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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Building Physics Division
Washington, DC 20234

March 1984

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THE ROLE OF COLOR IN LIGHTING FOR MEAT AND POULTRY INSPECTION

Belinda L. Collins
James A. Worthey

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

The role of color in lighting for meat and poultry inspection is discussed. A review of literature relevant to the problem of quality of illumination is presented, along with literature specific to agricultural and veterinary problems. A psychophysical study of the accuracy of detecting and identifying selected defects in meat and poultry was conducted under five light sources: incandescent, cool white fluorescent, cool white deluxe, high pressure sodium (HPS), and low pressure sodium (LPS). The results indicated that more errors were made under the last two sources, and that the inspection task was rated as more difficult under these sources. In addition, spectroradiometric measurements were made of defective and adjacent "normal" tissue to document the kinds of spectral reflectances that exist in four species: chicken, cattle, turkey, and swine. These measurements indicated that differences in spectral reflectance characterized much of the tissue studied. Based on these data, recommendations are made to avoid the use of light sources with poor color rendering qualities and low color temperatures for the inspection task.

Key words: chromaticity, color, color appearance, color rendering, energy-efficient light sources, illumination, inspection, meat, poultry, spectral reflectance.

FOREWORD

This report documents the results of National Bureau of Standards (NBS) research in support of the U.S. Department of Agriculture (USDA), in fulfillment of USDA/NBS Interagency Agreement No. FSIS 12-37-432, entitled "Lighting Quality Guidelines." The report summarizes work conducted during the period July 1983 through February 1984.

We wish to acknowledge the helpful interest and guidance of the sponsor's Project Officers, Mr. John Wu and Mr. Ralph Thompson, of the Food Safety and Inspection Service, the willing cooperation of the USDA inspectors, and processing facilities who participated, and the invaluable assistance of Dr. Robert Turnquest of USDA.

DISCLAIMER

Certain commercial equipment, instruments, or materials are identified in this report to specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

ACKNOWLEDGMENTS

The authors wish to acknowledge the efforts of all those who participated in this project and who provided insightful comments during the review process. We are particularly grateful to the following people: Mrs. Mary Natrella, Dr. Gerald Howett, Mr. Jim Heldenbrand, Dr. Arthur Rubin, Mr. Bob Booker, and Mr. Larry Kaetzel, as well as Ms. Lisa Gray.

EXECUTIVE SUMMARY

Although current U.S. Department of Agriculture (USDA) regulations for meat and poultry inspection provide specific requirements for illumination levels (illuminance) for inspection stations, they do not provide any guidelines for the color or quality of the illumination. As a result, a light source which does not render color accurately can potentially be used.

Commercially available light sources vary widely in their ability to reveal colors accurately in comparison with a reference source. Some, although energy efficient, have poor color rendering properties.

USDA sponsored a project at the National Bureau of Standards (NBS) to explore the role of color in the meat and poultry inspection process. Three approaches were followed in the project: a review of published research; a psychophysical study of the detectability and recognizability of meat and poultry defects under light sources with different color rendering properties; and spectroradiometric measurements of selected tissue samples in four species.

The review of the literature indicated very little research on the specific problem of color rendering and light quality for meat and poultry inspection. The research literature defining color and color rendering is summarized to provide background information to those unfamiliar with these concepts. In addition, some information is presented on the perception of colors under different light sources, as well as on some issues in lighting for veterinary and agricultural use.

For the psychophysical experiment, meat and poultry inspectors participated in a study designed to determine if light sources with different color rendering properties had differing effects on the ability to detect and identify common defects and disease. In this experiment, 18 poultry and 16 meat inspectors observed 5 different meat or poultry tissue samples under each of 5 different light sources. Light sources included: incandescent, cool white fluorescent, cool white deluxe fluorescent, high pressure sodium (HPS), and low pressure sodium (LPS).

The results indicated that more errors were made for detecting and identifying tissue samples under HPS and LPS lamps than under the other sources. It was also found that inspectors rated their task as more difficult under HPS and LPS, and provided many negative comments about these two light sources. While problems arose with selecting samples that properly represented the meat tissues customarily seen by red meat inspectors, results for the cattle portion of the experiment demonstrate error trends similar to the results found in the poultry portion.

Spectroradiometric measurements were also made of the tissue samples studied in the psychophysical experiment for chickens and cattle as well as for turkey and swine tissue. These measurements demonstrated clear differences in lightness and spectral reflectance between a defect and its adjacent, more normal surroundings. While further analysis is needed to assess the effects of manipulating light source characteristics (such as spectral power distribution) on the color

differences believed to exist in the tissue samples, these measurements represent one of the first field determinations of the spectral composition of meat and poultry tissue. Such measurements are an essential first step in calculating the effect of light source variation.

The conclusions include a recommendation that sources with color rendering indices (CRI) (and color temperatures) equal to or less than that for HPS should not be used for meat and poultry inspection. Sources with CRI equal to or greater than that for cool white fluorescent lights appear adequate along with sources with color temperatures equal to or greater than that of the incandescent source used in the psychophysical study. Further research is needed, however, to determine if performance can be improved (or inspector visual comfort increased) for sources with truly good rendering characteristics. In addition, mathematical calculations are needed to predict the role of specific light sources on the color differences associated with meat and poultry tissue.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

1. INTRODUCTION

At the present time, all meat and poultry intended for human consumption is fully inspected by the U.S. Department of Agriculture (USDA) for disease, contamination, and defects. The inspection is done at one or more inspection stations staffed by USDA personnel along the normal production line. USDA regulations for inspection specify that adequate light must be provided specifically for each inspection station. Specified illumination levels (illuminance) given in the regulations vary with the inspection station and species.

The USDA regulations currently make no specific requirement for the quality of the illumination. The advent of high-intensity discharge (HID) light sources, with improved energy efficiency (luminous efficacy) but often poor color-rendering properties has raised the issue of the importance of the color-rendering properties and spectral distribution characteristics of the light source used for the inspection process. At present, any light source may be used, even one which distorts the appearance of the colors of the product.

As a result, USDA sponsored a project at the National Bureau of Standards (NBS) in which the role of color in lighting for meat and poultry inspection was examined. In this project, several concurrent tasks were undertaken to define the role of color in the inspection process. In the first, existing research literature was reviewed. Second, a psychophysical experiment was conducted to determine the accuracy of detecting defects under selected light sources for poultry and cattle inspection. Third, the spectral reflectance of selected samples of normal and rejected tissue from four animal and poultry species was measured spectroradiometrically.

The present report summarizes the results of the NBS research, and provides recommendations to USDA for minimal levels of color rendering needed for inspection stations. It also provides background information on the general role of color in lighting as a framework for the recommendations.

1.1 BACKGROUND INFORMATION ON THE INSPECTION PROCESS

Before discussing results from the NBS research, some background information on the meat and poultry inspection process is needed. In a typical packing house, the animal or bird is suspended by its feet, killed, bled, and immediately processed. Following the kill, it begins its movement through the packing plant with different processing procedures occurring along the line. It is inspected by USDA at specified locations as it moves through the plant. Inspection procedures for poultry and red meat differ due to size and line-speed differences.

There are currently two types of inspection process for young chickens--traditional and modified traditional. (USDA regulations allow either process in a poultry plant.) For the traditional inspection process, the whole bird including the viscera is viewed by only one inspector at a line speed which varies according to the processing plant. Illumination levels (illuminance) are required to be 50 footcandles (fc) at the inspection surface. For the modified traditional inspection (MTI), the outside of the bird is first viewed

by one inspector who uses a mirror to see the back side. Line speed here is 70 birds per minute. Next two inspectors view the viscera, and interior cavity, alternating birds for an effective line speed of 35 birds per minute, per inspector. Lighting levels for MTI are required to be 150 fc. Illuminance requirements for turkey inspection are similar to those for traditional chicken inspection.

For red meat inspection, both swine and cattle, inspection typically occurs at three stations along the line. At the first station, the head station, the inspector examines the head for problems in the lymph nodes, eyes, etc. At the second inspection station, the viscera table, the inspector examines the internal organs by sight, slicing, and touch. The third inspection occurs at a "rail" station where the carcass is examined. Although detached, the viscera and head remain associated with the carcass until they have been checked for signs of disease that could force condemnation of the entire carcass. Typical speeds for red meat inspection vary widely and depend on the plant slaughter rate. Slaughter rates vary from one per hour to 300 per hour for cattle, and from one to 1100 per hour for swine. Illumination levels are recommended to be 50 fc. An antemortem inspection is also conducted. Lighting levels are typically lower here.

1.2 LITERATURE REVIEW

A computerized literature search was conducted to determine if there had been previous research on the role of lighting quality and color appearance in meat and poultry inspection. This search included an examination of data bases for human and veterinary medicine, agricultural inspection, color rendering and lighting, and general engineering. Relatively little recent research on illumination engineering for meat and poultry inspection was discovered, with almost no information on the problem of lighting quality and color. Those documents that provide relevant information will be discussed below.

One of the few sources that directly addresses the problem of lighting for poultry inspection was written by the Joint Committee on Farm Lighting of the Illuminating Engineering Society and of the American Society of Agricultural Engineers. Their report on "Lighting for the Poultry Industry" (1970) provided guidelines for lighting in processing plants as well as poultry farms. For processing plants, it recommended a general lighting level of 70 fc (excluding killing and unloading areas), and 100 fc for government inspection and grading stations. It noted that factors which affect the quality of a lighting installation are: uniformity (the ratio of maximum illumination to minimum); minimization of shadow and glare (from direct beam radiation or reflection from glossy surfaces); light source color; and environmental factors such as room surface reflectance. No mention was made of the color rendering properties of the light source, however. The report recommended limiting use of clear mercury and high pressure sodium (HPS) to outdoor applications, while allowing indoor use of improved mercury and metal halide with suitably shielded luminaires. It noted, however, that all these lamps are characterized by slow restart. While slow restart is not usually a problem for fluorescent lamps, they may not operate properly under cold conditions (requiring a special ballast and enclosure to maintain lamp temperature). They may have problems starting under conditions

of high humidity, as well. In addition, a common problem in such processing plants is that of water spray striking and breaking a hot lamp. This problem can be minimized by careful luminaire design.

The report also presented data obtained with the Visual Task Evaluator (VTE)[1/] for illumination levels needed to perform different visual tasks in the poultry inspection process. The following results were measured for poultry: to detect white spots on liver and spleen (1.1 fc); detect bruise on carcass (2.8 fc); detect 1/2-in diameter breast blister (11.0 fc); detect synovitis (28.0 fc); detect bruise on wing joint (57.0 fc); and detect liver leukosis or tumor (1000 fc). No recommendations were given for the color rendering properties of light sources for the detection of such poultry defects.

Ries (1982) reported results from a survey of lighting for meat packing and processing plants. He noted that use of incandescent lighting can lead to a large electric energy bill, not only for lighting but also for cooling equipment to remove the heat from the lights. He suggested that use of incandescent lights can account for as much as 27-44 percent of the total electric bill if the cost of cooling is included. Ries commented that a comparison of the lumens-per-watt output (or luminous efficacy) of seven different potential light sources for packing plants indicated that incandescent, quartz, and mercury vapor lamps were potentially less efficient, while fluorescent, multi-vapor (metal halide) and both high and low pressure sodium were potentially much more efficient. (Despite the high efficiency of low pressure sodium, Ries suggested that it should be confined to outdoor use because of its monochromatic nature.)

Ries noted that the following constraints apply to lighting a processing plant: bulb breakage and replacement (due to water hitting the bulb); fixture corrosion due to atmospheric moisture; and cold temperatures in refrigerated rooms (where heat from lights is a particular problem). The cost of electric lighting includes the cost of electricity to operate the lights, replacement or relamping costs, energy to remove heat dissipated by the lamps, and initial lamp costs.

Ries presented calculations showing that reductions in lighting cost associated with changing from incandescent (tungsten) lighting to HPS at one site were as great as 85 percent. At another site, a reduction of 69 percent occurred after switching from mercury to HPS, while at a third, changing from incandescent to fluorescent led to a 70 percent reduction in operating costs. Thus, switching to more efficient sources has a dual potential for reducing overall electric costs. The lamps with higher luminous efficacy require less electric power to provide a given illuminance and consequently generate less heat.

[1/] The IESNA Handbook (1982, p. 1-30) defines the VTE as a: "contrast reducing instrument which permits obtaining a value of luminance contrast, called the equivalent contrast C of a standard visibility reference task giving the same visibility as that of a task whose contrast has been reduced to threshold when the background luminances are the same for the task and the reference task."

The Illuminating Engineering Society of North America (IESNA) (1981) noted the following items that must be considered in estimating lamp costs: cost to operate the lamp; lumen output; luminaire dirt depreciation; initial lamp cost; replacement cost; and rated life. Different lamp types vary in: sensitivity to ambient operating temperatures, warm-up and restart times, and optimal operating position. The IESNA (1981) gives the following estimates for lamp life:

Incandescent--750-1000 hours
Fluorescent--10,000-20,000 hours
Metal halide--15,000-20,000 hours
Mercury--24,000+ hours
High Pressure Sodium--20,000-24,000 hours
Low Pressure Sodium--18,000 hours

Although each of these factors must be considered when selecting a light source for meat and poultry processing, one of the most important factors has not even been mentioned--namely, the color rendering properties of the light source. Currently available light sources vary in color rendering with the highly efficient sources often having poorer color rendering properties than less efficient ones. The color-rendering properties of a light source determine a person's ability to perceive colors presented under that source, and consequently play a key role in the meat and poultry inspection process.

1.2.1 Background Information on Color and Lighting

Before discussing the color rendering properties of light sources, some background information on color is necessary. The color of an object such as a piece of meat depends on three things: the spectral power distribution of the light source (or energy emitted by the source at each wavelength); the spectral reflectance of the object; and the spectral sensitivity of the observer's eye. In the present report, the observer is assumed to have normal color vision characterized by three types of color receptors, sensitive in the blue, green, and red regions of the visible spectrum.

One of the most common systems for specifying the color of an object or light is the system specified by the Commission Internationale de l'Eclairage (CIE). This system is based on the principle that three fixed colored lights (or primaries) can be mixed to match any other color. The amounts of the three primaries needed for this match have been termed the tristimulus values. The CIE specified a Standard Observer based on the average match values given by a number of observers (Wyszecki and Stiles, 1967). The values given by the CIE 1931 Standard Observer are considered representative of the normal human eye (for stimuli subtending visual angles between 1 and 4°).

The CIE system defines three functions of wavelength, $\bar{x}$, $\bar{y}$, and $\bar{z}$, which represent the tristumulus values of single wavelengths of the spectrum. Hurvich (1981) points out that specifying the color of an object requires knowledge of the reflectance spectrum of an object's surface and the spectral energy distribution of the light source illuminating the object. If these two distributions are multiplied together, and then multiplied again by the standard observer

stimulus values at each wavelength, and the resultant values added together for all wavelengths, one obtains a set of summed numbers termed the X, Y, and Z tristimulus values of the illuminated object. Together, these three numbers describe the color of a light as a stimulus to color vision. For many purposes, it is convenient to work with a different set of numbers (Y, x, y), in which Y has the same meaning, while

$$x = \frac{X}{X+Y+Z}$$

and

$$y = \frac{Y}{X+Y+Z}$$

The quantities x and y are termed "chromaticity coordinates;" chromaticity (x,y) is the physical correlate of a light's color, independent of intensity. The intensity information is carried by Y, and the CIE system is so contrived that Y is equal (or proportional) to luminance as measured by ordinary light meters.

If chromaticity (x,y) is computed for monochromatic lights throughout the visible spectrum, and plotted as a graph with the x and y axes scaled equally, the result is a curve called the spectrum locus; it may be labelled along its length with wavelength in nanometers. The open end of the spectrum locus may be closed with a straight line, called the line of purples. Any color encountered will plot on or inside this closed curve. The plot of chromaticities containing the spectrum locus, illustrated in figure 1, is referred to as the chromaticity diagram.

The color of an object[1] is dependent not only on its spectral reflectance, but also on the spectral power distribution of the light illuminating it. The ability of different illuminants to reveal colors is known as color rendering.

1.2.2 Color Rendering and Color Temperature

The CIE chromaticity system takes a basic scientific fact, that only three numbers are needed to specify a light as a stimulus to color vision, and reduces it to a practical and explicit measurement method. This is the basis of the applied science of colorimetry, which provides a workable means of prediction and communication for makers and buyers of dyes and pigments, color televisions, and so forth. Colorimetry is used in illumination engineering for the specification of lamp colors. The more pressing problem in illumination, however, is one for which colorimetry does not provide a simple answer: "How will a particular light source affect the color appearance of objects?" This is known as the problem of "color rendering."

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[1] Non self-luminous

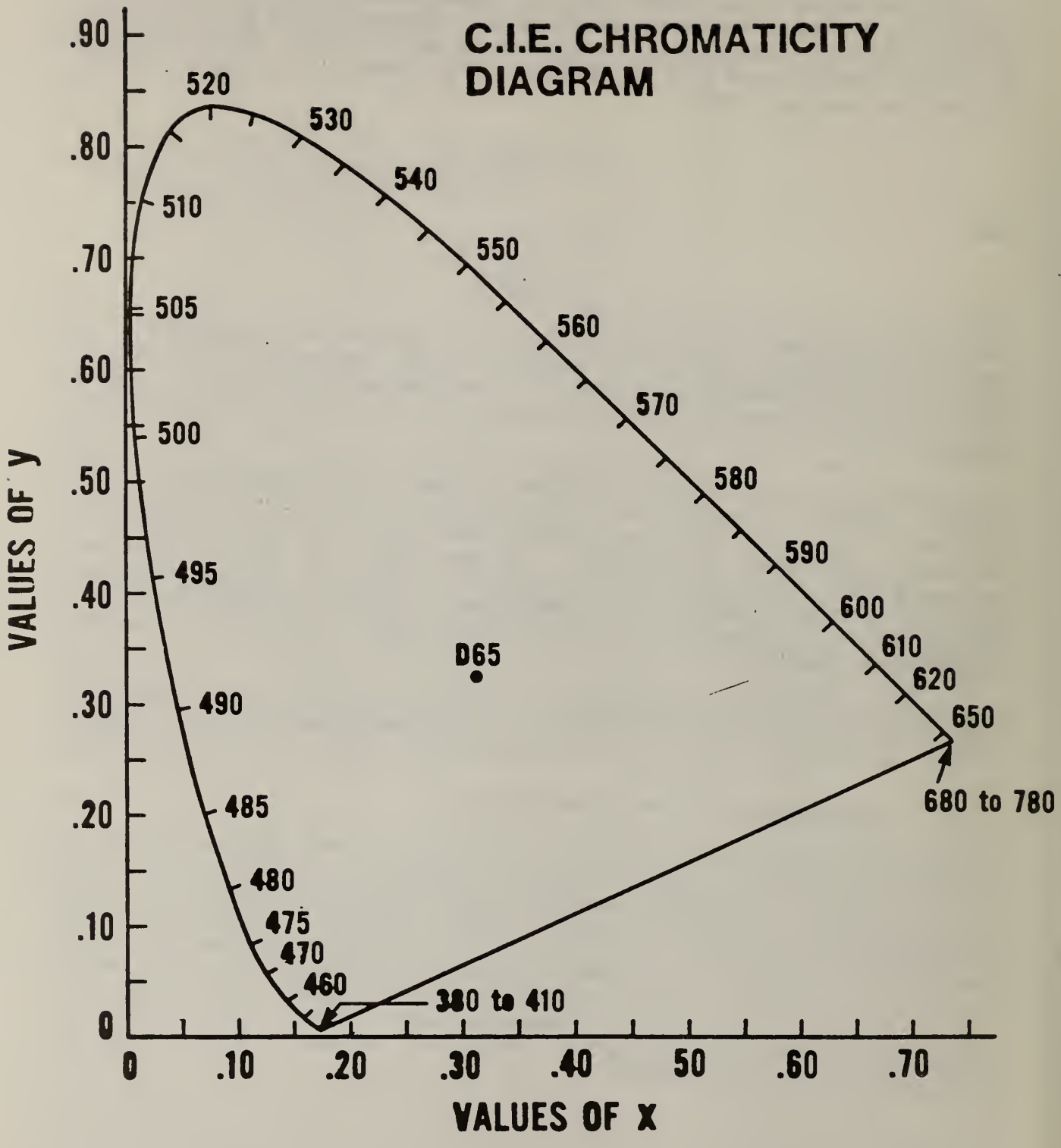

Figure 1. CIE chromaticity diagram

y treatment of color rendering must deal with issues that are absent when one nly wishes to describe an isolated light as a stimulus to color perception:

1. The objects lighted by a source could be anything, yet one seeks to generalize about the objects' appearance when the source is changed.

2. Whereas the CIE scheme of colorimetry is essentially a model of the initial response (absorption) of the visual receptors, a productive discussion of color rendering must deal with the eye's adaptation to different lighting environments, an issue ignored in calculating chromaticity. Adaptation data are available, of course, but models to summarize these data are a topic of current research.

3. Some standard of good color rendering is needed. It is easy to choose a standard, such as daylight or some approximation to daylight, but the question of the reasons for this choice remains. Could another light be better than daylight?

In subsequent sections of this paper, we try to skirt the conceptual difficulties of the color-rendering problem by looking at specific visual tasks and specific color contrasts.

The Color Rendering Index, like the chromaticity system, is officially defined in a publication of the CIE (1974). It is intended to be a "measure of the degree to which the perceived colours of objects illuminated by the source conform to those of the same objects illuminated by a reference illuminant for specified conditions" (CIE, 1974, p. 74). A standard set of "objects" is used, comprised of eight color chips, representing the hue circle from red through yellow and green to blue and back to red. A family of reference illuminants is defined, and the one to be used is that which is nearest in chromaticity to the test source. (In large measure, this sidesteps the adaptation problem.) The chromaticity coordinates of the eight chips in a uniform color space are computed for the test light, with a further small correction for adaptation if necessary, and then the color shifts are found by which these coordinates differ from those that the chips would have under the reference light. Finally, the CRI is computed to be 100 minus a certain constant times the sum of the magnitudes of the color shifts. Thus a "perfect" CRI is 100, with no color shifts at all, and any imperfect light has a CRI less than 100. Color rendering indices of less than zero are possible. Color Rendering Index is the commercially accepted way to specify lamp spectral quality. As such, it is used in the present report.

