target, he made fewer correct and more incorrect responses, until at 225 yards, he made about as many wrong as right responses. The changes noted in response frequencies for each catagory are shown in Figure 9 with the open circle points. Each open circle is a proportion, shown on the left ordinate for the catagory of response. The change with increasing distance may be noted easily.

In considering how a single value may be used to represent these changes in response, it might at first be thought that if the proportion of detections ("yes", target present responses) were corrected for the proportion of false positives ("yes", target absent responses) a usable quantity would be obtained. Such a procedure would be essentially the conventional form of data treatment used in a "yes - no" psychophysical experiment. However, there is now ample evidence (Ref. 4, 5, 6) that critical problems surround this form of analysis due to questions concerning the observer's criterion level for responding affirmatively. Without examining this problem in detail, it may be noted that our experiments allowed for a high proportion of false positive responses, and were done under conditions such that criterion shifts were almost inevitable. In connection with the latter point, comments will be added later concerning the physical conditions which literally forced such changes upon the observers.

In general, it was felt that a highly ambiguous measure would result for our data if the detection proportion corrected for false positive responses was used. Alternatively, it was felt that our data might more meaningfully be interpreted in some other terms where their characteristic features entered a single representative quantity in an unambiguous manner. These considerations led us to think in information terms, where the assumption is made that we can take the technical sense of information and consider that it has a reasonable counterpart in the conventional sense. Granted this assumption, we can treat our data for the specific information content of the set of responses for a given condition and arrive at a measure of stimulus information to be gained from knowing the responses.

The basic derivation, due to Dr. Wilfred M. Kincaid of these laboratories, leads to the following equation:

$$M = 1 + 3.32 \left[-P(Y) \log P(Y) - P(N) \log P(N) + P(SY) \log P(SY) + P(SN) \log P(SN) + P(S'Y) \log P(S'Y) + P(S'N) \log P(S'N) \right]$$

In which

- M = stimulus information gained from knowing the response (the representative quantity to be used)
- $P(Y)$ = Proportion of "yes" responses to total responses
- $P(N)$ = Proportion of "no" responses to total responses
- $P(SY)$ = Proportion of "yes" responses made when a target was present, to total responses
- $P(SN)$ = Proportion of "no" responses made when a target was present, to total responses
- $P(S'Y)$ = Proportion of "yes" responses made when a target was absent, to total responses
- $P(S'N)$ = Proportion of "no" responses made when a target was absent, to total responses
- 3.32 = Constant to convert to system of logarithms base 2

Under the terms of the foregoing equation, if the observer always responds correctly, maximum information is gained from his responses concerning the presence or absence of the target. Since the target was presented during half of the observation trials, the maximum value for a trial would be one bit as an information quantity. It may be shown, also, that if the observer always responds "yes" (or "no") or, if he responds correctly and incorrectly equally often, M goes to zero indicating that no information is obtained concerning the stimulus knowing only the observer's responses. It is the case, too, that if the observer is always wrong, maximum information results which should not be surprising (although this did not occur during our experiments). Some further features of the statistic and additional comments are given in Appendix B. For purposes of further description of results, the information quantity, M, will be used as defined in the foregoing equation. Returning to the data shown in Figure 9, the value of M, shown on the right hand ordinate, is plotted for the set of responses at each observing distance. It may be seen that at the nearest distance, 135 yards, the observer gives maximum information. As he was placed successively further from the target, the value of M falls until at about 200 yards it reaches a value so low as to be no information at all. In the material that follows, the information quantity M will be used to represent observers' levels of performance, and by direct implication, target visibility, as the dependent variable in graphic representation in a manner similar to the foregoing example.

Results from the specific sets of experiments follow. These results deal with detection only, and information concerning target identification is given in a later section. Photographic illustrations for several different experimental conditions are contained in this report. Not every condition could be photographed. Reference to these illustrations will be made at the appropriate points.

A. Experiments With Uniform Terrain Background

(1). Starlight Illumination

An initial set of experiments studied the targets under this condition with three observers. However, a serious error in procedure was brought to light and these data were discarded. The condition was repeated with C.S. as observer and the results are expressed in Tables I A, B and II A, B for the M-48 tank and M-59 APC targets. Tables I A and II A show the frequency-of-response data, and Tables I B and II B show latencies for the respective conditions. In Tables I A and II A, the figure in parenthesis following each frequency of response figure is the proportion for that frequency to the total number of observations. Similar tables are given for the remaining experimental conditions. Figure 10 shows graphically the results for this condition. The illumination was so low that the anti-tank gun target (referred to as ATG hereinafter) could not be seen from the observer's booth at the nearest practical disposition on the terrain which means that its visibility distance would be less than 120 yards.

From Figure 10, it may be seen that the tank and APC show a very similar pattern of loss of visibility with increasing distance. Both remain fairly visible to about 190 yards and then rapidly are lost to the observer. It should be noted that in the terrain position used, the targets were about ten inches (equivalent of 30 yards) lower than the observer. When they were nearer, he responded to a disproportionately larger target since he could see more over their top. The targets could be seen only in peripheral vision and appeared as indistinct black lumps against the faintly visible ground. The presence of any non-uniformities (as will be noted later) made the observers task completely impossible. It is interesting to note that under this worst condition of visibility but with a uniform surround for the target, its visibility remains fairly good as far as it does. Discussion of the point will be given in a later section, but it may be noted, now, that the target here acts much as in more basic psychophysical experiments with reference to angular size of the target and contrasts present.

(2). Moonlight Illumination

Tables III A, B, IV A, B, and V A, B show the results for the tank, APC, and ATG targets respectively, under moonlight illumination. Figures 11, 12, and 13 show these results in graphic form. Figures 21 and 22 show the vehicle targets for this condition. It may be noted that under moonlight, the tank does not appear to be highly visible to observers at any distance shown. The nearest distances employed in this instance were the first found, informally, which did not yield high or perfect detection levels. Hence at 700 yards, for C.H. and C.S., M would have been 1.0. This was true for W.D. at about 600 yards. Beyond these distances, performance was less than perfect as shown in the figure. It was noted for this target and the others as well, that it was detected entirely in peripheral vision as a dark target. Essentially, it was a black blob which, at increasing distances, was very hard to pin down and was never seen with high confidence. In the later discussion section, more consideration will be given to the phenomenal aspects of the target.

The APC target appears generally to be a little more visible than the M-48 tank under these conditions. This finding is reversed for later searchlight conditions. Greater observer variation is seen also for this target. It may be noted that observers C.H. and C.S. show a reversal in the trend of their data. This corresponded to a real reversal of a phenomenal nature. For both observers the target at first became more difficult to see (with increasing distance) and then, at a particular distance, became anomolously visible. With further increases in distance, the target became impossible to see. A similar phenomenon was noted for the ATG target although it is not as well reflected in the data. By way of accounting for such reversal, it may be noted that while the target surround was relatively uniform, it was not absolutely so. Thus, at a sufficiently close distance, the observer saw some non-uniformities in his field of view. By virtue of the relation of target size (and shape, probably) these residual non-uniformities were not easily confused with the target. However, as the viewing distance was increased, the target became less distinct and greater confusion was possible. However, since the non-uniformities in the field were minimal, it is probably that with even greater observing distances, they went below threshold leaving the target somewhat more visible because it was then in a virtually uniform background in comparison with the earlier situation. This would give rise to the anomalous result noted and attest to the complexity of the perceptual task. The question as to the greater visibility of the APC compared with the tank is reserved for later discussion.

The ATG target, as shown in Figure 13, is considerably less visible than either of the vehicles used. One observer, W.D. continued to report the presence or absence of this target with some accuracy at a surprisingly great distance, but in general from 400 to 500 yards, it was essentially undetectable. As with the other targets, this was detected only peripherally and was only a dark target.

(3). Searchlight Illumination

Under these conditions, the targets were illuminated by a single searchlight either (a) along the observer's line of sight, or (b) displaced from the observer the equivalent of 75 yards. The searchlight duration for a given observation was 1, 2, 4, 8, or 15 seconds. Also, two searchlights were used each displaced the equivalent of 75 yards on the right and left of the observer respectively. The two lights alternately illuminated the target at a 1-second flicker rate and provided continuous illumination for 2, 4, 8 or 16 seconds. Figures 23 and 24 illustrate the appearance of the APC and the anti-tank gun and crew target illuminated by a single searchlight displaced to the right of the observer.

Under all these conditions the tank and the APC targets were always detected even at 1500 yards range. For this reason, extensive data were not obtained. The ATG target, being smaller and more irregular in shape, was never detected at 1500 yards.

Considering the ATG target further, when the observer was moved to 1200 yards from the target and the searchlight was displaced 75 yards to his right, the target was detected fairly easily for searchlight durations as short as 4 seconds. With further reduction of the duration of illumination, performance became poorer as shown in Table VI. Two features of the task were noted. First, the target itself was not detected, but instead its shadow, thrown to the left was seen. This was in distinction to the fairly visible outline of the vehicle targets in addition to their shadows. Secondly, the anti-tank gun and crew probably could be seen at somewhat greater distances if sufficient time were allowed. The effect of reduced illumination time was to given the observer too little time to seek out the target. There were few false positive responses. If the observer had time to find the target, the response was definite; if not, there was nothing else which could be confused with it.

One further set of observations was made with the ATG target under these general conditions. For these, the searchlight was along the observer's line of sight. At 1200 yards, the target could not be seen at any duration of the searchlight. When the observer was moved closer to the target, it suddenly became visible at between 900 and 1000 yards. This appeared to occur because at this distance, the shadow of the target, previously concealed behind it, became visible over the top of the target. In fact, the shadow outlined the target very plainly making it highly identifiable in comparison to when the shadow was visible only as thrown to the side by the earlier searchlight condition.

The effects of searchlight flicker were studied informally in the foregoing conditions. It appeared that the targets were so visible under all the searchlight configurations that it would be more profitable to reserve extensive study for these targets in non-uniform surroundings. Under such modified conditions, usual field conditions would be more nearly approximated and the results should have more applicability. It was noted, however, that with flicker the observer gained an advantage in that the target shadow "wig-waged" and became a little more noticeable. The question remained at this point as to whether, with other objects in the field which would become more noticeable, confusion might occur with flicker. Information relating to this point is given in a later section.

B. Experiments With Non-Uniform Terrain Background

For these experiments, the terrain was modified to add bushes and trees in the areas shown in Figure 8. The observer looked for the target in a fairly clear alleyway of vegetation. Three target positions were used, also as shown in Figure 8. The different target positions permitted an evaluation of differing degrees of non-uniformity of immediate surround. The target in the "mid-field" position, used in the moonlight and searchlight experiments just described, was still seen with a fairly uniform surround. Brush and trees were closer for the "upper field" position. When in the "tree position", the target was seen against a close background of vegetation.

(1). Moonlight Illumination

Results for sessions with the M-48 tank target in the mid-field position are given in Table VII A, B and in Figure 14 for observer C.H. The appearance of the target is seen in Figure 25. This figure may be compared with Figure 21 to note the changes introduced by the terrain additions. This condition is completely similar to the earlier condition except for the non-uniformities added to the terrain. For this reason, it permits a comparison of results showing the effect of the non-uniformities added. The present results show that the target is fairly visible up to 500 to 600 yards in the moonlight alone. Beyond this, it loses detectability and by 700 yards, is essentially not detected. Referring to Figure 11, the same target and illumination with a uniform terrain, it may be seen that at even 900 yards, the observers were still responding with fairly good accuracy.

(2). Searchlight Illumination

A much more thorough exploration of the effects of searchlight illumination was carried out for this condition of terrain than was done earlier. Because there are several variables which can be manipulated in this situation, the results can be organized in a number of different ways for presentation. For this reason the several remaining tables will be cited first, and data drawn from them for more meaningful graphic presentation. Table VIII gives such data for observer C.H. and C.S., for the M-48 tank in the upper field position and several distances from the observer. The various searchlight configurations are shown in the left hand column of the table. SL-C means that the searchlight was projected along the observer's line of sight. If the searchlight was displaced from the observer, this is shown as to distance and direction of displacement. The flicker conditions all used the same displacement of two lights. One was the equivalent of 75 yards to the left and the other an equal equivalent distance to the right. For the flicker sessions, the first figure is the duration of a single light flash and the second, the total continuous time of illumination. Table IX shows similar information for the tank target in the tree position, for observer C.H.

Table X shows results for the APC target in the upper field position in a like manner for observer C.H. and C.S., and Table XI gives this information for the target in the tree position. Data for the remaining target, the anti-tank gun and crew are shown in Table XII for observer C.H.

Illustrations of the appearance of the vehicle targets illuminated by a single searchlight displaced to the observer's right are shown in Figure 26 - 29. Figures 26 and 27 show the tank in the upper field position with the searchlight displaced 75 and 150 yards respectively. Figures 28 and 29 are similar illustrations for the APC target. Smaller displacements for the searchlight cannot be photographed readily since the camera must be closer to the target than the searchlight and hence interferes with the illumination. Illustrations are not shown for targets in the tree position since they are practically impossible to distinguish in a photograph at this location.

Combining data from Tables VIII and IX for the most meaningful comparison leads to Figures 15, 16, and 17. Figure 15 shows the change in visibility for the tank with increased distance of the observer from the target. This comparison is for the condition in which the target is in the tree position, illuminated by a single searchlight along the observer's line of sight for a duration of 4 seconds per observation. It may be seen that under these conditions, performance is fairly accurate at 1000 yards but gets progressively poorer with increased distance.

Since the foregoing information is all for the searchlight on the observer's line of sight, the effect of varying its displacement from the observer is to be shown next. We selected the single observing distance of 1350 yards since performance was relatively poor (M = .193), with the expectation that displacing the searchlight from the observer would result in some degree of improvement. Figure 16 shows our results arranged to show such effects. Two durations were employed. The first we employed was 4 seconds. As anticipated, performance improved being as good at 40 yards as it subsequently was at 75 yards displacement. With greater displacement there was some loss in performance which will be commented on later. It is possible to show the effect of flicker, here, also. The single point labeled 1-sec-F, 4-sec-total is shown for this purpose and is noticeable lower than the 4 second continuous illumination curve at the 75 yards displacement.

The second curve labeled 8-sec duration in Figure 16, is not in error although it at first might appear so. After results were at hand for the 4-second condition, the 8-second condition was employed to assess such further improvement as could result from additional time to search for the target. Instead of improvement, the opposite occurred. This result was sufficiently startling that it was checked with additional observations, as was done for certain of the points on the 4-second curve. The finding, to be discussed more fully later on, held up in that additional observation time simply degraded performance for this target under these conditions.

Considering that the foregoing results might be due to unique circumstances in which the tree background became more confusing with additional observing time, the effect of both duration of the searchlight and the background were assessed with the target in the upper field position as shown in the next figure, 17. In this figure, the target distance is fixed at 1512 yards. It was necessary to use the extreme distance because at nearer distances, performance for the more open upper-field target position would be practically perfect even at the shortest searchlight duration. In this analysis, curves are shown for each target position and performance is plotted as a function of searchlight duration. For both target positions, increasing the duration of the searchlight illumination only leads to improvement of the observer's performance. The difference in visibility for the target for the two locations in the terrain is quite marked. Also, it may be seen that the greatest gain in performance is for the target in the more open position and occurs mainly within 10 seconds. Further comment will be made later relative to the latter point.

The dashed line curve shown in Figure 17 allows a comparison of searchlight flicker at this point, also. The flicker data, also, are for the target in the upper field position. At the total illumination times of 4 and 8 seconds, performance was definitely better than for equal continuous illumination durations. The shadow of the target quickly "wig-waged" the observer to a detection from this relatively open location in the terrain. With 15 seconds total flicker at the 1-second rate, the task became phenominally more difficult as reflected at the right of this curve.

