MODERN COUNTER-SURVEILLANCE IN COMBAT CLOTHING

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INTRODUCTION

Before World War II, personal camouflage was needed only in daylight, because night-time surveillance was limited to use of the naked eye. Since that time surveillance devices have been developed that enable an enemy to observe military personnel effectively, both by day and night. Both aerial photography and the sniperscope extend vision into the infrared, allowing an observer to take advantage of differences in the reflection properties of terrain and clothing. An image intensifier increases his visual sensitivity at night by many orders of magnitude. Because the present military environment emphasizes the use of small, mobile units, the Combat Development Objectives Guide states that an individual soldier must have maximum freedom from enemy observation, if he is to complete his mission successfully. This paper describes the development of a colorant system for combat clothing that satisfies the reflectance requirements for camouflage protection against detection by all of these modern surveillance devices, as well as by visual observation.

The Problem

These surveillance devices function on the basis of the radiation that is reflected from troops and other objects in the terrain. Figure 1 shows the regions of the spectrum in which each device operates to its best advantage, and illustrates that these devices depend primarily on infrared radiation. The sniperscope makes use of a band of light near 1000 nanometers (nm), while both the image intensifier and infrared photography are most responsive to that portion of the infrared that lies just beyond the visible spectrum (700 to 900 nm).

The reason for counter-surveillance measures is to minimize the probability of detection of individual soldiers to effectively low levels. This requires a low contrast between a uniform

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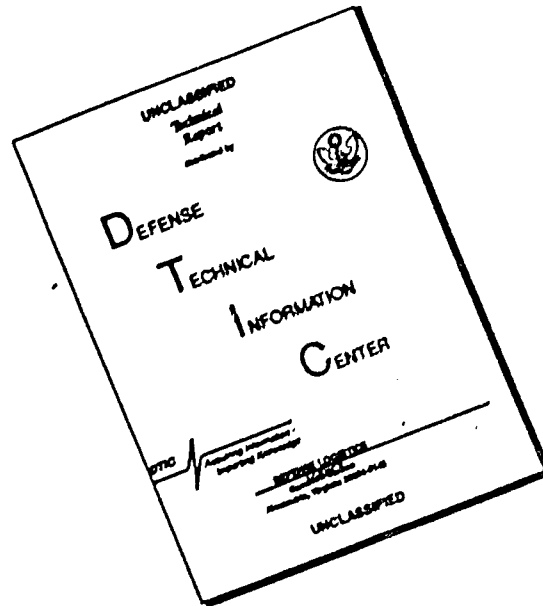
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and the background against which it is viewed, by whatever detection
device may be used. The contrast of an object in a uniformly illum-
inated field depends largely on the reflectances of the object and
the background. To develop an effective camouflage colorant system,
one must know the reflection properties of both the uniform and typ-
ical terrains. Figure 2 shows the reflectances of typical leaves,
both fresh and dry, in the region of the spectrum we are considering.
Figure 3 is a comparable set of curves for some soil specimens.

Earlier research has led to colorant systems now in use for
camouflage against visual observation and detection by the sniper-
scope. It has also been possible to devise relatively simple color-
ant systems to provide camouflage against visual surveillance and
that by either infrared photography or the image intensifier. In
the past, however, it had not been possible to develop colorant sys-
tems that afford suitable camouflage protection against all four
methods of surveillance; visual observation, infrared photography,
the image intensifier, and the sniperscope.

The Objective

Our long-range goal is a significant reduction in the prob-
ability of detection of our troops by an enemy using visual observa-
tion and any of the modern surveillance devices. The objective of
this research study is the development of a system for coloring com-
bat clothing and equipage to provide camouflage against surveillance
by the four systems cited above.

The Criterion

Figures 2 and 3 show that the reflectances of common com-
ponents of the terrain are higher in the near infrared than in the
visible spectrum. They also show that the reflectance curves for
terrains vary from one location to another. To cope with variations
in terrain coloration, it has been possible to select compromise
colors for visual camouflage. In an analogous manner, it should be
possible to define criteria for counter-measures against detection
by other devices, that is, levels of reflectance that clothing
should have in each spectral region to assure generally low contrast
in a variety of terrains.

Based on known physical data and field observations, a
criterion has been derived that represents the spectral reflectance
of ideal camouflage in terrains that contain substantial vegetation,
when viewed by the four surveillance systems used to their best ad-
vantage. A uniform that has a reflectance curve between 400 and
1200 nm similar to that shown in Figure 4 can be expected to afford
camouflage protection against observation by the four devices we are
considering. The lower values of reflectance at the longer wave-

lengths pertain to the use of the sniperscope, where illuminating and viewing conditions significantly differ from those of the others.