Another common way of specifying lamp color is known as color temperature. It is defined by the IESNA (1981), p. 1-8, as the "absolute temperature of a blackbody radiator having a chromaticity equal to that of the light source." As the temperature of a blackbody radiator (completely radiating source) is increased from about 800 to 10,000 K, it shifts in color from red to yellow (3000 K) through white (5000 K) to blue. Further, "the locus of blackbody chromaticities on the x, y diagram is known as the Planckian locus. Any chromaticity represented by a point in this locus may be specified by color temperature" (p. 5-13). The IESNA cautions that color temperature specifies the chromaticity

only of a light source and does not represent its SPD. Light sources with similar chromaticities (color temperatures) may differ widely in SPD. In addition, the perceived color of the light source (or blackbody) depends on the observer's adaptation state. The current CIE color rendering index compares the color rendering of a test lamp to that of a standard lamp with the same [correlated] color temperature. The IESNA (1981, p. 5-14, 5-15) notes that:

> "When it becomes possible to compute the effects of constancy and adaptation so that the results agree accurately with the facts of experience, it will then be possible in calculating the color rendering properties of a lamp to take correctly into consideration differences in lamp color, as well as differences in spectral power distribution of lamps that have the same color."

1.2.3 Visual Clarity

Aston and Bellchambers (1969, p. 259) observed that lamps of good color rendering gave to a scene a quality which seemed to go beyond "normal" appearance:

> For a given level of illumination (assuming this to be adequate for the purpose) it is generally accepted that a well-designed and balanced interior colour scheme, when illuminated by fluorescent lamps giving good color rendering, will be more attractive than the same interior illuminated by a source of poorer spectral quality. Observation has shown that the attractiveness is not due to the quality of the colour rendering of individual hues alone, but that some additional factor, variously referred to as colour or visual 'clarity', added to the attractiveness of the interior [Emphasis added.]

To test this idea in a systematic way, two identical colorful room-models were constructed, which could be lit by different fluorescent lamps. Observers were presented with the two models side-by-side. A dimmer was provided for one of the lights, and observers were instructed "to adjust the level in the lefthand cabinet ... so that the overall clarity of the scene is the same in both cabinets. By overall clarity is meant the satisfaction gained by you personally, discounting as far as possible any obvious differences in colour and brightness" (Aston and Bellchambers, 1969, p. 260). A lamp of good color-rendering always appeared on the left, and it was found that observers would accept a lower level of this light as providing equal "clarity" with a given level of lower color-rendering light. For instance, observers considered an illuminance of 800 lux from warm-white tubes to be equivalent to about 450 lux of the high color-rendering light.

Similar visual clarity results were found by Bellchambers and Godby (1972) and by Thornton and Chen (1978). While it had usually been assumed that only sources with broad spectral power distributions (SPD's) could provide desirable color rendering, Thornton and Chen's "good" lamp was a "prime color" type, whose SPD has much of its power in narrow bands at about 435, 530, and 620 nm.

nton and Chen propose an explanation of visual clarity in terms of a light's lity to make colors more or less distinguishable. It is easy to see that ghts do vary in this regard, because a monochromatic illuminant reduces all objects to shades of the same color. This issue may be thought of in terms of "discrimination" or of colorfulness. Suppose that under an illuminant of good color rendering, two object colors are just barely discriminable. If another light has the tendency to make these colors less different, then they will not be discriminable; they will look alike. On the other hand, a set of diverse object colors might simply become less diverse, hence less "colorful" under the second light.

Thornton (1972) observed that if a set of color chips, such as those used in the definition of CRI, are lighted by a test lamp, and then their colors are plotted in a uniform color space, they define a polygon or "gamut". The area of this gamut is a measure of how well object colors can be discriminated under a lamp. This is more of a "performance" measure than CRI, since the standard of a perfect SPD is not chosen in advance. Nevertheless, the rankings of illuminants by gamut area are in considerable agreement with those given by the CRI. In other words, daylight is not just a customary standard of lighting quality, it is actually a good performer with regard to color discrimination. A "prime color" lamp, similar to that mentioned above, gives a gamut area slightly larger than daylight (Thornton, 1972). With respect to such a lamp, gamut area clearly gives a different ranking than CRI, since CRI makes daylight best by definition.

Because the gamut calculation depends on the choice of eight specific color chips, it may appear arbitrary. Worthey (1982) found a way to describe differences among illuminants which does not depend on an arbitrary selection of colored objects. Reasoning from a comtemporary opponent-colors model of color vision, he derived formulas expressing a light's ability to reveal color contrasts. One computation yields a number predicting the magnitude of blue-yellow contrasts under a light; a second computation gives a number predicting red-green contrasts.

Calculation of these numbers for a variety of illuminants shows that while differences in blue-yellow rendering are generally small, differences in red-green rendering are large. Common fluorescent lamps, including cool white, systematically reduce red-green contrasts. So do high-pressure sodium vapor and high-pressure mercury vapor. This reduction in red-green contrasts can explain the results of the visual clarity experiments, since red-green contrasts are known to contribute to the perceived distinctness of borders (Frome, Buck, and Boynton, 1981). That is to say, lamps such as those which ranked poorly in the visual clarity experiments reduce the distinctness of borders in a scene which has a variety of colored objects. A similar argument can be made that certain lamps may reduce the perceived brightness of a scene, since color contrasts contribute to brightness. This argument is particularly applicable to high-pressure sodium light, since, according to Worthey's calculations, it is perfectly normal with respect to blue-yellow contrasts, but poor with respect to red-green (Worthey, 1982). These conclusions regarding clarity and brightness merit further experimental work. The actual ranking of illuminants according to red-green rendering is little different from a ranking according to gamut area.

Xu (1983) also sought to quantify illuminant performance in a way that did not involve the arbitrary selection of a set of color chips. He defined a measure called "color-rendering capacity" which is a measure of "the maximum possible number of different colors that can be displayed by a given illumination" (Xu, 1983, p. 1709). He observed that objects are sources of information, while light acts as an information carrier. Thus, color-rendering capacity is a measure of a light's ability to transfer information about objects, via the human color sense (Xu, 1983). Again, the ranking of illuminants by Xu's method is not radically different from a ranking by other methods. Perhaps the most important feature of Xu's work is that while Thornton (1972) and Worthey (1982) were implicitly concerned with a light's ability to reveal color information, Xu (1983) based his calculations directly on the information-theoretical concept of the number of different messages that a system can convey.

In summary, the visual clarity experiments, the color gamut calculations, the opponent-color calculations, and the color-rendering capacity calculations are all concerned with the same set of facts. That is, that color vision is a source of information about objects, and that many common light sources tend to lose this information--to one degree or another--by making colored objects look less different from one another than they would under normal daylight. In these methods, daylight is not chosen arbitrarily as a standard; rather, daylight is demonstrated to perform well in revealing color contrasts.

1.3 RESEARCH RELEVANT TO LIGHTING FOR MEAT/POULTRY INSPECTION

The lighting community has conducted extensive research on the problem of color rendering and appearance, though not specifically for meat or poultry inspection. Much of this research is beyond the scope of the present report, but will be addressed briefly here to provide some insight into the effects of varying the spectral composition of a light source on the appearance of colors viewed under it. The illumination research has typically focused on the prediction of color appearance and subjectively rated quality for different illuminants. Researchers have often assessed the effect of varying the illuminant on the appearance of a set of color chips. For example, Loe, Rowlands and Watson (1982) reported the subjective assessment of light quality in an art gallery, and on a color discrimination task involving colored chips. They varied both the illuminant (incandescent and different fluorescent lamps were studied) and the illuminance (either 300 or 1000 lux--30 to 100 fc).

Results from the color discrimination task indicated that increasing the illuminance did not affect task performance, but that changing the illuminant did. Illuminants with CRI in excess of 85 (and with a large gamut area) produced the best results. Interestingly, Loe et al. (1982) found that the tungsten light they used was not preferred for viewing paintings. They suggested that this may have occurred because its gamut area was smaller than that of two other fluorescent sources.

Boyce (1976) assessed performance on a color discrimination task involving colored chips for four different fluorescent lights and two different illuminance levels. Again, he found that increasing the illuminance level from 300 to 1000 lux (30 to 100 fc) did not improve performance. Subsequently Boyce and

Simons (1977) found that performance did improve slightly with higher illuminance, but only for participants aged 55 and older. Boyce commented that "The conclusion to be drawn from this is that even if colour discrimination does improve with illuminance above, say 300 lux, the effect is likely to be small. The implication therefore is that the use of good color rendering lamps is a considerably more relevant factor than illuminance in determining performance at color discrimination tasks at least as long as the illuminance is above the 300 lux suggested by the IES code as the minimum illuminance for continuously occupied interiors. It should also be noted that it will be advantageous to use good color rendering lamps at a lower illuminance rather than poor color rendering lamps at a higher illuminance in situations where the total lighting wattage is fixed" (Boyce, 1976, p. 11).

While Boyce's results on a color discrimination task indicated that one particular brand of fluorescent lamp (Northlight™) produced the most satisfactory results, similar research is needed for sources commercially available in the U.S. Specific recommendations about the "best" lamp for meat and poultry inspection can not be made on the basis of Boyce's results due to differences in the kinds of color discriminations required, and in the spectral power distributions of commercially available sources sold in the United States and the United Kingdom. Boyce's results do indicate that the spectral power distribution of a lamp affects the ability to discriminate colors accurately even for different commercially available fluorescent and incandescent lamps. Boyce commented that these results are of interest to other tasks where color discrimination is important. One such task is the "examination of foodstuffs for freshness or the medical examination of patients for diseases where the skin color is an important symptom. For such tasks the best light source is the one that gives the most accurate rendering of the color relative to the source under which the internal criterion was developed" (Boyce, 1976, p. 3).

In addition to the illumination engineering reseach, recent literature on lighting for human and veterinary medicine was examined to determine if there were any research on the role of color and lighting quality in detecting disease. Relatively little research on this subject appears to have been conducted.

One study by Charters (1966) noted that lighting for veterinary diagnosis and treatment rooms should provide maximum assistance. "This means a high level of illumination, freedom from unwanted shadows, and a quality of light which will ensure the instant recognition of changes in the colour of objects seen under it" (p. 29). He recommended use of fluorescent lighting due to its relatively high efficiency and because it is available in a wide range of colors. One lamp in particular was viewed as very close to "north sky daylight which is usually accepted as the best light by which to make accurate colour assessments" (p. 30).

Culver and Allard (1980) discussed the effects of lighting on the detection of allergic reactions in the skin of veterinary patients. They noted that overhead direct lighting reduced the contrast between the light and dark areas of the allergic reaction, whereas indirect light from the side appeared to make the reaction easier to interpret.

Finney (1973) discussed various quality measurements that can be made for agricultural products. He noted that quality characteristics include factors such as shape, color, size, density, moisture content, firmness, tenderness, oil content, flavor, etc. "Quality control of agricultural products, therefore, is concerned with instruments and techniques that can be used to measure accurately or to estimate the physical and chemical properties that are associated with the quality of the end product" (p. 1). Finney's book deals with different nondestructive evaluation methods, such as light transmittance and reflectance techniques, sonic and ultrasonic tests, and radiographic methods; all of which are tests involving the application and subsequent measurement of energy to a product. Light transmittance and reflectance measurements have been used to measure surface appearance--an important consideration in estimating the quality of agricultural products. This procedure is used for detecting defects as well as for sorting and analyzing different levels of quality. Most of these techniques have been applied to fruits and vegetables rather than to meat or poultry, but the techniques of nondestructive evaluation are equally valid for the latter.

Hall and Bobrick (1968) discussed problems related to establishing the optimal visual conditions for a dental operating suite. They suggested an illuminance of 2500 fc as desirable for general dental surgery. Although more recent research might reasonably have stressed the need to maximize contrast, rather than simply provide illuminance, recommendations for high illuminance appear common in the medical/dental/veterinary literature. The authors noted that the color quality of dental illumination is also extremely important due to the need to detect disease and to match restorations and dentures to the natural teeth for a wide variety of potential viewing conditions. In considering possible sources with good color quality, they rejected ordinary tungsten with a color temperature of about 3000 K because it has too much energy at the red end of the spectrum, and not enough in the blue. They noted that "This incandescent source tends to distort the colors of tissue within the mouth and, in particular, may mask the visual symptoms of dental disease--which emerge as a change in color with the addition of a component in the blue end of the spectrum. Since the incandescent is lacking in blue, this clue is lost" to the dentist (Hall and Bobrick, 1968, p. 19). The problem with fluorescent light[1/] is almost the opposite. "Because of the strong emission lines in the blue and green of a fluorescent source, healthy gum tissue tends to appear unhealthy (instead of vice-versa, as in the case of the incandescent source)" (Hall and Bobrick, 1968, p. 19). As a result, Hall and Bobrick suggested the use of a 3000 K incandescent lamp filtered to appear as a source operating about 4200 K, to achieve a color rendering index of about 90. Their study is one of the few which assessed the effect of varying light source on the color appearance of human or animal tissue.

The study presented in the following pages is a further attempt to delimit the role of light source in the accurate recognition of defective or diseased animal/poultry tissue. Data from a psychophysical study of tissue recognition under different light sources will be presented first, followed by measurements of the spectral reflectance of different meat and poultry tissue.

1/ These authors presented spectral source data for cool white deluxe leading one to assume that their comments apply to this source.

2. PSYCHOPHYSICAL EXPERIMENT ON POULTRY AND RED MEAT

2.1 OVERVIEW

To assess the role of the spectral distribution of the light source in meat and poultry inspection, a psychophysical experiment was conducted. This experiment was intended to test the hypothesis that sources with poorer CRI decrease an inspector's ability to reject defective and diseased tissue. The underlying theory is that these sources diminish the differences in color between a defect[1/] and the surrounding tissue.

In the experiment, conducted at both red meat (cattle) and poultry (chicken) packing houses, a portable light box was used to simulate the inspection station. This box allowed the presentation of different tissue specimens under different, commonly available light sources. It provided an area through which a tissue specimen could move in an attempt to simulate the movement on a normal inspection line. The box was designed to control the visual environment surrounding a tissue specimen, so that the effect of varying the light source on the inspection task could be studied.

For both poultry and meat, the inspector's normal task is to view each specimen as it moves past (suspended from a chain or lying on a moving surface, depending on the inspection station), and determine if a defect or disease is present. The inspector may condemn the specimen outright, take it off the line for veterinary inspection, or simply have a defective area "trimmed" or cut off. All of these actions require that he/she notice the defect or disease. For the psychophysical experiment, the ability to perform the task was defined as accuracy in making a pass/reject judgement and in identifying the nature of a defect. Although inspectors may also touch and slice tissue to find defects, particularly for red meat, the present study concentrated only on visual cues.

The same experimental design was used for the psychophysical experiment on both chickens and cattle. Five different tissue samples were selected by USDA veterinarians as representative of commonly occurring defects or diseases that would require one of the actions noted above by the inspector. Each sample was viewed under each of five light sources by one inspector at a time. The light source was changed after an inspector had viewed the five specimens. The five sources were selected to provide a broad range of CRI, from incandescent light to LPS. No attempt was made, however, to present the five specimens continuously, although a normal production line is in continuous movement.

2.2 APPARATUS

A portable light box was constructed to accomodate a series of interchangeable light sources (see figure 2). The box provided a viewing area, 20 in wide by 18 in deep by 14 in high, which was painted flat (medium) gray. The light sources could be placed one at a time in an upper compartment (20 in by 18 in

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1/ The term "defect" will be defined in the present report to include defect, disease, or contamination.

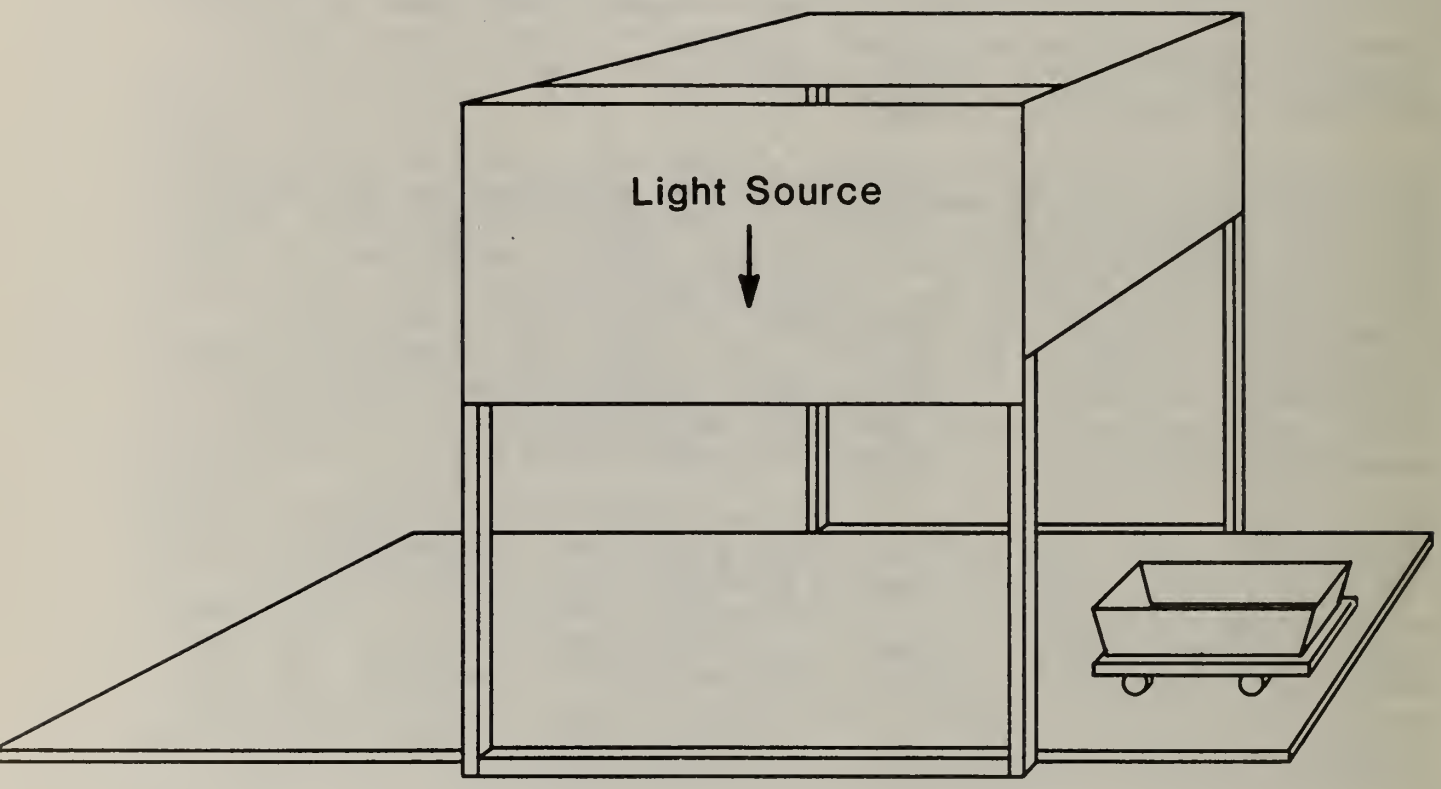


Figure 2. Sketch of portable light box

by 8 in) which was painted glossy white to maximize inter-reflections. The white upper compartment served to reduce the changes in lighting geometry resulting from light-source substitution. The light exited through a slit at the front of the upper compartment.

Light sources included incandescent or tungsten (TUN), fluorescent cool white (CW), fluorescent cool white deluxe (CWX), high pressure sodium (HPS), and low pressure sodium (LPS). These sources were chosen to provide a range of color rendering values from very good, incandescent, to very poor, LPS. Table 1 provides a further description of the sources, along with nominal color rendering index values from the IESNA Handbook (1981). Figures 3 and 4 present spectral power distributions of the actual light sources used in the experiment.

Table 1. Light Source Data

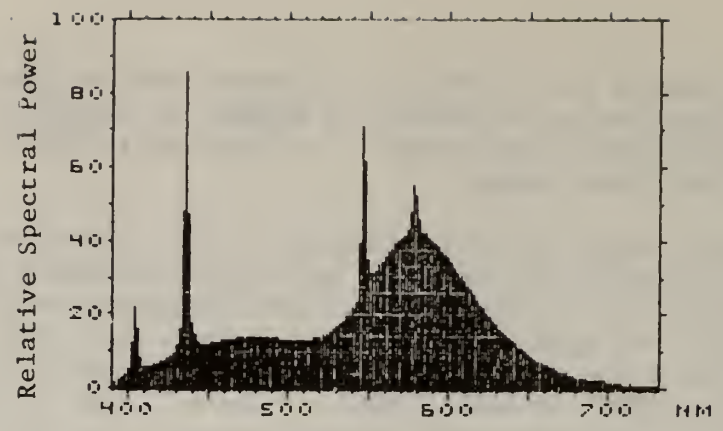
Source	Composition	Measured Color Temperature	Nominal Color Rending Index[1/]
Incandescent TUN	2 - 150 W bulbs	2765 K	100
Fluorecent CWX	2 - 15 W bulbs	4151 K	89
Fluorescent CW	2 - 15 W bulbs	4062 K	62
High Pressure Sodium HPS	1 - 35 W bulb	1772 K	21
Low Pressure Sodium LPS	1 - 18 W bulb	1740 K	- 44

2.3 PARTICIPANTS

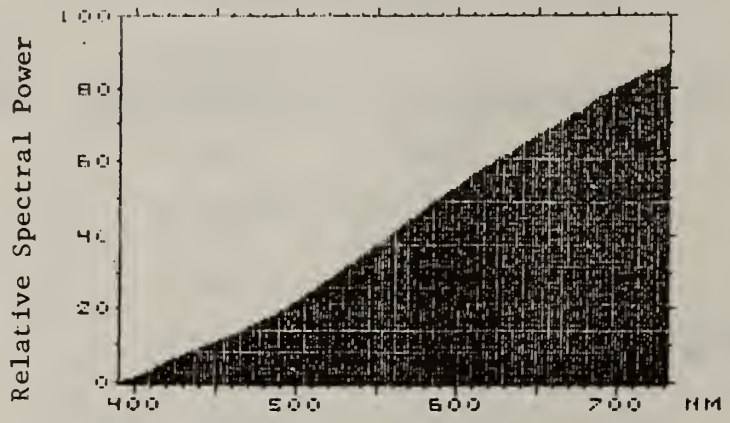
All participants for both the meat and poultry psychophysical experiment were USDA inspectors who volunteered for the study. The range of inspection experience was from 6 months to at least 22 years, with most inspectors having from 6 to 10 years experience. Eighteen inspectors paticipated in the poultry study, 9 males and 9 females. Sixteen inspectors participated in the red meat study, 14 males and 2 females. Four of these participants were veterinarians serving as the inspector-in-charge of a red meat plant.