Considering next information for the M-59 APC target, data are shown from Tables X and XI in Figure 18, 19 and 20. In Figure 18, the visibility of the APC for two conditions of searchlight displacement (SL-C and SL-75-R) is shown as a function of distance of the observer from the target. It may be seen that with the searchlight projected on the observer's line of sight, the target is detected only poorly as close as 1000 yards compared with the instance where the searchlight is displaced 75 yards to the right of the observer. For the latter situation, performance is very good to nearly 1200 yards and then drops very rapidly to become as poor as with the first configuration of the searchlight. In general, the APC is less visible than the M-48 tank and reasons for this will be given in a later discussion. It was possible to graph two additional points for flicker conditions in this figure, also. With 1-second flicker, performance is noticeably poorer than with continuous illumination for the same total time. When the flicker rate is decreased to two seconds, performance improves. From Table XI, it may be seen that if the 2-second flicker is continued for a total of 8 seconds, performance becomes perfect.

The effect of differing searchlight durations are shown in Figure 19 for the APC target. Data are shown for two observers. For this target position, increased duration resulted in improved detection. Two sets of flicker observations are shown also. Again, for a target in the fairly open upper field position, some improvement is noted for flicker compared with the condition of continuous illumination.

Figure 20 shows the effect of searchlight displacement for the APC target. In Figure 19 it already has been shown that a substantial improvement in visibility results for this target when the searchlight is displaced 75 yards to the right of the observer, compared with the SL-C arrangement. The present Figure indicates that the improvement results primarily after displacements of about 60 yards have occurred. With further displacement of the searchlight, as with the tank target, some loss of visibility appears to take place. Also, as with the tank target, the analomous result that doubling the duration of the searchlight illumination produces a reduction in performance level for the observer is noted, although to a lesser extent.

Final results concern the anti-tank gun and crew target. Data for the limited study given this target are shown in Table XII. From this table it may be seen that at approximately 900 yards the visibility of this target in the fairly open upper field position ranges from good to poor depending on the searchlight duration and displacement. The best results were obtained from the flicker condition shown. However, increasing the observers distance only an additional 200 yards made the target very difficult to detect. When the target was placed in the tree position, it became impossible to detect at all even at much closer distances. Since the target was fairly visible at as great as a range 1200 yards under searchlight illumination on the earlier uniform terrain, the effect of concealment for this type of target by vegetation is fairly well demonstrated. In the case of this type of target, if there are nearby bushes or trees, confusion results; viewed against bushes or trees, such a target readily blends into the background as neither the tank or APC can do.

The final comments in this section concern the response latency data shown in certain of the preceding tables. In order to keep this report within some limit, no detailed analysis will be presented of these data although they will be considered further in the next section. It may be seen on inspection that the average times taken by observers was fairly consistent depending on the catagory of response and the difficulty of the immediate observing task. The shortest response times are seen in general for '"yes", target present' responses while the false positive, or '"yes", target absent' responses generally take as long as a correct or incorrect "no" response. All responses tend to increase in latency as the observer's task became more difficult due to increased observing distance, with the correct positive responses increasing the most. Over a variety of conditions it may be noted that the range of average latencies was from as short between 5 and 10 seconds to as long as 50 to 60 seconds. The three observers differed in latencies typical of their responses.

IV. DISCUSSION OF RESULTS

First to be considered are the results from the starlight and moonlight conditions. It was noted earlier that under these conditions targets were phenomenally dark targets (relative to their background). An observer was able to detect them only by using peripheral vision. An observer's ability to do this seemed to depend upon some kind of scanning technique in which a distinguishable terrain feature (such as a particular patch of trees in the extreme background) was used for relative orientation. When attempting to judge the presence or absence of the target, the observer scanned in the direction of the orientation feature of the terrain but attended to the peripherally aroused sensations in the area where the target should be. Scanning was necessary because of the generally indistinct appearance of terrain features even under moonlight. It should be added that since between the observer and the model there was essentially a void, nearby terrain features present in the field were not available to aid orientation in our simulator studies.

When observing even a fairly close target under these conditions, it could be held in phenomenal regard only a short time. When the observer's distance was increased, the target tended to appear less frequently and disappear more rapidly. The limit of a given target's visibility was characterized by such a fleeting appearance that the observer generally lacked confidence in his judgments entirely. All observers were impressed by the "noise" inherent under these conditions. Although the terrain appeared uniform in the target area, it was very diffuse and the peripheral phenomena sensed often were as convincing when the target was absent as when it was present. The task, generally, was very difficult.

It was noted earlier that our exploratory experiments of the tank target in moonlight led us to believe that we had failed to achieve the maximum distances for detection for the uniform terrain condition. Following, we developed the altered procedure reported. In connection with the later findings it was stated that the target, under the starlight and moonlight conditions appeared to behave very much as targets in a more basic psychophysical study for uniform targets against a uniform background. To supplement this point it may be noted, from photometric information, that a reasonable value for the tank contrast with its background for starlight and moonlight would be about -.50. Considering the background to have a luminance of 10^{-5} foot lamberts and given this target contrast, the minimum visual angle for the target to be detectable at the 50 percent level of probability can be estimated crudely from visual detection data (Ref. 7). Under these conditions, about 40 minutes of arc represents the minimum detectable angular size of a target. This would correspond to the APC or tank about equally well at about 300 yards from the observer. Under these conditions our targets remained visible to slightly over 200 yards and were still detected very occasionally at 300. The complexity of having no discrete fixation point for the observer and having, actually, a relatively non-uniform field of view (compared with the more pure psychophysical case) make for losses of detectability of about the order to account for our results.

A similar analysis made for moonlight conditions shows that the threshold detection angle would be about 7 minutes of arc. This would correspond to the width of one of our vehicle targets at about 1850 yards range. Again, residual non-uniformities in the field of view, lack of discrete and consistently optimal orientation, and other complexities can be cited to account for not reaching such an extreme visibility distance under this condition of our study.

However, under the above mentioned conditions we have shown visibility distances approaching limits of observer sensitivity. These results exceed the performance conventionally expected · seen, given only starlight or moonlight illumination. While some qualifications will be made shortly, our results suggest that certain observer capabilities along these lines might be worthy training objectives. If observers could take better advantage of existing natural illumination, possible targets may be located prior to more revealing active observation is initiated using searchlights.

Probably at best, under starlight, unaided vision is not particularly helpful. However, given added auditory and motion cues under these conditions, possible targets can be located and supplementary optical aids employed for the advantage they might give. Under these conditions, when a target seems probable, even a brief duration of searchlight illumination would make the detection and identification highly certain.

Under moonlight illumination a greater range of visibility was seen. The remarks of the preceding paragraph are considerably more pertinent here. The observer can scan a fairly large target area. Since he is not revealing his position by doing so, an unlimited time can be provided. (Actually, for a given area detection may occur in a fairly short time so observing techniques might well involve discrete observations in specified areas). If an observer has had the advantage of previous reconnaissance under better illumination, the moving of a target into the area may well be seen by him within the limits we have noted. Optical aids then may be adequate for complete identification or at least a more certain detection. At all distances that moon illumination is adequate for some degree of detection, the increase of detectability and identifiability with added searchlight illumination is very marked (given an optimal searchlight configuration, of course).

Two additional questions concern our findings under these conditions of illumination. First, to what extent are they representative of what may be expected in the field. Second, what are the roles of training and motivation to achieve such results. Following discussion of these questions, attention will be given to the factor of identification and to the degrading effects of increased field non-uniformities.

With reference to the first question, above, the visit of the writer and observer C.S. for the field studies at Fort Knox gives some indication of an answer. During the first run of the evening of June 27, the moon was nearly full and oriented with respect to the target area almost exactly as in our simulator studies. During this run it was possible to look for either an M-48 tank or M-59 APC target at distances of 500, 700, 1000, or 1175 yards after they moved into position but before the searchlight was turned on. Dark adaptation could not be optimal because of the presence of the searchlight as well as other illumination in the observing area. Also, there was a mildly dense ground fog visible in the target area. However, both the writer and C.S. could detect the presence of the tank or the APC at 500 and 700 yards with the unaided eye. At 500 yards, detection was certain; at 700 it was poorer but still occurred.

The preceding figures compare well with our model study findings for the non-uniform terrain. Had the ground fog been absent, somewhat greater visibility would have resulted although with the highly non-uniform terrain conditions probably not much improvement would be seen. It may be added that these targets, when detected, were identifiable using seven power binoculars. Finally, it should be added that at the field test and in the model study, the moon's angular location relative to the target position and observer was optimal for target detection as may be inferred from Gordon's study cited previously (Ref. 3).

The roles of motivation and training can only be discussed in a speculative manner. However our experiences during the course of the studies give rise to definite opinions concerning these variables. In the first place, it has been shown that trained observers in psychophysical experiments can perform better than naive (Ref. 8). In the more complex field situation, the differences between trained and untrained performance may well be greater. During our earliest experiments, the writer (already a "trained" observer in the general sense) probably achieved peak performance during a few exploratory sessions. However, observer C.S., and subsequently W.D., began observing sessions relatively naive to the nature of the task. For four consecutive two-hour sessions, observer C.S. could not perform better than chance when he was more than about 650 yards range. Nearly up to this point, his responses were perfectly accurate. (One should note this range in connection with comments to follow concerning identification of targets, later).

Following these sessions, two additional sessions resulted in a fairly rapid improvement (within each session) in which the target could be detected at successively greater distances. When C.S.'s performance became stable, he was able to give some detections at nearly 1200 yards range. His account of the change indicates the learning of appropriate scanning and fixation techniques and, more importantly, to "tease out" the phenomenally vague and intangible target from the unfamiliar visual display. Recalling that the observer was not informed of the accuracy of his responses during a series of observations, it may be inferred that more rapid improvement would result with immediate reinforcement of responses. Fairly extensive improvement was seen, however. Similar improvement occurred for observer W.D. and, in addition, he did not improve substantially until he became willing to respond affirmatively even though the response might be a false positive. Following this shift in motivation (or set) his improvement was nearly as great as for C.S. It may be noted in the figures where data are shown for the other observers in addition to the writer, their final performance was as good or better than the writer's.

The possibility of using a model simulator for training purposes is evident and should be considered. There is, of course, precedent in various instances in military training programs. Once constructed, a model simulator offers a relatively inexpensive and readily available means of presenting information and promoting acquaintance with field conditions. Conditions can be highly controlled. Demonstrations of the capabilities of an observer as well as better exposition of techniques employed are readily possible. The step is surprisingly short from a well simulated field situation to actual field conditions.

Using a model simulator for training purposes requires evaluation, however, in its own right. Face validity is high and, perhaps, has been misleading in the past. Earlier programs have not shown clearly that any particular advantage was gained by observers so trained. Such failure in the past has been due, in the writer's opinion, to first, not having specific and measurable criteria for performance as objectives during training, and, secondly, not having similar criteria for subsequent evaluation. Generally it has been agreed that such devices are interesting and motivating but the actual effects on field performance have been difficult if not impossible to evaluate. Our study, as an investigation of observer capabilities, is quite specific as to measurable aspects of performance. (In fact, the pattern of a training study was reported a little earlier. Having at hand performance data for one, trained observer, it was possible to continue practice on the part of new observers until they had reached similar levels of performance.) Possibilities for training use certainly merit considerable further investigation.

In our original outline it was noted that identification data were sought. The earliest studies showed clearly that the vehicle targets would always be identified as such without confusion with the anti-tank gun and crew target. This was because of the difference in visibility distances involved and because the observer was generally aware of the range to the target area. For the two vehicles under moonlight and uniform terrain conditions, one set of observations were taken with the writer as observer to estimate the maximum range at which each vehicle could be identified. The APC could be distinguished as such out to about 600 yards and the tank a little further. Actually, in both instances the targets were only vaguely identifiable at even shorter ranges, due probably because they were viewed in peripheral vision (about 5 degrees from central). Within the ranges noted, the tank had a vague humped appearance whereas the APC was squat and more spread out in appearance. Beyond the ranges noted the targets remained readily detectable, as shown earlier, but quite indistinguishable.

Data presented in Figure 14 showed that the tank visibility under moonlight in the non-uniform terrain condition was very poor beyond about 600 yards although it had been considerable better for the uniform terrain condition. This range for detection in non-uniform terrain appears to correspond to the range for identification noted above. It was confirmed in the writer's experience that when the terrain was non-uniform the task became essentially an identification task. Any number of equally detectable visual stimuli were present along with the target and the characteristic shape of the target had to be perceived to some extent in order to achieve any accuracy of responding.

When the nature of the observing task is considered for the searchlight conditions, the role of target identifiability becomes even more pronounced. Probably for most conditions when the visibility of the target used was less than perfect, factors of confusion with other visible stimuli were basic to the results. This interpretation is plausible when the detectability of the targets is assessed as was done earlier for the conditions of natural illumination. In Figures 30 and 31 several figures show the principal photometric values which can be assigned portions of the targets under typical searchlight illumination. Figure 31 shows these values for the APC target illuminated with the searchlight at 1000 yards, displaced 75 yards right of the observer. Figure 23 shows this target much as the observer saw it. Two aspects of the target are evident as detection features. The horizontal front panel and treads form a roughly rectangular bright target against a somewhat darker background. The sloping front panel, not reflecting as much light to the observer, forms a roughly equal sized rectangular dark target with the background. In addition to the target, its shadow may be seen and this forms a high contrast dark target with the remaining background. Considering only the rectangular areas noted, the lighter has a contrast of about .70 with the general surroundings and should be detectable to an observer at about 3000 yards range on the same line of sight. The dark target area has a similar contrast of about -.40 and would be detectable to a distance of about 2100 yards. The shadow obviously would be more detectable in these terms than the sloping front.

Such an analysis is more difficult for the tank and will not be attempted. Reference to Figures 26 and 31 shows similar but less well defined areas of high contrast with the background and within the target as well. Consequently, such analysis if successful, should show this target to be detectable well beyond the maximum range of interest. Of course, if both the observer and the searchlight are moved further from the target the background level is reduced. To some extent contrasts may be changed also. However, this reduction in level of illumination would still leave the vehicle targets highly detectable, especially if their shadows are visible as well.

If the targets are detectable, in principal, at ranges where we have already shown their visibility to be quite poor, then the loss of visibility must be accounted for. Our data shown for both the tank and the APC in the successive mid-field and tree positions support the contention that as the background becomes more non-uniform visibility suffers. To the observer, the task becomes an identification task because not only can the targets be detected but so can everything else in the immediate surround. The problem becomes that of distinguishing the target from the other objects seen. For the tree position this is very difficult indeed. These terrain conditions, incidentally, were very similar to those of the field study at Fort Knox; our informal observations in the field with searchlights compare closely to our results from the corresponding conditions of the model study.

Two results for searchlight conditions were noted which may be explained more adequately now. First, it was noted that the tank target was more visible than the APC under searchlight illumination. This was particularly true for the targets in the tree position. Reference again to Figure 31 shows that the luminance of the tree background was somewhat lower than the terrain ground itself. In this location, the sloping front of the APC goes to lower contrast with the background. Also, the vehicle shadow may be lost due to additional ground shadows. This leaves only the smaller area of the vertical front panel and treads to be detected. When one successfully locates the front panel under these conditions, it is fairly visible. However, its dimensions are smaller in proportion to distinguishable aspects of the surroundings and much harder to find. Visibility was lost accordingly.

The tank, on the other hand, has its internal contrast features distributed to form a single pattern. Parts of the tank might become low in contrast with the tree background but the over-all pattern would not be changed. Also, the tank being a taller vehicle tends to overlay its shadow on the tree background more than the APC. Consequently, it seems reasonable that the tank should be more visible under these conditions than the APC.

In the variation of searchlight duration described earlier, it was noted that for the most non-uniform terrain condition, there appeared to be an optimal observing time. Increased time beyond this amount actually appeared to handicap the observer. The writer's experience tells what happened. When the searchlight came on, the target area was quickly scanned. The most likely thing to look like a target was, of course, the target itself. Hence, if enough time was afforded to scan the target area, the first impression was likely to be correct (regarding the presence or absence of the target). If more than this time were allowed, there were many parts of the target area which could be imagined as a target. The tree position target location was a veritable "ink blot" situation for targets if one studied it for any length of time. Hence, given the additional time, the observer formed a judgment and then tended to lose confidence in it before being required to state it. This led to definitely degraded performance.