TECHNICAL APPROACH

The Idealized Curve

The idealized curve of Figure 4 has a higher reflectance at wavelengths between 700 and 900 nm than it does at wavelengths beyond 900 nm. This is the feature of the theoretical curve that is most difficult to duplicate in reality. Dyes known to absorb strongly at 1000 nm have been used to control the reflectance to levels deemed necessary to afford camouflage against sniperscope observation. Such dyes, however, absorb even more strongly between 700 and 900 nm than they do at 1000 nm. Thus, one should not expect to duplicate, by simply reflection processes alone, a reflectance curve that has lower reflectances near 1000 nm than it does at shorter wavelengths.

The idealized curve, itself, provides a clue to the starting point for research. Its shape resembles the apparent reflectance curves obtained for fluorescent surfaces, in that one part of the curve rises to values that are higher than those at the longer wavelengths that usually define a maximum reflectance base line. This led to the proposal that the idealized curve could be duplicated by dyes that had fluorescent emission in the near infrared, if such colorants could be found.

Infrared Fluorescence

When a dye absorbs electromagnetic radiation, the molecule is elevated to an energetic (excited) state that is short-lived. For the molecule to return to its original ground state, the absorbed energy must be dissipated quickly by one or more available paths. For most dyes on fabric, these paths usually involve photo-chemical processes or direct conversion to heat. Fluorescence, however, is observed when the absorbed energy is directly re-emitted as electromagnetic radiation without being diverted into alternative paths.

Early literature references to luminescence in the infrared begin with that of Pauli in 1911,[1] who claimed to be the first to have observed luminescence in the infrared. Dhere and co-workers[2,3] reported in 1936 that the fluorescence of the living leaf of the geranium extends as far into the infrared as 830 nm. In a survey of about 200,000 mineral specimens, Barnes[4] reported that nearly 1500, representing about 75 mineral types, exhibited some degree of infrared fluorescence. Prior to the present work, the only example in the literature of an organic textile dye that exhibits infrared fluorescence on fabric was reported by Stearns in 1943.[5]

Experimental Approach

It is clear from the foregoing that the first phase of the experimentation was a search for dyes that exhibit fluorescence in the near infrared. Figure 5 shows the absorption and fluorescence spectra of a thiazine dye, Methylene Blue, in methanol. A characteristic of the fluorescence process is that the wavelengths of emitted light are longer than those of the light that was absorbed. For many dyes, the difference in wavelength between the absorption and fluorescence peaks is 50 to 100 nm. In this research we have sought dyes that fluoresce in the near infrared. For a dye to fluoresce near 750 nm, for example, it should absorb light in the red end of the visible spectrum. Such dyes are green or blue, a fact that provided another clue in our search for colorants by which the idealized curve could be reproduced on a textile fabric.

The second phase of our research was to develop a means of incorporating a selected infrared fluorescent dye into a colorant formulation to provide the other characteristics shown in the idealized curve. This combination of colorants was then applied to a fabric in such a manner as to preserve the fluorescence.

The third phase of the study was a preliminary field evaluation of the prototype fabric, using the sniperscope, the image intensifier, and infrared photography.

EXPERIMENTAL RESULTS

Survey of Dyes

To detect fluorescence in the near infrared, in our survey of dyes we used a specially designed photometer.[6] The specimen is illuminated with a tungsten lamp limited by selected filters[7] to the visible spectrum. Light emerging from the specimen by reflection and fluorescence is intercepted in front of the photo-detector by a filter that transmits only light in the near infrared. Since the reflected light is limited to the visible spectrum, the only energy that reaches the detector is that produced by fluorescence in the infrared. The spectral response curve for the infrared fluorophotometer rises to a peak at about 830 nm and has a band width of about 130 nm. This is similar to the spectral response curve shown for infrared photography in Figure 1.

In the search for useful colorants, 250 dyes were applied to a variety of fabrics and examined with the infrared fluorophotometer. Of these, 75 displayed some degree of infrared fluorescence, a fact not previously reported in the literature.[8,9] Table I is a list of those dyes that were found to fluoresce most strongly, while Table II lists those that were moderately fluorescent. The numerical values in the last column show the relative intensity of

TABLE I

DYES THAT FLUORESCE MOST STRONGLY IN THE INFRARED

C. I. Name	Chemical Type	Fabric Type	Fluorescence Intensity
Basic Blue 4	oxazine	polyacrylic	160
Basic Blue 3	oxazine	polyacrylic	155
Direct Blue 108	oxazine	polyamide	96
Direct Blue 106	oxazine	polyamide	82
Direct Blue 109	oxazine	polyamide	72
Direct Blue 107	oxazine	polyamide	68
Direct Violet 54	oxazine	polyamide	63
Basic Blue 9	thiazine	polyacrylic	62

TABLE II

DYES THAT FLUORESCE MODERATELY IN THE INFRARED

C. I. Name	Chemical Type	Fabric Type	Fluorescence Intensity
Basic Violet 4	triarylmethane	polyacrylic	48
Basic Green 3	triarylmethane	polyacrylic	45
Basic Blue 26	triarylmethane	polyacrylic	45
Basic Blue 36	triarylmethane	polyacrylic	42
Direct Blue 1	disazo	cotton	42
Acid Green 16	triarylmethane	polyamide	41
Acid Green 3	triarylmethane	polyamide	40
Direct Blue 25	disazo	cotton	37
Basic Violet 3	triarylmethane	polyacrylic	37
Basic Green 1	triarylmethane	polyacrylic	37
Direct Blue 14	disazo	cotton	36
Direct Blue 109	oxazine	cotton	35
Basic Violet 5	azine	polyacrylic	33
Direct Blue 22	disazo	cotton	32
Basic Blue 7	triarylmethane	polyacrylic	32
Basic Blue 9	thiazine	cotton	32

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fluorescence as measured by the fluorophotometer.