The color vision of each inspector was screened individually by the American Optical Pseudo-Isochromatic Plates for Testing Color Perception (1965). All inspectors in the poultry study had normal color vision. Two of the red meat inspectors made 6 errors on the color vision test, and one refused to take the

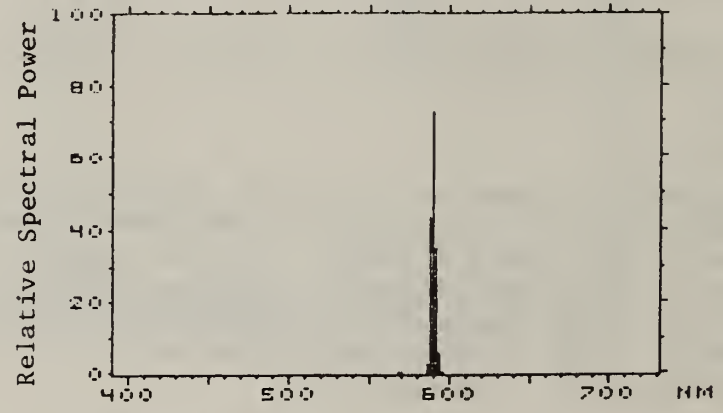
1/ Source - IESNA Handbook (1981).



a. Relative spectral power distribution of source #1, Cool White Fluorescent

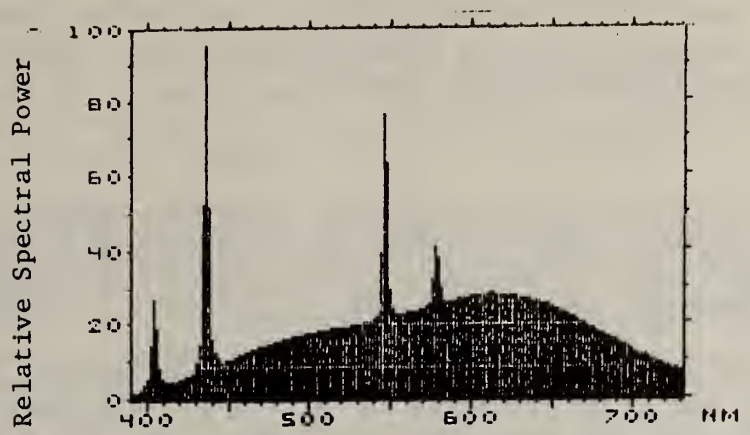


b. Relative spectral power distribution of source #2, Incandescent

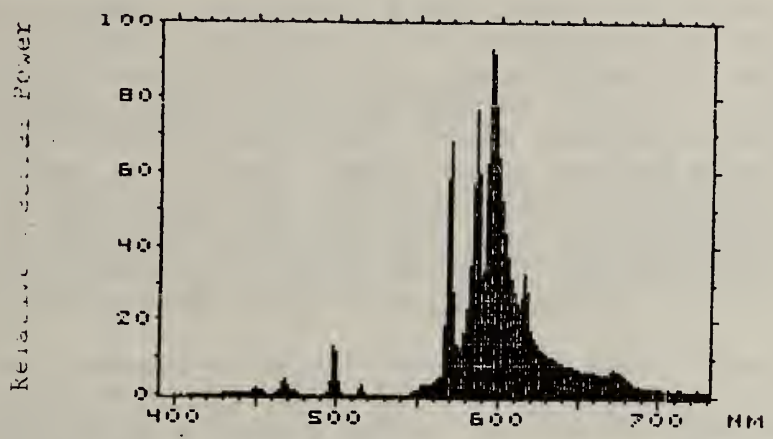


c. Relative spectral power distribution of source #3, Low-pressure Sodium. This source qualifies as monochromatic. It has the effect of eliminating color vision, except if fluorescent materials are present

Figure 3. Relative spectral power distribution functions of three of the light sources used in the simulated inspection experiments. These data were measured with with the telescopic spectroradiometer, from the surface of the PTFE whiteness standard, in the apparatus used for the inspection experiments



a. Relative spectral power distribution of source #4, Cool White Deluxe Fluorescent



b. Relative spectral power distribution of source #5, High-pressure Sodium

Figure 4. Relative spectral power distribution functions of two of the light sources used in the simulated inspection experiments. Measurement conditions were the same as in the previous figure

test. Since American Optical considers 5 or more errors to indicate red - green deficiency, some of the red-meat data are reported with and without the responses of the two possible color defective observers. Further testing is required for a definitive diagnosis, however.

2.4 PROCEDURE

The following description of the experimental procedure applies to both the red meat and poultry studies. The experiment was conducted on site at each processing plant, in a room normally used as a conference room or office. If windows were present in the room, they were covered to eliminate supplementary light.

At the beginning of the experiment, each inspector was brought into the experimental room, and given the Research Participant Agreement and Privacy Act Advisory Statement. At this time, inspectors were given the opportunity to decline to participate in the experiment. (One inspector did decline.) They were also told that the data describing their performance would be confidential, and that their name would not be recorded with their data, to ensure their privacy. The experimental instructions were then read and questions answered. Table 2 provides a copy of the instructions. The instructions asked participants to do three things after viewing each tissue sample: pass or reject it; identify the problem if any; and rate the ease of making the decision for each light source on a scale of 1 to 5 (where 1 meant easy and 5 meant difficult).

Time for each inspector to respond with a pass/reject judgment was also recorded manually by an experimenter with a stopwatch. The timing for a given trial began when the cart was started. The timing stopped when the inspector gave his/her decision. Because the cart did not instantly enter the viewing area, the sample was effectively obscured from view for about 2 sec. Thus, the actual decision-making time was always about 2 sec shorter than the response time recorded. Nevertheless, starting the stopwatch concurrently with the cart provided a convenient and consistent starting point. Although use of a manual timing procedure increased scatter in the data, it provided a reasonable means of estimating the relative effects of the different sources studied.

During the experiment, tissue samples were placed in (numbered) metal pans which could be placed on top of a motorized wooden cart (12 in by 9 in). This cart moved from left to right through the viewing area at a speed intended to simulate normal production line speed for chickens and to limit viewing time. Flexible baffles of aluminum foil were attached to both the right and left sides of the viewing area to obscure the approach and departure of the tissue sample and further limit viewing time. A lace curtain was also dropped in front of the viewing area to obscure the sample as it passed back through the box after the inspector's judgment. This blocked a clear view of the sample, while maintaining the experimental illumination. Room lights were turned off, but supplemental illumination was provided through a large aperture in the top of the light box so that source color would be the same. Horizontal illumination levels were maintained at 50 to 70 fc in the center of the viewing area, although there was variation from front to back of this area.

Table 2. Instructions to Participant

We are doing an experiment on lighting for meat and poultry inspection stations. We need your help in assessing the effectiveness of different lights. This particular study is intended to simulate your normal task on the inspection line, but using different lights.

We will show you different samples of meat (poultry) tissue under each light. You will see both good and bad samples. As you see each sample, we want you to decide if you would pass or reject each sample. By "reject" we mean condemn, hang back or trim. We would like you to make this decision as rapidly as you normally do. Tell us either "pass" or "reject," as soon as the sample disappears from view. We would then like you to tell us the reason for your decision. Finally we would like you to tell us how easy your decision was for the light source, by using a rating scale of 1 to 5, where 1 means easy and 5 means difficult.

To summarize, as each sample goes past you, we would like you to do three things.

1) Decide if the tissue sample should be passed or not passed. Tell us "pass" or "reject" based on your decision. Please tell us as quickly as possible.

2) Tell us the reason for your decision.

3) Tell us how easy your decision was on a scale of 1 to 5. The number 1 means easy and 5 means difficult.

We will then go to the next meat sample. You will see 5 samples under each light. Then we will change the lights and show you another series of samples. A total of five different lights will be used. Each judgment should take no more than one minute, so that the whole session should be done in about 35 minutes. If you become fatigued or uncomfortable, you are free to rest or stop the experiment.

Your data are covered by the Privacy Act and the Research Participant Agreement, which we will ask you to initial.

Thank you very much for your participation.

Do you have any questions?

After an inspector had completed the color vision test, and indicated that he/she understood the instructions, he/she was taken out of the experimental room. The first test light was then placed in the box. The inspector was then brought back into the room, and seated at a comfortable viewing distance from the light box (about 30 in). He/she was reminded to view each sample and make a pass/reject decision as rapidly as possible (to simulate the normal inspection process), and then to identify the problem (if any) and provide a rating of the ease of their decision. Five similar types of samples were seen under each of the five lights. Inspectors left the experimental room while each source was changed. At this time, their comments and their overall opinion of the source for the inspection task were recorded. Because each sample was viewed under each light source, each inspector saw a total of 25 samples. An experimental session took about 30-40 min to complete. Order of both sample and light source presentation was randomized for each participant.

2.5 POULTRY PSYCHOPHYSICAL STUDY

2.5.1 Sample Selection

Poultry samples were selected to be representative of commonly occurring defects, particularly those in which color might aid visual detection. Of the five samples that were selected, four were defective, and one normal. Because a pilot study had shown that chickens dry out over time, samples were changed after every 3-4 inspectors (or after about 2 hours). Samples were kept moist with wet paper towels when not in the viewing area to minimize drying. Nevertheless, the samples varied throughout the experiment, with no one sample being seen by every inspector. In an attempt to control sample uniformity, the inspector-in-charge, a USDA veterinarian, verified that each sample selected was a good representation of a type of defect. Figure 5 illustrates some examples of samples used in the study. A deliberate attempt was made to ensure uniformity of presentation, with all birds being about the same size, and all shown with viscera present. (Even though not all the birds in figure 5 contain viscera, viscera were added to them for presentation during the experiment.)

The following types of poultry samples were used: (1) normal; (2) tumor; (3) septicemia; (4) air sacculitis; and (5) gall stain. (For the last three inspectors, the tumor was replaced by leukosis because no chickens with tumors were available at that time.) These particular samples were chosen on the basis of color differences, frequency of condemnation in USDA statistics, and expected availability during the experiment.

2.5.2 Results for Pass/Reject Decisions

Data were collected and analyzed for several response categories. These included pass/reject decisions; identification judgments; rated ease of performing the task; response time; and comments about each source. Data and statistical analyses will be presented for each category in turn.

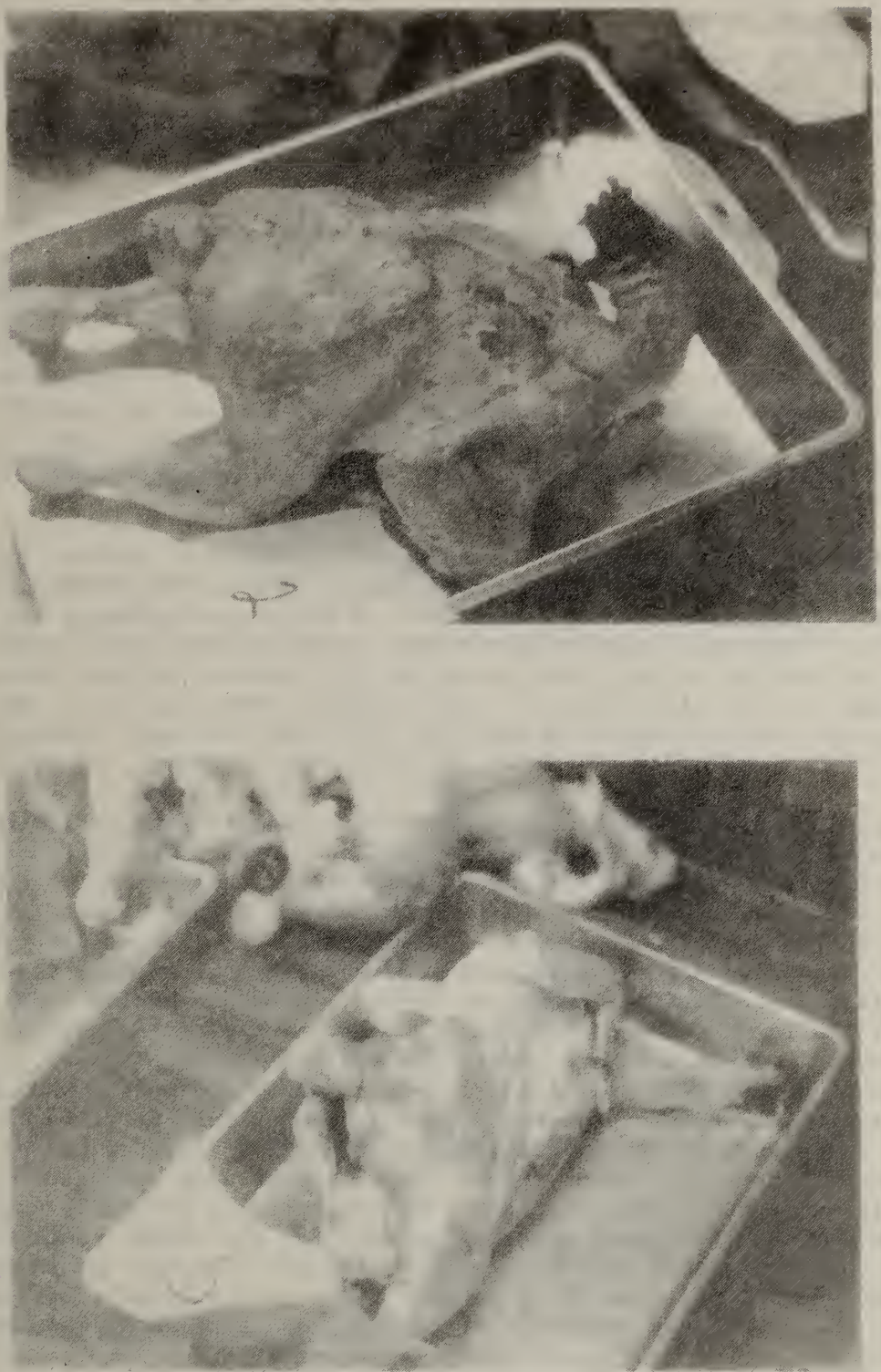


Figure 5. Selected samples used in poultry study

The pass/reject judgment represents the very first decision that an inspector makes. Inspectors were instructed that "reject" meant anything wrong with the sample from outright condemnation to "hang back for veterinary inspection" to "trim". "Pass" meant nothing wrong with the sample at all. A USDA veterinarian verified that the samples represented reasonable pass/reject decisions that would actually be made by the inspectors at each participating plant.

Table 3 presents the tabulated pass/reject errors for all samples (from 1 to 5) for each source. Samples are identified at the top of this table, while sources are identified along the left-hand side. The pass/reject data were tabulated to provide frequency counts of the number of errors made for a given sample under a given source. (This tabulation or "contingency table" results in a series of 25 entries or "cells" for the combination of five sources and samples.) A chi square (χ^2) analysis of this table was performed to test whether there was an interacting effect of light source and sample type on the number of errors made; in other words, whether relatively more errors were made for some samples under some light sources, than others. This analysis was significant ($p < 0.001$).

Smaller contingency tables were made to compare the number of correct and incorrect pass/reject decisions for light sources and then for samples. Table 4 presents this comparison for light sources. A chi square analysis was used to test whether there was a significant effect on error rate due to light source alone by looking at the total erors for all samples for each source. This comparison was not significant. Other analyses comparing CW or TUN (they had the same error rate) separately with CWX, HPS, and LPS, were also not significant.

Table 5 presents several comparisons of the errors made for the individual samples. The first, given in 5a, compares the total errors for each sample under all 5 light sources. The chi square analysis of this comparison was significant ($p < 0.001$), indicating that the number of errors in pass/reject decisions varied depending on the sample. Examination of the table suggests that fewer errors were made for septicemia and more for air sacculitis. Additional comparisons examined the number of errors for these samples under each light source. Table 5b compares the number of errors and correct decisions for the normal sample. The chi square analysis was significant ($p < 0.001$), indicating that more errors were made for the normal sample under LPS than under any other light source. Table 5c presents a similar comparison for air sacculitis. The chi square analysis of these data was also significant ($p < 0.025$). This comparison demonstrates that fewer errors than might be expected occurred for air sacculitis under LPS. This result may seem surprising initially until one stops to consider that the large number of errors for the normal sample under LPS suggests that inspectors tended to reject even good chickens under this source. Consequently, it is conceivable that the air sacculitis sample was rejected, not because of any knowledge of the sample's true condition, but simply because it "looked bad" under LPS. The identification data (see 2.5.3) were taken to explore the possibility that the light source affected an inspector's ability to identify sample type accurately.

Inspection of the data suggested that inspector performance varied somewhat. As a result, the performance of a subset of inspectors was analyzed. This

Table 3. Pass/Reject Errors for All Inspectors for Poultry

18 Inspectors

		Samples					
		Normal	Tumor	Septicemia	Air Sacculitis	Gall Stain	Total
Source	CW	0	4	2	9	3	18
	TUN	0	5	0	11	2	18
	LPS	9	7	1	2	5	24
	CWX	0	5	1	11	4	21
	HPS	1	7(8)[1]	3	9	8	28(29)
	Total	10	28(29)	7	42	22	109(110)

$\chi_2 = 42.15$, df = 16, $p < .001$

1/ Parentheses indicate total when leukosis is included.

All χ^2 analyses done with leukosis included in the total.

Table 4. Comparison of Number of Errors in Pass/Reject Decisions for All Sources for Poultry

		Errors	Correct
Source	CW	18	72
	TUN	18	72
	LPS	24	66
	CWX	21	69
	HPS	29	61
		110	340

$\chi^2 = 5.17$, df = 4, NS

Table 5. Comparison of Number of Errors in Pass/Reject Decisions for All Samples for Poultry

a. Total Errors in Decisions for Each Sample for All Sources

		Errors	Correct
Sample	Normal	10	80
	Tumor	29	61
	Septicemia	7	83
	Air Sacculitis	42	48
	Gall Stain	22	68

$\chi^2 = 49.21$, df = 4, $p < .001$

b. Error Distributions for the Normal Sample for Each Source

		Errors	Correct
Source	CW	0	18
	TUN	0	18
	LPS	9	9
	CWX	0	18
	HPS	1	17

$\chi^2 = 34.88$, df = 4, $p < .001$

c. Error Distributions for Air Sacculitis for Each Source

		Errors	Correct
Source	CW	9	9
	TUN	11	7
	LPS	2	16
	CWX	11	7
	HPS	9	9

$\chi^2 = 12.32$, df = 4, $p < .025$

Table 6. Decision Data for a Subset of 11 Poultry Inspectors

a. Total Errors for All Sources and Samples - 11 Inspectors

		Samples					
		Normal	Tumor	Septicemia	Air Sacculitis	Gall Stain	Total
Source	CW	0	0	0	2	0	2
	TUN	0	2	0	5	0	7
	LPS	5	3	0	1	4	13
	CWX	0	3	0	4	1	8
	HPS	0	4	0	4	4	12
	Total	5	12	0	16	9	42

χ^2 analysis inappropriate

b. Total Decisions for All Samples for Each Source

		Errors	Correct
Source	CW	2	53
	TUN	7	48
	LPS	13	42
	CWX	18	47
	HPS	12	43

$\chi^2 = 10.85$, df = 4, $p < .05$

c. Total Decisions for Each Sample for All Sources

		Errors	Correct
Sample	1	5	50
	2	12	43
	3	0	55
	4	16	39
	5	9	46

$\chi^2 = 21.53$, df = 4, $p < .001$

analysis examined performance of a subset who made zero or one errors in the pass/reject task under cool white light--the customary light for inspecting chickens. Table 6 presents the tabulated pass/ reject data for a subset of 11 inspectors. Table 6a presents the total errors for each source and sample. Table 6b compares errors in decisions for each light source for this subset of inspectors. The chi square analysis was significant for this table ($p < 0.05$) indicating that light source affected the error rate. Comparison of errors for cool white with errors for LPS, HPS, and CWX were also significant ($p < 0.05$). Table 6c presents the total errors for each sample. The chi square analysis for this comparison was also significant ($p < 0.001$). This more detailed analysis suggests that inspectors who made few errors under cool white light were significantly hindered in their ability to do the inspection task when the light source was changed, particularly to HPS and LPS.

2.5.3 Identification Data

The first set of data reported (see 2.5.2) concentrated on pass/reject decisions as the initial response. This decision, however, could allow a sample to be "rejected" for the wrong reasons. The identification data allow a further look at the effect of the light source on the accuracy of identifying defects with chickens. Thus the second set of data collected was the identification of the specific defects associated with the samples.

Table 7 tabulates the identification responses for each sample under each source. A judgement of their correctness was made after discussion between the researchers and the inspector-in-charge. In a number of cases, the response given was simply "trim". This is a nominally correct action for gall stains and single tumors, but not for air sacculitis or septicemia. Hence, the "trim" response was counted as correct for gall stain and tumor, but incorrect for air sacculitis and septicemia. Table 7 also presents the judgement of the correctness of the identification response. The total number of errors is greater for table 8 than table 3, because some samples were rejected correctly (table 3), but identified incorrectly (table 8).