Probably the optimal duration would vary among observers and with the specific situation. If knowledge of the probable target location is good, some fairly short duration of the searchlight flash may not only be adequate but best for the task. In our studies knowledge of target location was high. We always found, however, that a searchlight 1-second flash was too short to scan within the area illuminated, and 2 seconds quite marginal in the same respect. A flash of 4 seconds appeared optimal, as noted, for targets located in the tree position. For the upper field condition, greater visibility ranges were obtained and it was evident that 4 seconds of searchlight illumination did not lead to as confident judgments as when 8 seconds illumination were provided. Doubling the searchlight duration again led in no case to any further substantial improvement on the tasks. It is the writer's opinion, based on these studies and observation at the field tests that from 8 to 10 seconds is adequate for any attempt by a solitary observer to judge the presence or absence of a target in the beam of the searchlight if the probable target locations are reasonably easy to identify.

The effect of flicker probably merits much further study. Some conclusions can be drawn from our experiments, however. For targets in the open, flicker rather definitely improves detectability due to the "wig-wag" effect. In part this may be due to the fact that the shadow of the target may be detected more readily than the target itself. Many times it is probable that only the shadow is seen. Under flicker conditions, the shadow appears alternately at one boundary then the other boundary of the target. Under these conditions, two borders of the target are seen in succession, and the target is more readily perceived as such; the shadow, moving with flicker, is not misperceived as a substantial object. With non-uniform terrain, however, the same factors may make every bush and large rock equally improved in visibility and lead to poorer observer performance instead.

Our experience with flicker showed that it required some getting used to. Initially, when one searchlight came on, the observer would scan forward along the ground path of the light beam. As this went off and the other searchlight came on, he turned his direction of sight to scanning the second light path. This resulted in considerable overshooting and retracing which was confusing as well as fatiguing. With further experience, however, observers found that they simply directed their line of sight towards the terrain and within the first two alternations, would lock-in on the common area of illumination. In this regard, the 1-second flicker rate was always uncomfortably fast whereas the 2-second rate was quite acceptable. As noted earlier, when flicker was continued very long (15 seconds) the observer became confused. This probably was due to losing fixation within the field and returning to the less efficient beam-scanning behavior; at least in the writer's experience, such a tendency was compelling on the long durations of 1-second flicker.

Final consideration will be given to the effects of differing searchlight separations from the observer. In nearly all our experience, increased separation from searchlight to observer results in improved target visibility up to about 75 yards separation. Beyond this displacement, there may be some loss. In our experiments we did not have the effects of atmospheric light from the searchlight. For the conditions of no displacement between observer and searchlight, we have obtained artificially high detection levels since under these conditions, the observer must look through a substantial veil of back-scattered light. This veil would markedly reduce contrast for the target and also affect the observer visually (adaptation level, pupil responses, and "eyeball" veiling glare) in a very adverse manner.

While observing during Fort Knox field tests, the writer was able to detect a tank at 500 yards by moonlight alone. When looking at the same target along the searchlight beam (from the first adjacent platform) the target barely could be made out at all. The writer then attempted to assess the range of this interference by moving to a platform about 10 yards displaced. From this vantage point the immediately adverse effect of the searchlight seemed drastically reduced. Of course, the extensive data of the field study bear more formally and adequately on these considerations.

From the observations described, however, it would seem that insofar as our illumination scaling was done correctly, the searchlight displacement findings are probably adequate except for the SL-C conditions since the task confronting the observer seems to be a complex identification task rather than a simple detection task. In other words, most of the stimuli may be far enough above detection threshold levels under the conditions of our study that the back scatter from the searchlight would interfere seriously only in its immediate neighborhood. (Some further information of this point is treated in Appendix A.)

As noted earlier, because of limitations of time and relative emphasis given to studying searchlight forms of illumination, no study was given to flare illumination. Gordon's research (Ref. 3) is directly relevant to flare conditions. In general, he found that when the flare was directly behind either the observer or target, its visibility was best. As it was displaced to the side, in azimuth, visibility decreased. Comparisons cannot be made between Gordon's and our study to assess relative performance under searchlight and flare illumination. Such relationships probably are worthy of further investigation.

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TABLE I

Results for M-48 Tank on Uniform Terrain, Observed Under Starlight Illumination

A. Response Frequencies

Observer	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Correct Responses: Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Wrong Responses: Total Wrong	Total	M.
C.S.	135	5(.50)	5(.50)	10(1.00)	0(0.0)	0(0.0)	0	10	1.00
	180	5(.50)	4(.40)	9(.90)	1(.10)	0(0.0)	1(.10)	10	.608
	202	7(.35)	6(.30)	13(.65)	4(.20)	3(.15)	7(.35)	20	.067
	225	6(.30)	7(.35)	13(.65)	3(.15)	4(.20)	7(.35)	20	.067

B. Average Response Latencies (Seconds)

Observer	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Correct Responses: Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Wrong Responses: Total Wrong	Total	M.
C.S.	135	10.4	18.0	--			--	--	--
	180	21.2	25.8	--	48.		--	--	--
	202	25.3	23.5	--	20.0	33.3	--	--	--
	225	19.5	32.9	--	27.7	28.3	--	--	--

TABLE II

Results for M-59 APC on Uniform Terrain, Observed Under Starlight Illumination

A. Response Frequencies

		Correct Responses			Wrong Responses				
Observer	Distance Observer to Target (Yds)	"Yes" Target Present	"No" Target Absent	Total Correct	"Yes" Target Absent	"No" Target Present	Total Wrong	Total	M.
C.S.	135	5(.50)	5(.50)	10	0	0	0	10	1.00
	180	5(.50)	5(.50)	10	0	0	0	10	1.00
	202	3(.30)	3(.30)	6	2(.20)	2(.20)	4	10	.037
	225	9(.30)	11(.37)	20	4(.13)	6(.20)	10	30	.090
	270	4(.20)	7(.35)	11	3(.15)	6(.30)	9	20	.011

B. Average Response Latencies (Seconds)

		Correct Responses			Wrong Responses				
Observer	Distance Observer to Target (Yds)	"Yes" Target Present	"No" Target Absent	Total Correct	"Yes" Target Absent	"No" Target Present	Total Wrong	Total	M.
C.S.	135	8.2	13.2	--			--	--	--
	180	9.8	30.2	--			--	--	--
	202	27.3	29.3	--	29.5	31.5	--	--	--
	225	26.0	34.4	--	41.3	36.8	--	--	--
	270	19.0	22.3	--	26.3	17.3	--	--	--

TABLE III

Results for M-48 Tank on Uniform Terrain, Observed Under Moonlight Illumination

A. Response Frequencies

Observer	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Total Wrong	Total	M.
C.S.	792	26(.50)	19(.37)	45	6(.13)	0	6	51	.562
	900	20(.50)	16(.40)	36	4(.10)	0	4	40	.608
	1008	19(.46)	16(.39)	35	4(.10)	2(.05)	6	41	.409
	1116	12(.40)	11(.37)	23	4(.13)	3(.10)	7	30	.226
	1224	8(.39)	7(.34)	15	4(.18)	2(.09)	6	21	.143
C.H.	900	12(.40)	13(.43)	25	2(.07)	3(.10)	5	30	.346
	1008	15(.38)	13(.32)	28	7(.18)	5(.12)	12	40	.124
	1116	9(.30)	10(.33)	19	5(.17)	6(.20)	11	[illegible]	.050
W.D.	762	4(.40)	4(.40)	8	1(.10)	1(.10)	2	10	.290
	900	33(.37)	35(.39)	68	10(.11)	12(.13)	22	90	.210
	1008	19(.38)	21(.42)	40	4(.08)	6(.12)	10	50	.283
	1116	11(.28)	15(.38)	26	5(.12)	9(.22)	14	40	.074

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TABLE III (Cont'd)

B. Average Response Latencies (Seconds)

Observer	Distance Observer to Target (Yds)	Correct Responses "Yes" Target Present	Correct Responses "No" Target Absent	Total Correct	Wrong Responses "Yes" Target Absent	Wrong Responses "No" Target Present	Total Wrong	Total	M.
C.S.	792	21.7	49.7	--	39.2		--	--	--
	900	36.0	60.1	--	54.4		--	--	--
	1008	30.5	55.1	--	59.5	45.6	--	--	--
	1116	31.5	38.3	--	42.6	45.6	--	--	--
	1224	26.9	31.8	--	33.9	34.4	--	--	--
C.H.	900	9.5	26.1	--	13.5	39.3	--	--	--
	1008	15.4	34.7	--	23.7	22.8	--	--	--
	1116	16.2	24.3	--	24.5	24.6	--	--	--
W.D.	762	17.8	22.0	--	24.8	25.7	--	--	--
	900	20.1	34.5	--	35.8	37.9	--	--	--
	1008	29.4	40.6	--	32.4	43.5	--	--	--
	1116	35.4	43.4	--	30.6	53.8	--	--	--

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TABLE IV

Results for M-59 APC on Uniform Terrain, Observed Under Starlight Illumination

A. Response Frequencies

Observer	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Total Wrong	Total	M.
C.H.	579	5(.50)	5(.50)	10	0	0	0	10	1.00
	792	4(.40)	2(.20)	6	3(.30)	1(.10)	4	10	.041
	900	7(.35)	5(.25)	12	5(.25)	3(.15)	8	20	.027
	1008	5(.50)	4(.40)	9	1(.10)	0	1	10	.642
	1116	2(.20)	3(.30)	5	2(.20)	3(.30)	5	10	.001
W.D.	792	5(.50)	4(.40)	9	1(.10)	0	1	10	.608
	900	15(.50)	12(.40)	27	3(.10)	0	3	30	.608
	1008	12(.40)	13(.43)	25	2(.07)	3(.10)	5	30	.346
	1116	6(.20)	11(.37)	17	4(.13)	9(.30)	13	30	.021
C.S.	792	5(.50)	5(.50)	10	0	0	0	10	1.00
	1008	15(.50)	8(.27)	23	6(.20)	1(.03)	7	30	.346
	1116	9(.45)	8(.40)	17	1(.05)	2(.10)	3	20	.412
	1224	9(.45)	5(.25)	14	4(.20)	2(.10)	6	20	.127

TABLE IV (Cont'd)

B. Average Responce Latencies (Seconds)

Observer	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Correct Responses: Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Wrong Responses: Total Wrong	Total	M.
C.H.	579	3.3	15.8	--			--	--	--
	792	12.1	31.2	--	28.9	18.0	--	--	--
	900	16.0	26.5	--	14.1	22.8	--	--	--
	1008	9.6	29.2	--	33.6		--	--	--
	1116	18.0	22.3	--	11.8	30.4	--	--	--
W.D.	792	21.0	30.6	--	18.6		--	--	--
	900	25.3	47.0	--	49.1		--	--	--
	1008	21.4	45.6	--	24.2	35.9	--	--	--
	1116	40.5	50.1	--	40.7	39.7	--	--	--
C.S.	792	26.8	31.2	--			--	--	--
	1008	37.2	57.8	--	70.5	30.4	--	--	--
	1116	28.4	59.0	--	40.0	36.2	--	--	--
	1224	27.6	30.0	--	36.0	42.3	--	--	--

TABLE V

Results for Anti-Tank Gun and Crew, Observed on Uniform Terrain Under Moonlight Illumination

A. Response Frequencies

		Correct Responses			Wrong Responses				
Observer	Distance Observer to Target (Yds)	"Yes" Target Present	"No" Target Absent	Total Correct	"Yes" Target Absent	"No" Target Present	Total Wrong	Total	M.
W.D.	351	15(.50)	15(.50)	30	0	0	0	30	1.00
	414	4(.40)	5(.50)	9	0	1(.10)	1	10	.608
	468	12(.40)	14(.47)	26	1(.03)	3(.10)	4	30	.469
	540	9(.30)	13(.43)	22	2(.07)	6(.20)	8	30	.177
	612	10(.33)	9(.30)	19	6(.20)	5(.17)	11	30	.050
	684	9(.45)	6(.30)	15	4(.20)	1(.05)	5	20	.220
C.S.	351	5(.50)	5(.50)	10	0	0	0	10	1.00
	414	11(.38)	8(.28)	19	6(.22)	4(.12)	10	29	.057
	468	12(.40)	10(.33)	22	5(.17)	3(.10)	8	30	.170
C.H.	351	20(.40)	20(.40)	40	5(.10)	5(.10)	10	50	.290
	414	13(.43)	13(.43)	26	2(.07)	2(.07)	4	30	.416
	468	13(.43)	13(.43)	26	2(.07)	2(.07)	4	30	.416
	540	9(.30)	9(.30)	18	6(.20)	6(.20)	12	30	.037

TABLE V (Cont'd)

B. Average Response Latencies (Seconds)

Observer	Distance Observer to Target (Yds)	Correct Responses "Yes" Target Present	Correct Responses "No" Target Absent	Total Correct	Wrong Responses "Yes" Target Absent	Wrong Responses "No" Target Present	Total Wrong	Total	M.
W.D.	351	14.4	21.2	--			--	--	--
	414	20.0	36.0	--		34.9	--	--	--
	468	27.1	40.9	--	77.4	37.9	--	--	--
	540	22.1	43.8	--	35.1	46.1	--	--	--
	612	12.3	30.2	--	21.0	29.4	--	--	--
	684	14.7	34.4	--	27.8	11.3	--	--	--
C.S.	351	15.6	32.9	--			--	--	--
	414	21.7	29.4	--	36.3	27.6	--	--	--
	468	41.9	38.5	--	43.8	56.2	--	--	--
C.H.	351	10.6	26.2	--	10.5	21.8	--	--	--
	414	15.9	37.3	--	37.4	23.7	--	--	--
	468	17.3	31.3	--	25.4	41.6	--	--	--
	540	28.3	38.2	--	35.3	27.0	--	--	--

TABLE VI

Frequency of Response Results for Anti-Tank Gun and Crew Observed on Uniform Terrain Under Searchlight Illumination (Observer: C.H.)