From the dyes listed in Table I, Basic Blue 4 was selected for further consideration and applied to a variety of fabric types. It was found that the fluorescence for this dye was most intense when applied to acrylic fibers, less so on polyamide, and absent on cotton. Because the dye molecules can interact with certain fibers in a manner that quenches fluorescence, it is important to choose a fabric substrate that will allow the return of the excited state molecule to the ground state by fluorescence.

Application to Fabric

Figure 6 shows the spectral curve for combined fluorescence and reflectance for Basic Blue 4 applied to an acrylic fabric when illuminated with a xenon arc used as a simulated daylight source. This figure also shows the curve for a dyed specimen in which Basic Blue 4 was included in a formulation to produce an olive green shade.

Although the curve for the olive green shade does not match the idealized curve in the infrared, the important feature to note is that the reflectance is higher in the intermediate region than it is at the longer wavelengths. As pointed out earlier, this is the most difficult feature of the idealized curve to reproduce. The task that remained was to find a means of lowering the entire infrared portion of the curve to proper levels, while still preserving the effect of fluorescence in the region between 700 and 900 nm.

When dyes that were known to absorb at longer wavelengths were added directly to the formulation, fluorescence was quenched. Light emitted by fluorescence was simply re-absorbed by neighboring molecules of the absorbing colorant before it could emerge from the surface of the fabric.

A technique of blending two fibers was also attempted. One lot of acrylic fibers was dyed with the fluorescent formulation. The other lot (cotton) was dyed with a vat dye that absorbed strongly throughout the near infrared to about 1200 nm. When these lots were thoroughly blended to form a uniformly colored surface, the expected fluorescence was almost entirely lost, presumably for the reason described above. The conclusion from both of these attempts was that fluorescent portions of the fabric must be separated from absorbing areas sufficiently to allow the fluorescent emission to emerge from the fabric surface before it is re-absorbed by other colorants.

The problem of quenching was eventually overcome by devising a 2-component grid pattern.[10] A fabric was made by weaving two black rayon yarns alternately with four undyed acrylic yarns in

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both the warp and filling directions. This produced a checkered fabric in which the undyed areas were about 1/8 inch square, as shown in Figure 7. The rayon contained carbon black, a colorant that strongly absorbs all wavelengths of light we are considering. As woven, the fabric consists of two distinct areas, one having high reflectance, the other low. The fabric was then dyed with the fluorescent dye formulation illustrated in Figure 6 to produce an over-all olive green shade.

Figure 8 shows the reflectance curve for an area of the fabric, both before and after dyeing. The effect of the black yarns was to lower the level of reflectance of the fabric before dyeing to about 30 per cent. If non-fluorescent dyes had been used, the resulting reflectance curve would have been lower than the upper curve at all wavelengths. By fluorescence, however, it was possible to lift the reflectance curve above that of the undyed fabric within a narrow range of wavelengths. By separating the fluorescent areas from the non-fluorescent areas sufficiently, each area is able to act independently of the other without quenching the fluorescence.

Evaluation

When the dyed fabric is viewed at distances beyond 15 feet, the checkered pattern blends into a uniform shade that is indistinguishable from olive green. To estimate the effectiveness of the general technique, observations were made with the devices we have been discussing. The experimental fabric was displayed as a panel about six feet long and four feet high, with a similar panel of a standard fabric. Both panels were erected at the northern edge of an open field with a background of brush, tall weeds, and trees.

Photographs of the panels were made at noon on a sunny day in September, using Polaroid infrared film and a Wratten 87 filter that excluded all visible light. The spectral response of the film under these conditions is that shown for infrared photography in Figure 1. The close-up view in Figure 9 shows the local setting for the panels. Figure 10 is a view of the panels in the same setting photographed at a range of about 30 meters.

Both photographs demonstrate that the standard fabric appears conspicuously dark against a background one often encounters in a field situation. The experimental fabric shows that the use of infrared fluorescence with the 2-component grid pattern technique permits a control of reflectance to levels that decrease the contrast of a fabric when viewed by infrared photography against typical field backgrounds.

Night-time observations were also made with an image intensifier. These showed that, for this surveillance device too, the contrast was much lower for the experimental fabric than for the comparison fabric, which appeared conspicuously dark. Spectrophoto-

metric measurements show that the reflectance of the experimental fabric near 1000 nm is close to 25 per cent, a value that affords camouflage protection against observation with the sniperscope.