Table 8a tabulates the number of errors in identifying types of samples under the different light sources. A chi square analysis of these data was significant ($p < 0.01$). This result indicates that there was a significant interaction between light source and sample on the number of errors of identifying different samples. Smaller contingency tables were made for correct vs. incorrect identifications for each light source (table 8b) and sample (table 8c). These analyses indicated that significant differences in the accuracy of identification occurred ($p < 0.001$), for both samples and sources. The greatest number of errors was made under LPS followed by HPS. (Error rates were similar for CWX, CW, and TUN.) In the previous section, the greatest number of errors (pass/reject) had been made for HPS, since a common response to LPS was to "reject" samples, a spuriously correct response (see table 3). The inspectors appeared to condemn everything under this source without knowing exactly what the problem was, except that it "looked" bad. When asked to identify the problem specifically, they had much more trouble, as indicated by the greater number of identification errors for LPS. The identification data can also be

Table 7. Identification Decisions for Each Sample for Each Source for 18 Poultry Inspector

	Source	Sample Normal	Score*	Tumor	Score	Septicemia	Score	Air Sacculitis	Score	Gall Stain	Score
1	1 CW	Ok	1	tumor	1	sep	1	lesion on liver	1	gall	1
	2 TUN	Ok	1	tumor	1	sep	1	air sac	1	contam	1
	3 LPS	Ok	1	tumor	1	sep	1	air sac	1	Ok	0
	4 CWN	Ok	1	tumor	1	sep	1	poss air	1	no prob.	0
	5 HPS	Ok	1	tumor[1]	1	sep	1	poss sac air sac	1	contam	1
2	1	Ok	1	tumor	1	sep	1	Ok	0	trim	1
	2	Ok	1	tumor	1	sep	1	Ok	0	contam	1
	3	Ok	1	tumor	1	dehydrated contam.	1	contam	0	contam	1
	4	Ok	1	tumor	1	cadaver	1	Ok	0	trim	1
	5	Ok	1	tumor	1	sep	1	Ok	0	Ok	0
3	1	Ok	1	Ok	0	Ok	0	Ok	0	bile	1
	2	Ok	1	Ok	0	cadaver	1	Ok	0	bile	1
	3	Ok	1	Ok	0	discolored	1	grease	0	grease	0
	4	Ok	1	discolored	0	cadaver	1	a lot of red	0	bile	1
	5	Ok	1	Ok	0	Ok easy	0	Ok	0	bile	1
4	1	Ok	1	tumor	1	hang back	0	air sac	1	trim	1
	2	Ok	1	tumor	1	dehydrated	1	air sac	1	trim	1
	3	Ok	1	tumor	1	dehydrated	1	air sac	1	Ok	0
	4	Ok	1	tumor	1	dehydrated	1	air sac	1	Ok	0
	5	Ok	1	tumor	1	dehydrated	1	air sac	1	Ok	0
5	1	Ok	1	tumor	1	sep	1	bad liver	1	gall	1
	2	Ok	1	Ok	0	sep	1	Ok	0	gall	1
	3	soot	0	tumor	1	sep	1	soot	0	diesel	0
	4	Ok	1	Ok	0	sep	1	trim viscera	1	gall	1
	5	Ok	1	tumor	1	sep	1	viscera problem	1	gall	1
6	1	Ok	1	Ok	0	trim	0	Ok	0	trim	-
	2	Ok	1	Ok	0	trim	0	Ok	0	gall	1
	3	Ok	1	Ok	0	black	1	has spots on it	0	grease	0
	4	Ok	1	trim	1	trim	0	Ok	0	gall	1
	5	Ok	1	Ok	0	Ok	0	Ok	0	Ok	0
7	1	Ok	1	tumor	1	cadaver	1	air sac	1	gall	1
	2	Ok	1	tumor	1	cadaver	1	air sac	1	gall	1
	3	sep	0	soot	0	sep	1	air sac	1	trim spots	0
	4	Ok	1	Ok	0	cadaver	1	air sac	1	gall	1
	5	Ok	1	Ok	0	sep	1	air sac	1	Ok	0
8	1	Ok	1	tumor	1	trim back	0	trim liver	1	gall	1
	2	Ok	1	Ok	0	trim	0	trim to get red off	0	gall	1
	3	Ok	1	Ok	0	trim	0	Ok	0	trim	1
	4	Ok	1	tumor	1	trim looks red	0	Ok	0	trim	1
	5	Ok	1	Ok	0	trim back	0	probs. w/ liver	1	gall	1

1 = correct
0 = incorrect
- = no answer

Table 7. Continued

	Source	Sample Normal	Score	Tumor	Score	Septicemia	Score	Air Sacculitis	Score	Gall Stain	Score
9	1	Ok	1	tumor	1	sep	1	Ok	0	Ok	0
	2	Ok	1	tumor	1	sep	0	Ok	1	Ok	0
	3	feces swollen liver	0	tumor	1	grease all over	0	air sac	1	grease	0
	4	Ok	1	tumor	1	sep	1	Ok	0	Ok	0
	5	Ok	1	tumor	1	sep	1	trim leg	0	Ok	0
10	1	Ok	1	Ok	0	sep	1	Ok	0	gall	1
	2	Ok	1	tumor	1	sep	1	trim leg	0	gall	1
	3	sep	0	Ok	0	sep	1	Ok	0	sep	0
	4	Ok	1	Ok	0	sep	1	prob. w/ liver Ok	0	sep	0
	5	Ok	1	tumor	1	sep	1	Ok	0	Ok	0
11	1	Ok	1	tumor	1	sep	1	air sac	1	gall	1
	2	Ok	1	tumor	1	sep	1	air sac	1	gall	1
	3	Ok	1	tumor	1	sep	1	air sac soot	1	Ok	0
	4	Ok	1	tumor	1	sep	1	air sac	1	gall	1
	5	Ok	1	tumor	1	sep	1	air sac	1	gall	1
12	1	Ok	1	tumor	1	sep	1	Ok	0	Ok	0
	2	Ok	1	tumor	1	sep	1	Ok	0	gall	1
	3	abnormal viscera	0	trim breast	1	sep	1	prob. w/ liver	1	gall	1
	4	Ok	1	trim breast	1	sep	1	Ok	0	gall	1
	5	Ok	1	Ok	0	sep	1	Ok	0	gall	1
13	1	Ok	1	Ok	0	sep	1	prob. w/ liver ok	0	Ok	0
	2	Ok	1	Ok	0	sep	1	Ok	0	Ok	0
	3	Ok	1	unnatural Ok	0	sep	1	sep	0	Ok	0
	4	Ok	1	Ok	0	sep	1	Ok	0	Ok	0
	5	leukosis	0	Ok	0	sep	1	liver ?	1	Ok	0
14	1	Ok	1	tumor	1	sep	1	air sac	1	gall	1
	2	Ok	1	tumor	1	sep	1	air sac	1	gall	1
	3	Ok	0	ok	0	sep	1	sep	0	greenish	0
	4	Ok	1	tumor	1	sep	1	air sac	1	gall	1
	5	Ok	1	tumor	1	sep	1	air sac	1	gall	1
15	1	Ok	1	bruised leg	0	sep	1	Ok	0	gall	1
	2	Ok	1	tumor	1	sep	1	Ok	0	gall	1
	3	bad liver	0	bad skin	0	all dried up	1	all dried up-dark	0	grease all over	0
	4	Ok	1	bruised leg	0	sep	1	Ok	0	gall	1
	5	Ok	1	Ok	0	sep	1	Ok	0	gall	1

Table 7. Continued

	Source	Sample Normal	Score	Leukosis	Score	Septicemia	Score	Air Sacculitis	Score	Gall Stain	Score
16	1	Ok	1	leukosis	1	Ok	0	Ok	0	bile	1
	2	Ok	1	leukosis	1	looks dark hang back	1	looked dry Ok	0	bile	1
	3	bile outside	0	trim breast	0	no obvious problem	0	bile on wing	0	bile	1
	4	Ok	1	leukosis	1	Ok	0	Ok	0	bile	1
	5	Ok	1	leukosis	1	Ok	0	Ok	0	bile	1
17	1	Ok	1	leukosis	1	sep	1	enlarged heart	1	gall	1
	2	Ok	1	leukosis	1	sep	1	Ok	0	gall	1
	3	looks grey	0	leukosis	1	sep	1	air sac	1	gall	1
	4	Ok	1	leukosis	1	sep	1	Ok	0	gall	1
	5	Ok	1	leukosis	1	sep	1	Ok	0	gall	1
18	1	Ok	1	leukosis	1	sep	1	air sac	1	gall	1
	2	Ok	1	leukosis	1	color bad	1	Ok	0	gall	1
	3	Ok	1	trim	1	sep	1	air sac	1	Ok	0
	4	Ok	1	leukosis	1	sep	1	air sac	1	gall	1
	5	Ok	1	Ok	0	sep	1	Ok	0	gall	1
Total											
Errors of Identification		10		32		17		52		30	
Pass/fail Errors		10		28		7		42		22	

Table 8. Accuracy of Identification of Samples for 18 Poultry Inspectors

a. Errors in Identification for Each Sample and Source

		Samples					
		Normal	Tumor	Septicemia	Air Sacculitis	Gall Stain	Total
Source	CW	0	5	5	9	3	22
	TUN	0	5	2	13	2	22
	LPS	9	8	3	9	13	42
	CWX	0	6	3	11	4	24
	HPS	1	8	4	10	8	31
	Total	10	32	17	52	30	141

$\chi^2 = 32.17$, df = 16, $p < .01$

b. Errors in Identification for Each Source for All Samples

		Errors	Correct
Source	CW	22	68
	TUN	22	68
	LPS	42	48
	CWX	24	66
	HPS	31	59

$\chi^2 = 15.12$, df = 4, $p < .001$

c. Errors in Identification for Each Sample for All Sources

		Errors	Correct
Sample	Normal	10	80
	Tumor	32	58
	Septicemia	17	73
	Air Sacculitis	52	38
	Gall Stain	30	60

$\chi^2 = 55.22$, df = 4, $p < .001$

examined by simply tabulating the total number of errors for each source. This tabulation (given in the TOTAL column of table 8a) indicates that the greatest number of errors--42, or nearly half the 90 decisions--occurred for LPS. For HPS, nearly one-third--or 31--of the identifications were incorrect. The other three sources showed lower frequencies of errors--about one-quarter the total decisions. Performance was typically poor for all samples under HPS.

With respect to the samples themselves, the greatest number of identification errors was made for air sacculitis followed by tumor and then the gall stain (see tables 8a and 8c). It is possible that many errors occurred for air sacculitis because this sample was located near the bottom of the viewing pan in the viscera of the chicken, and was perhaps more difficult to see. (The inspectors had been instructed that no defects were hidden from their direct view, however.) Fewer errors were made for the normal chicken and the one with septicemia. As noted before, errors of incorrectly rejecting the normal bird occurred almost entirely under LPS.

2.5.4 Rated Ease of Task Performance

Table 9 presents mean ratings for the decision difficulty given by an inspector for each source after viewing a sample. In this task, each inspector rated the difficulty of making the decision[1/] using a scale of 1 to 5 where 1 meant easy and 5 meant difficult. These ratings were then summed for each source for all samples and all inspectors and then averaged. Mean ratings for the light sources were as follows: 1.3 for TUN; 1.4 for CW; 1.6 for CWX; 2.1 for HPS; and 3.8 for LPS, with a possible range of 1 to 5. (To meet the assumptions of the analysis of variance with regard to normality of the distribution and homogeneity of variance, a square root transformation (Natrella, 1984) was performed on the ratings given by each inspector.) Two separate two way analyses of variance were then calculated for the transformed data using Minitab (1984). The first, was a comparison of each inspector's rating for each source, to determine if different light sources were rated differently. This analysis was significant ($p < 0.001$). There was also a significant tendency ($p < 0.5$) for inspector ratings to vary as function of light source. The second, was a comparison of inspectors over samples, to see if there were an effect of the sample (in other words, were different samples rated as easier, or more difficult regardless of light source). This analysis was indicated that differences in rating the samples were not significant. In addition, a tabulation was made of the number of times each source was given each rating. A χ^2 analysis of this tabulation, shown in table 10, was significant ($p < 0.001$). This result indicates that source 3, LPS, received ratings of 3, 4, or 5, much more frequently than CW, TUN, or CWX. Similarly, HPS tended to receive higher ratings more frequently than did the other sources. Thus, the inspectors apparently found the task more difficult to do under both HPS and LPS.

1/ It was difficult at times to determine which decision (pass/reject or identification) was being rated, since some inspectors identified the sample first, and then gave their rating.

Table 9

Rating Data for Poultry Inspection

a) Mean Rating Data for Each Poultry Inspector for Each Source

Inspector	CW	TUN	LPS	CWX	HPS
1	1.0	1.2	3.6	1.0	1.4
2	1.8	1.0	3.0	2.0	1.0
3	1.0	1.0	2.0	1.2	1.0
4	1.2	1.0	4.2	1.0	1.0
5	1.0	1.0	1.8	1.0	1.0
6	1.0	1.0	1.0	1.0	1.8
7	1.2	1.6	4.4	2.4	3.6
8	2.2	1.0	5.0	1.8	1.8
9	2.0	2.0	5.0	2.0	3.0
10	1.0	1.0	5.0	1.4	1.0
11	2.0	1.0	4.4	2.0	3.0
12	1.0	1.0	5.0	1.4	2.6
13	2.6	2.6	5.0	3.6	5.0
14	1.6	1.0	3.6	1.0	3.0
15	1.0	1.2	3.0	1.0	1.8
16	1.0	1.0	5.0	2.0	2.0
17	1.8	1.8	5.0	2.2	3.2
18	1.0	1.6	2.4	1.4	1.0
Mean	1.41	1.28	3.80	1.63	2.12

b) Mean Rating Data for Each Sample for Each Source Summed over Inspectors

		Sample 1	2	3	4	5
Source	CW	1.33	1.33	1.39	1.56	1.41
	TUN	1.22	1.22	1.17	1.44	1.28
	LPS	3.94	4.00	3.50	3.72	3.83
	CWX	1.50	1.67	1.67	1.83	1.50
	HPS	2.05	1.89	2.05	2.05	2.55
	Mean	2.01	2.02	1.96	2.12	2.13

Table 10. Frequency That Each Rating (1 to 5) was Given for Each Light Source for Poultry

Source	Rating 1	2	3	4	5	
CW	61	21	8	0	0	90
TUN	72	11	7	0	0	90
LPS	13	3	17	13	44	90
CWX	50	26	11	3	0	90
HPS	43	9	29	2	7	90
Total	239	70	72	18	51	450

$\chi^2 = 299.72$, df = 16, $p < 0.001$

2.5.5 Comments About the Light Sources

After each inspector had seen the five samples under a given light source, he/she was asked for comments about the source. These comments are tabulated by source in Table 11, just as they were given by the inspectors. In an attempt to quantify these comments, an arbitrary rating scale was devised in which two researchers independently rated each comment. In this scale, a "poor" light source was given a -1, a neutral source a 0, and a "good" source a +1. Any differences between the researchers' ratings were averaged. The range of possible scores was from -18 to +18. This scoring procedure resulted in the following scores: incandescent, +12; cool white, +15; HPS, -6; cool white deluxe +7; and LPS, -17.5. An overview of the comments suggests that the inspectors were very negative about LPS, somewhat negative about HPS, positive about incandescent and cool white deluxe, and very positive about cool white (the source to which they were accustomed).

2.5.6 Response Time Data

The findings from the pilot study with poultry inspectors suggested that the inspectors responded more slowly under some light sources than others. As a result, an attempt was made to determine response time as a function of light source in the main experiment. While these data are subject to experimental error due to the reaction time of the experimenter recording them, they provide some hint that the inspection process may go more slowly under certain (unfamiliar, perhaps) light sources. (One experimenter made all the recordings, but in some cases a time could not be recorded due to a malfunction of the cart or some other error.) Recorded response times included approximately 2 seconds of initial cart travel time in which the inspector could not see the sample. Response times were summed over all samples for all inspectors for each of the five sources. An average response time for each source was calculated along with a one way analysis of variance, using MINITAB (1984). The average response time was 4.4 sec for CW and TUN; 4.9 for LPS; 4.4 for CWX; and 4.5 for HPS. These data are presented in table 12. While the analysis of variance was significant at the $p < 0.10$ level, not the customary 0.05 level, it does suggest a tendency toward longer reaction time with LPS.

2.6 RESULTS FROM RED MEAT PSYCHOPHYSICAL STUDY

2.6.1 Sample Selection

The red meat psychophysical experiment was conducted at a large cattle processing plant, located near several other plants including a cow and bull (older cattle) plant. Samples for the experiment were drawn from all plants in the vicinity, but even so, it proved to be impossible to get all desired pathologies for each inspector in the experiment. Other problems arose because the sheer size of the cattle prohibited using the entire animal. As a result, because each sample was cut to a size that would fit on the experimental cart, no inspector viewed an entire viscera or head as is customary during the normal inspection process. An attempt was made to use similarly sized pieces of meat during the experiment to avoid recognition of specific samples, but comments by some inspectors made it clear that they did remember at least some samples. Because

Table 11. Comments About Each Light Source by Poultry Inspectors

Cool White

Ratings	Comments
1	Light fine, too
0	No Comments
1	Light much better
0.5	Normal light; no problems
1	Light pretty good
1	Better light to work with
1	Like this light
0.5	Light seemed a little softer (after tungsten)
1	Light much better; clearer; more distinct; better than previous two lights (LPS and HPS); liked light
1	Easy to judge; no problems with light
0	Comparable to first light (CWX); very little difference; reddish; would have to get used to
1	Lighting just fine; similar to normal inspection; might be brighter
1	Better light; more normal; not bright enought; bird in natural coloring
1	Can see pretty good
1	Light pretty good; similar in brightness to previous one (tungsten)
1	Like the white lights; this more soft white with less potential for glare
1	Could see pretty good
1	Light real good

Total = +15

Incandescent

1	Light fine--No problems
0	No comments
1	Best light so far (was last light used)
1	Not bad; no problems
1	Light good (presentation position only allows me to see 60-75 percent of bird)
-1	Glare-like; would not like to work under it all the time
1	Light sharp; more the same across the bird; less change from bird to bird; previous light seemed to dry out chicken (was CWX)
1	Liked light; seemed a bit bright
-0.5	Light not clear; leaves condition of chicken dull; with shadow
1	Bright enough
1	Best light so far; clearest; no problems with lite
1	Pretty close to first light; could see just fine
1	Light not real different from others; more what I'm used to
1	No problems with light; harder to see than under first light; not much difference other than that
1	Liked light; no problem; bright enough
1	Nice bright white light; could see glare on chicken if bird were wetter; like lighting, though
1	Light seemed normal; good; no problems
-0.5	Awful bright; glare problem; could work under it

Total = +12

Table 11. (Continued)

LPS

-1	Light makes birds dark and discolored
-0.5	Dehydrated birds; lights seemed to be brighter
-1	Chicken doesn't have normal color; looks pale and dehydrated; wouldn't want to have to inspect under this light; difficult to make accurate decision
-1	Too dark; chicken looks dehydrated; strange
-11	Would not want to use light to inspect chickens; changes appearance of birds--darkness-bird appears to have soot or diesel grease on it
-1	Chicken black; grease spots; wouldn't want to work under it
-1	Light makes chicken look black; did not like light; not like to inspect under it; chicken looked drenched with soot; more difficult than other lighting
-1	Didn't like light at all; everything looked grey and dark; hard to pick up abnormalities
-1	Dingy light; do not like light; would not want to work under it; makes eyes hurt; glares into face
-1	Light is kind of difficult to see with; need a brighter light to make decisions, particularly with fast line speed
-1	Chicken looked black; light did highlight air sac on viscera; couldn't inspect, though, under this light
-1	Definitely would not want to work under this light; too dark; everything looks grey
-1	Miserable light; would quit if had to work under it; can't see true color of bird; bird looks "dead" and dehydrated; not natural lighting; changes color totally
-1	Poor light to work by; no bird looks like normal bird; whole bird looked greenish
-1	Birds look all dried up; too dark; skin doesn't look right; don't like this light; wouldn't want to work under it
-1	Good for halloween party; can't tell what color skin is; things on skin don't stand out; can't see shades
-1	Skin looks grey; all look like seps; light is poor; hate to have to work under it
-1	Wouldn't want to work under light; difficult to tell bruises, sores; difficult light

Total = -17.5

Cool White Deluxe

1	Light, fine; bright; could see bird; see better than one before (HPS); need a bright light to see all the way into bird
1	Birds don't looks as dehydrated under this light; lighting reasonable; good flesh color to birds
0.5	Much bright light; problem with red birds
0	No comments
-0.5	Lights make chicken look red
1	Generally easy to do
0	Position of bird difficult to get used to
1	Light didn't seem as bright; easier on eyes
0.5	About like previous light; no great differences; could have been a hair brighter

Table 11. (Continued)

Cool White Deluxe Continued

1	Easy to decide; light brighter; other light dull
1	Pretty good light; problem with darkened room
-1	Light seemed darker; not quite as bright; don't prefer light
-1	Don't like light as well--seemed more strain
1	Could see real good; seemed like what I'm used to
0.5	Light seemed pretty bright
-0.5	Light is not intense enough; like the color white
1	Didn't look like fluorescent light; could see pretty well
0.5	Wasn't as good as last two [CW and HPS]; not as bright; could work under it; normal bird looked different

Total = +7

HPS

-1	Not too bright; dimmer; yellow; not as white; hard to make decision--bird looked dimmer
1	Light is good (but lying down position causes problems--can't see whole bird)
-1	Much better than first light (LPS) still has glow that kind of shades chicken; wouldn't want to inspect under this light; need bright, lighter light
-1	Light seems dimmer; not as bright
0	No problem with bird under light;
-1	Light bright and glary
-1	Bright; sort of glow; glare, wouldn't want to work under it; would have headaches before day is over; chicken looked bluish; not good light
0.5	Light seemed bright; room dark; sort of what I'm used to
1	Light better; clearer; no glow back into face; better than some lights
0.5	Could see with light; could be brighter
0.5	Pretty good light; not as good as first [CWX]; could work under it; take some getting used to; reddish, yellowish tint
-1	Wouldn't want to use light; more dim than other one; would rather have first light [CW]
-1	Yellow; don't like light; strain on eyes; not certain of what I'm seeing; terrible light; very difficult
-1	Hard to see under (not as hard as last one [LPS]; hard to see directly what problem is
-1	Don't like light as well as others; not bright enough; made birds look sort of yellow;
-1	Slightly orange; makes leukosis less obvious and stand out less
-0.5	Light not as bright; not as easy as first [TUN]
1	Light seemed real good; wouldn't mind working under it
-1	Hard to see under--not as hard as last one (LPS); hard to see directly what problem is
-1	Don't like light as well as others; not bright enough; made birds look sort of yellow;
-1	Slightly orange; makes leukosis less obvious and stand out less
-0.5	Light not as bright; not as easy as first (TUN)
1	Light seemed real good; wouldn't mind working under it.

