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Abstract
Fluorescent whitening agents (FWAs) are chemicals added to most fabrics and papers during manufacture to increase color temperature, "whiteness," and "brightness." FWAs accomplish this by absorbing energy in the ultraviolet (UV) part of the spectrum and emitting it as visible blue light. Recently, hunters have become concerned that FWA could be reducing the effectiveness of their camouflage clothing. As a result, some manufactures have begin making their camouflage clothing (camo) without FWA, and a spray-on product has been introduced to block the action of FWA. Radiometric spectra recorded from 300 to 500 nm under full sun and deep shade conditions suggest, however, that these concerns might not be fully justified. In fact, the FWA made some camouflage cloth samples a better match to the spectra of natural foliage in the UV portion of the spectrum, and the use of a spray to block the action of the FWA reduced the match of some camouflage samples to the foliage in portions of the visible blue spectrum (400-500 nm).

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THE EFFECT OF FLUORESCENT WHITENING AGENT ON HUNTER CAMOUFLAGE CLOTHING

By

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A thesis submitted to the faculty of the
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Biography of Daniel Beckner: Born March 14, 1959 in Georgia, Dan Beckner is the oldest of six children. He began his education in southern California and graduated from Kirkland High School in 1977. He graduated from Walla Walla College in 1983 with a Bachelor of Science degree in Industrial Education. Currently, he is completing work for the Doctor of Optometry at Pacific University in Forest Grove, Oregon. Following graduation, he plans to practice optometry in the Pacific Northwest.
ABSTRACT

Fluorescent whitening agents (FWAs) are chemicals added to most fabrics and papers during manufacture to increase color temperature, "whiteness," and "brightness." FWAs accomplish this by absorbing energy in the ultraviolet (UV) part of the spectrum and emitting it as visible blue light. Recently, hunters have become concerned that FWA could be reducing the effectiveness of their camouflage clothing. As a result, some manufacturers have begun making their camouflage clothing (camo) without FWA, and a spray-on product has been introduced to block the action of FWA.

Radiometric spectra recorded from 300 to 500 nm under full sun and deep shade conditions suggest, however, that these concerns might not be fully justified. In fact, the FWA made some camouflage cloth samples a better match to the spectra of natural foliage in the UV portion of the spectrum, and the use of a spray to block the action of the FWA reduced the match of some camouflage samples to the foliage in portions of the visible blue spectrum (400-500 nm).

KEYWORDS
Camouflage, vision, ultraviolet, hunting, fluorescence, optical brightener, fluorescent whitening agent, clothing
Camouflage involves the art and science of disguising something from an enemy, usually by making it appear to be part of the natural terrain. In its modern implementations, camouflage has been highly developed for military and hunting purposes. Military camouflage must make its wearer appear to be part of the background when viewed by humans and/or by sophisticated detection equipment which can be sensitive to wavelengths outside of the range of normal human vision. In the case of hunting, the camouflage must disguise the hunter from game animals, but relatively little is known about the visual characteristics of many of these animals. Thus, a garment printed with dyes designed to make a hunter appear to be part of the background when viewed by another hunter might stand out "like a ripe red tomato on a green vine" when viewed by a game animal.\(^a\)

Recently, several makers of hunters' camouflage clothing have become very concerned about the possibility that the fluorescent whitening agent\(^b\) which is added to most fabrics during manufacture could be making their clothing "glow," and this might make a camouflaged hunter visible to a game animal. To illustrate this possibility, a photograph in a recent issue of Bowhunting magazine article\(^1\) shows a camouflaged hunter appearing to be much brighter than the surrounding background. Although the photograph was probably made by illuminating the hunter with a fairly strong UV source, the story associated with it, and similar stories,\(^2\) have had a significant effect on the hunting community. Reportedly, many camouflage makers are now obtaining mill fabric without FWA, some hunting equipment companies are heavily advertising products that are "UV Free," and a spray-on product, U-V-KILLER,\(^c\) designed to block the action of FWA has been introduced.