CONCLUSIONS

To reduce the effectiveness of modern surveillance systems, it is necessary that the reflectance of fabrics for combat clothing follow an idealized spectral reflectance curve that covers the visible spectrum and the infrared to about 1200 nm. This curve rises from low values in the visible spectrum to a maximum in the region between 700 and 900 nm and falls to somewhat lower values beyond 900 nm. The shape of this curve is such that it can be duplicated only by using colorants that are fluorescent in the near infrared. As part of this research, a survey of dyes disclosed for the first time that about 75 dyes were fluorescent in the infrared.

An infrared fluorescent dye alone was not able to confer the reflectance properties needed for camouflage against the variety of surveillance devices we are considering. In fact, fluorescence was quenched, when other dyes were added to bring experimental reflectance curves into conformity with the idealized curve. It was, therefore, necessary to separate physically the fluorescent dyes from colorants needed to lower the general level of reflectance in the infrared.

To avoid quenching of fluorescence and at the same time lower the infrared reflectance, a special technique was devised for using these dyes. A checkered fabric was designed in which part of the fabric consisted of strongly absorbing yarns and part consisted of yarns that were later dyed with infrared fluorescent dyes. In this manner, the two components of the over-all coloring system were able to perform their necessary functions independently and without interference, with the result that a reflectance curve was obtained that had the camouflage characteristics described by the idealized curve.

Field observations with infrared photography and an image intensifier confirmed the camouflage value of the newly developed colorant formulation, because the experimental fabric was far less conspicuous in a typical terrain than currently used fabrics. Thus, a single coloring system for clothing can afford camouflage protection against visual observation and detection by infrared photography, the sniperscope, and the image intensifier, when that coloring system is based on dyes that are fluorescent in the near infrared.

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6. Ramsley, A. O., U. S. Patent 3,422,266, January 14, 1967.

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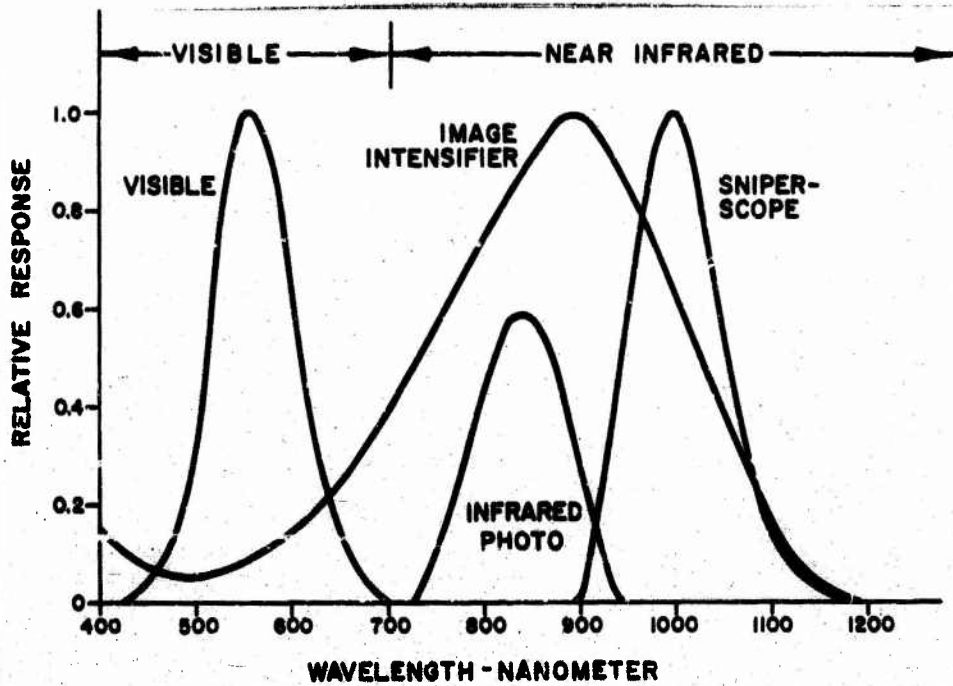
Fig. 1: Response as a function of wavelength for human vision, an image intensifier, infrared photography, and the sniperscope.
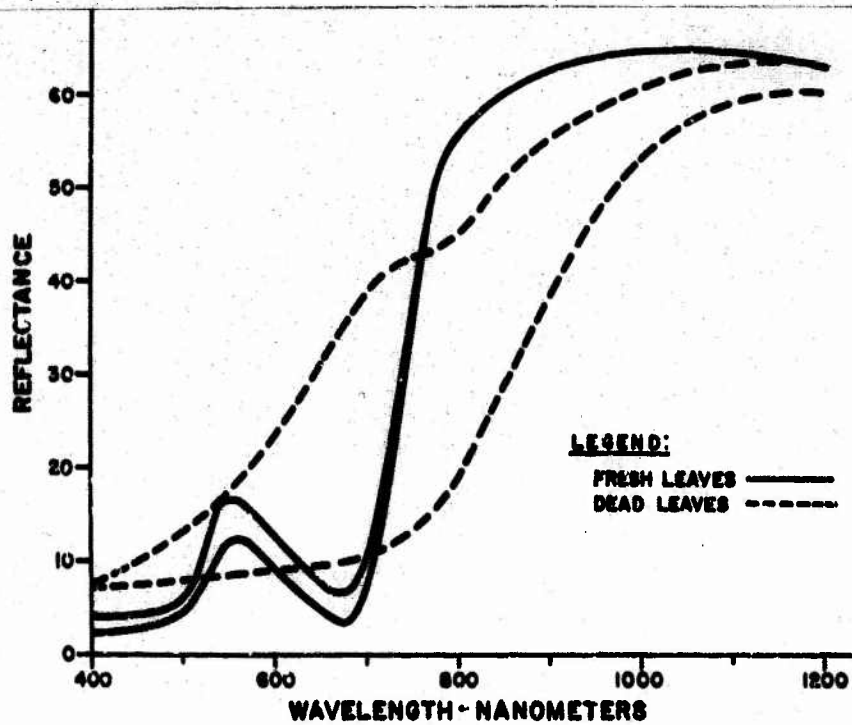
Fig. 2: Range of spectral reflectance for typical fresh leaves (_____) and dry leaves (- - - - - - -).