Illumination	Distance Observer to Target (Yds)	Correct Responses "Yes" Target Present	Correct Responses "No" Target Absent	Total Correct	Wrong Responses "Yes" Target Absent	Wrong Responses "No" Target Present	Total Wrong	Total	M.
SL 75yds R 8sec	1200	9(.45)	10(.50)	19	0	1(.05)	1	20	.72
SL 75yds R 4sec	1200	10(.50)	10(.50)	20	0	0	0	20	1.00
SL 75yds R 2sec	1200	8(.40)	10(.50)	18	0	2(.10)	2	20	.61
SL 75yds R 1sec	1200	6(.30)	10(.50)	16	0	4(.20)	4	20	.40

TABLE VII

Results for M-48 Tank on Non-uniform Terrain Observed Under Moonlight Illumination (Midfield Position)

A. Response Frequencies

Observer	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Total Wrong	Total	M.
C.H.	477	10(.50)	10(.50)	20	0	0	0	20	1.00
	594	12(.40)	15(.50)	27	0	3(.10)	3	30	.608
	666	9(.30)	13(.43)	22	2(.07)	6(.20)	8	30	.240
	810	5(.25)	6(.30)	11	4(.20)	5(.25)	9	20	.014

B. Average Response Latencies (Seconds)

Observer	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Total Wrong	Total	M.
C.H.	477	5.6	18.0	--			--	--	--
	594	15.0	24.0	--		22.8	--	--	--
	666	11.0	22.8	--	14.3	24.6	--	--	--
	810	28.8	30.0	--	15.9	25.8	--	--	--

TABLE VIII

Frequency of Response Results for M-48 Tank on Non-uniform Terrain Under Searchlight Illumination (Upper Field Position)

A. Observer C.H.

Simulated Illumination	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Correct Responses: Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Wrong Responses: Total Wrong	Total	M.
SL-C 1sec	1008	5(.50)	5(.50)	10	0	0	0	10	1.00
SL-75yds R 1sec		5(.50)	5(.50)	10	0	0	0	10	1.00
1sec F 2sec T		5(.50)	5(.50)	10	0	0	0	10	1.00
SL-C 2sec	1512	7(.35)	10(.50)	17	0	3(.15)	3	20	.492
SL-C 8sec		9(.45)	9(.45)	18	1(.05)	1(.05)	2	20	.535
SL-75yds R 2sec		6(.30)	8(.40)	14	2(.10)	4(.20)	6	20	.127
SL-75yds R 4sec		6(.38)	10(.50)	16	0	4(.20)	4	20	.396
SL-75yds R 8sec		7(.35)	10(.50)	17	0	3(.15)	3	20	.492
SL-75yds R 15sec		9(.45)	9(.45)	18	1(.05)	1(.05)	2	20	.535
1sec F 4sec T		10(.50)	10(.50)	20	0	0	0	20	1.00
1sec F 2sec T		23(.38)	30(.50)	53	0	7(.12)	7	60	.562
1sec F 15sec T		6(.30)	10(.50)	16	0	4(.20)	4	20	.396

B. Observer C.S.

Simulated Illumination	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Correct Responses: Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Wrong Responses: Total Wrong	Total	M.
SL-75yds R 1sec	1512	6(.30)	10(.50)	16	0	4(.20)	4	20	.396
SL-75yds R 2sec		10(.50)	10(.50)	20	0	0	0	20	1.00
1sec F 2sec T		15(.38)	18(.45)	33	2(.05)	5(.12)	7	40	.359

TABLE IX

Frequency of Response Results for M-48 Tank Observed on Non-uniform Terrain Under Searchlight Illumination (Tree Position) Observer C.H.

Simulated Illumination	Distance Observer to Target (Yds)	Correct Responses "Yes" Target Present	Correct Responses "No" Target Absent	Total Correct	Wrong Responses "Yes" Target Absent	Wrong Responses "No" Target Present	Total Wrong	Total	M.
SL-C 4sec	1008	9(.45)	10(.50)	19	0	1(.05)	1	20	.758
SL-C 4sec	1242	13(.43)	13(.43)	26	2(.07)	2(.07)	4	30	.416
SL-C 4sec	1350	7(.35)	8(.40)	15	2(.10)	3(.15)	5	20	.193
SL-C 8sec		7(.35)	8(.40)	15	2(.10)	3(.15)	5	20	.193
SL 37yds R 4sec		7(.35)	10(.50)	17	0	3(.15)	3	20	.493
SL 37yds R 8sec		5(.25)	5(.25)	10	5(.25)	5(.25)	10	20	.011
SL 75yds R 1sec		12(.40)	14(.47)	26	1(.03)	3(.10)	4	30	.469
SL-75yds R 8sec		15(.37)	14(.35)	29	6(.15)	5(.13)	11	40	.157
SL-150yds R 4sec		7(.35)	8(.40)	15	2(.10)	3(.15)	5	20	.193
1sec F 4sec T		6(.30)	9(.45)	15	1(.05)	4(.20)	5	20	.220
SL-75yds R 2sec	1512	6(.30)	5(.25)	11	5(.25)	4(.20)	9	20	.014
SL-75yds R 4sec		6(.30)	5(.25)	11	5(.25)	4(.20)	9	20	.014
SL-75yds R 8sec		7(.35)	5(.25)	12	5(.25)	3(.15)	8	20	.027
SL-75yds R 15sec		4(.20)	3(.15)	7	7(.35)	6(.30)	13	20	.061

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TABLE X

Frequency of Response Results for M-59 APC, Observed on Non-uniform Terrain Under Searchlight Illumination (Upper Field Position)

A. Observer C.H.

Simulated Illumination	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Total Wrong	Total	M.
SL-75yds R 2sec	1512	7(.35)	9(.45)	16	1(.05)	3(.15)	4	20	.290
SL-75yds R 4sec	1512	6(.30)	9(.45)	15	1(.05)	4(.20)	5	20	.220
SL-75yds R 15sec	1512	9(.45)	10(.50)	19	0	1(.05)	1	20	.758
1sec F 2sec T	1512	4(.20)	9(.45)	13	1(.05)	6(.30)	7	20	.094
1sec F 4sec T	1512	7(.35)	10(.50)	17	0	3(.15)	3	20	.492
2sec F 4sec T	1512	7(.35)	10(.50)	17	0	3(.15)	3	20	.492

B. Observer C.S.

Simulated Illumination	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Total Wrong	Total	M.
SL-75yds R 1sec	1512	5(.33)	4(.27)	9	3(.20)	3(.20)	6	15	.034
SL-75yds R 2sec	1512	9(.45)	6(.30)	15	4(.20)	1(.05)	5	20	.220
SL-75yds R 4sec	1512	11(.37)	12(.40)	23	3(.10)	4(.13)	7	30	.226
1sec F 2sec T	1512	6(.30)	7(.35)	13	3(.15)	4(.20)	7	20	.067

TABLE XI

Frequency of Response Results for M-59 APC, Observed on Non-uniform Terrain Under Searchlight Illumination (Tree Position)

Simulated Illumination	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Total Wrong	Total	M.
SL-C 4sec	1008	6(.30)	8(.40)	14	2(.10)	4(.20)	6	20	.127
SL-C 4sec	1100	7(.35)	8(.40)	15	2(.10)	3(.15)	5	20	.193
SL-75yds R 4sec	1100	10(.50)	10(.50)	20	0	0	0	20	1.00
SL-C 4sec	1175	10(.25)	13(.33)	23	7(.27)	10(.25)	17	40	.024
SL 37 R 4sec	1175	11(.27)	11(.27)	22	9(.23)	9(.23)	18	40	.011
SL 54 R 4sec	1175	13(.33)	13(.33)	26	7(.17)	7(.17)	14	40	.064
SL 75 R 4sec	1175	18(.30)	23(.38)	41	7(.12)	12(.20)	19	60	.100
SL 150 R 4sec	1175	18(.45)	19(.47)	37	1(.03)	2(.05)	3	40	.642
SL-C 8sec	1175	5(.25)	6(.30)	11	4(.20)	5(.25)	9	20	.014
SL 37 R 8sec	1175	5(.25)	6(.30)	11	4(.20)	5(.25)	9	20	.014
SL 75 R 8sec	1175	9(.45)	10(.50)	19	0	1(.05)	1	20	.758
1sec F 4sec T	1175	18(.45)	16(.40)	34	4(.10)	2(.05)	6	40	.402
1sec F 8sec T	1175	8(.40)	7(.35)	15	3(.15)	2(.10)	5	20	.193
2sec F 4sec T	1175	18(.45)	20(.50)	38	0	2(.05)	2	40	.758
2sec F 8sec T	1175	10(.50)	10(.50)	20	0	0	0	20	1.00
SL-C 4sec	1242	4(.20)	3(.15)	7	7(.35)	6(.30)	13	20	.067
SL 37 R 4sec	1242	10(.25)	9(.23)	19	11(.27)	10(.25)	21	40	.004
SL 75 R 4sec	1242	11(.27)	13(.33)	24	7(.17)	9(.23)	16	40	.031
SL-C 8sec	1242	4(.20)	2(.10)	6	8(.40)	6(.30)	14	20	.127
SL 75 R 4sec	1350	6(.20)	10(.33)	16	5(.17)	9(.30)	14	30	.007
SL 150 R 4sec	1350	1(.10)	4(.40)	5	1(.10)	4(.40)	5	10	.007
SL 75 R 8sec	1350	5(.25)	8(.40)	13	2(.10)	5(.25)	7	20	.084
SL 150 R 8sec	1350	2(.20)	3(.30)	5	2(.20)	3(.30)	5	10	.001
2sec F 4sec T	1350	10(.25)	12(.30)	22	8(.20)	10(.25)	18	40	.014
2sec F 8sec T	1350	7(.35)	7(.35)	14	3(.15)	3(.15)	6	20	.117

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TABLE XII

Frequency of Response Results for Anti-Tank Gun and Crew, Observed on Non-uniform Terrain Under Searchlight Illumination (Upper Field Position) Observer C.H.

Simulated Illumination	Distance Observer to Target (Yds)	Correct Responses: "Yes" Target Present	Correct Responses: "No" Target Absent	Correct Responses: Total Correct	Wrong Responses: "Yes" Target Absent	Wrong Responses: "No" Target Present	Wrong Responses: Total Wrong	Total	M.
SL 75 R 1sec	910	8(.40)	6(.30)	14	4(.20)	2(.10)	6	20	.127
SL 75 R 2sec	910	9(.45)	10(.50)	19	0	1(.05)	1	20	.758
SL-C 4sec	910	3(.15)	9(.45)	12	1(.05)	7(.35)	8	20	.007
SL 75yds R 4sec	910	9(.45)	10(.50)	19	0	1(.05)	1	20	.758
1 sec F 4sec T	910	10(.50)	10(.50)	20	0	0	0	20	1.00
1 sec F 2sec T	910	7(.35)	9(.45)	16	1(.05)	[illegible](.15)	4	20	.323
SL 75yds R 8sec	1116	8(.27)	11(.37)	19	4(.13)	[illegible](.23)	11	30	.05[illegible]

APPENDIX A

In order to relate the model simulator studies better with field test data, documentation was obtained for the inherent luminances of targets and their backgrounds as used in the field tests. This documentation, carried out by Mr. Pritchard of these Laboratories, was obtained using the photoelectric telephotometer to measure directly the luminances of targets and backgrounds under the field conditions employed.

Two points of comparison may be made from this documentation. First, the degree of correspondence for levels of illumination established for the model may be compared with that occurring in the field. Secondly, comparison may be made of relative contrasts for selected portions of the targets and backgrounds.

With regard to the first comparison, above, only two sets of data from the field tests provide the desired information. This was because at the time documentation was obtained in this regard, following the actual tests, a limited number of target conditions had been studied when the last remaining 2500 watt searchlight lamp burned out. The remaining documentary data were obtained using a 2000 watt lamp and although the contrast information is of use in comparison with model simulator conditions, no absolute comparisons are possible.

The sets of documentary data obtained when the 2500 watt lamp was available provide the comparisons of inherent luminances appearing below.

A. Tank, 1000 yards, observer Post 6 (separated from searchlight approximately 140 yards)
(luminance in foot lamberts)

Area Measured	Field Study	Model Study (SL75 R)
L Track	.0090	.0154
Center	.0047	.0088
R Track	.0104	.0183
Turret	.0058	.0150
L Bkgnd	.0106	.0170
Tank Shadow	.0029	.0015
R Bkgnd	.0104	.0148
Top Bkgnd	.0022	.0150
Bottom Bkgnd	.0019	.0154

B. Tank, 1000 yards, observer Post 1 (adjacent to searchlight)

Area Measured	Field Study	Model Study (SL-C)
L Track	.0780	.0162
Center	.0685	.0134
R Track	.0744	.0244
Turret	.0658	.0146
L Bkgnd	.0780	.0185
R Bkgnd	.0780	.0150
Top Bkgnd	.0560	.0150
Bottom Bkgnd	.0780	.0166

Examination of the foregoing information shows, first, that fairly close correspondence results when measures were taken with the searchlight displaced at its maximum distance from the observer post. The luminance values shown for the model target are approximately twice corresponding measures taken in the field. It is possible that greater accuracy could be achieved in the model study in arranging the searchlight beam to center exactly on the target and illuminate it with peak candle power. This possibility, at least, is consistent with the difference noted.

When the measures were taken with the searchlight very little displaced from the observer post, shown in the second set of data above, the luminance values obtained for the field study are about a half log unit greater in each instance compared with corresponding measures for the model simulator. This result is indicative of the effect of light back-scatter at positions adjacent to a searchlight. The telephotometer, in the field, received a considerable amount of back-scattered light which increased the apparent luminance for selected target areas, and, as well, reduced contrasts between these areas. Due to the absence of scaled atmosphere in the model studies, these effects are not seen. Although the luminance values for target areas are higher, they are very little higher for the SL-C condition compared with the SL 75 R condition.

The field data obtained using the 2000 watt lamp may be used to evaluate the range of effect of searchlight back-scatter on contrasts. For this purpose, the luminance values obtained at 500 yards for the front center of the APC and also the sloping portion of the front are listed below as measured at the first five observer posts. Post 1 is adjacent to the searchlight. Approximate separations for the other locations are shown in parentheses.

Obs. Post:	#1	#2(10yds)	#3(20yds)	#4(40yds)	#5(80yds)
Slope Front	.100	.023	.017	.013	.011
Center Front	.097	.023	.022	.018	.013
Ratio (contrast)	1.03	1.00	1.12	1.14	1.12

From the preceding analysis, it may be seen that the high increase in luminance for target areas due to searchlight back-scatter is essentially gone when one moves from Post 1, adjacent to the target, to Post 2, ten yards removed. The remaining values reflect some further change, but of a much smaller magnitude. The "contrasts" noted between the two selected target areas increase with greater separation of observer and searchlight, and cease to show back-scatter effects at Post 3, 20 yards from the searchlight. In the model studies, the searchlight displacement labeled SL-C would not have the realism of field conditions due to the absence of scaled atmosphere and resulting absence of back-scatter. However, if displacement of 10 or 20 yards is sufficient to obviate back-scatter effects, our other conditions should otherwise constitute adequate simulation.

To get a better idea of the correspondence for target and terrain contrasts between the model and field conditions, the following comparison may be made. The set of field data for the tank measured at observer Post 5 (80 yards displaced from searchlight) may be converted to relative values by determining the ratio of each area measured to the center area as a reference point. This leads to the values to be shown shortly. Similar treatment is given to measures on the model simulator for the tank at the equivalent distance for the similar displacement of the searchlight. These values are shown below for comparison with the first set.

Area Measured	Field Tank	Model Tank
L Track	1.55	1.66
Center	1.00	1.00
R Track	1.55	2.00
Turret	1.12	1.66
L Bkgnd	2.00	1.89
Tank Shadow	.78	.02
R Bkgnd	2.00	1.66
Top Bkgnd	.89	1.24
Bottom Bkgnd	1.55	1.66

It would appear that the internal contrasts for our tank target are a little greater than for the tank in the field. Also, contrast for the tank with the background at the top and bottom terrain areas is greater for the model. Terrain at the sides does not form as high a contrast. In the field, terrain ahead of the tank sloped away from the searchlight and the woods behind the tank, although in its projected background, were quite distant. Our terrain was simply more uniform in a relative sense.

The contrast of the tank shadow and adjacent parts of the terrain and target is much greater in the model situation than in the field. However, in the field the 2000 watt searchlight lamp provided less illumination on the target and, at the time of measurement, a full moon was illuminating the terrain also. The luminance of the shadow, in the field measurements was .002 foot lamberts which could be due to moonlight primarily and possible some space light present.

The field study data provide a basis for much more extensive comparisons than can be attempted here. With the exception noted, the correspondence between model and field conditions appears, in physical terms, reasonably close. In the text there are several points of comparison in terms of observer performance as well. An examination of all of these points of comparison is necessary to determine how much confidence can be given to the extension of the model simulator findings to field conditions.