Because this topic is of considerable interest to both the hunting and visual science communities, this paper will review the use of FWA in fabrics, briefly discuss a portion of what is known about the vision of large game animals, and present data showing how the U-V-KILLER (TM) spray affects actual samples of camo.
FLUORESCENT WHITENING AGENT

Many fabrics appear somewhat yellow-white in their natural state, and, as they age, the action of light, atmospheric chemicals, etc. causes them to yellow even more. This yellowing occurs because of a relative increase in the reflectance of long wavelength light by the fabric and a resultant decrease in color temperature. Over the years, bluing agents have been used to "brighten" and whiten fabrics by increasing short wavelength reflectance, and bleaches have been used to remove longer wavelength reflecting substances. Because these approaches were not totally satisfactory, textile manufacturers now add FWA during the milling process to essentially all fabrics and papers; the main exceptions seem to be newsprint, toilet paper, and special-order fabrics.

Several whitening chemicals are in current use, but most of them have similar features. The typical FWA is a stilbene derivative that absorbs energy in the ultraviolet part of the spectrum at about 380 nm and radiates it in the visible blue at about 430 nm (Figure 1). Thus, the FWA takes a part of the spectrum not seen by humans and converts it into visible light by fluorescence. The added blue light compensates for any yellow appearance of the fabric and makes it look whiter by raising its color temperature.

FWA is most effective in white fabric because if the fabric is dyed the FWA is covered and does not receive the UV light necessary for it to fluoresce. Although the FWA is tightly bonded to the fabric during milling, some of the material is removed by laundering. To compensate for this, most laundry detergents now include FWA (often listed on the package as "optical brighteners") which is deposited during washing. As compared to white fabric, not as much FWA is deposited during the washing of heavily dyed fabric because the dye covers potential FWA binding sites; the effect of the FWA is therefore most noticeable on white or light colored fabrics. Some FWA is, however, added to almost all fabrics during laundering and
the fluorescence of the deposited FWA justifies detergent makers' claims that their products make fabrics "brighter than white."

GAME ANIMAL VISION

Relatively little is known about the vision of large game animals such as deer, elk, and moose, in part because these animals are difficult to work with in a typical research laboratory. With respect to the sensitivity of these animals in dim light, Neitz\textsuperscript{a} has suggested that ungulates (hoofed animals) probably have a visual system that is more sensitive than that of humans. Reasons for this include the large eyes and pupils of the ungulates, a reflecting layer (tapetum lucidum) behind the retina which allows light to pass through the receptor layer twice, a high proportion of rods in the retina, and a lens that absorbs less short wavelength light than the lens of an adult human.

It is probable that ungulate game animals have lenses that resemble those from very young humans in that they transmit further into the ultraviolet portion of the spectrum than the lenses of adults.\textsuperscript{4} If the ungulates have receptors that are capable of detecting short wavelength light, this would give them greater sensitivity in the UV portion of the spectrum than adult humans. Evidence for this UV sensitivity is somewhat scattered, but UV sensitive receptors have been found in the rat,\textsuperscript{5} and even human receptors have some sensitivity in the near UV.\textsuperscript{6}

With respect to color sensitivity, many game birds have excellent color vision, but it was once believed that carnivores, like dogs, and ungulates were essentially color blind. It is now known that dogs possess color vision,\textsuperscript{7} and some ungulates also seem to have color vision. For example, Neitz and Jacobs\textsuperscript{8} have shown that pigs (which are ungulates) probably have color vision, goats might have color vision,\textsuperscript{9} and Zacks has shown that deer can discriminate certain colors.\textsuperscript{10}

It has been suggested\textsuperscript{8} that if ungulate game animals do posses color vision, it is most likely dichromatic with only two photopigments in the cone receptors as opposed to the three cone
photopigments that humans have. A dichromatic color vision system in the ungulates might combine a long wavelength sensitive pigment with a short wavelength sensitive pigment that could have significant sensitivity in the UV. This could give the ungulates more sensitivity in the near UV than adult humans, and this possibility has caused the makers of camo to be concerned that their clothing would reflect (or emit) more UV light than the natural background. Excessive UV would not be seen by adult humans because of absorption by the lens, but it could be seen by ungulates; this could reduce the effectiveness of a hunter's camouflage.