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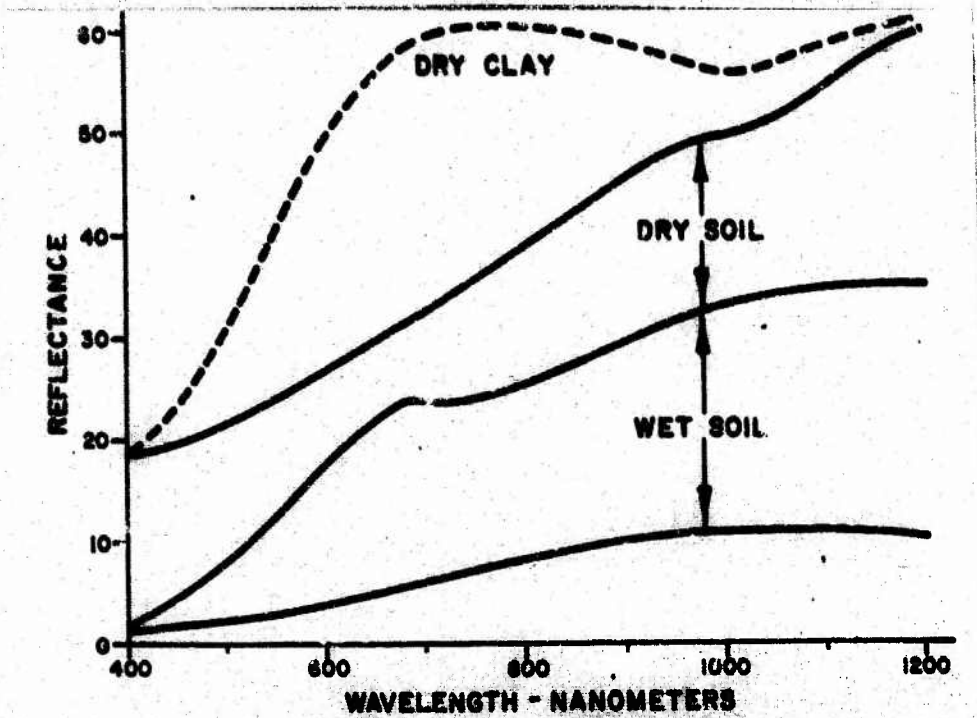
Fig. 3: Spectral reflectance curves for typical wet and dry soils.
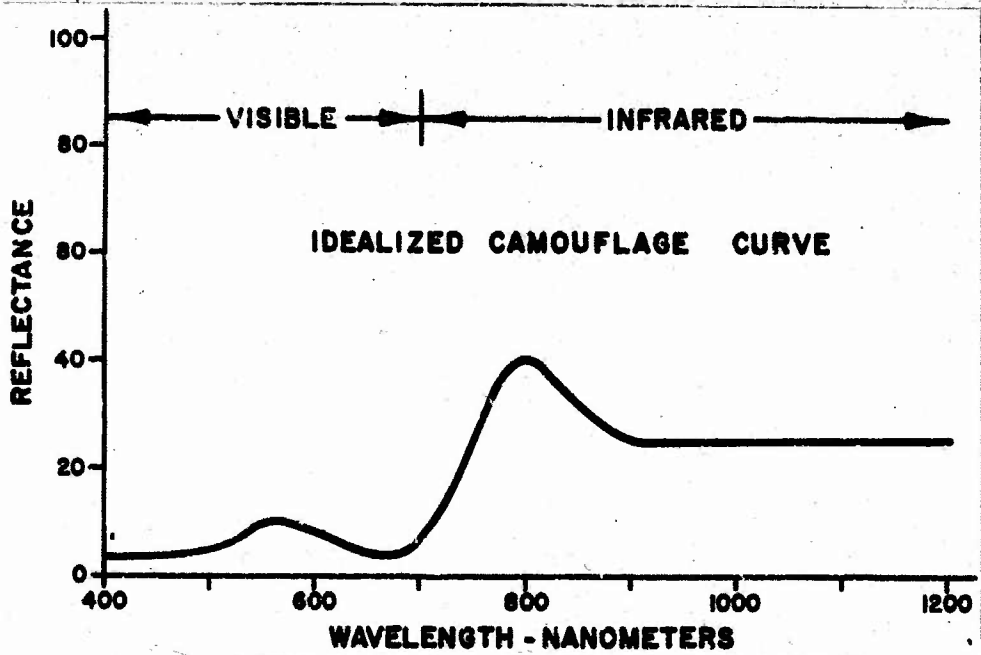
Fig. 4: Idealized spectral reflectance curve
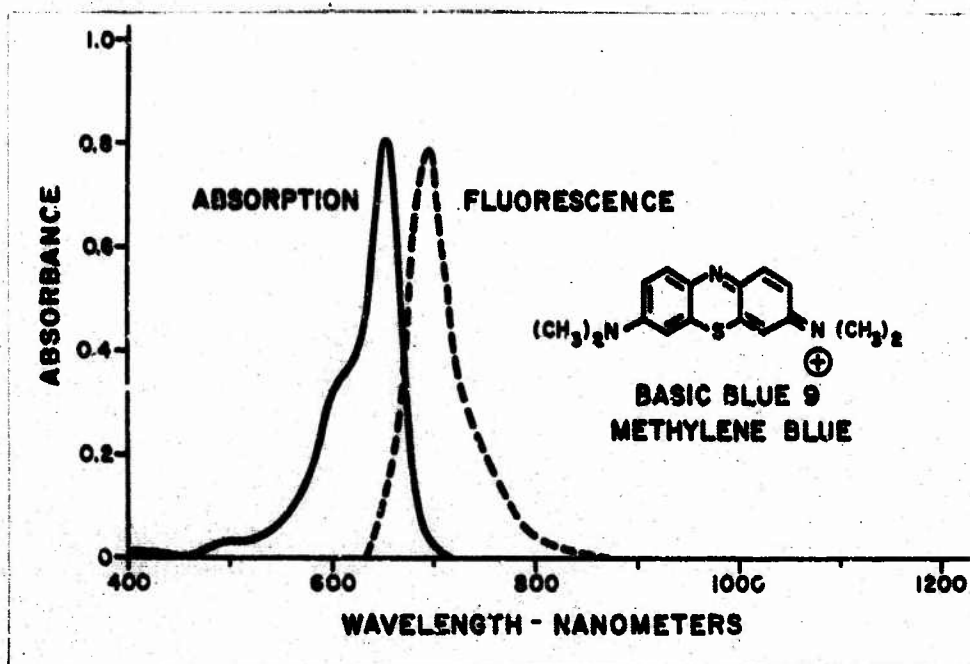for camouflage in typical vegetated terrains.