Total = -6

Table 12. Mean Response Time for Light Sources by Poultry Inspectors

Source	N[1]	Mean	Std. Dev.
CW	78	4.4	1.386
TUN	86	4.4	1.354
LPS	87	4.9	1.628
CWX	85	4.4	1.258
HPS	83	4.5	1.386

$F = 2.20$, $df = 4, 414$, $p < .10$

[1] Total observations = 90

an entire viscera, head, or carcass could not be presented, the overall simulation was much less accurate than for the poultry portion, where the entire bird plus viscera could be easily used. In addition, a greater portion of the red meat inspection process is tactile--the tissue is sliced deliberately to get the "feel" of it, as well as to bring hidden organs (and defects) to view. Consequently, the red meat data must be viewed with more caution than the poultry data.

In addition, it proved impossible to obtain similar samples throughout the entire experiment, so that substitution of dissimilar defects had to be made. Consequently, some types of red meat samples varied for different groups of inspectors, while other sample types remained the same. Thus, sample 1 was always telangiectasis (telang) of the liver (a disease characterized by black spots); sample 5 was always an abscess or lesion (acti) of a lymph node in the head; and sample 4 was always lung tissue, with either pneumonia or congestion (with both being presented randomly to each subject). Sample 3 varied, during the study, being a normal liver for the first seven inspectors, and either a normal liver or a normal spleen for the final nine. Sample 2 varied the most, being a sawdust lesion in the liver for the first four subjects; an emaciated heart or heart with a growth for subjects 5-7; and heart muscle with EM (eosinophilic myositis--an inflammation of muscle tissue associated with parasites), for the remaining nine inspectors. The EM sample did not become available until the second day of the experiment, although it had been identified as a desirable tissue from the beginning. (Anecdotal reports from the inspectors and veterinarians had indicated that EM is very difficult to detect under HPS.)

2.6.2 Red Meat Pass/Reject and Identification Data

As might be expected from the discussion of the problems in obtaining samples discussed above, the results from the red meat psychophysical experiment were not nearly so clear-cut as from the poultry experiment. In addition, two of the red meat inspectors had been identified as possibly color defective by the AO test. Consequently, data reported the tables in 2.6.2 are given for all 16 inspectors, and in parentheses for the 14 inspectors who made fewer than five errors on the test used. Further testing would be necessary to categorize the two inspectors as definitely color deficient.

Table 13 tabulates the pass/reject data for red meat. Table 13a gives the number of pass/reject errors for all sources and samples. A chi square analysis was not possible for these data due to the large number of cells with low expected frequencies. Table 13b tabulates the number of errors/correct responses for all samples summed over all light sources. Because of the extent to which sample types varied in the red meat experiment, no separate χ^2 analysis was performed to examine the effect of sample. Table 13b indicates, nevertheless, that numerous errors were made for the normal sample - more than for any other sample type. Unlike poultry, this sample was frequently incorrectly rejected under all light sources, although the most errors did occur under HPS and LPS. Sample 3 was varied to make the experiment more difficult and to avoid the inspector's recognizing the liver sample, but the second sample, a spleen, proved to be very difficult to identify accurately. This sample was rejected as defective 15 of the 20 times that it was presented,

Table 13. Tabulation of Pass/Reject Data for Red Meat Inspectors

a. Tabulation of Pass/Reject Errors for 16 Meat Inspectors

		Samples					
		1	2	3(Normal)	4	5	Total
Light Source	CW	1	1 (0)[1]	3 (2)	2 (1)	2 (2)	6 (5)
	TUN	2	0 (0)	5 (5)	1 (1)	1 (1)	9 (9)
	LPS	3	1 (0)	8 (6)	0 (0)	0 (0)	12 (9)
	CWX	1	2 (1)	6 (6)	3 (2)	1 (1)	13 (11)
	HPS	2	0 (0)	8 (7)	2 (1)	0 (0)	12 (10)
	Total	9	4 (1)	30 (26)	8 (5)	4 (4)	55 (45)

χ^2 not appropriate

b. Tabulation of Errors for Each Sample for All Sources

		Errors	Correct
Sample	1	9 (9)	71 (61)
	2	4 (1)	76 (69)
	3	30 (26)	50 (44)
	4	8 (5)	72 (65)
	5	4 (4)	76 (66)

c. Comparison of Errors for Each Source for All Samples

		Errors	Correct
Source	CW	9 (5)	71 (65)
	TUN	9 (9)	71 (61)
	LPS	12 (9)	68 (61)
	CWX	13 (11)	67 (59)
	HPS	12 (10)	68 (60)

$\chi^2 = 1.48$, df = 4, NS

d. Comparison of Correct Responses/Errors for LPS and for HPS

LPS

		Errors	Correct
Sample	1	3 (3)	13 (11)
	2	1 (0)	15 (14)
	3	8 (6)	8 (8)
	4	0 (0)	16 (14)
	5	0 (0)	16 (14)

$\chi^2 = 22.16$, df = 4, $p < 0.1$

HPS

		Errors	Correct
Sample	1	2 (2)	14 (12)
	2	0 (0)	16 (14)
	3	8 (7)	8 (7)
	4	1 (1)	15 (13)
	5	0 (0)	16 (14)

$\chi^2 = 27.43$, df = 4, $p < .001$

[1] Numbers in parentheses indicate total errors with two color defectives excluded.

under all light sources, possibly because it had a "spotty" appearance. As a result, it proved difficult to identify the effect of light source on rejection of normal meat tissue (unlike the poultry experiment where this type of error only occurred for LPS and HPS). A chi square analysis of the data in table 13c for light source was not significant, indicating no real differences in the total error rates for each source. Chi square analyses for each sample under LPS and then under HPS shown in table 13d were significant however, with the most errors occuring for the normal sample. No other comparisons were statistically significant. The fewest errors typically occurred for CW and TUN, as with poultry. (The two inspectors categorized as color deficient typically made more errors under LPS, CWX, and HPS than under CW or TUN.)

Table 14 tabulates the errors for the identification data. As for poultry, these data were categorized and scored using a USDA pathologist to verify the accuracy of the scoring. Again, data are given with color defectives included and excluded (parentheses). Table 14a presents the total errors of identification for each source and sample. A chi square analysis was not appropriate for this table. The comparison of total errors for each source, given in table 14b, was significant ($p < 0.001$), with more errors occurring for LPS.

Table 14c compares the total number of errors for each sample. This comparison was signficant ($p < 0.001$ for the chi square analysis). Here, the problem was a greater number of errors for sample 4, where many inspectors had problems identifying lung congestion due to blood clots correctly. Table 14d presents data for HPS and for LPS. Significantly more errors were made only under HPS ($p < 0.05$). Both samples 3 and 4 had a large number of errors under these two light sources. Surprisingly, relatively few errors occurred for EM and the other samples shown as number 2. This may be because EM is normally found after slicing the tissue, and here it had already been "found". The abscess/lesion (number 5) and the telang (number 1) also proved relatively easy to identify accurately. Error rates were higher for all sources for the color defectives, although the increase was most pronounced for LPS.

Thus, as with poultry, error rates increased for passing/rejecting and identifying samples under both HPS and LPS. Similarly, fewer errors occurred under both CW and TUN. Unlike poultry, slightly more errors occurred under CWX. While analysis of the errors for this source for both pass/reject and identification data did not reach significance, the reasons for this increase, if real, remain puzzling. Otherwise, the data are in accord with the poultry data, and with expectations, indicating that the various tasks performed by the inspectors were performed less accurately under HPS and LPS, and more accurately under CW and TUN.

2.6.3 Rating Data, Comments, and Response Time Data for Red Meat

Table 15 presents the rating data given by all[1] red meat inspectors for the ease/difficulty of inspecting the samples under each light source. Table 15a

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[1] Color defective data were included in the analyses presented in 2.6.3 since these inspectors were experienced, evidently able to compensate for their defect, and represented the range of personnel at this facility.

Table 14. Tabulation of Identification Data for Red Meat Inspectors

a. Identification Errors for 16 Meat Inspectors

		Samples					
		1	2	3(Normal)	4	5	Total
Light Source	CW	2 (1)	4 (3)	2 (2)	4 (3)	4 (3)	16 (12)
	TUN	2 (2)	3 (2)	5 (5)	7 (6)	2 (1)	19 (14)
	LPS	5 (3)	8 (7)	9 (7)	11 (10)	4 (3)	37 (30)
	CWX	1 (1)	5 (4)	6 (6)	5 (4)	5 (4)	22 (19)
	HPS	2 (1)	3 (3)	8 (7)	7 (6)	2 (1)	22 (18)
	Total	12 (6)	23 (19)	30 (27)	34 (29)	17 (12)	116 (93)

^{2} inappropriate

b. Comparison of Identification Responses for All Sources

		Errors	Correct
Source	CW	16 (12)	64 (58)
	TUN	19 (14)	61 (56)
	LPS	37 (30)	43 (40)
	CWX	22 (19)	58 (51)
	HPS	22 (18)	58 (52)

^{2} = 14.29, df = 4, NS, $p < .001$

c. Comparison of Identification Responses for All Samples

		Errors	Correct
Sample	1	12 (6)	68 (64)
	2	23 (19)	57 (51)
	3	30 (27)	50 (43)
	4	34 (29)	46 (41)
	5	17 (12)	63 (58)

^{2} = 19.84, df = 4, $p < .001$

d. Comparison of Identification Responses for LPS and HPS

LPS

		Errors	Correct
Sample	1	5 (3)	11 (11)
	2	8 (7)	8 (7)
	3	9 (7)	7 (7)
	4	11 (10)	5 (4)
	5	4 (3)	12 (11)

^{2} = 8.35, df = 4, NS, $p < .10$

HPS

		Errors	Correct
Sample	1	2 (1)	14 (13)
	2	3 (3)	13 (11)
	3	8 (7)	8 (7)
	4	7 (6)	9 (8)
	5	2 (1)	14 (13)

^{2} = 10.41, df = 4, $p < .05$

Table 15. Rating Data for Red Meat Inspection

a. Mean Rating Data for Each Red Meat Inspector for Each Source

Inspector	Source CW	TUN	LPS	CWX	HPS
1	1.0	1.8	4.4	1.8	2.8
2	1.0	1.0	5.0	1.0	1.0
3	1.8	1.0	4.6	1.8	2.6
4	1.2	1.6	3.4	1.0	2.6
5	1.0	1.0	3.4	1.0	1.4
6	1.0	1.0	4.6	1.0	2.6
7	1.8	1.8	3.8	1.0	3.0
8	1.0	1.0	5.0	2.2	3.8
9	1.8	2.0	5.0	2.0	4.0
10	2.0	1.0	5.0	1.6	3.4
11	2.4	1.6	5.0	1.0	2.2
12	1.4	1.2	3.8	1.6	2.0
13	1.0	1.0	5.0	1.6	3.2
14	1.8	2.8	4.0	2.2	2.8
15	1.8	1.6	5.0	1.4	3.4
16	2.0	1.0	4.0	1.8	2.4
Mean	1.5	1.4	4.44	1.5	2.7

b. Mean Rating Data for Each Sample for Each Source Summed over Inspectors

		Sample 1	2	3	4	5	Mean
Source	CW	1.56	1.31	1.69	1.62	1.31	1.50
	TUN	1.25	1.38	1.56	1.38	1.44	1.40
	LPS	4.06	4.50	4.69	4.56	4.38	4.44
	CWX	1.50	1.50	1.50	1.44	1.56	1.50
	HPS	2.44	2.75	3.0	2.69	2.62	2.70

c. Frequency of Times that Each Rating was Given to Each Source

		Rating 1	2	3	4	4
Source	1-CW	49	24	5	2	0
	2-TUN	54	22	2	2	0
	3-LPS	2	2	10	11	55
	4-CWX	46	29	4	1	0
	5-HPS	9	25	31	11	4
	Total	160	102	52	27	59

$\chi^2 = 369.50$, df = 16, sig < 0.001

provides the mean rating data for each inspector for each source averaged over the 5 samples. Incandescent was rated as 1.4; cool white, 1.5; cool white deluxe, 1.5; HPS, 2.7; and LPS, 4.4. These results suggest that red meat inspectors found their task particularly difficult under HPS and LPS. These two sources received noticeably higher ratings than in the poultry experiment (2.7 vs. 2.1 for HPS, and 4.4 vs. 3.8 for LPS), while the other three sources received about the same rating.

The square root of each rating given by an inspector was calculated and two two-way analyses of variance performed. This analysis showed significant differences in the overall mean ratings for each source ($p < 0.01$). A similar analysis of variance performed for the rating data for each sample was not significant, indicating that the differences in ratings were due to the light sources, and not to the samples.

Table 16 presents the comments made by the red meat inspectors about each source. The arbitrary rating scale procedure used for the poultry inspector comments (see 2.5.5) was applied to the comments by red meat inspectors. The range of possible scores was from +16 to -16. This procedure resulted in the following scores: Incandescent, 10.5; Cool White, 8.5; LPS, -16; Cool White Deluxe, 8.5; and HPS, -6.5; As with poultry, inspectors were extremely negative about LPS, and moderately negative about HPS. As with the poultry inspectors, they were accustomed to inspecting under CW (some had been exposed to both TUN and HPS, however). Their comments about cool white, cool white deluxe, and incandescent were generally favorable. Many inspectors commented that HPS and LPS caused definite problems with accurate color recognition of the meat samples presented.

Finally, table 17 presents the mean response time data. Again, these data include about 2 seconds when the sample was obscured from view. In addition, the cart moved at a somewhat greater speed than the normal line speed for red meat, although, of course, only a very small portion of the animal was presented. Thus, these data reflect the experimental and not actual inspection response times. Inferences about actual line speeds and reaction times cannot be made from these data. The data were collected to determine if alterations in light source would affect the response time. An analysis of variance of response time indicated that there was a significant difference in mean response time ($p < 0.01$), with that for LPS being the longest, and that for CW being the shortest. Again, these data suggest that the task is more difficult--takes longer--for sources such as LPS and HPS.

2.6.4 Discussion of Red Meat Results

As noted earlier, the individual results for the red meat psychophysical experiment are not as conclusive as those for the poultry inspection. The failure to find many significant differences in the number of errors for the pass/reject and identification tasks is believed to be due to the enormous differences between the sample presentation and the normal inspection task where defects must be found in an entire head, viscera, or carcass. In addition, the use of substitute samples (intended to decrease familarity with a particular sample) resulted in many spurious errors, particularly for the normal and lung

Table 16. Comments About Each Source by Red Meat Inspectors

Cool White

Rating	
1	Inspection pretty easy; liked color and texture; it's white & I can see better; pathology readily identifiable
1	Liked this light much better [than LPS]; better, easier to see; used to this light; different lighting causes problems
1	Looked kind of bluish; but looked good
1	About as easy [as CWX]; more relaxed light; easier for a longer period of time
-1	Seemed to strain eyes more [than CWX]
1	Very good in most instances
1	Light is a lot better than yellow one [HPS]; fairly normal light; not much different from what I'm used to
1	Good light; no distortion; natural; toss up with [incandescent]; not as bright; no reflections into face
1	Decent enough light; things sharp
0.5	Could work with light; pretty good; not great
-0.5	Wasn't quite as sure as with other lights
0.5	Light brings EM up--brought out yellow texture; best light for EM; but had different effect on lung - seemed duller; product looked different
1	All the colors easy to see; all the white lights pretty close
1	Light not too bad; first one [CWX] better than this; but this is whole lot better than second [LPS]
0.5	Seemed almost the same as earlier one [CWX]
0.5	Not too bad lights

Total = 10.5

Incandescent

-0.5	Light seemed dimmer [than CW]; pneumonia wasn't as recognizable; telang more noticeable - looked darkened
1	Fine; liked light
1	Good color; pretty true to life; true colors; sawdust lesion pretty good
-1	Bad glare from light
1	No strain on eyes
1	Best light so far
1	Pretty much normal light
1	Liked light; didn't distort anything except spleen; could do inspection task under light
0	Not quite as sharp as first one [CW]; probably acceptable
1	Light convenient to eye; like light; better; more relaxing to eye
1	Seems brighter; definitely better; caused some problems in that pathology didn't stand out; demarcations mellowed

Table 16. (Continued)

Incandescent (cont.)

1	Light much better; gives different look [than HPS, LPS]; but not like true light from natural sources
1	Same as last [CWX]; but seemed just a bit clearer; much better than first; [LPS]; no trouble doing inspection
0	Light brings out yellowish tint in tissues; more so than one before
-1	Can't stand yellowish light; harder to see what you're looking at
1	Lights good for task; pretty natural

Total 8.5

LPS

-1	All coloration lost; would be almost impossible at viscera table; whole carcass and viscera very difficult to inspect
-1	Looks dull in color; would not like to do normnal inspection task under it
-1	Terrible light; hard to distinguish what was good from bad
-1	Awful hard to tell - strange looking lesions; don't like light
-1	Terrible light; wouldn't want to inspect with it; would miss too much
-1	Wouldn't recommend light; changes normality of colors; wouldn't want to do inspection under yellow light
-1	Everything is grey; thought man [operating cart] had died
-1	Light no good; everything looked black
-1	Nothing looks true to life; not acceptable
-1	Gives appearance of grey to black to green; wouldn't want to do inspection task under it
-1	Very bad light; extremely hard to work under all day
-1	Really hard to tell by what you see
-1	Don't put this light in packing house
-1	Light is terrible; wouldn't want to work under light; turns everything dark
-1	All look dark; couldn't work under these conditions
-1	Terrible light; even hand looked bad; bad light; don't want to do inspection task

Total = -16

Cool White Deluxe

0.5	Coloration of specimens not as pronounced as with [CW] but similar; pneumonia not quite as defined; much better than [LPS]; [difficult to do EM under HPS]
1	Liked light; no problems at all
-1	Seems bluish; doesn't show true colors; not as good as incandescent; hard to distinguish blues and reds; not as clear
1	A lot easier to see; tell what defect was; glare

Table 16. (Continued)

Cool White Deluxe (cont.)

1	Light was good [sample goes by fast]
0	Natural light is best
1	Fine; fairly normal light source
0	Last one [CW] brighter; no change in color
1	Looked like second light [TUN]; acceptable
-1	Too bright; appearance of tissue lighter than normal; seemed brighter; gives yellowish/orange color
1	Like light better than first [HPS]; good light
1	Enhances EM & brings out yellow; does something different to lung; could do inspection task under it
1	A lot easier to see normal color of tissue
1	Very good light; brings out what's wrong with tissue
1	Light seems easier than 1st one; more like natural light
0	Not bad light; ok to do inspection

Total = 8.5

HPS

+1	Like light; easy to work under; intensity could be brighter; might be difficult to detect dark purple or light pink
1	Like light; no trouble at all
-1	Sawdust and parasites not in true colors; light not as true, does not show true color of product
-1	More yellow; sawdust lesion hard to see; anything with yellow color taken away from; not as good as other lights
-0.5	Wasn't the best light; not the worst
-1	Better than yellow [of LPS]; still discoloring effect to actual product
-1	Didn't like at all; gives everything a yellow cast; could create havoc with old cattle
-1	Light not bright enough; kind of yellowish, distorted; normal light is whitish; easy to see abscess and telang; hard to see pneumonia
-1	Don't care for light; eyes did seem to adjust; but wouldn't want to do inspection task; seemed darker & more yellow
-1	Not best light for looking; did point out abscess; distorts pneumonia; would not want to do inspection task; would get confused
1	Relatively easy to inspect under light
1	Much better than first [LPS]
-1	There are a lot better lights; some colors stand out, others not; EM particularly difficult; color of lynph node poor
0	Brings out yellowish tint in tissue
-1	Worst light of 3 [TUN & CWX]; hard to see; to distinguish something
-1	Didn't think light very good; not what used to seeing

Total = -6.5

Table 17. Mean Response Time Data for Red Meat Experiment

Source	N[1]	Mean	Std. Dev.
CW	73	4.7	1.23
TUN	74	4.8	1.12
LPS	72	5.4	1.34
CWX	74	4.8	1.44
HPS	74	4.9	1.18

$F = 3.81$, $df = 4, 362$, $p < .01$

[1] Total observations = 80

samples. The significant results for the rating, the pass/reject, and identification tasks are in the same direction as the data from the poultry experiment. Taken together, these data suggest strongly that both HPS and LPS increase errors as well as the difficulty of doing the inspection task. The data also suggest that cool white (CW) and incandescent (TUN) light appear to be adequate sources, in terms of a lower error rate and rated ease of task performance. Comments by the meat inspectors, some of whom had worked in a facility lighted largely by HPS, suggested that HPS (and by inference, LPS) make the inspection task much more difficult.

These data should not be taken to mean that cool white fluorescent is the ideal light source or that it represents the best use of a given electric power allotment. General theoretical calculations (Worthey, 1982; Thornton, 1972) indicate that cool white light diminishes color contrasts relative to natural daylight of a similar color. Further work is necessary to determine the optimum source for meat and poultry inspection in terms of color rendering, energy expenditure, and visual comfort.

3. SPECTRORADIOMETRIC MEASUREMENTS

3.1 BACKGROUND INFORMATION

Color vision may be defined as that ability by which the eye distinguishes objects according to the shapes of their spectral reflectance functions. Under this definition, which is not the only one in use, "color" does not include the dimension of light versus dark. Useful information regarding such things as the identities of metals in a shop, or the ripeness of fruit, may be revealed by color contrasts. Quite possibly, color plays a role in the discovery of defects by meat and poultry inspectors. In this section, we assume nothing in this regard, but undertake to show through physical data that color vision is of potential importance in the discovery of many pathologies. To the extent that color vision is important, then the color rendering of lighting for meat and poultry inspection is important. These physical (reflectance) data will not by themselves answer the regulatory question, "what light should be required," but will address the underlying basic question, "why does color-rendering matter at all?" Used as inputs to the appropriate calculations, these data could be used to evaluate in detail the suitability of various lights for the inspection task.