Some apparent confusion about how an FWA works in clothing has added to the concerns about this possibility. Several papers and the product literature from the makers of U-V-KILLER (TM) spray refer to FWA as a "UV brightener" and seem to suggest that the action of an FWA is to make a garment reflect or emit more UV light. The product label from U-V-KILLER (TM) states, in part: "Washing in regular detergent deposits U. V. Brightener Dyes on your CAMOS.... These brighteners reflect U.V. light causing colors to appear whiter and brighter. Animals and insects are EXTREMELY sensitive to the U.V. end of the spectrum. Brighteners make your clothing glow and you are easily seen by game animals and night vision scopes. U-V-KILLER (TM) blocks the reflective dyes and lets you blend into the natural background."

This confusion is also carried into several publications. For example, in an article on the use of U-V-KILLER (TM), the author states: "I'm convinced that wearing camouflage that does not reflect UV light makes a difference in my hunting." Another article makes the following comment about the FWA used in detergents: "The soap packaging commonly lists these dyes among the contents as UV (ultraviolet) brighteners or whiteners. Their purpose is to reflect rather than absorb UV light."

This confusion probably results from the use of the term "UV brightener" to refer to FWA. In reality, the FWA does not reflect UV light nor does it increase the brightness of a garment in the UV. Instead it absorbs UV energy thereby reducing the reflection of the
garment in this spectral region. The blue glow of a camouflage
garment as shown on the U-V-KILLER (TM) packaging is not caused by
the garment reflecting UV, but by the visible blue light emitted from
the FWA in the garment. To remove this glow, a UV absorbing dye
such as U-V-KILLER (TM) can be used, but this dye is effective in
stopping the blue glow not because it blocks UV reflection from the
garment, but because it keeps the UV light from exciting the FWA
and causing it to fluoresce.

Given that the U-V-KILLER (TM) blocks the effect of FWA in
camo, the important question then becomes whether or not it is
necessary to do this. Does the FWA really reduce the effectiveness
of camouflage clothing?

CAMOUFLAGE

For camouflage to be effective, it must make the wearer
appear to be part of the background, which is usually foliage. This
means that the camouflage garment must not display the outline of
the hunter by being uniformly brighter or dimmer than the foliage,
and the camouflage must not appear to be a different color than the
foliage. Since game ungulates probably see their world as shades of
only two basic colors, the foliage must not appear to be one of these
two colors while the camouflage garment appears to be the other
color.

In general, a good way to insure that camouflage is effective
involves matching the radiometric spectrum of light coming from
the garment to the spectra coming from actual samples of foliage.
An excellent example of this involves US Army green camouflage
clothing made for wear in the woods during spring and summer. The
dyes in this clothing are designed to give a reflection spectrum that
exactly matches the spectrum of plant chlorophyll; therefore, a
person wearing this type of clothing would be very difficult to
detect against a background of green plants.

How should camouflage garments be designed to make hunters
difficult to detect by game animals that might have visual
sensitivities different than those of humans? Again it makes sense
to match the radiometric spectrum of the garment to the spectrum
of the surrounding foliage. If the spectrum for a camouflage garment lies within the family of spectra from different natural foliage samples at every wavelength, the camouflage should work well. However, if there are wavelengths for which the camouflage reflects (or emits) significantly more (or less) energy than any of the foliage samples, the camouflage is suspect. For example, if camouflage garments containing FWA produce more energy in the blue (or UV) part of the spectrum than samples of foliage, and if a game animal's visual system is sensitive to this part of the spectrum, the camouflage would not work well. However, if the light energy coming from the camo is within the range of energies from foliage samples at every wavelength, and the camouflage has patterns which break up the outline of the hunter, the camo should be effective no matter how sensitive an animal is to light at different wavelengths.

RADIOMETRIC SPECTRA FROM CAMOUFLAGE CLOTH AND FOLIAGE

To assess the effectiveness of camouflage with FWA and to show the changes produced by using U-V-KILLER (TM) spray, radiometric spectra were determined for cloth and natural foliage samples under field conditions. Spectra were measured by using a Jarrell Ash monochromator (82-410) attached to a R213 photomultiplier tube (17-732E) with regulated power supply and output indicator. The 4.0 mm apertures on the monochromator gave a half-band width of 10 nm. The system was calibrated from 300 to 700 nm by reference to a neutral response detector (pyroelectric radiometer, Molelectron PR200); the radiant source used for this calibration was a tungsten halogen lamp operated with a voltage-stabilized power supply.