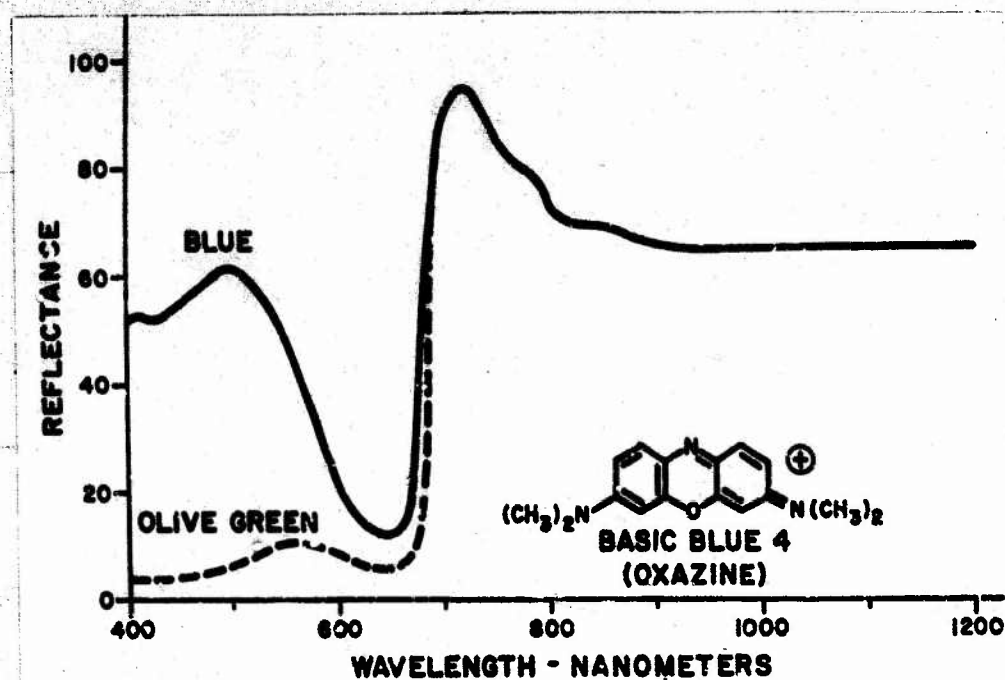Fig. 5: Absorption and fluorescence spectra of Basic Blue 9 (Methylene Blue) in methanol.