Based on the fundamentals of color science, we may state four rules for interpreting these data:

1. If two objects have exactly the same spectral reflectance function, then color vision is of very little use in telling the one from the other, or in seeing the one against a background of the other. This is true, irrespective of the choice of lighting. If a particular discrimination made by an inspector involves only objects of identical spectral reflectance, then the spectral power distribution (SPD) of the light source would be of little consequence for this discrimination. (One is tempted to say that color vision is of no consequence in such a case; however, color could still play a role in shape perception because of the tendency for highlights to differ in color from their background. Suppose, for instance, that an underlying abscess causes a bump on the surface of a liver. The bump itself is "liver-colored," but is made visible by shading and highlights. The highlights are not liver-colored, but white.)

2. If the spectral reflectance of one object is proportional to that of another object, then color vision may aid in telling them apart, but the color difference will be accompanied by a lightness difference. A particular pair of proportional reflectances, for instance, might represent a dark red and a lighter red. The lighter red would appear not only lighter, but also redder (more saturated). The SPD of the light source would be of greater importance than in the first case.

3. If two objects have different spectral reflectances (not equal and not proportional) then the eye may be able to discriminate these objects on the basis of color, depending on the SPD of the light source. Color may very well convey information which is not conveyed through lightness differences or any other cues. In general, the two objects will differ in color under

a broad range of lights, but some lights will "render" the color contrast ("color difference") between them as large, while other lights will make the color difference small or even zero. As an extreme example, a light source that emits all its radiant energy in a very narrow wavelength band, called a "monochromatic" light, loses all color differences and renders all objects (save certain fluorescent ones) in shades of a single hue. To the extent that spectral reflectance differences distinguish healthy tissue from unhealthy or lesions from their backgrounds, color rendering is an important concern.

4. It is helpful to think of colors and the effect of lighting upon them, in terms of color contrasts between particular objects, rather than of the appearance of colors in isolation. There are two reasons for this. First, there are cases in which color is important to vision, even though no one color is abnormal; a broken and protruding bone contrasts in color with muscle, even if both bone and muscle are normal in color. Second, the eye "adapts" to different lights, so that no simple physical measure has a precise connection with perceived color. By speaking in terms of specific contrasts, we can make practical statements that do not mislead, while minimizing any detailed discussion of the adaptation problem. (The more common approach to color rendering (IESNA, 1981) asks how much individual surfaces are displaced in color. This is not the key practical question however, and it makes the adaptation problem a little more obtrusive than it needs to be. The idea of emphasizing contrast is borrowed from the retinex theory (McCann, McKee and Taylor, 1976), which describes adaptation quantitatively with the hypothesis that contrasts at borders govern perception.)

In what follows, we first describe how the spectral reflectance measurements were taken. Then we show that many spectral reflectance differences--potential color differences--are available to aid the meat and poultry inspection tasks.

3.2 APPROACH

3.2.1 Method of Measurement

Spectroradiometric measurements were taken with a Photo Research™ Model PR-710 Spot Spectrascan™ Spectroradiometer. Important features of this instrument for the present work include:

1. A telescopic viewing and measuring system which permits the operator to aim and focus on the exact surface desired, and to observe whether the specular component of reflection is included or excluded.

2. A high-resolution, low-flare lens which can be focused from 44 mm to infinity. The measured area is circular and subtends 0.5 degrees. At 44 mm, the measured spot is approximately 0.5 mm across, which is just small enough to permit measuring the spectral radiance of a large leukotic spot on a chicken liver, for instance.

3. The instrument can be transported for field work.

4. It incorporates a microcomputer and one floppy disk drive which:

   a. permit long-term storage of spectral radiance data on the floppy disk.
   b. can output numerical and graphical data to the printer-plotter.
   c. can pass data to another computer system.
   d. can divide a spectral radiance function by the previously stored spectral radiance of a white standard, in order to provide spectral reflectance.
   e. provide automatic output of derived quantities such as luminance and chromaticity.

5. It has a fixed spectral range of 390 to 730 nanometers (nm), covering the visible spectrum, and reads out at intervals of 2 nm.

3.2.2 Measurement Technique

Reflectance of a surface is a measure of the fraction of incident light that an object reflects; a very white object has a reflectance of almost 1.0, while a very black object has a reflectance approaching 0.0. Reflectance measured as a function of wavelength is called spectral reflectance. Many surfaces are partly mirror-like ("specular"); if they are illuminated by a single light-bulb for instance, some of the incident light contributes to highlights, which are essentially little mirror images of the light bulb. The rest of the light is either absorbed or reflected diffusely. In measuring reflectance, it is important to know if one is observing the reflected light within a highlight or away from a highlight (Nicodemus, Richmond, Hsia, Ginsberg, and Limparis, 1977). This is described as measuring reflectance with "specular included" or "specular excluded."

On non-metallic objects, highlights generally have the approximate color of the incident light, while non-highlight areas have the characteristic color of the object (Raloff, 1982). While highlights may provide the eye with important information on object geometry, the "specular excluded" reflectance conveys the color of the object. For this reason, we measured spectral reflectance of healthy and diseased tissue as specular excluded, with a few exceptions.

The measurement involved these steps:

1. With a small source at a selected reference distance (usually 7 inches) along the normal to the sample's surface, we measured the spectral radiance of a standard white surface of packed polytetrafluoroethylene (PTFE) (Weidner and Hsia, 1981). The small source was an incandescent bulb, whose voltage was kept constant to within a few percent. The packed PTFE surface is such a good approximation to a perfect white, that its spectral reflectance may be taken as 1.0 throughout the visible spectrum.

   Within the general area to be measured, such as the normal epidermis of an entire chicken, we chose a spot for the measurement. We put the small source at the reference distance along the normal to the spot. A special apparatus was constructed to simplify proper placement of the light source.

3. We focused the spectroradiometer on the spot. The angle of viewing was assumed not to be critical, except that any highlight should be excluded from the measured area. Exclusion of the highlight is done by direct observation through the telescopic viewing system.

4. We measured the spot's spectral radiance.

5. The radiance found in step 4 was divided by that found in step 1, to get the spectral reflectance (technically, the spectral reflectance factor).

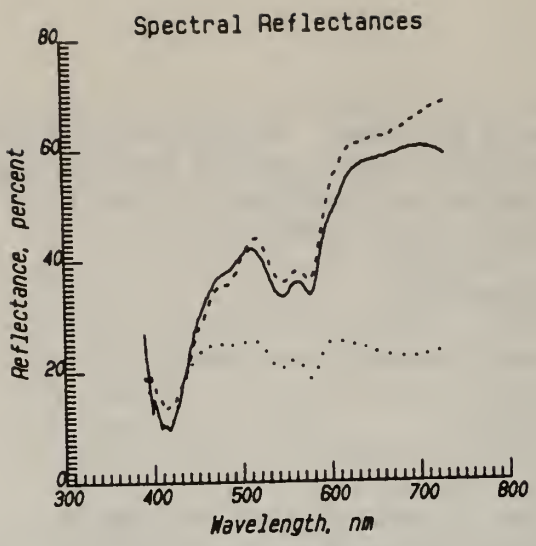
The procedure and provision for lighting used are inferior in sophistication to those which would be used in a physics laboratory. The net effect of this is to put some uncertainty on the absolute magnitude--but not the shape--of the reflectance curves obtained. However, the direct-viewing spectroradiometer does permit good reliability in the task of aligning the intended spot and including or excluding specular reflection. Furthermore, since this instrument measures the entire spectrum simultaneously, the shape of the spectral radiance functions should be unaffected by small time variations in incident light intensity. As the eye also collects and uses data in a way that does not hinge on precise measurement of absolute reflectance, we can say that these data have satisfactory accuracy in the context of vision and lighting.

3.3 SPECTRORADIOMETRIC MEASUREMENTS

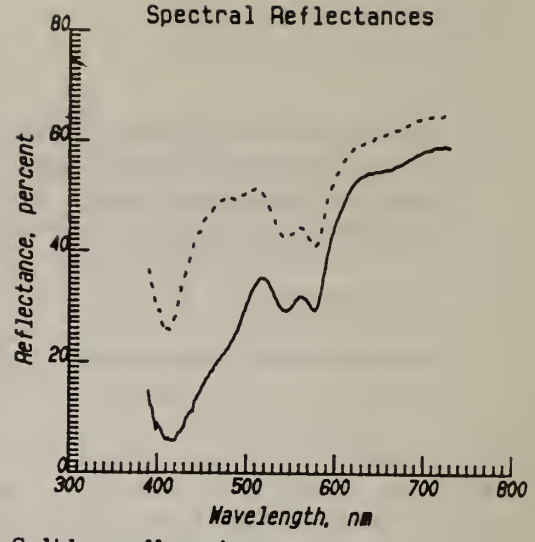
Spectroradiometric measurements were made of tissue samples from each of four species. These included: chickens, turkeys, swine, and cattle. Tissue samples were selected on the basis of availability on the day measurements were made. Consequently, not all major defects responsible for condemnation in each species are represented. Reflectance measurements were typically made for a defect and for nearby "normal" tissue, to indicate the extent to which differences in color occur in samples actually seen by inspectors. The surrounding tissue is "normal" relative to the defect--its spectral reflectance may well differ from the corresponding tissue in a truly normal sample.

The spectral radiance data for normal and defective samples for four species were transformed to spectral reflectance data relative to the white standard. Then the data for each defect and its adjacent "normal" tissue were plotted in a series of comparison graphs (see figure 6 for example). These graphs present percent reflectance as a function of visible wavelength from 390 to 730 nm. Note that the range of values for percent reflectance varies for different samples. At least two kinds of comparison may be made for each figure. The first is that of differences in spectral characteristics, represented by changes in the shape of the curve (and normally perceived as differences in color). The second is that of differences in lightness, represented by changes in the height of the curve (or percentage reflectance). Combinations of the two may also be observed. Inspection of these graphs indicates, that for many of the defects measured, differences in the shape of the spectral curve (or in color) play an important role.

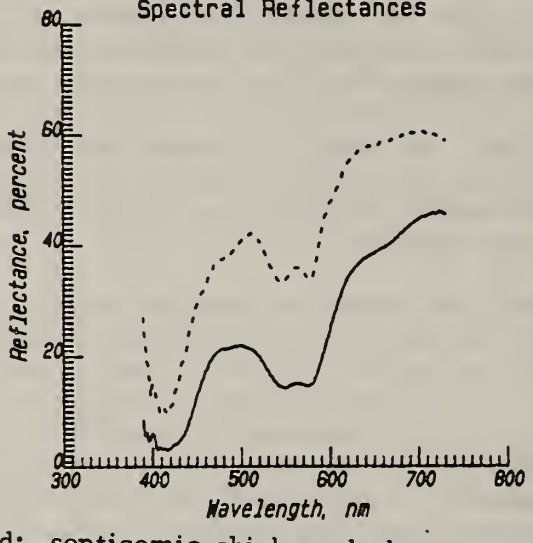
Figures 6 and 7 present data for chicken defects, similar to those studied in the psychophysical portion of the experiment. Figure 6a shows different areas



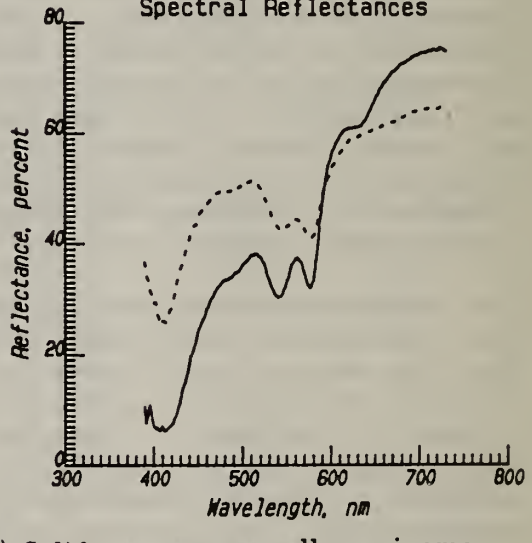
a) Solid: normal chicken skin.
Dashed: bruised bird, yellowish area.
Dotted: bruised bird, bluish area.



b) Solid: gall stain.
Dashed: more normal area, same bird.

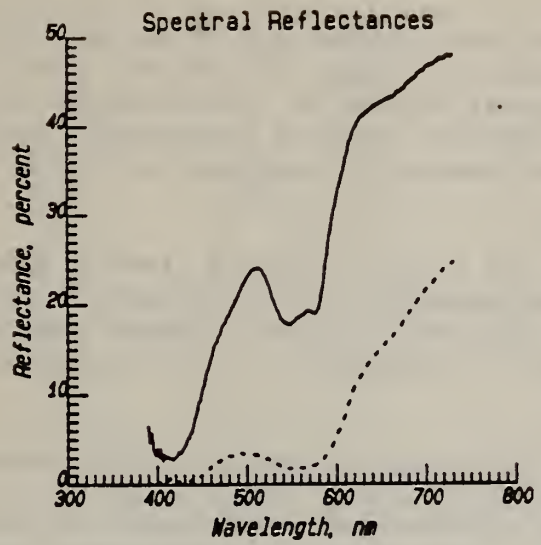


c) Solid: septicemic chicken, dark area.
Dashed: normal epidermis, same data as solid curve in (a).

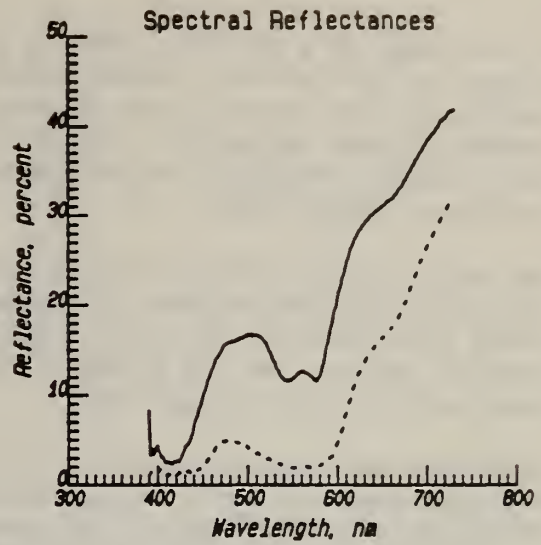


d) Solid: squamous cell carcinoma.
Dashed: adjacent "normal" area of epidermis.

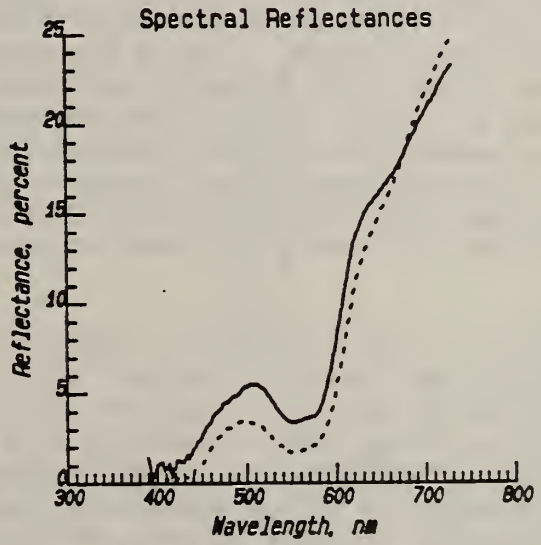
Figure 6. Spectral reflectance functions of chicken epidermis, presented as comparisons of defective with "normal" areas.



a) Solid: yellowish spot in leukotic liver.
Dashed: more normal area, same liver.



b) Solid: yellowish spot in leukotic spleen.
Dashed: more normal area, same spleen



c) Solid: "normal" area of a liver with air sacculitis.
Dashed: "normal" area of a leukotic liver. This is a "control" comparison between similar surfaces.

Figure 7. Spectral reflectance functions of internal organs in chicken, presented as comparisons of diseased with "normal" areas.

of bruising on a chicken, showing both bluish (lower curve) and yellowish areas, as well as more normal nearby tissue. Figure 6b compares a gall stain similar to that used in the psychophysical portion of the experiment with normal chicken epidermis. Figure 6c compares a septic (septicemic) epidermis with normal epidermis, while figure 6d presents a comparison of a skin carcinoma with more normal skin.

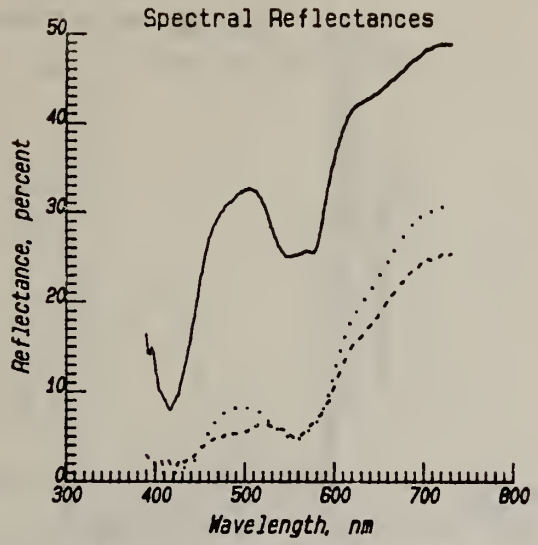
The comparisons shown in figure 7 are for internal chicken tissues, characterized by much lower reflectances. Figure 7a presents a yellowish spot on a leukotic liver with more normal liver tissue. Similarly, figure 7b shows a yellowish spot of leukosis on the spleen. Figure 7c compares air sacculitis on a chicken liver with an unaffected area.

Figures 6 and 7 are characterized by differences in spectral characteristics and lightness between a defective and normal area. The leukotic spots and bluish bruise show some of the greatest differences in lightness, but the graphs generally show differences in spectral characteristics to a greater or lesser extent.

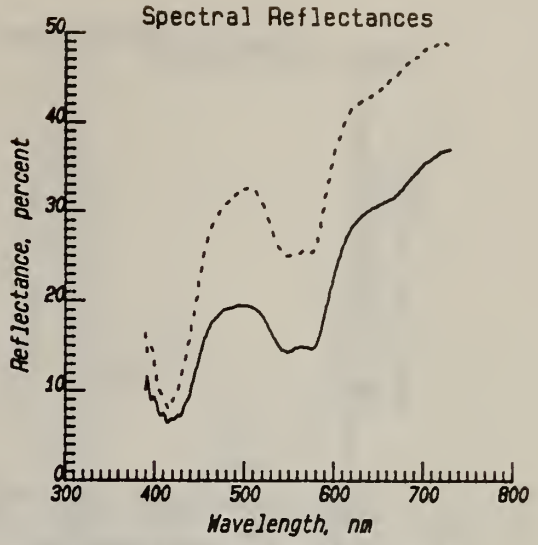
Figures 8 to 12 present spectral reflectance data for cattle. Figure 8a compares abscessed tissue, containing both the abscess and the immediately adjacent inflamed area, with more distant normal liver tissue. There is a marked lightness difference for the white area along with some difference in spectral characteristics. Figure 8b compares the white area of two different liver abscesses which differ more in lightness than in spectral characteristics. Figure 8c compares the small abscess of 8b with more normal liver tissue in the immediate surround. Figure 8d compares the "normal" tissue surrounding each abscess. In this case, the two spectral reflectances are very similar with differences only at very short wavelengths. Figure 9 presents data primarily for cattle viscera (except figure 9d). Figure 9a compares inflamed mammary tissue with a more normal area of tissue, while figure 9b compares a sawdust lesion in the liver with more normal liver tissue. Figure 9c compares fecal material on the spleen with an uncontaminated area of spleen. Finally figure 9d shows two different areas of bruising with non-bruised flank tissue. Again differences in spectral characteristics emerge for the various comparisons, particularly for 9b and 9c.

Figure 10 presents additional data for cattle viscera. Figure 10a shows a pulmonary adhesion with adjacent "normal" tissue. Figure 10b compares both a white and inflamed red area of an abscess with a normal area of diaphragm. Finally, figure 10c shows another comparison of fecal contamination with an uncontaminated area, this time for lung tissue. The figure 10 comparisons are a less dramatic depiction of wavelength and lightness differences (except 10c) than some of the other spectral reflectance data for cattle.

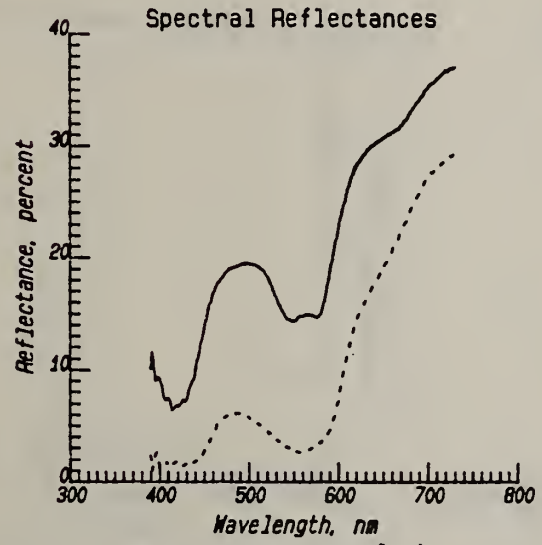
Figures 11 and 12 present data for some of the defects studied in the cattle psychophysical experiment. Figure 11a presents the spectral reflectances found for EM, compared with normal heart and fat tissues. Figure 11b presents liver tissue with and without the dark spots of telang. Figure 11c shows comparisons for a kidney with chronic nephritis (not used in the psychophysical study). Figure 11d shows data for acti (an abscess of the lymph nodes in the head).