APPENDIX B

The derivation of the equation for M shown in the text is quite straight forward. We begin with the statement of several terms and relationships as follows:

(1) $I(S)$ = initial degree of uncertainty in S
(2) $I(R)$ = degree of uncertainty in R
(3) $I(R,S)$ = degree of uncertainty in combined R and S
(4) $I_R(S)$ = degree of uncertainty in S given R

With (1) and (4) we have:

(5) $I(S) - I_R(S)$ = extent of reduction of $I(S)$ given knowledge of R (equivalent to <u>stimulus</u> <u>information</u> <u>gained</u> by knowing R)

Then, from standard works on information theory:

(6) $I(R) + I_R(S) = I(R,S)$

Adding $I(S)$ to each side of equation (6) and changing signs leads to:

(7) $I(S) - I_R(S) = I(R) + I(S) - I(R,S)$

Note that the left hand side of (7) is the defined term (5). Also, because in our experiments, on a given observation trial the stimulus was equally likely to be present or absent, we know that $I(S) = 1$ bit. Hence a solution for the right hand side of (7) evaluates $I(S) - I_R(S)$ and gives us the stimulus information gained by knowing R. To accomplish this, we substitute for $I(R)$ and $I(R,S)$ as follows, using response data to obtain the particular probabilities:

(8) $I(R) = -[P(Y) \log_2 P(Y) + P(N) \log_2 P(N)]$

and

(9) $I(R,S) = -[P(S,Y) \log_2 P(S,Y) + P(S,N) \log_2 P(S,N) + P(S',Y) \log_2 P(S',Y) + P(S',N) \log_2 P(S'N)$

substituting from (8) and (9) in (7), rewriting $I(S)$ as 1, and using the appropriate constant to convert from logarithms base 10 to base 2, we have:

(10) $I(S) - I_R(S) = 1 + 3.32\,[-P(Y) \log P(Y) - P(N) \log P(N) + P(S,Y) \log P(S,Y) + P(S,N) \log P(S,N) + P(S',Y) \log P(S',Y) + P(S',N) \log P(S',N)]$

Designating $I(S) - I_R(S)$ with the symbol M, as the measure of stimulus information gained by knowing R, we have the formula cited in the text.

The features of this relationship are easily shown. If an observer always responded "yes", we would of course gain no stimulus information. In terms of the above equation, $P(Y) = 1$ and $P(N) = 0$ which gives us:

$$M = 1 + 3.32 \, [-0-0 + 1/2 \log 1/2 + 0 + 1/2 \log 1/2 + 0] = 0$$

Also, if the observer is right (S, Y) and (S', N) as often as wrong (S', Y) and (S, N), $M = 0$. If he makes no wrong responses, maximum stimulus information is gained and $M = 1$. (This would be true if no right responses were made, also the system needs some external knowledge of accuracy in order to decode the responses!)

Since the measure M was derived to provide a basis for avoiding the ambiguous effects of criterion differences in the yes-no procedure used, it would be well to illustrate the relative freedom of this measure with an example. Consider two sets of data. The target has been presented 10 times during 20 observation trials. In the first, an observer has given the following responses:

	"Yes" Target Present	"No" Target Present	"Yes" Target Absent	"No" Target Absent
Frequency	10	0	5	5

A second observer gives these responses:

	"Yes" Target Present	"No" Target Present	"Yes" Target Absent	"No" Target Absent
Frequency	5	10	0	5

It may be noted that the first observer has responded "yes" 15 times even though the target was presented on 10 times during the 20 trials. The second observer, on the other hand, has been willing to respond "yes" far less frequently. The first has a high false positive rate; the second a low rate.

The proportions in each of these examples are treated first, by the conventional method. The detection proportions (from "yes", target present responses) is adjusted in terms of the proportions of false positive responses ("yes", target absent). Usually this is done by employing the following relationship:

$$P' = \frac{P-C}{1-C}$$

Where: P' = corrected detection proportion
P = raw detection proportion
C = proportion of false positives

In terms of the above equation, the first data set would have to be represented by a <u>corrected</u> detection proportion of 1.00. The second would yield the corrected detection proportion of .50.

If we analyse the same two sets of data for the stimulus information quantity, M, we would find that not different but the <u>same</u> values would result. For each data set M would be 0.31. Thus if, as is possible, the sets are from two different observers in the same situation, one is not providing more stimulus information than the other. It might be the case that the first observer is highly willing to give false positive responses whereas the second is highly unwilling to do so. The freedom of the data measure, developed in information terms, from effects of such criterion differences becomes fairly obvious.

It was not possible to analyse the information statistic in terms of sampling and bias. Since in a series of observations the target was presented on 50% of the trials, these question are probably not serious. In any event, our measure is precisely defined and appears to provide for less ambiguity in interpreting results.

Figure 1. The model simulator.

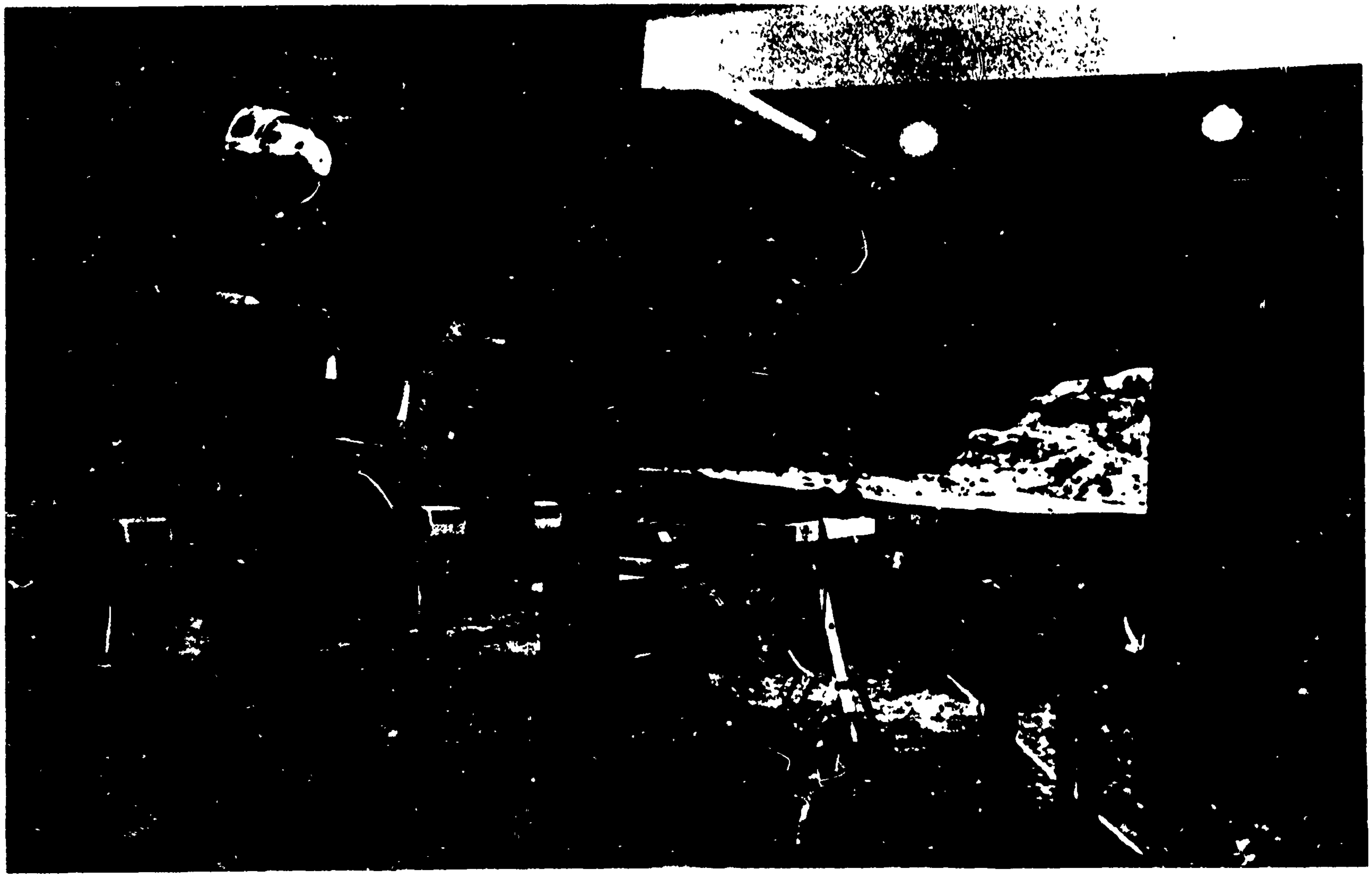

Figure 2. Experimental room and equipment.

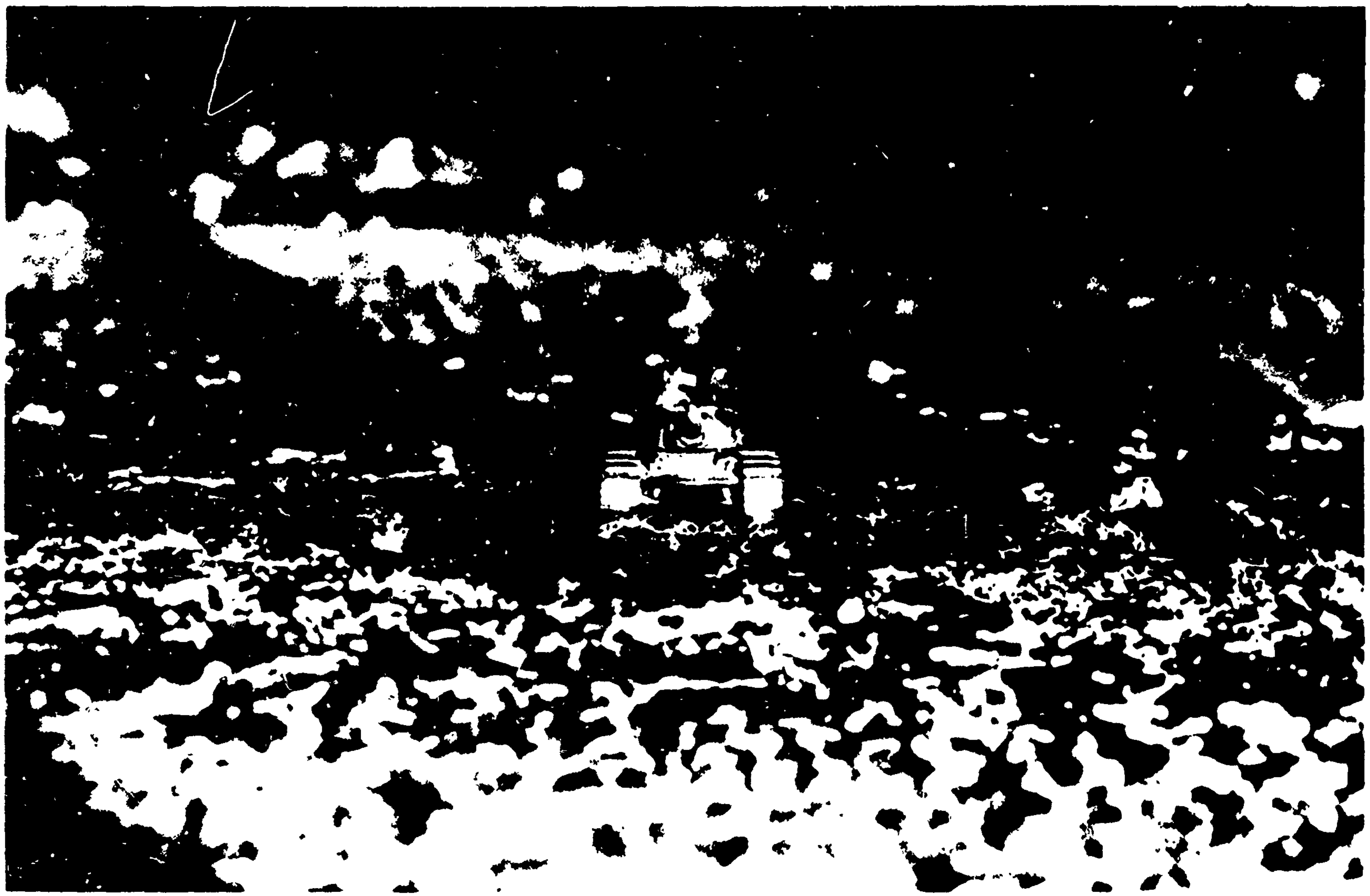

Figure 3. M-48 tank scale model.

Figure 4. M-59 APC scale model.

Figure 5. Anti-tank gun and crew scale model.

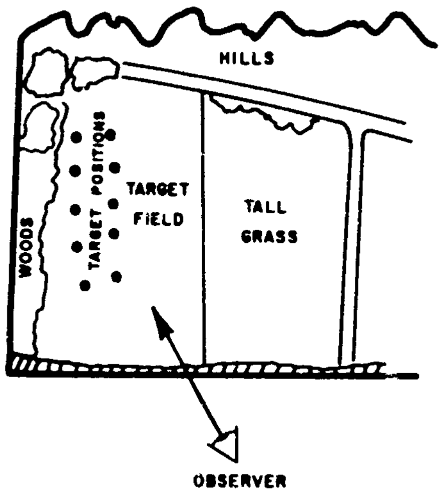

Figure 6. Map of original target positions during exploratory experiments.

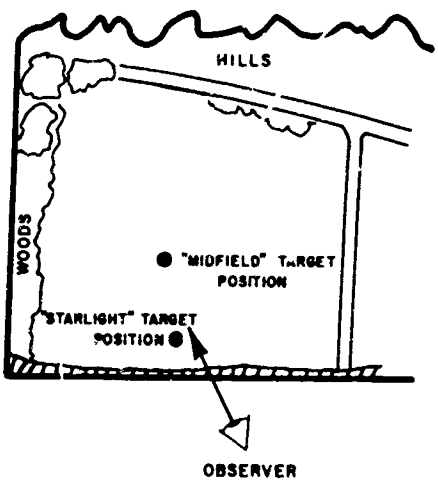

Figure 7. Map of final uniform target field and target positions.

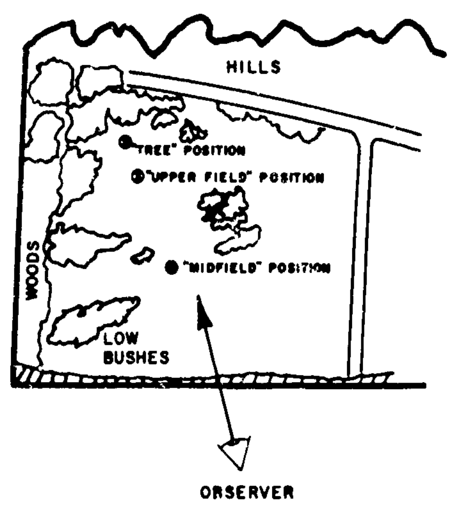

Figure 8. Map of non-uniform target field and target positions.

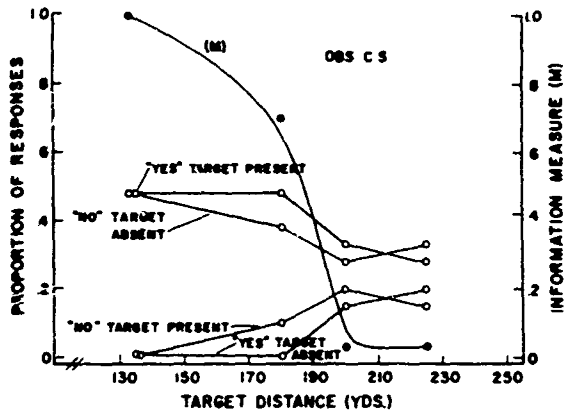

Figure 9. Results for M-48 tank, observed on uniform terrain under starlight illumination, showing relation between frequency of response data and information measure M.

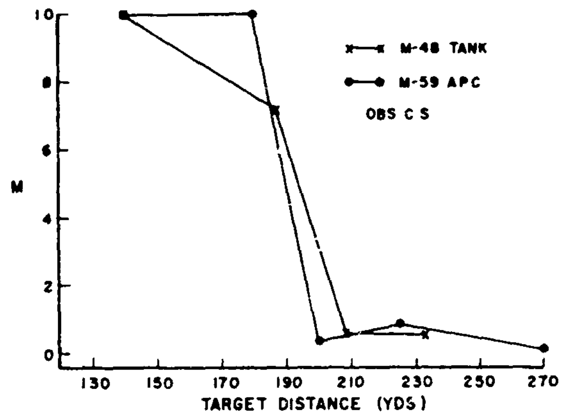

Figure 10. Results for M-48 tank and M-59 APC, observed on uniform terrain under starlight illumination.