Fig. 6: Combined reflectance and fluorescence curve for an acrylic fabric dyed using Basic Blue 4 alone and in a dye formulation to produce an olive green shade.
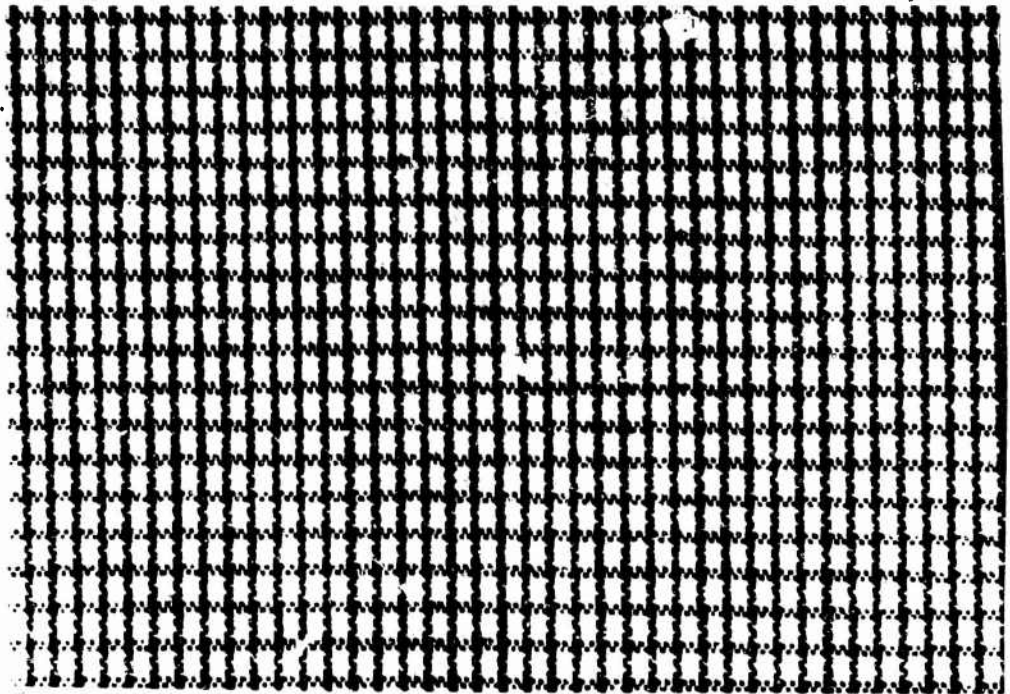
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Fig. 7: Fabric made by alternating black rayon yarns and undyed acrylic yarns in both warp and filling directions.
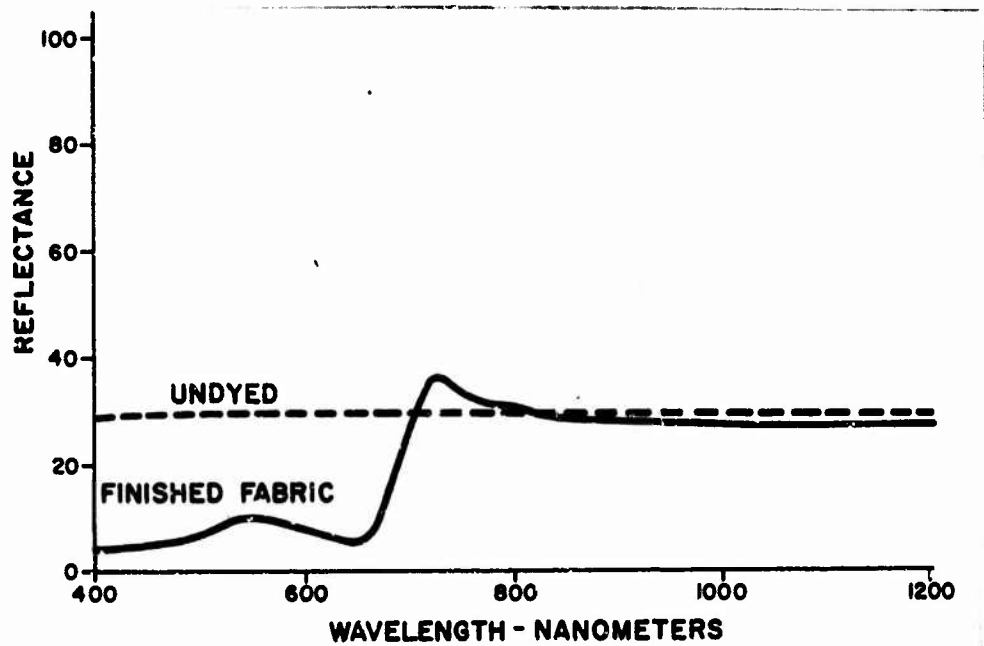