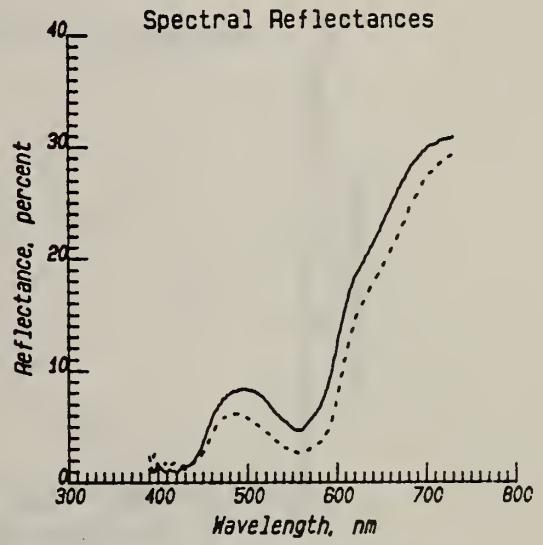
a) Solid: liver, white area of abscess in steer.
Dashed: liver, inflammation near abscess.
Dotted: liver, adjacent "normal" area.



b) Solid: liver, white area of small abscess.
Dashed: liver, white area of larger abscess, same liver. Note that this is a "control" comparison of nominally similar areas.

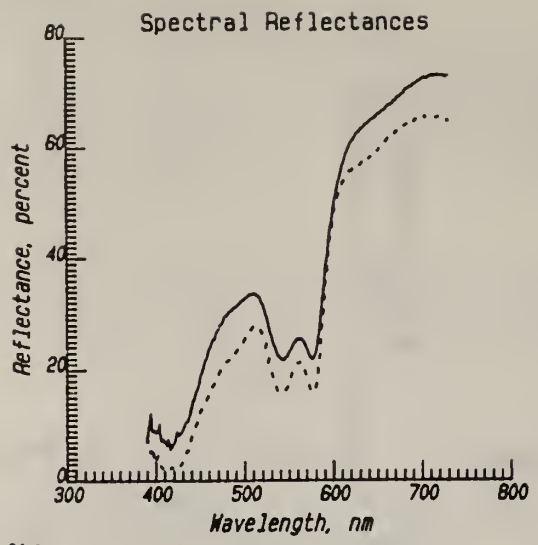


c) Solid: liver, small abscess. Same data as previous graph.
Dashed: liver, more normal area.

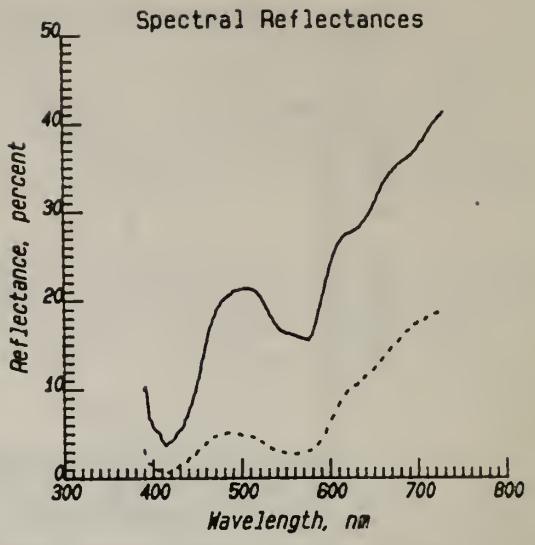


d) Solid: liver, normal area, steer.
Dashed: liver, another normal area, different liver. This is another "control" comparison, showing the variability within "normal" liver.

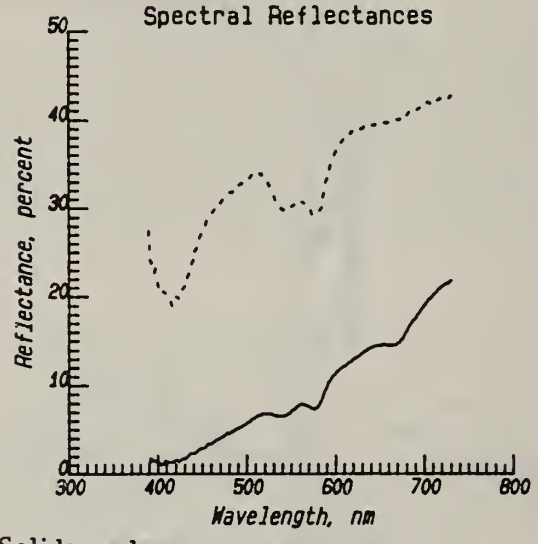
Figure 8. Spectral reflectance measurements of liver in cattle, presented as comparisions of defective areas with "normal" areas.



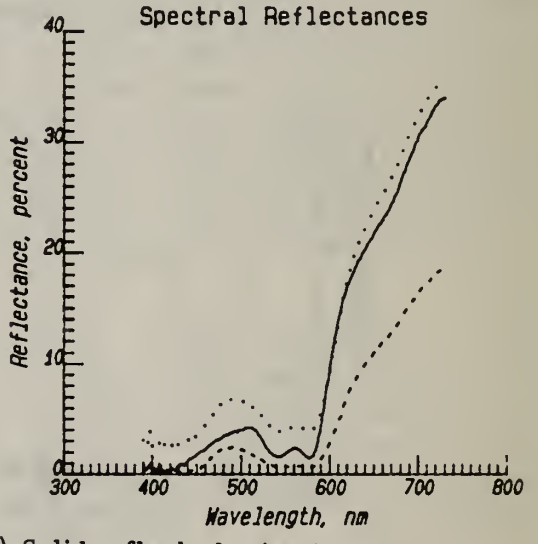
a) Solid: mammary tissue, inflamed area.
Dashed: mammary tissue, more normal area.



b) Solid: liver, "sawdust lesion."
Dashed: liver, more normal adjacent area.

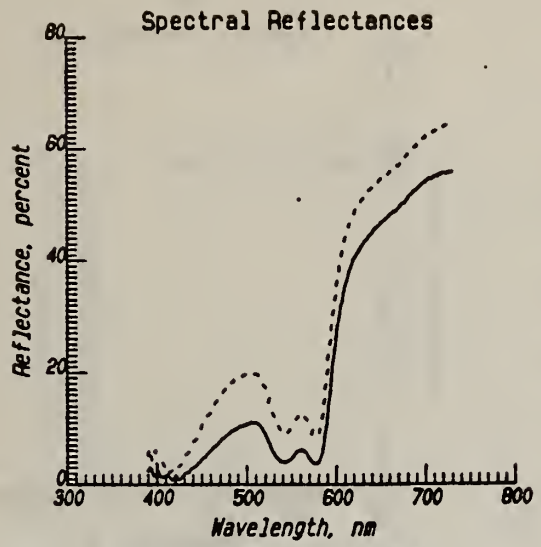


c) Solid: spleen, contaminated with fecal material.
Dashed: spleen, adjacent "normal" area.

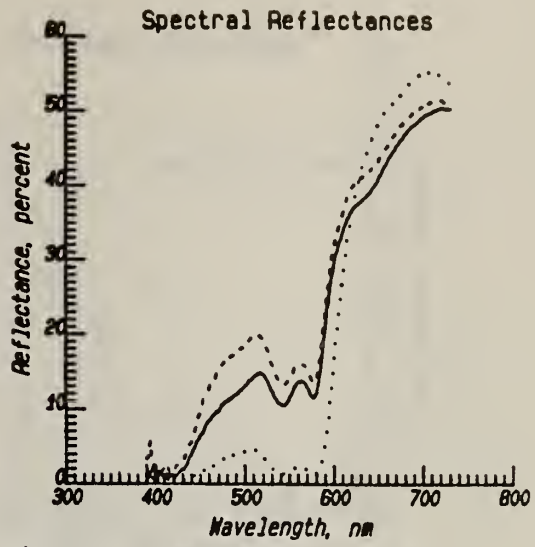


d) Solid: flank, bruise in peripheral tissue.
Dashed: flank, bruised, peritoneal side.
Dotted: flank, more normal tissue.

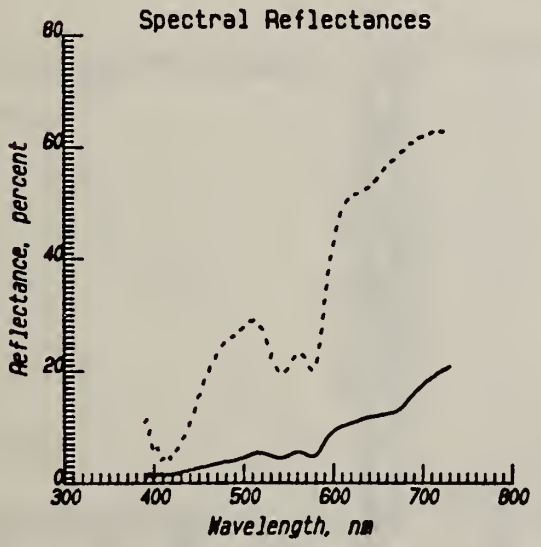
Figure 9. Spectral reflectance measurements of internal areas in cattle, presented as comparisions of defective areas with "normal" areas.



a) Solid: lung, pulmonary adhesion.
Dashed: lung, adjacent "normal" area.

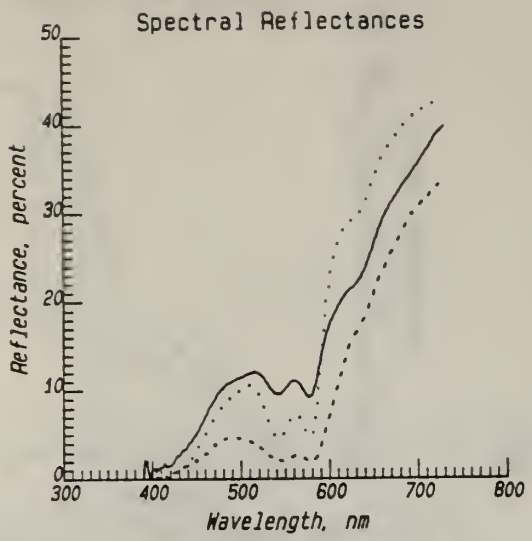


b) Solid: diaphragm with white abscess.
Dashed: diaphragm, adjacent "normal" area.
Dotted: diaphragm, inflamed red area.

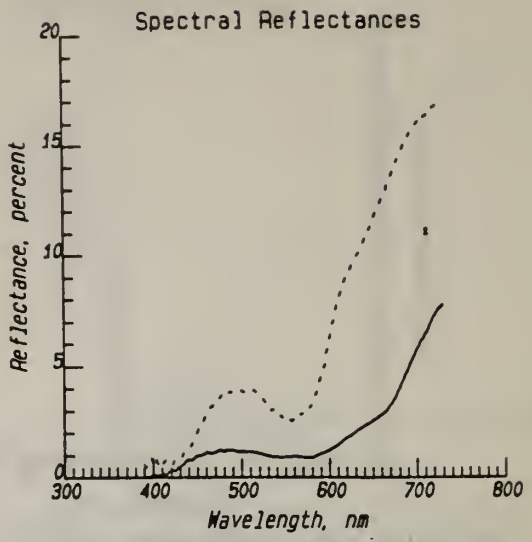


c) Solid: lung, contaminated with fecal material.
Dashed: lung, uncontaminated area.

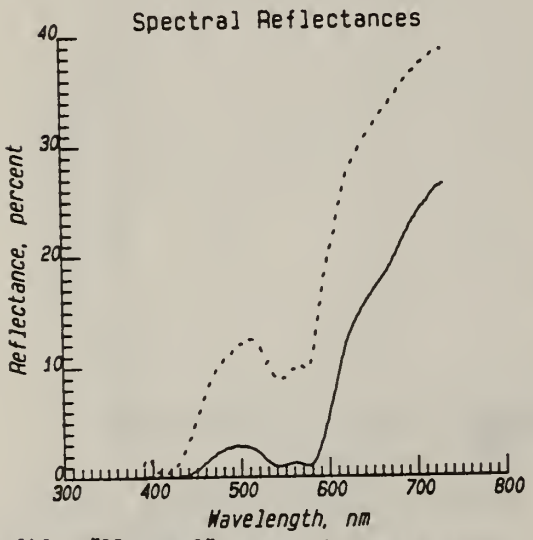
Figure 10. Spectral reflectance measurements of internal areas in cow, presented as comparisions of defective areas with "normal" areas.



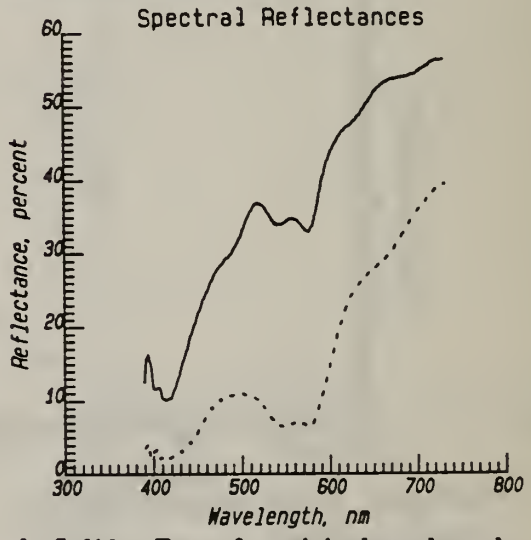
a. Solid: Eosinophilic myositis in cattle heart, greenish (yellowish) spot.
Dashed: Adjacent normal pink heart muscle.
Dotted: Nearby white fat with some blood on it---normal.



b. Solid: Telangiectasis in liver, dark spot with no surrounding red area included. (Only a large spot can be isolated in this way.)
Dashed: Nearby, more normal, area of same liver.

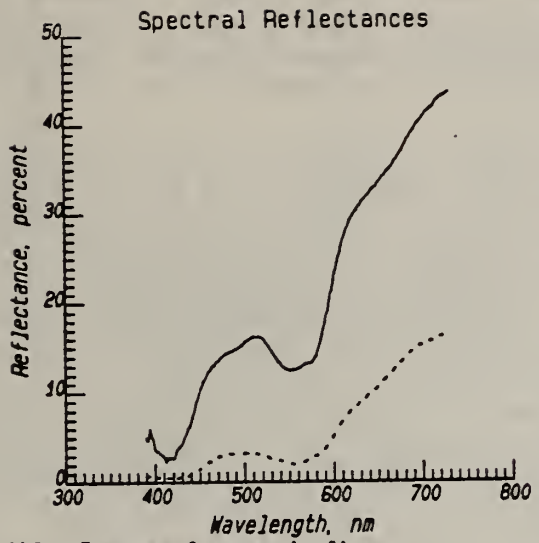


c. Solid: "Normal" area of kidney with chronic nephritis.
Dashed: Abnormal yellowish (whitish) area of kidney with chronic nephritis.

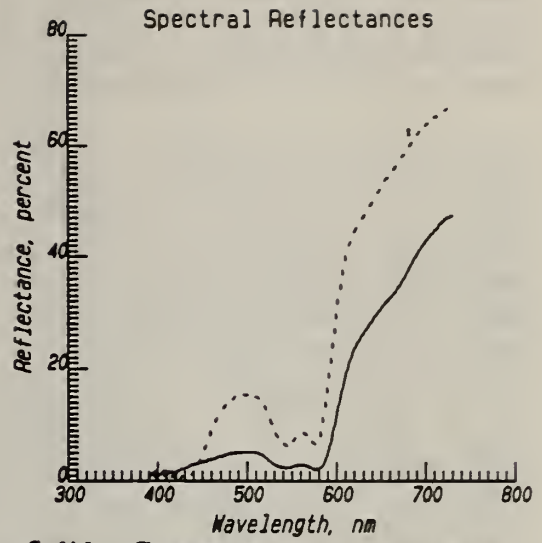


d. Solid: Pus of acti in lymph node, head.
Dashed: "Normal" pinkish-gray area of same lymph node.

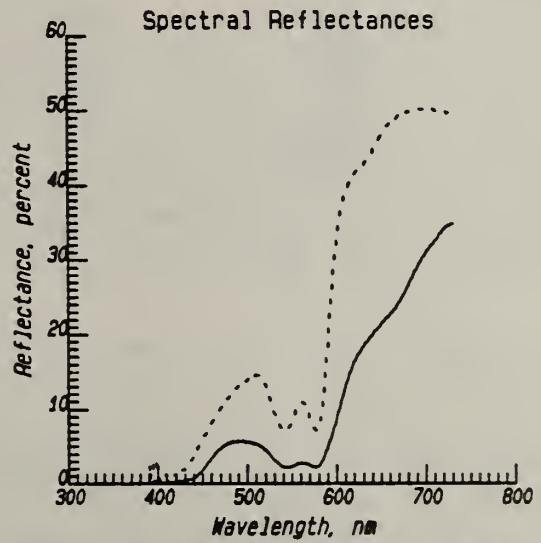
Figure 11. Spectral reflectance measurements of internal areas in cattle, presented as comparisons of diseased areas with normal areas.



a. Solid: Large abscess in liver, whitish area.
Dashed: "Normal" reddish area, same liver.



b. Solid: Congested lung, abnormal reddish area.
Dashed: "Normal" pinkish area, same congested lung.



c. Solid: Pneumonic lung, dark area.
Dashed: "Normal" pinkish area, same pneumonic lung.

Figure 12. Spectral reflectance measurements of internal organs in cattle, presented as comparisons of diseased areas with normal areas.

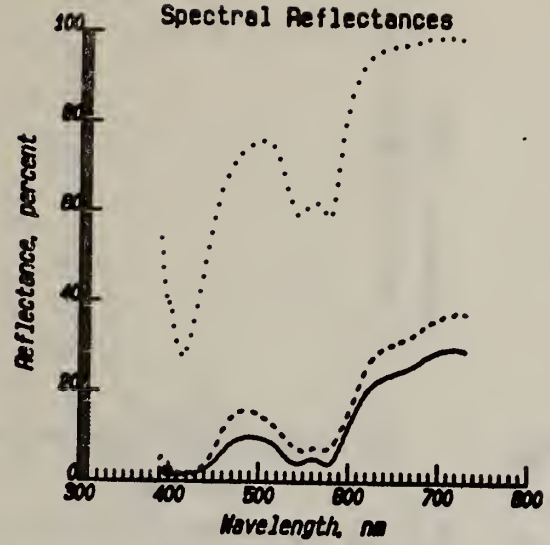
Both figures 11b and 11d demonstrate noticeable differences in spectral characteristics and lightness.

Figure 12a presents additional data for a liver abscess, characterized by both color and lightness differences from normal liver tissue. Figures 12b and 12c present data for both congested and pneumonic lung tissue. Figure 12b shows greater differences in spectral reflectance between adjacent tissue samples, than does 12c, although some differences are apparent for the latter, as well.

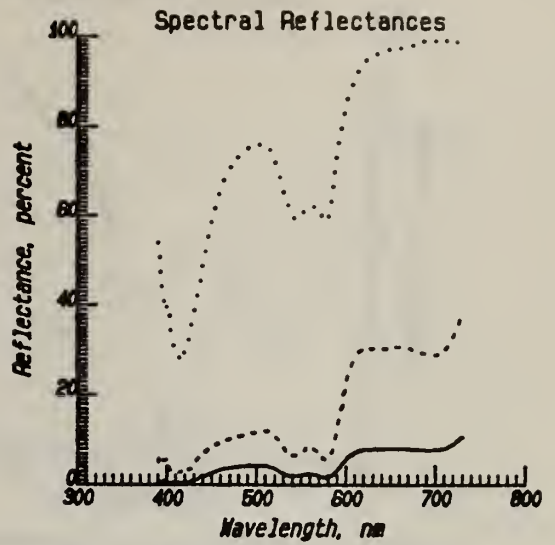
Figures 13 to 14 present data for turkeys. Figure 13a shows reflectance data for various portions of a septic turkey, compared with a normal epidermis. Figure 13b compares two different areas of a fresh wing bruise with more normal epidermis. Figure 13c shows an older healing bruise on a humerus. This bruise was characterized by a distinctive greenish cast. Figure 13d also shows a healing bruise, again with a greenish cast. Figure 13 demonstrates marked differences in response to spectral composition for all comparisons of defective and normal tissue samples. There are also differences in percent reflectance for the various samples. Figure 14 presents data for turkey viscera and internal areas. Except for 14c, the turkey viscera are characterized by much lower reflectances than the epidermal samples. Figure 14a compares a whitish granuloma with a more normal area of turkey liver, while 14b shows a dark area of liver with bile build-up along with a more normal red area of liver. Figure 14c compares data from the gizzard of a septic turkey. Air sacculitis was also present on the gizzard. Finally, 14d compares fecal contamination with an uncontaminated area of peri-renal fat. Again the data shown in figure 14 demonstrate marked differences in the pattern of spectral reflectance for various portions of defective and normal tissue.

Figures 15-19 present comparison data for swine. Figure 15 provides a series of comparisons for swine epidermis. Thus, figures 15a and 15b compare two different hair tufts with adjacent skin. (The normal skin in 15b is characterized by a much lower spectral reflectance than that of 15a. Note the difference in the scale of the ordinate.) Figures 15c and d compare different melanotic lesions with surrounding epidermal tissue. The melanotic lesions are characterized by very low spectral reflectance, unlike the surrounding epidermis. Since this lesion appears as a black spot on a light background, it is one for which color vision is probably not important.

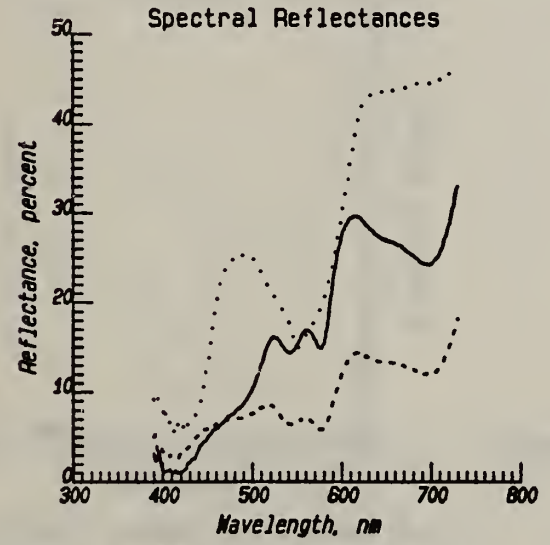
Figure 16 presents comparison data for internal swine tissue. Figure 16a compares pulmonary edema with normal lung tissue, while 16b compares two pneumonic splotches (with almost identical spectral reflectances) with normal lung tissue. Figure 16c presents an unusual and severe abscess. An abscess in the lung of a pig had extended through the pleura to reach the spine. The surface of this growth had the normal color of the pleura although the growth's shape, of course, was not normal. Measurements were made of a highlighted area (specular) and a non-highlighted area (specular excluded) to investigate the role of color in contributing to the perception of the shape of the abscess. Figure 16d compares pus in the parotid gland with more normal tissue. This last figure is characterized by only slight differences in spectral characteristics and lightness.