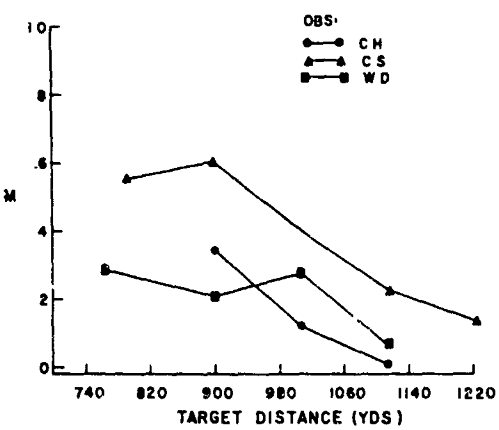

Figure 11. Results for M-48 tank, observed on uniform terrain under moonlight illumination.

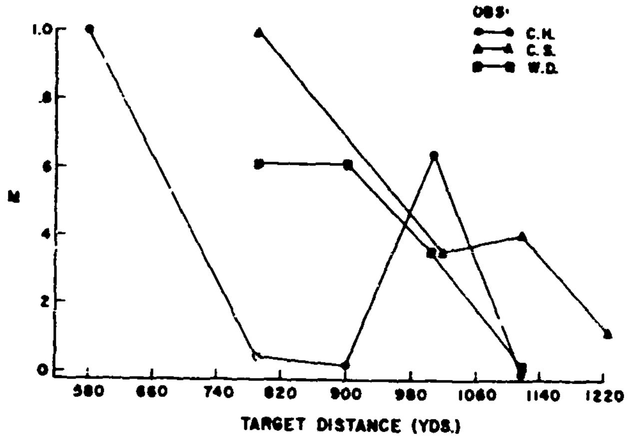

Figure 12. Results for M-59 APC, observed on uniform terrain under moonlight illumination.

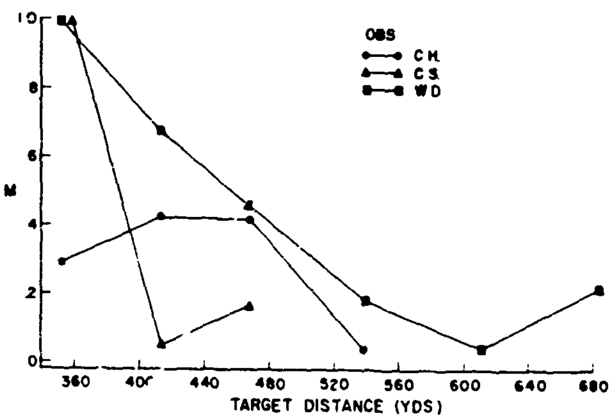

Figure 13. Results for anti-tank gun and crew, observed on uniform terrain under moonlight illumination.

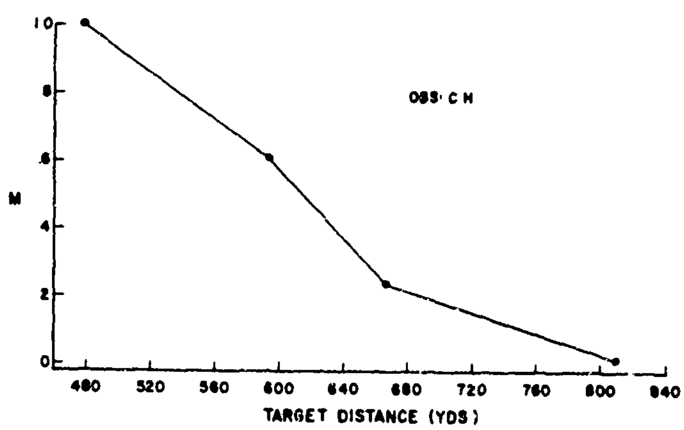

Figure 14. Results for M-48 tank, observed on non-uniform terrain in midfield position under moonlight illumination.

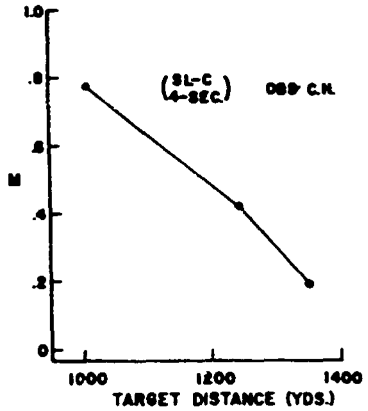

Figure 15. Results for M-48 tank, observed on non-uniform terrain in tree position under 4-sec searchlight illumination along observer's line of sight.

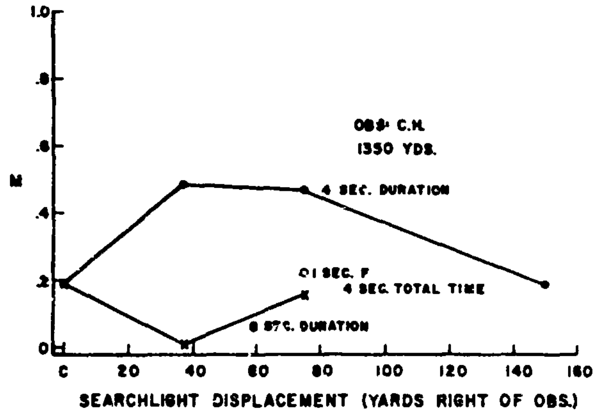

Figure 16. Results for M-48 tank, observed on non-uniform terrain in tree position illuminated by searchlight at differing displacements from observer.

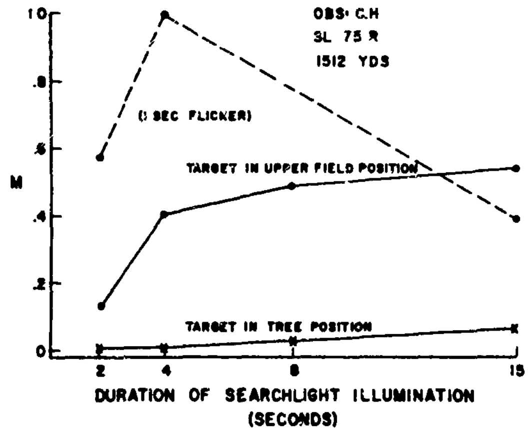

Figure 17. Results for M-48 tank, observed in different non-uniform terrain positions under differing durations of searchlight illumination.

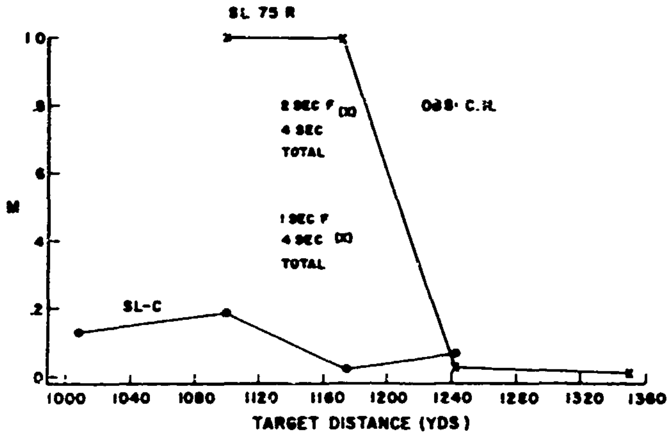

Figure 18. Results for M-59 APC, observed on non-uniform terrain in tree position under 4-sec searchlight illumination at differing displacements from observer.

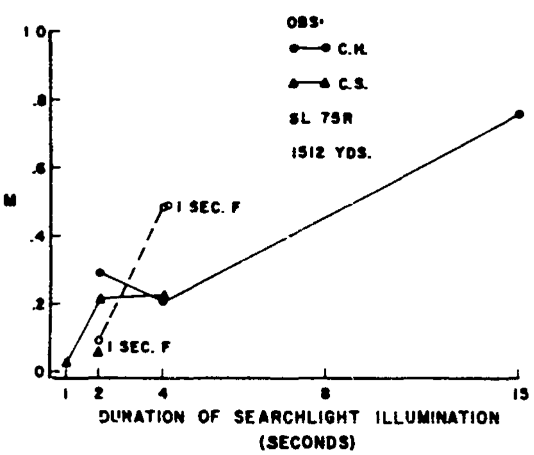

Figure 19. Results for M-59 APC, observed on non-uniform terrain in upper field position under differing durations of searchlight illumination.

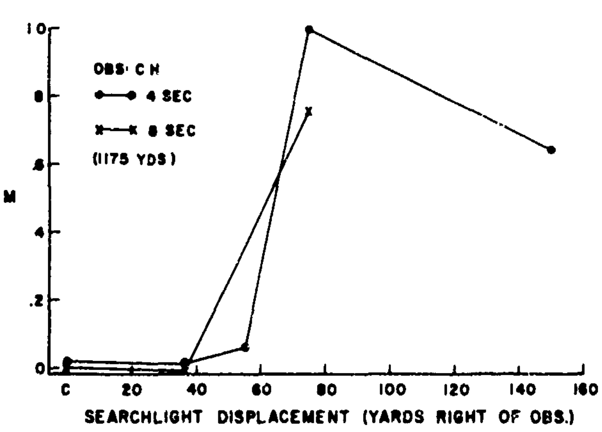

Figure 20. Results for M-59 APC, observed on non-uniform terrain in tree position illuminated by searchlight at differing displacements from observer.

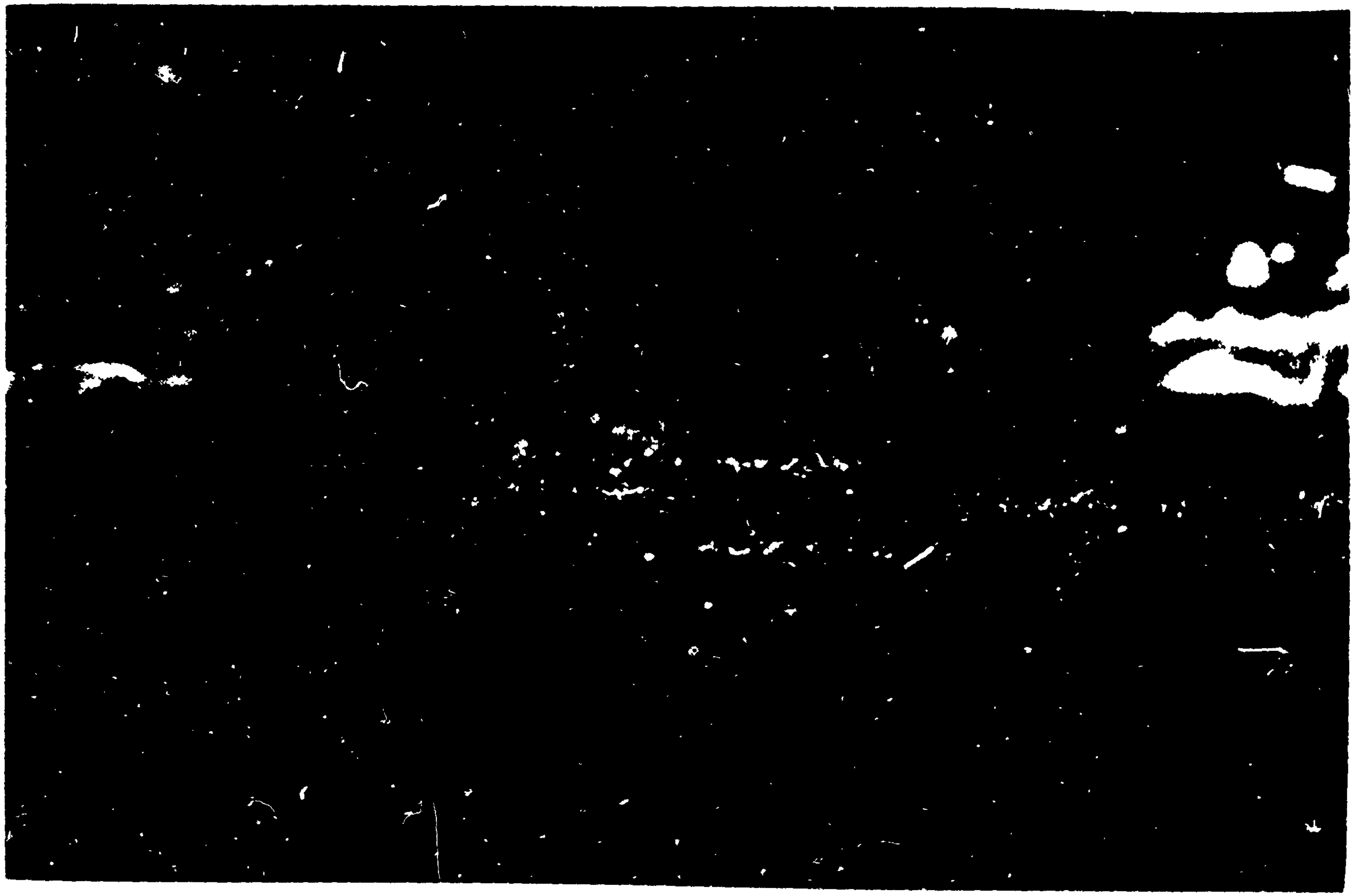

Figure 21. M-48 tank on uniform terrain (mid-field position) under moonlight illumination.

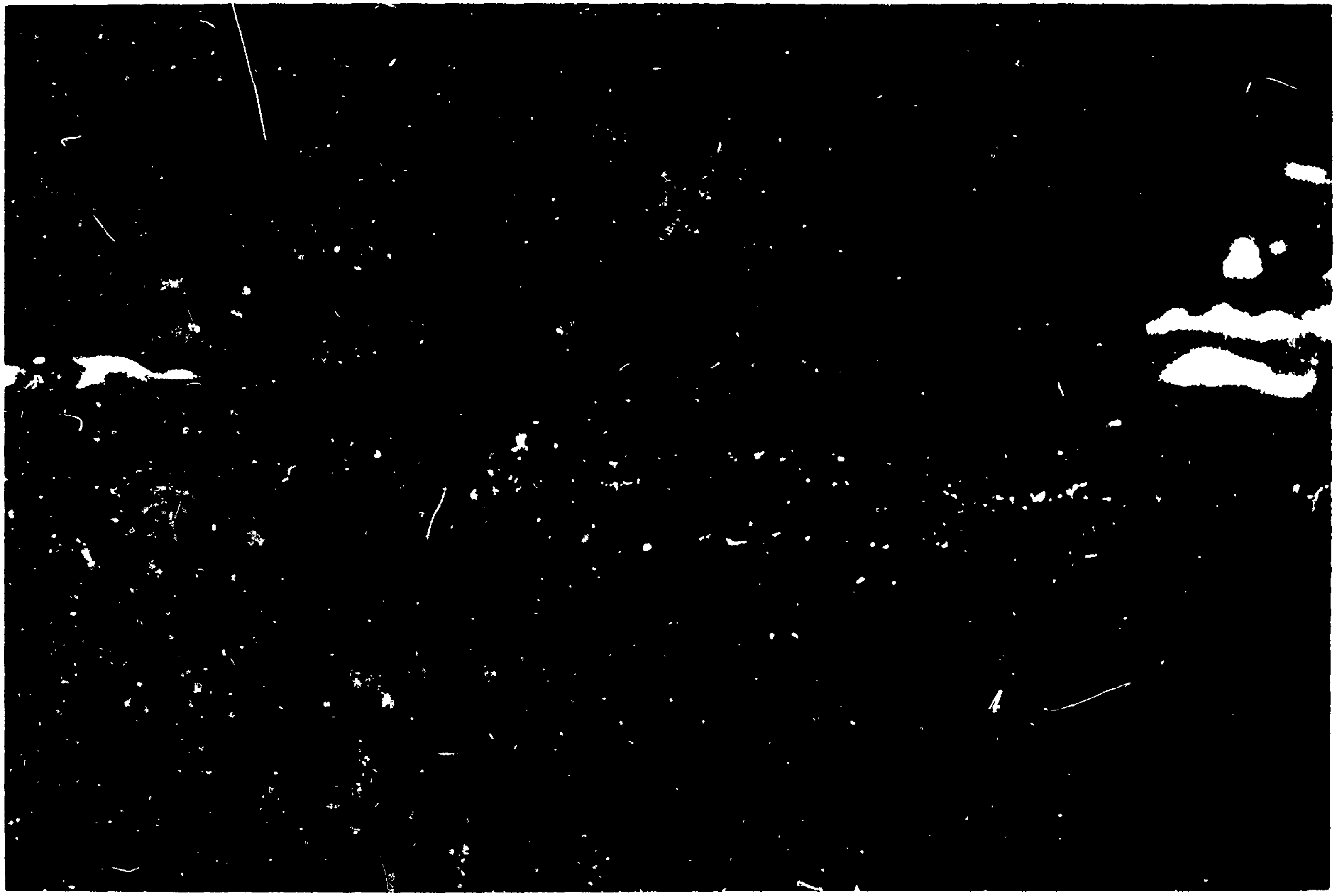

Figure 22. M-59 APC on uniform terrain (mid-field position) under moonlight illumination.