Spectra were measured on a clear, sunny day with very slight high overcast (Sept. 22, 1991) in the Pacific University arboretum located at an altitude of about 150 m in the woods about 15 km miles outside of Forest Grove, OR. The arboretum is well away from any artificial light sources and contains vegetation typical of western Oregon with a mix of fir, alder, various bushes, ferns, and yellow-green grasses.
Spectra were measured from about 2:00 to 4:00 p.m. with cloth and foliage samples placed in the direct sun, and from about 5:00 to 6:00 p.m. with samples placed in the deep shade. Sunset over the hills and trees surrounding the arboretum occurred at about 4:30 p.m. with actual sunset occurring at 7:06 p.m.

Cloth and foliage samples were mounted on 18 inch square boards and suspended perpendicular to the ground 1.0 m in front of the monochromator entrance aperture. The cloth samples included white 50/50 cotton-poly, a section from a regulation US Army green camouflage coat (Stock number 8415-01-184-1338), gray camo (trade marked Shado-Camo), and green camo. The white, gray, and green camo samples had FWA added during milling as indicated by the fact that they glowed in a dark room when illuminated by a strong UV source. The gray cloth had a small pattern of gray, brown, and white areas. The green cloth had a larger pattern (slightly larger than the Army pattern) of dark green, yellow-green, brown, and black colors; it was like the Army pattern except that it had yellow-green color patches which the Army camouflage did not.

Samples of the white, green, and gray camouflage materials were prepared as follows: new fabric, fabric washed 5 times in Tide detergent to deposit additional FWA, and new fabric sprayed with U-V-KILLER (TM) according to the manufacturer's instructions. For each sample of the green and the gray camouflage, care was taken to insure that exactly the same pattern was represented.

Spectra were also obtained from fresh samples of fir bark, fir branches with needles, ferns, and grasses. Their spectra were measured in exactly the same manner as were the spectra from the camo samples. Also, the overall spectra from an open field with trees, ferns, grasses, and other plants were obtained in sun and shade.

WHITE FABRIC SPECTRA

Spectra from the white fabric measured in the sun and in the shade (Figure 2) clearly show fluorescence of the FWA at about 440 nm and a reduction, but not total elimination, of this fluorescence by the U-V-KILLER (TM). These spectra are consistent with what is
known about the action of the FWA in the cloth and the UV absorber in the U-V-KILLER (TM) spray. Washing the white fabric in Tide detergent 5 times had only a very minor effect on the spectra (Figure 3) suggesting that laundering probably adds relatively little FWA to new fabric.

GREEN CAMOUFLAGE SPECTRA

Heavy printing with dark dyes can cover (quench) the FWA in the underlying fabric, and this can reduce the effect of both the FWA and the U-V-KILLER (TM). The spectra for new versus sprayed green camo in the sun (Figure 4) and in the shade (Figure 5) show the expected UV absorption by the spray, but, in the 400-500 nm region, the spray seems to increase the reflectance of the fabric. Spectra for the Tide washed fabric sample showed no effects of the laundering and are not presented.

Figures 6 and 7 show spectra from the foliage samples measured in full sun and shade, respectively. For camo to be effective in the area from which the foliage samples were derived, the camo must not have a spectrum that falls outside the range of the foliage spectra for any wavelengths. Figures 8 and 9 show the spectra for the new and sprayed green camo and the upper and lower boundaries of the foliage spectra in the sun and shade, respectively. The new camo spectra are slightly above the foliage spectra in the 350 to 400 nm range so the camo might appear too bright to an animal that was sensitive to these wavelengths. The U-V-KILLER (TM) darkens the cloth in this portion of the spectrum thus making it a better match for the foliage, but this effect is unrelated to the action of FWA in the fabric. In fact, without the FWA the camouflage would probably be an even worse match to the foliage in the UV portion of the spectrum.
Above 400 nm, the sun and shade spectra for the new green camo are well within the family of spectra from the natural foliage samples; this suggests that the new fabric would provide effective camouflage. Spraying the cloth with U-V-KILLER (TM), however, appears to reduce the effectiveness of the camouflage in the shade because the spray causes the cloth to reflect more light at about 420-440 nm than any of the foliage samples.