Fig. 8: Reflectance curves of the arrangement grid fabric before and after dyeing with infrared dyes to an olive green shade.
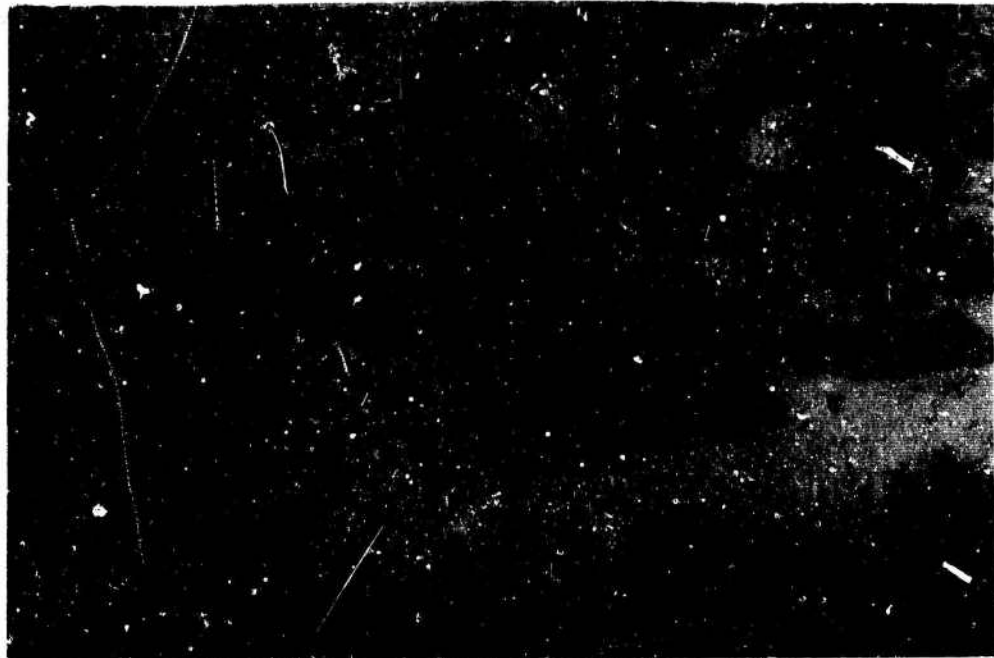
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Fig. 9: Close-up infrared photograph of panels made with the experimental fabric on the left and a standard fabric on the right.
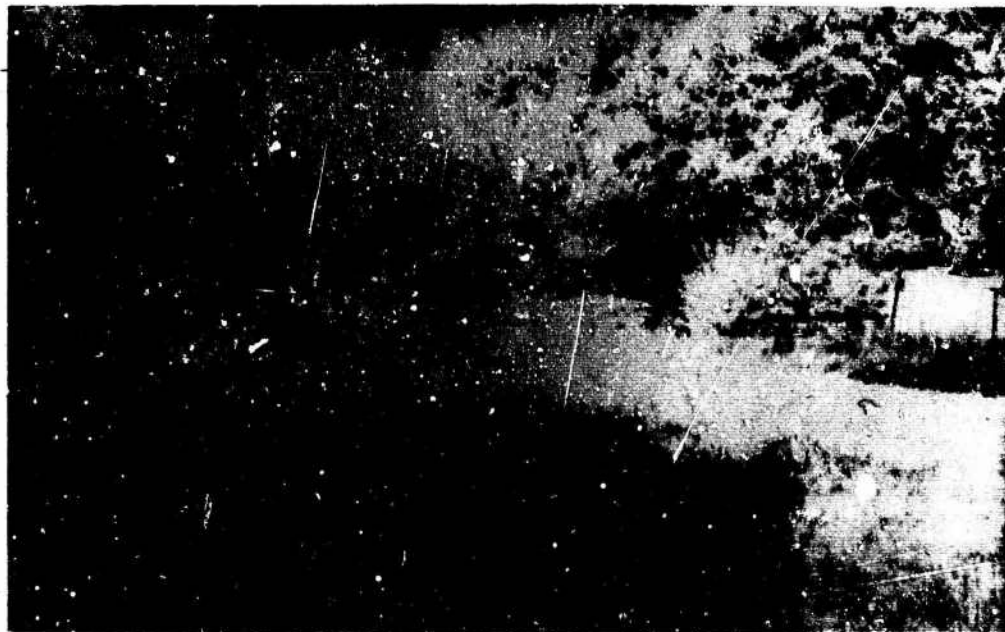

Fig. 10: Infrared photographs of panels at 30 meters with the experimental fabric on the left and a standard fabric on the right.