Figure 23. M-59 APC on uniform terrain (mid-field position) under illumination by searchlight 75 yards right of observer.

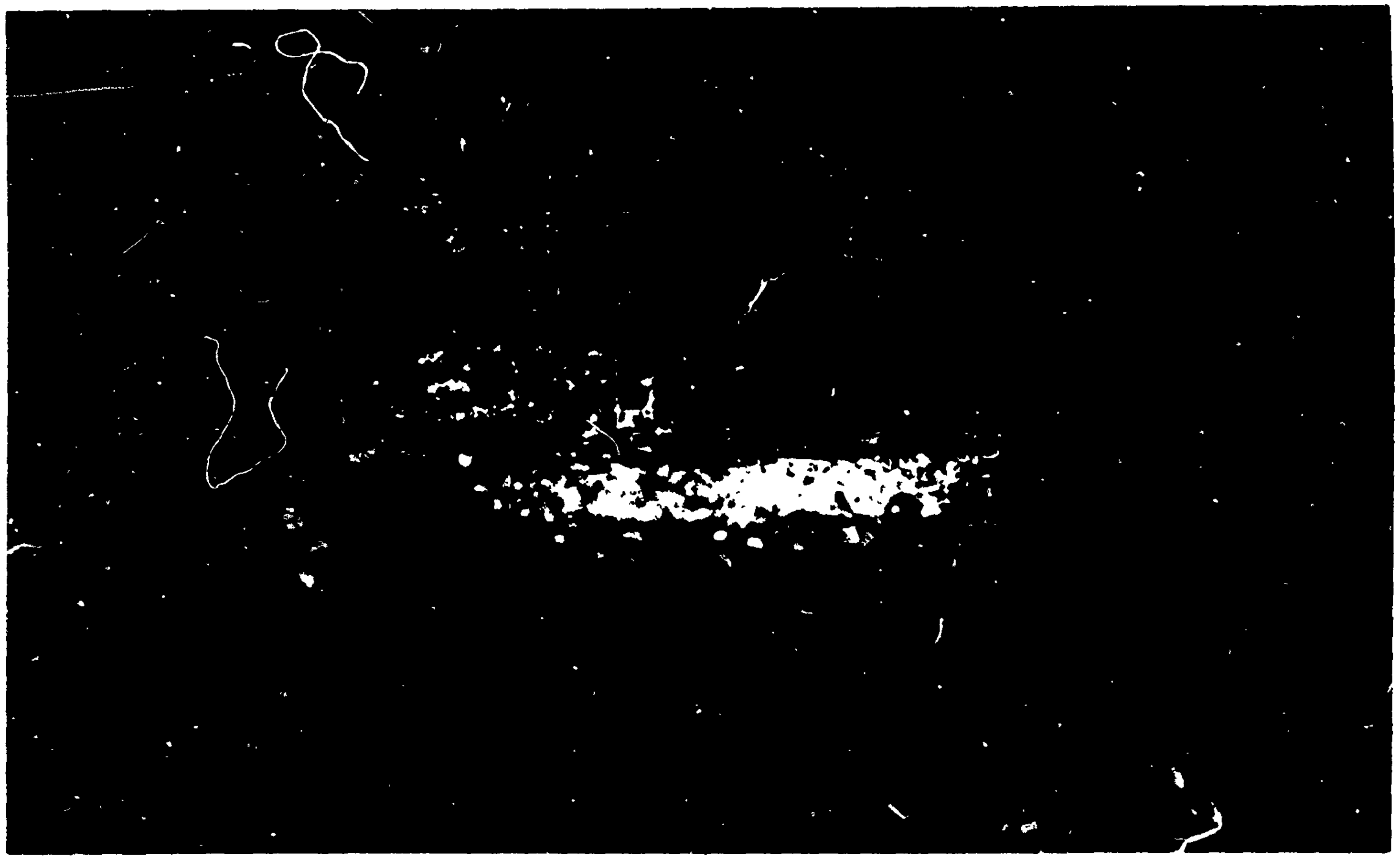

Figure 24. Anti-tank gun and crew on uniform terrain (mid-field position) under illumination by searchlight 75 yards right of observer.

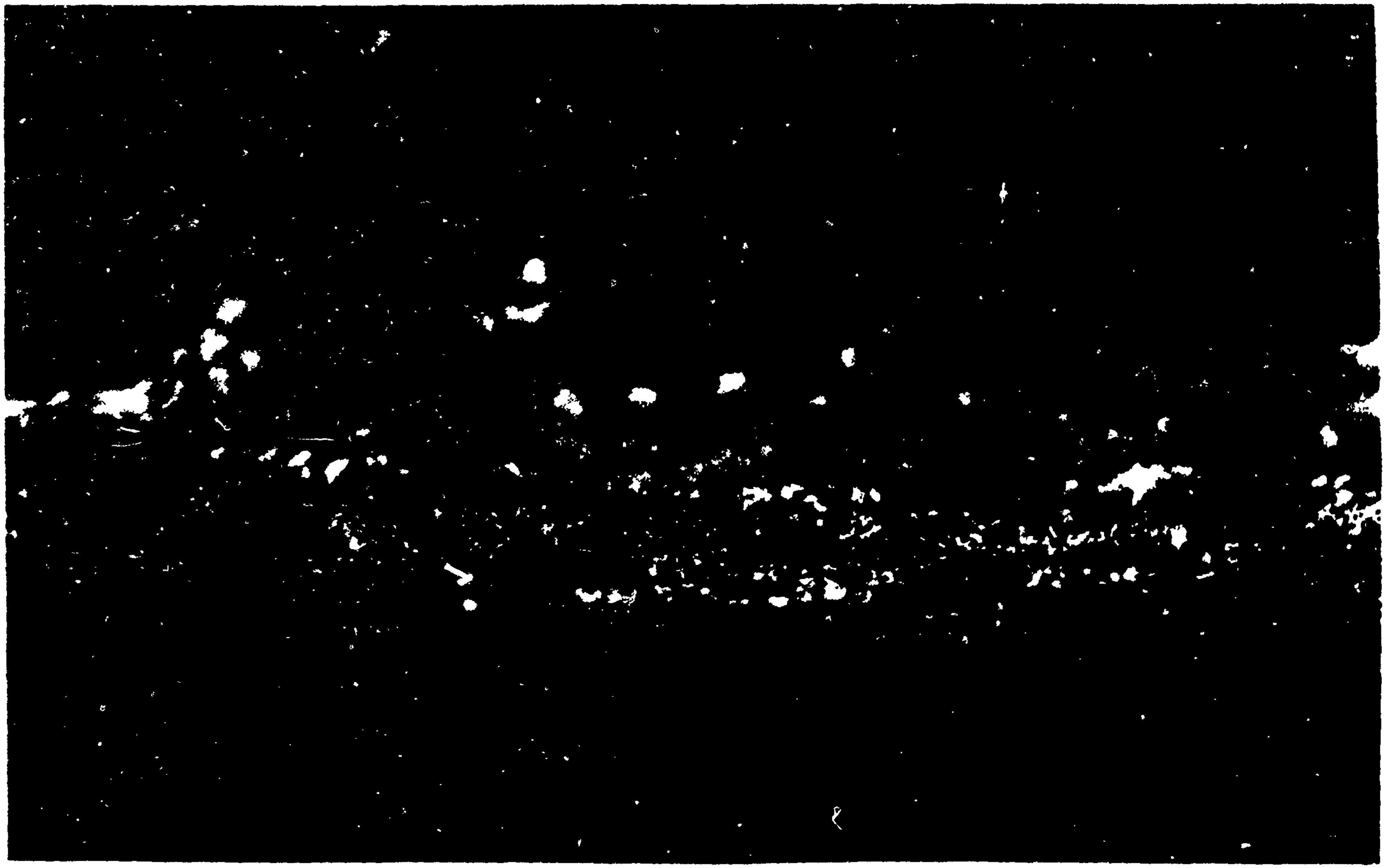

Figure 25. M-48 tank on non-uniform terrain (mid-field position) under moonlight illumination.

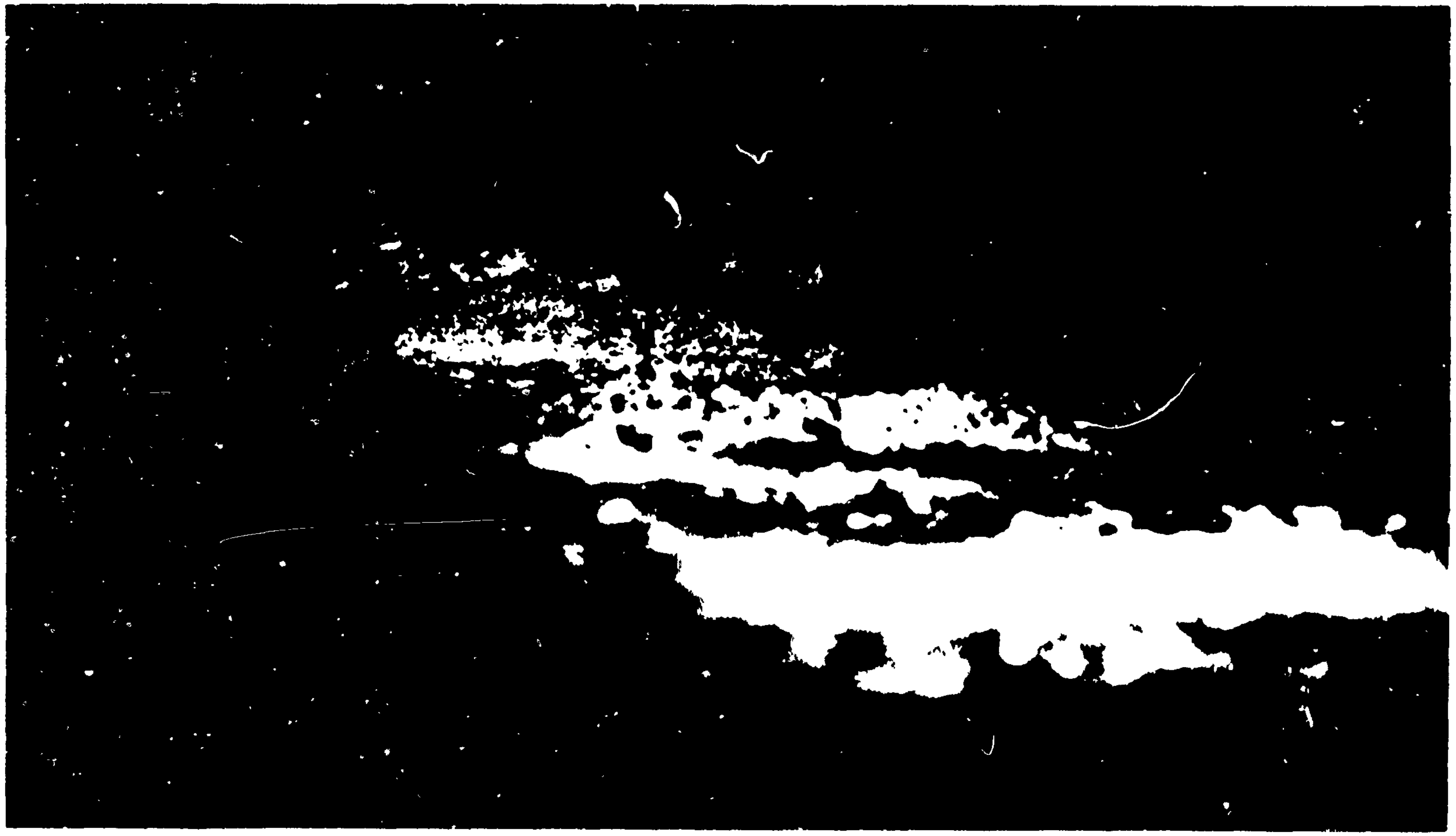

Figure 26. M-48 tank on non-uniform terrain (upper field position) illuminated by searchlight 75 yards right of observer.

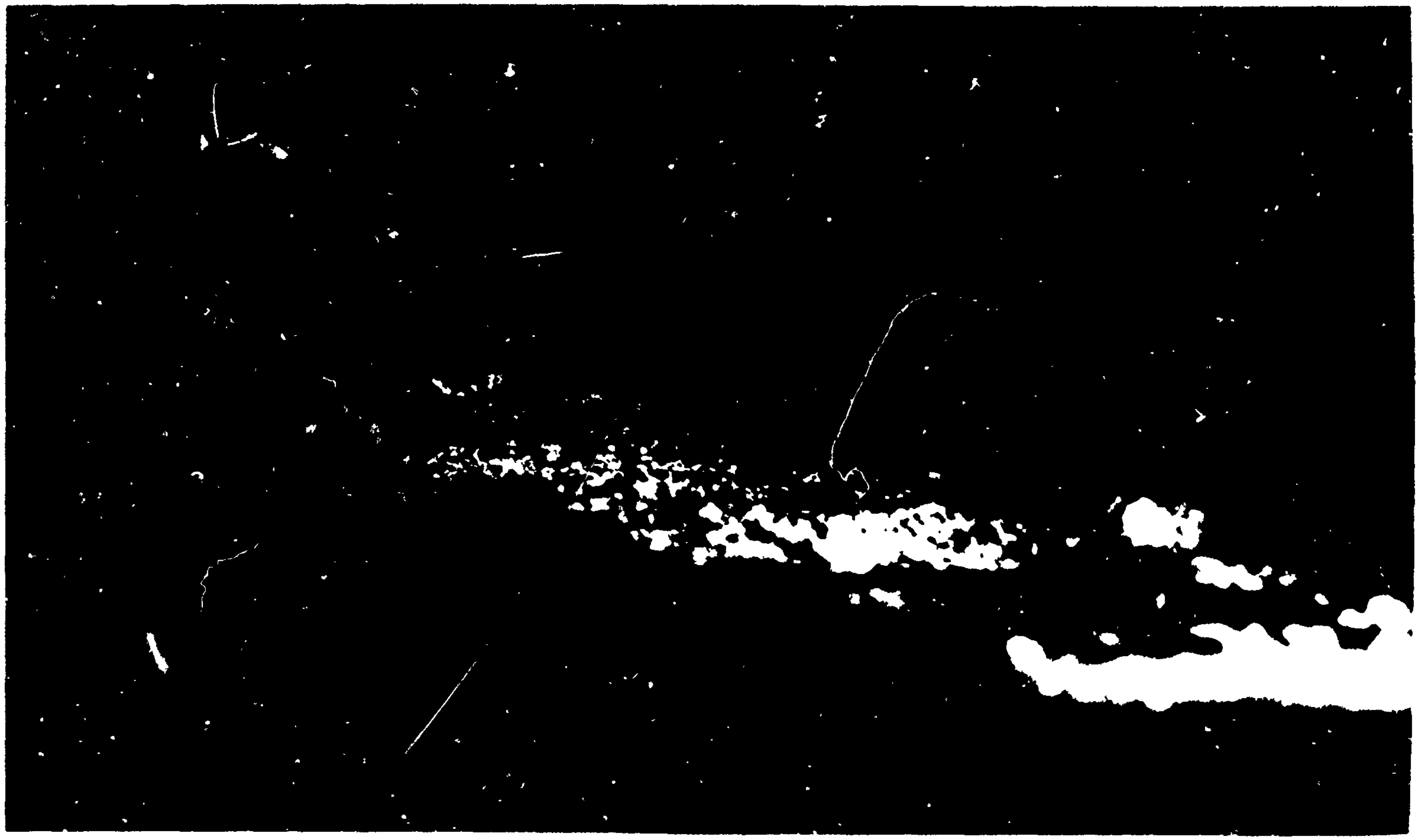

Figure 27. M-48 tank on non-uniform terrain (upper field position) illuminated by searchlight 150 yards right of observer.