ARMY GREEN CAMOUFLAGE

Figures 10 and 11 show the spectra for regulation US Army green camo (which is made without FWA) and for foliage in the sun and shade, respectively. The Army camo seems to be effective under both conditions; its spectra are almost an exact match for the fern spectra above 400 nm in both the sun and shade. Below 400 nm, the camo is still well within the range of foliage samples. This is not surprising because the army camo was designed to have a spectrum matching that of plant chlorophyll. The Army camo was not sprayed or washed in this study.

GRAY CAMOUFLAGE SPECTRA

Spectra from gray camo (trade name Shado-Camo) were also measured in the sun and shade. Ideally this camouflage color would be used in more arid hunting areas so it was not expected that its spectra would match the natural green foliage too well. Figure 12 shows spectra from new and U-V-KILLER (TM) sprayed fabrics, and the foliage spectra boundaries in the sun. Again the spray blocks the reflectance of the fabric in the 300 to 400 nm range, but increases the radiant power slightly in the 400-500 nm region. As expected, the new gray camo reflects too much light across most of the spectrum up to about 460 nm. Spraying with UV-Killer makes the
camo fit the foliage spectra better in 300 to 400 nm range, but makes it fit less well above 400 nm. In the shade (Figure 13), the same effects are seen; the spray causes the camo to reflect more light in the blue portion of the spectrum than the new fabric did.

**AMBIENT SPECTRA**

The reflection and possible fluorescence of a camo garment are direct functions of the ambient light illuminating the garment. To determine the ambient spectra of light in the atmosphere at the time the camo and foliage measurements were made, reflection spectra were obtained from a barium sulphate plate which had essentially equal reflectance at all wavelengths. Spectra from sun and shade conditions are shown on Figure 14. The spectra have been displaced vertically on the Figure for ease of viewing. The absolute levels of both visible and UV light decrease in the shade, and the relative proportion of UV to visible increases somewhat. If this trend continued into the very deep twilight, any fluorescence of the camo fabrics could became a factor.

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**DISCUSSION**

The ability of FWA to convert UV light, which is not seen by humans, to visible blue light has been exploited by fabric and paper manufacturers to make their products appear whiter and brighter. This action of the FWAs is well documented in the literature and has been demonstrated in this paper with various fabric samples, especially the white cloth. Contrary to some confusing suggestions in the hunting literature, FWA does not reflect UV light nor does it increase the brightness of a camo garment in the UV. This is true whether the camo is viewed either by a human or a game animal. FWA cannot increase the brightness in the UV no matter how much UV sensitivity a game animal might have and no matter what the spectrum is of the ambient light. This is simply because FWA absorbs UV light and does not reflect or emit it. In the UV portion of
the spectrum, the only thing that the addition of FWA to a camo garment can do is to darken it for animals that can see in the UV. This darkening might or might not be desirable depending on the dyes the camo manufacturer has used to print the camo pattern. In the case of the US Army camo, the match to the foliage is good in the UV portion of the spectrum so use of a spray-on dye which absorbed all of the UV light falling on the garment might reduce the effectiveness of the camo by making it too dark in the UV. In the case of the green and gray camo samples used in this study, the dyes the manufacturer used to print the camo patterns do reflect more UV light than the foliage samples considered, so the use of the U-V-KILLER (TM) made the match between the camo and the foliage better. Again, however, this effect has nothing to do with the FWA in the garment; it is caused by the fact that the camo manufacturer chose printing dyes that reflected too much UV light.

Since FWA absorbs UV and emits in the visible blue, perhaps hunters should be more concerned about the blue of the spectrum rather than the UV. Is it possible that the FWA could make a camo garment look too bright at about 430-440 nm? If this were the case, use of a UV absorbing dye like U-V-KILLER (TM) would be desirable because it would block the florescence of the FWA and reduce the brightness of the camo in the blue. The data from this project suggest that this is not the case. For the green camo samples, spectra above 400 nm for the new camo were within the range of foliage samples and there is no indication of the need for a UV absorbing spray. Surprisingly, the U-V-KILLER (TM) did not make the green camo darker in the blue, but instead made it brighter at several wavelengths, possibly because of reflectance by the carrier vehicle in the U-V-KILLER (TM). In fact, this effect was so strong that application of U-V-KILLER (TM) caused the green camo to appear slightly brighter in the shade than the foliage at 420 and 440 nm - right where it should have made the camo dimmer if its major effect was to block the action of the FWA.

The gray camo did not provide a good match to the foliage in the area where this study was conducted and would not have been very effective for hiding a hunter. The reflection of the gray camo
samples is too high across most of the spectrum in both sun and shade. The spectra do, however, demonstrate again that although the U-V-KILLER (TM) does reduce the reflectance of the camo in the UV, it increases it in the visible blue. This effect is especially strong in the shade and is much stronger than any reduction in FWA glow resulting from use of the U-V-KILLER (TM). The increased blue reflectance caused by the U-V-KILLER (TM) is probably also seen when the product is applied to blaze orange hunter clothing (an application recommended by ATSKO, Inc.). Figures in their product brochure show a blaze orange camo sample reflecting (or emitting) more light in the 400-550 nm portion of the spectrum after spraying with U-V-KILLER (TM). This brightening in the blue would be desirable if the camo garment a hunter was wearing initially appeared too dim in the blue part of the spectrum, but it would reduce the effectiveness of any camo that was printed with dyes that matched the foliage reflection spectra before the use of U-V-KILLER (TM).

In summary, if a person hunting under the ambient light levels considered in this study wanted to blend in with the spectra of typical foliage in western Oregon, standard US Army green camouflage would work very well. For persons using other camouflage cloth which might or might not contain FWA, the match to the foliage spectra is less certain, but there is no indication in this study of a serious compromise in the camo caused by FWA in the cloth. No evidence of a "glow" in the UV portion of the spectrum that would make a camo garment stand out from foliage like a "red tomato on a green vine" was found. In fact the use of the U-V-KILLER (TM) spray caused the camo samples to reflect less UV and more visible blue light than un-sprayed camo. If a camo was too bright in the UV and too dim in the visible blue under the ambient lights used in this study, the use of U-V-KILLER (TM) might correct this problem. However, if the camo dyes matched the spectra of the natural foliage to begin with, the U-V-KILLER (TM) would upset this match. Perhaps in the future, makers of hunter's camouflage will publish spectra of their garments and natural foliage spectra from
different areas so that hunters can determine the quality of the match between their camo clothing and the area in which they will be hunting.
Footnotes

a. Letter from Jay Neitz, PhD to Mr. Dan Gutting included in a booklet entitled "How game animals see the ultraviolet spectrum" by Kurt von Besser. This booklet is included in the combination packages of U-V-KILLER (TM) spray and SPORT WASH produced by ATSKO, Inc. Only the effects of the U-V-KILLER (TM) is reported in this study.

b. These agents are referred to on detergent labels as "optical brighteners," but many scientific resources refer to them as fluorescent whitening agents. Occasionally they are also referred to as "UV brighteners" which can lead to confusion because they do not increase the amount of light emitted or reflected by a fabric in the UV part of the spectrum. In fact, the FWA reduce the amount of light coming from the fabric in the UV because they absorb light in this region of the spectrum.

c. U-V-KILLER (TM) and SPORT-WASH (TM) are marketed by ATSKO, Inc., 2530 Russell S.E., Orangeburg, SC 29115. The 18 oz bottles of U-V-KILLER (TM) and SPORT-WASH (TM) retail in sporting goods stores for $10 to $15.

d. If the dichromatic system in the ungulates functions in the same manner as a human dichromatic system, the animal would see objects as combinations of only two colors. It would have a neutral point which could not be discriminated from white in the central portion of its spectrum, and would see all wavelengths above this point as one color and all wavelengths below it as a second color. No wavelengths on one side of the neutral point could be discriminated from other wavelengths on the same side of the neutral point; for example, if an animal's neutral point was at 500 nm, 480 and 430 nm stimuli could not be discriminated from each other on the basis of color. However, stimuli with wavelengths on opposite sides of the neutral point could readily be discriminated on the basis of color. This animal would not be able to discriminate wavelengths humans would see as blue from UV wavelengths, but could discriminate...
these wavelengths from longer wavelengths that would appear yellow or red to humans.