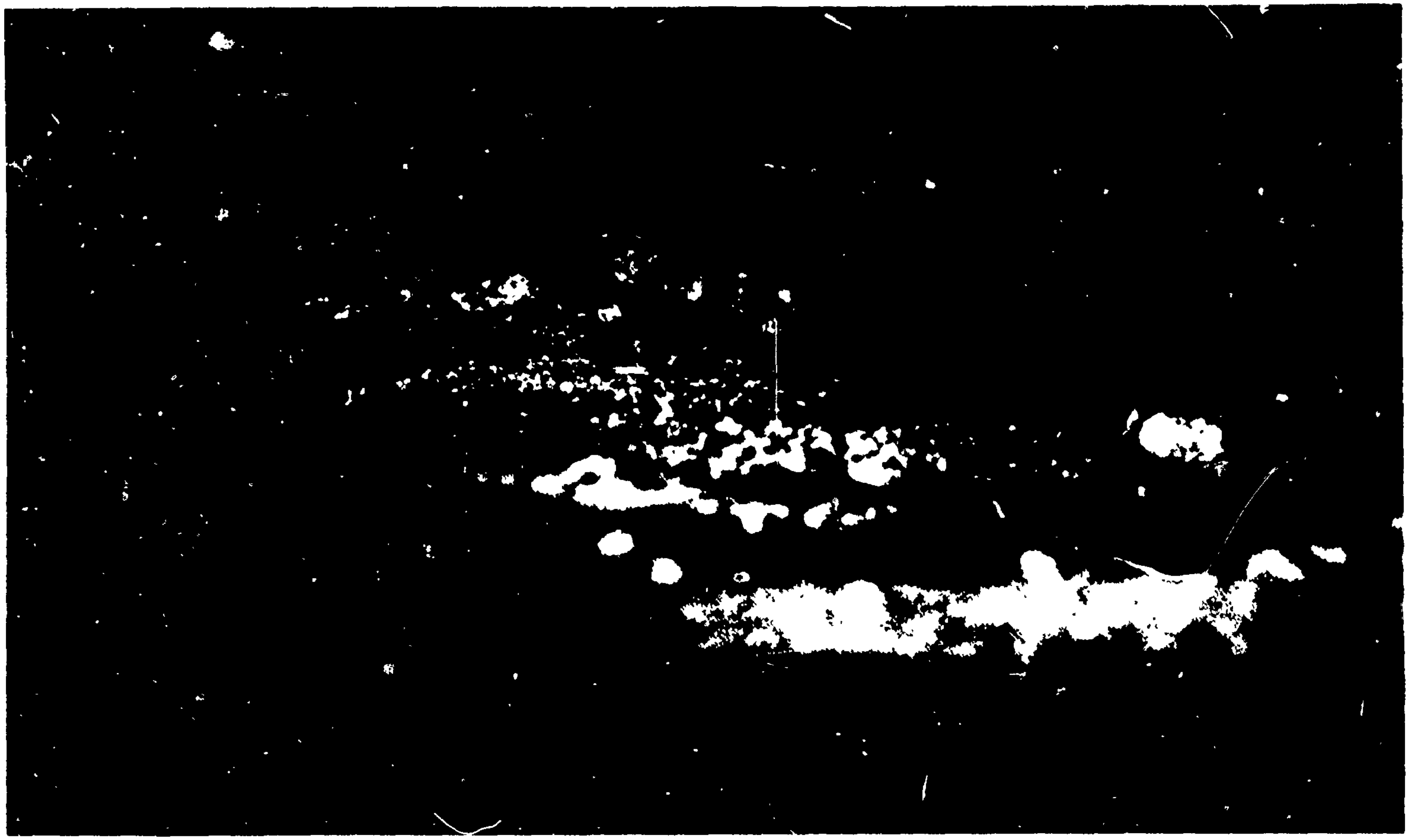

Figure 28. M-59 APC on non-uniform terrain (upper field position) illuminated by searchlight 75 yards right of observer.

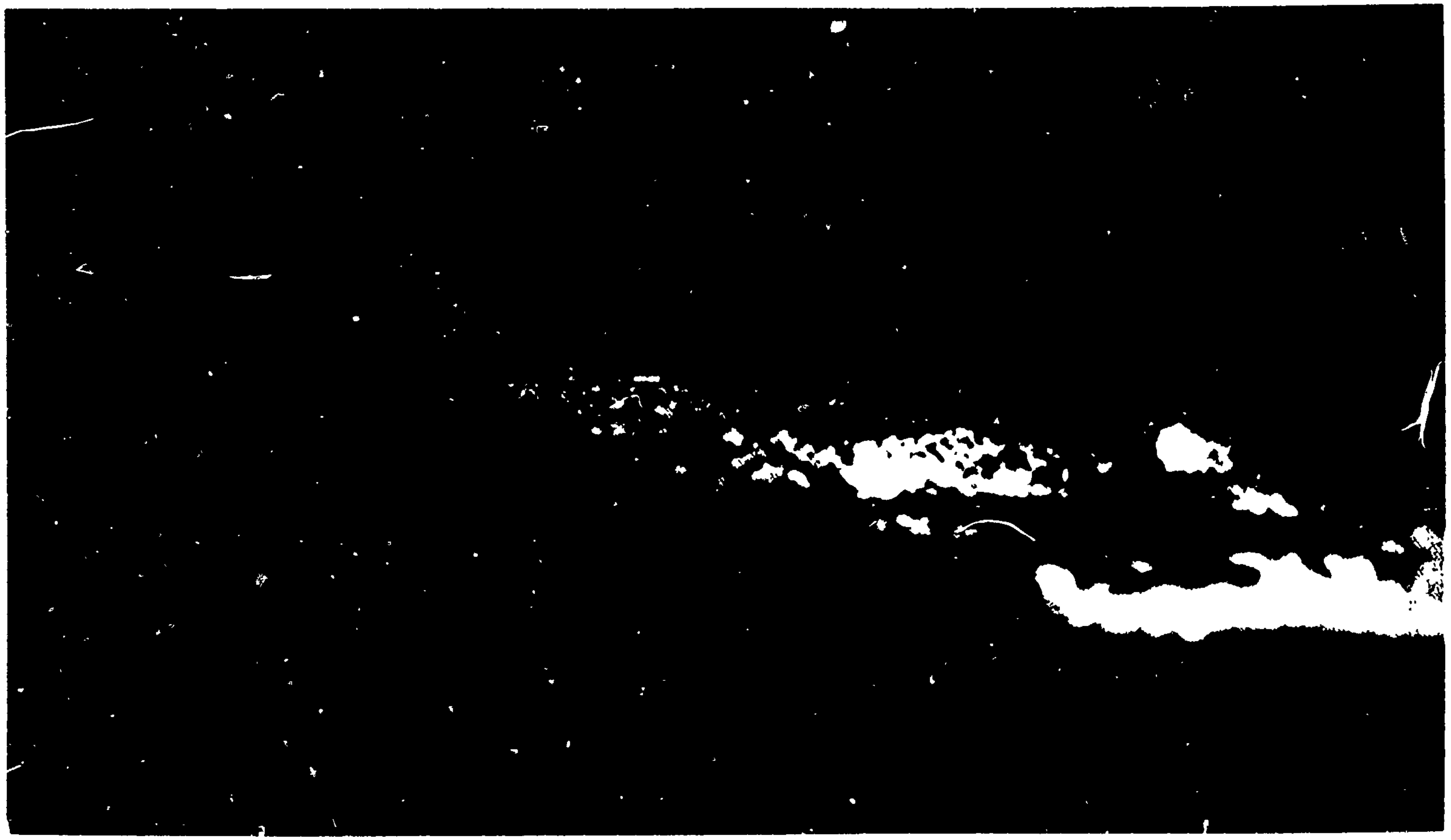

Figure 29. M-59 APC on non-uniform terrain (upper field position) illuminated by searchlight 150 yards right of observer.

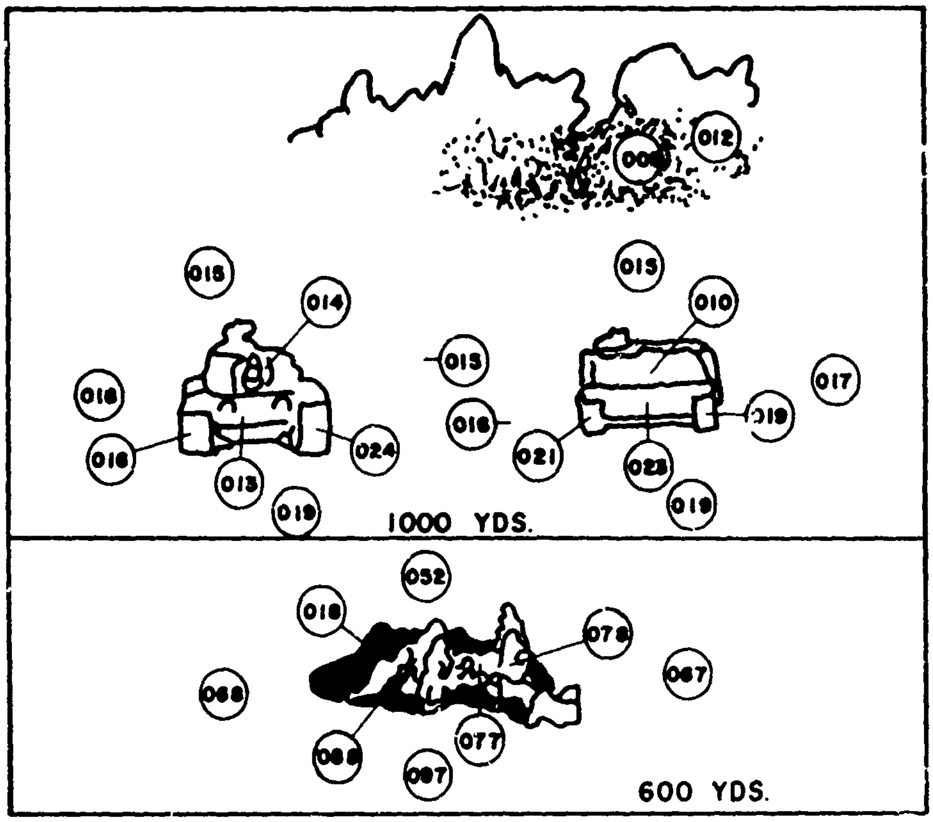

Figure 30. Target and terrain luminances for the three scale model targets when illuminated by searchlight along observer's line of sight.

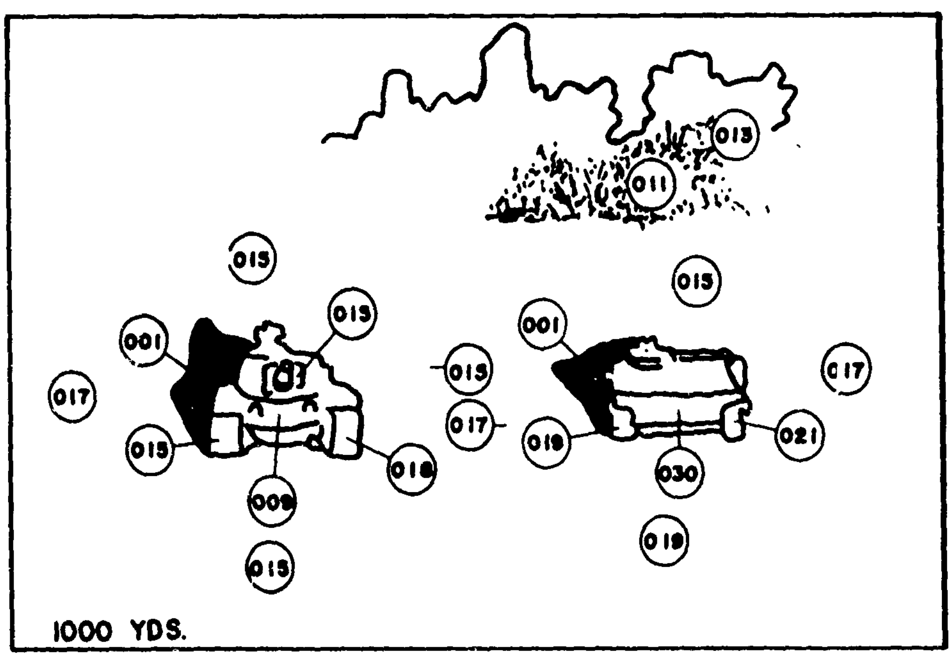

Figure 31. Target and terrain luminances for the scale model vehicle targets when illuminated by a searchlight 75 yards right of observer.

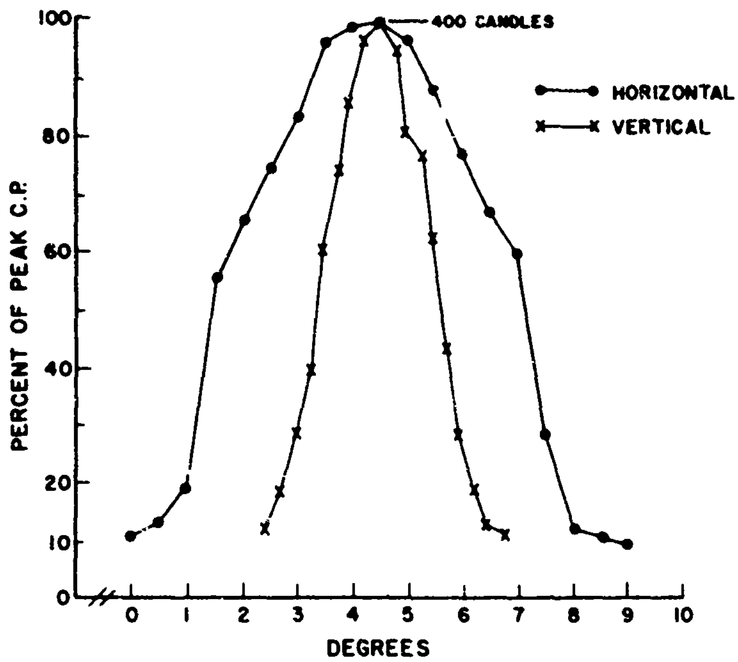

Figure 32. Candlepower distribution for simulated searchlight beam using corrector slide.

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13. ABSTRACT

The report summarizes experimental studies using a scale model simulator to determine visibility distances of military targets under certain nighttime illumination conditions. The experiments concerned both detection and identification of targets, which were observed along ground paths under simulated natural and artificial nighttime illumination. The studies were intended to provide a basis for better understanding and specifying the stimulus factors that influence target visibility under such conditions. Photometric data were used to relate the simulator conditions to actual field conditions.

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Models						
Night Illumination						
Simulators						
Target Detection						
Visibility						

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