e. From the booklet entitled "How game animals see the ultraviolet spectrum" by Kurt von Besser. This booklet is included in the combination packages of U-V-KILLER (TM) spray and SPORT WASH produced by ATSKO, Inc.

f. Radiometric spectra indicate the amount of energy coming from a stimulus at each of several wavelengths. Such a spectrum cannot be used to describe the overall "brightness" of the stimulus because it does not take into account the sensitivity of the observer to each wavelength. A photometric spectrum can be used to define brightness, but only for an observer with a known sensitivity to each wavelength. Since the sensitivity of game animals is unknown, photometric spectra cannot be used to describe the brightness of stimuli as the animals would see them. Although radiometric spectra cannot be used to define overall brightness, if the observer has a visual system that can detect a given wavelength, it is reasonable to assume that a stimulus producing greater energy at that wavelength would look brighter than a stimulus producing less energy.

g. The manufacturer of U-V-KILLER (TM) advocates its use on blaze orange hunting garments to reduce the fluorescence of the garment. According to ATSKO's product brochure, this will make the garment less visible to game animals, but will still allow the garment to be seen by other hunters. The brochure notes that garments sprayed to block their fluorescence exceed safety standards in all states.

h. Curves on the back cover of the brochure packaged with U-V-KILLER (TM) indicate that in very deep twilight and at night the relative amount of ambient UV light increases with respect to the amount of visible light. This change in ambient light could have an effect on camo spectra, but the significance of such an effect which would be most apparent at the very beginning and end of the legal
hunting period (hunting is allowed from one-half hour before sunrise to one-half hour after sunset in Oregon) is presently unknown.

The changes in ambient UV levels might not be quite as straight-forward as the brochure's graphs suggest, however. The relative proportion of UV in the ambient light is a function of many factors. The upper atmosphere absorbs most of the UV light from the sun so that it never reaches the surface of the earth. This is why the amount of UV in the ambient light tends to increase with altitude. Short wavelength light is also scattered out of sunlight more than long wavelength light so that direct sunlight appears redder at sunrise and sunset when the sunlight must pass through more of the atmosphere. However, atmospheric clouds and water vapor filter out or reflect more visible light than UV and this can increase the proportion of UV in the ambient light.

The proportion of UV also changes seasonally; in the winter when sunlight must pass through more of the atmosphere, the visible radiation is barely diminished but the UV at noon is cut by 50 percent or more. (Berman B. Getting a winter tan. Discover; Jan 1992:80.) These factors make it very difficult to generalize with any degree of certainty about the ambient light spectrum that would be encountered at any particular location and time without actually making measurements at that location and time. Such measurements are currently being made at typical hunting sites in Oregon.
FIGURE CAPTIONS

Figure 1. The effects of a typical FWA. Note the significant absorption by the FWA in the UV portion of the spectrum and the emission in the visible blue at about 430-440 nm. The addition of the FWA "darkens" the cloth in the UV and "brightens" it in the blue as indicated by the reflectance values over 100%. Figure shown is slightly modified from a figure supplied by Arthur Dale, CIBA-GEIGY, Inc.

Figure 2. Spectra obtained from new and U-V-KILLER (TM) sprayed white cotton/poly cloth in the sun and shade.

Figure 3. Sun and shade spectra obtained from new white cotton/poly cloth and cloth washed 5 times in Tide detergent.

Figure 4. Spectra from new and U-V-KILLER (TM) sprayed green camo in the sun.

Figure 5. Spectra from new and U-V-KILLER (TM) sprayed green camo in the shade.

Figure 6. Spectra from foliage samples and an open field in the sun.

Figure 7. Spectra from foliage samples and an open field in the shade.

Figure 8. Spectra from new and U-V-KILLER (TM) sprayed green camo in the sun and the limits of the foliage spectra in the sun as shown by solid lines.

Figure 9. Spectra from new and U-V-KILLER (TM) sprayed green camo in the shade and the limits of the foliage spectra in the shade as shown by solid lines.

Figure 10. Spectra from Army green camo and foliage in the sun.

Figure 11. Spectra from Army green camo and foliage in the shade.

Figure 12. Spectra from new and U-V-KILLER (TM) sprayed gray camo in the sun and the limits of the foliage spectra in the sun as shown by solid lines.

Figure 13. Spectra from new and U-V-KILLER (TM) sprayed gray camo in the shade and the limits of the foliage spectra in the shade as shown by solid lines.

Figure 14. Ambient spectra obtained by reflection from a barium sulphate surface.
REFERENCES

Acknowledgments

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FIGURE 1

SPECTRA FOR WHITE COTTON CLOTH
WITH AND WITHOUT FWA

ULTRAVIOLET

VISIBLE LIGHT

REFLECTANCE IN PERCENT

BLEACHED COTTON CLOTH
WITH FWA

BLEACHED COTTON CLOTH
WITHOUT FWA

WAVELENGTH IN NM
NEW WHITE FABRIC VS UV KILLER
SPRAYED WHITE FABRIC

RELATIVE RADIANT POWER

WAVELENGTH (NM)

- New Fabric in Sun
- Sprayed Fabric in Sun
- New Fabric in Shade
- Sprayed Fabric in Shade
NEW WHITE FABRIC VS
FABRIC WASHED IN TIDE

- - - New Fabric in Sun
- - - Tide Washed in Sun
- - - Tide Washed in Shade
- - - New Fabric in Shade

RELATIVE RADIANT POWER

WAVELENGTH (NM)

300 350 400 450 500
NEW VS U-V-KILLER SPRAYED GREEN CAMO IN THE SUN

RELATIVE RADIANT POWER

WAVELENGTH (NM)

- New Green Camo in Sun
- Green Camo Sprayed in Sun
NEW VS U-V-KILLER SPRAYED GREEN CAMO IN THE SHADE

RELATIVE RADIANT POWER

WAVELENGTH (NM)

- New Green Camo In Shade
- Green Camo Sprayed in Shade
FOLIAGE AND OPEN FIELD IN SHADE

RELATIVE RADIANT POWER

300 350 400 450 500
WAVELENGTH (NM)

Ferns in Shade
Fir Branches in Shade
Grass in Shade
Fir Bark in Shade
Open Field in Shade
NEW VS U-V-KILLER SPRAYED GREEN CAMO AND FOLIAGE BOUNDARIES IN THE SUN

- ● New Green Camo in Sun
- ○ Green Camo Sprayed in Sun

RELATIVE RADIANT POWER

WAVELENGTH (NM)
NEW VS U-V-KILLER SPRAYED GREEN CAMO AND FOLIAGE BOUNDARIES IN THE SHADE

RELATIVE RADIANT POWER

WAVELENGTH (NM)

- New Green Camo in Shade
- Green Camo Sprayed in Shade
ARMY GREEN CAMO AND FOLIAGE IN SUN

RELATIVE RADIANT POWER

0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6

WAVELENGTH (NM)

300 350 400 450 500

- • Army Green Camo in Sun
- • Fir Branches In Sun
- Grass In Sun
- Ferns in Sun
- Fir Bark in Sun
- • Open Field in Sun

FIGURE 10
ARMY GREEN CAMO AND FOLIAGE IN SHADE

- Army Green Camo in Shade
- Ferns in Shade
- Fir Branches in Shade
- Grass in Shade
- Fir Bark in Shade
- Open Field in Shade

RELATIVE RADIANT POWER

WAVELENGTH (NM)
NEW VS U-V-KILLER SPRAYED GRAY CAMO AND FOLIAGE BOUNDARIES IN THE SUN

- □ - New Gray Camo In Sun
- □ - Gray Camo Sprayed In Sun

RELATIVE RADIANT POWER

WAVELENGTH (NM)
NEW VS U-V-KILLER SPRAYED GRAY CAMO AND FOLIAGE BOUNDARIES IN THE SHADE

RELATIVE RADIANT POWER

WAVELENGTH (NM)

- - New Gray Camo In Shade

- - Gray Camo Sprayed In Shade
AMBIENT SPECTRA MEASURED IN SUN AND SHADE

- Spectrum In Sun at 2:04 pm
- Spectrum In Sun at 3:03 pm
- Spectrum In Shade at 5:10 pm
- Spectrum In Shade at 5:26 pm