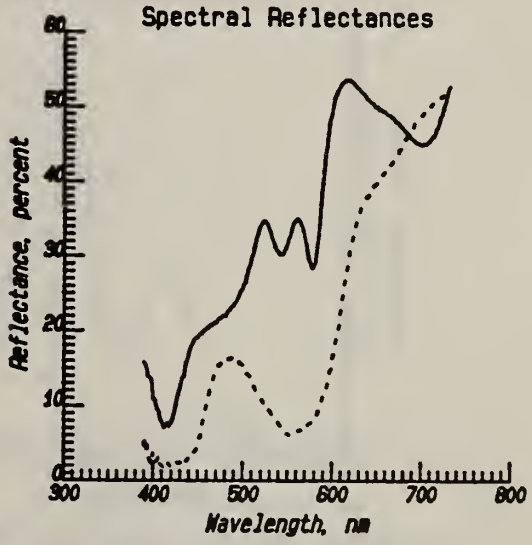
a) Solid: Septicemic breast
Dashed: Septicemic leg.
Dotted: normal epidermis, wing of another turkey.



b) Solid: fresh bruise on wing, dark red area.
Dashed: same bruised wing, lighter area.
Dotted: normal epidermis (nearly white), same wing.

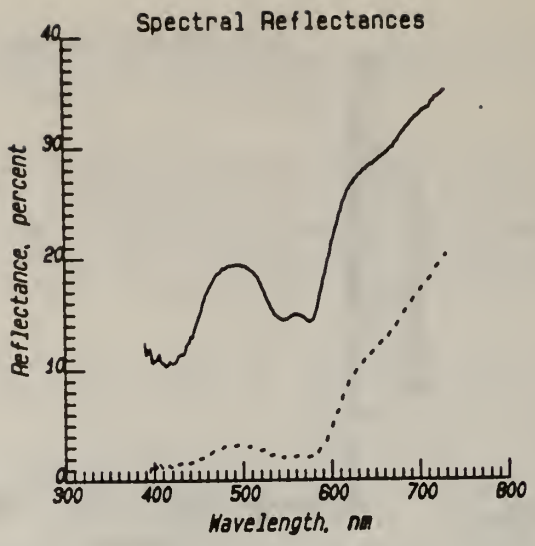


c) Solid: bruise in humerus, greenish area.
Dashed: "gray" area of same bruise---green overlying red.
Dotted: pink surrounding tissue.

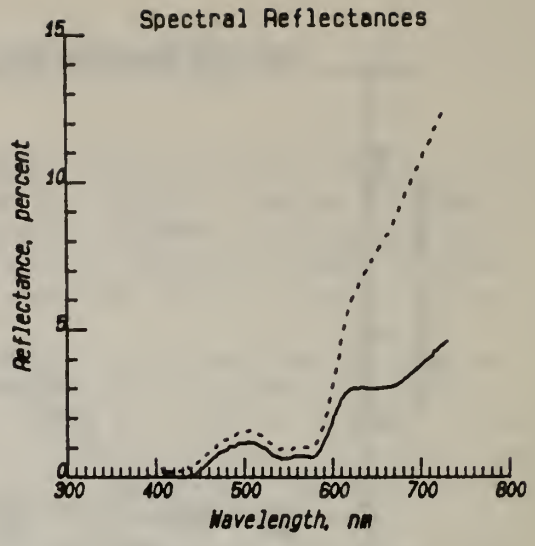


d) Solid: leg, old healing bruise.
Dashed: normal muscle, red area without skin.

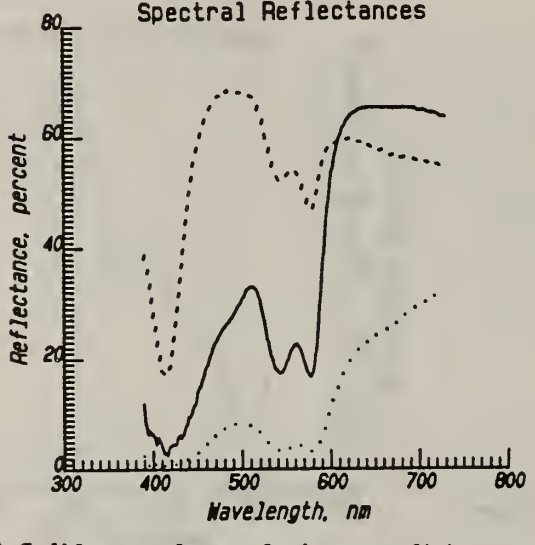
Figure 13. Spectral reflectance functions of external areas of turkey, presented as comparisons of defective with "normal" areas.



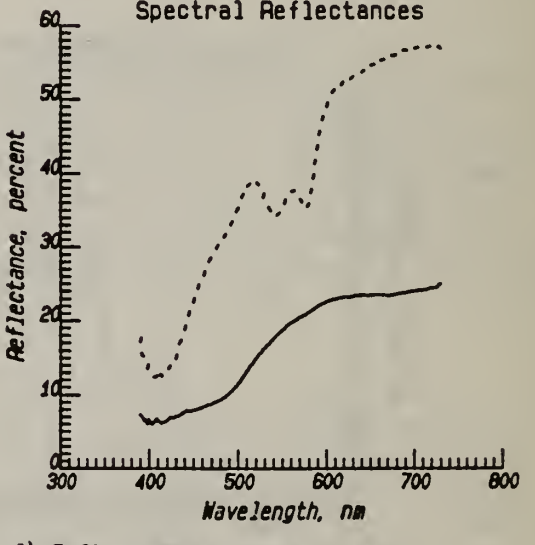
a) Solid: whitish area of granuloma in liver.
Dashed: adjacent "normal" area.



b) Solid: dark area of bile build-up in liver.
Dashed: red area of same liver.

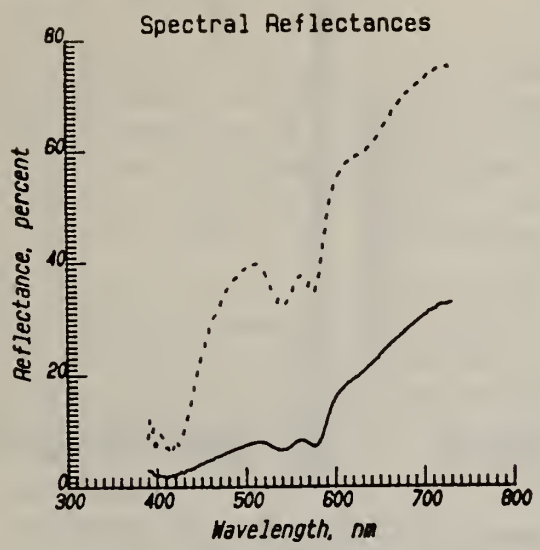


c) Solid: exudate of air sacculitis, overlying white fibrous area of gizzard.
Dashed: white area of same gizzard, air sac pulled away.
Dotted: septicemia, same gizzard, dark red area.

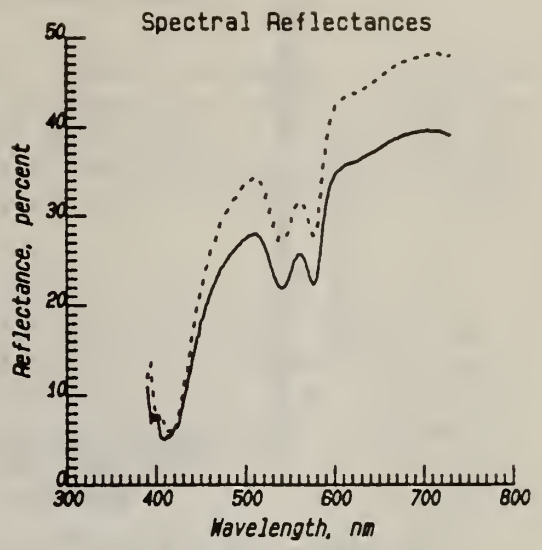


d) Solid: fecal contamination on peri-renal fat.
Dashed: peri-renal fat, not contaminated.

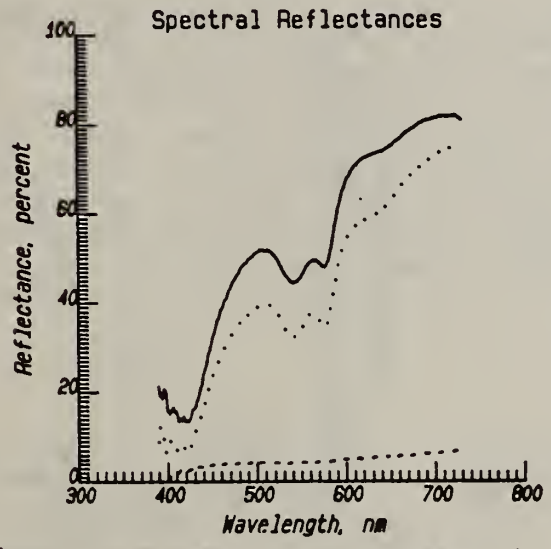
Figure 14. Spectral reflectances of internal areas of turkey, presented as comparisons of defective with "normal" areas.



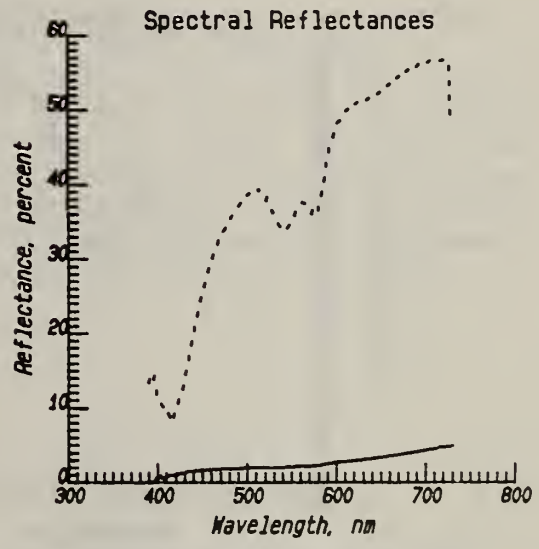
a) Solid: hair tuft on background of skin. The measurement spot covered parts of several hairs and also some skin.
Dashed: normal cream-colored skin.



b) Solid: hair tuft remeasured.
Dashed: normal skin, no hair.

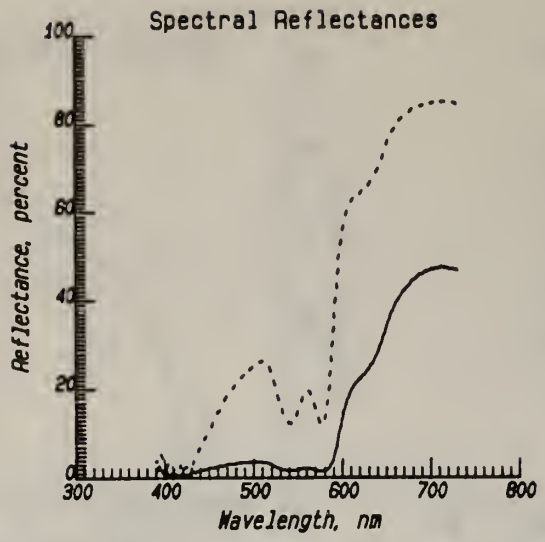


c) Solid: white surround of melanotic lesion.
Dashed: dark area of melanotic lesion. Note the large lightness difference.
Dotted: normal cream-colored area of skin.

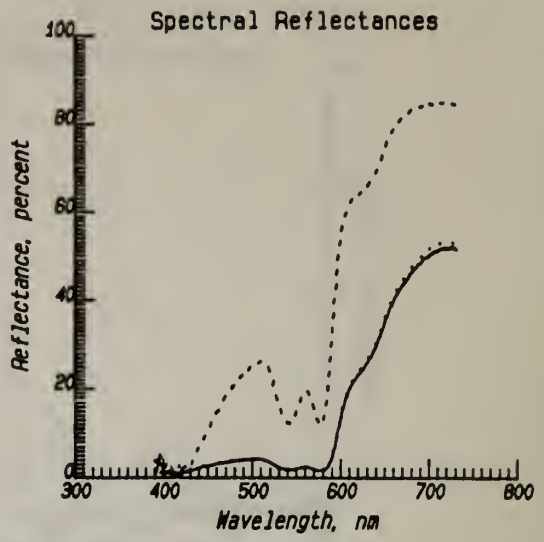


d) Solid: black area of melanoma.
Dashed: normal skin near melanoma.

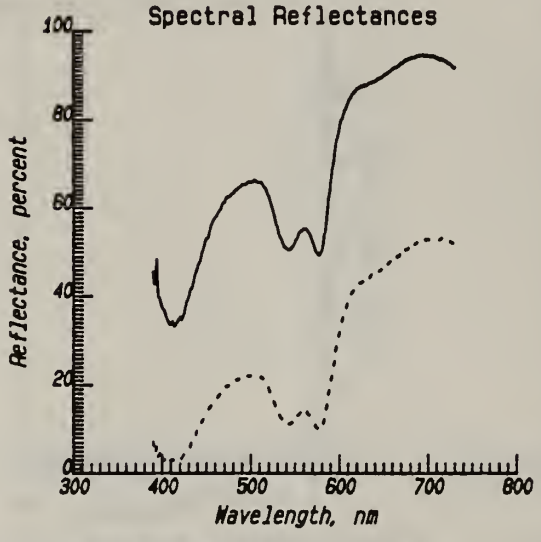
Figure 15. Spectral reflectance measurements of hog epidermis, presented as comparisons of defective areas with adjacent "normal" areas.



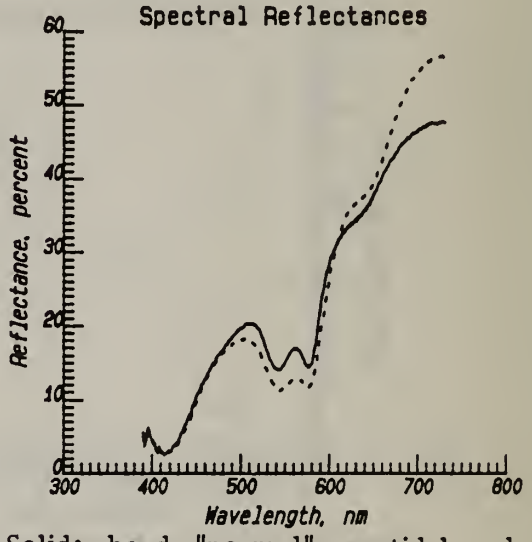
a) Solid: lung with edema in pneumonic area.
Dashed: lung, adjacent normal tissue.



b) Solid: lung, red splotch in pneumonic area.
Dashed: lung, adjacent "normal" tissue.
Dotted: lung, different red splotch in pneumonic area.



c) Solid: spine, abscess from lung, highlight.
Dashed: spine, same abscess, specular excluded. This surface had the normal color of mesentery, but these data indicate a role for color in the perception of shape.



d) Solid: head, "normal" parotid lymph gland.
Dashed: head, pus in parotid lymph gland.

Figure 16. Spectral reflectances of internal organs in hog, presented as comparisons of diseased areas with "normal" areas.

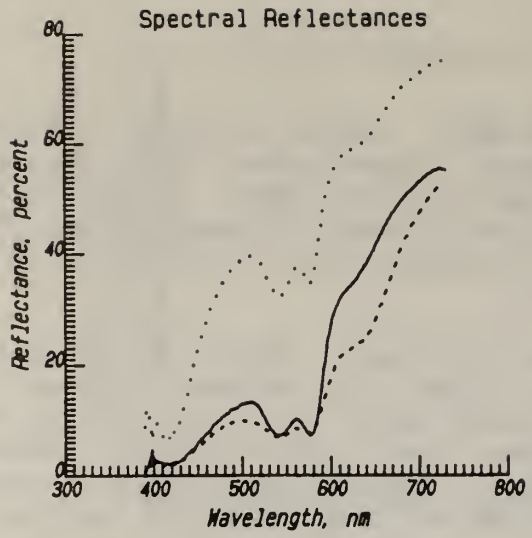
Figure 17 compares different areas of pig skin. Figure 17a shows two different areas of erythematous skin along with normal "cream-colored" skin. Figure 17b also shows erythema due to trampling along with normal skin. Figure 17c compares a white and red area of exostosis, while figure 17d presents foot tissue with and without arthritis. Figure 17 is characterized by differences in both spectral characteristics and lightness.

Figure 18 shows data for various internal pig organs. Figure 18a compares a melanotic lesion in mammary tissue with a normal fatty surround. Figure 18b presents a lung abscess against "normal" lung, while 14c shows splenitis and normal spleen. Figure 18d compares a kidney cyst filled with urine against a background of kidney, with the kidney alone. Since the cyst is transparent, its spectral reflectance depends strongly on the geometry of the lighting and viewing conditions.

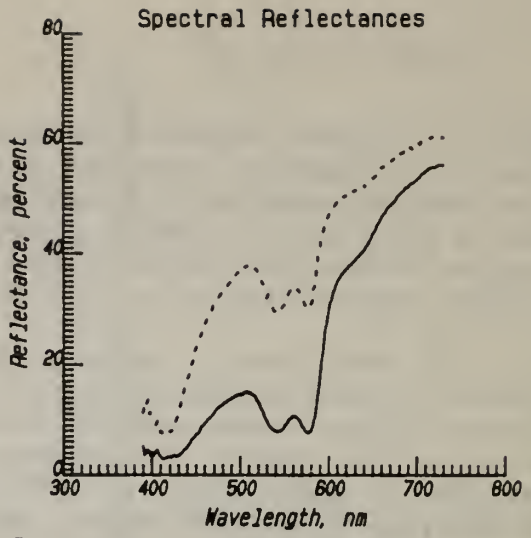
Figure 19 provides more internal organ comparisons for swine. Figure 19a compares a spot of white TB in the mesentery surrounding the intestine with a normal lymph node. Figure 19b shows two white milk spots on the liver, as well as normal liver. Finally, figure 19c presents an abcess with both the capsule and pus present along with a normal jowl.

In the preceding pages, the presence of differences in both lightness and spectral composition between defective and nearby more normal tissue has been documented.

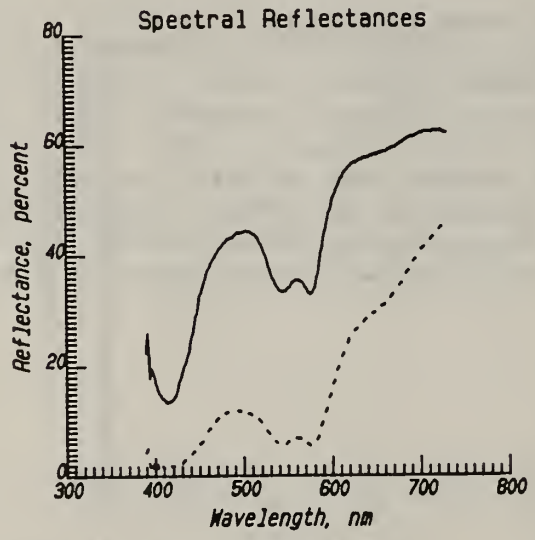
Additional analytical calculations are needed to predict the extent to which changes in light source spectral distribution will affect differences in color between defective and adjacent "normal" tissue. Small color differences, apparent under incandescent light or even cool white fluorescent light, may disappear under a source with poor color rendering such as HPS. In the psychophysical portion of the experiment, the samples most affected by light source manipulation were the gall stain, air sacculitis and normal tissue in chickens, and various lung problems in cattle. Observation of these samples indicated that they were characterized by small color differences--differences likely to be minimized by HPS and LPS.



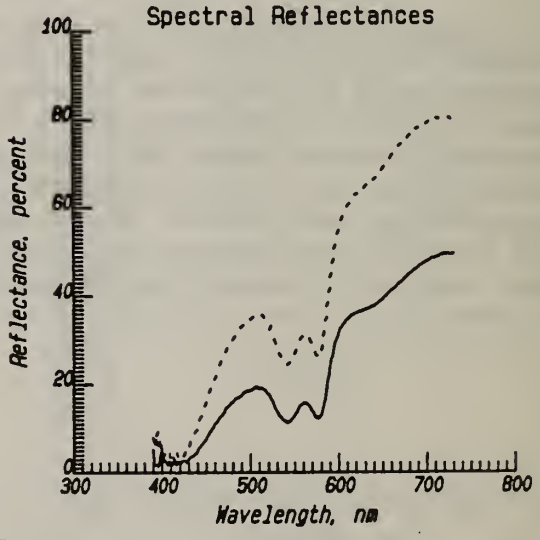
a) Solid: skin, erythema, bright red area.
Dashed: skin, erythema, dark brown area.
Dotted: skin, normal cream-colored area.



b) Solid: skin, bright red area of trample mark.
Dashed: skin, adjacent "normal" area.

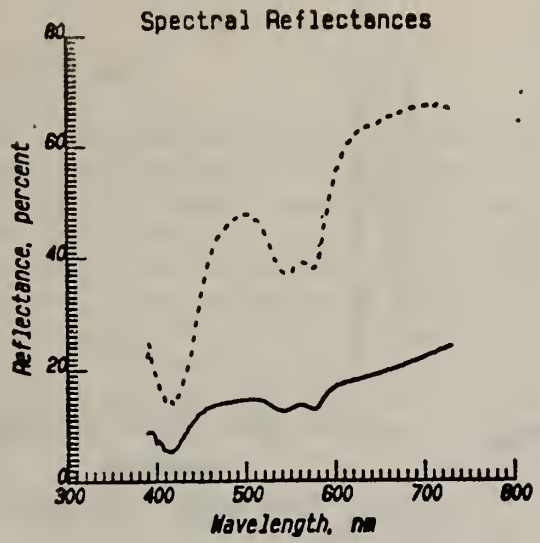


c) Solid: exostosis, white area.
Dashed: exostosis, red area.

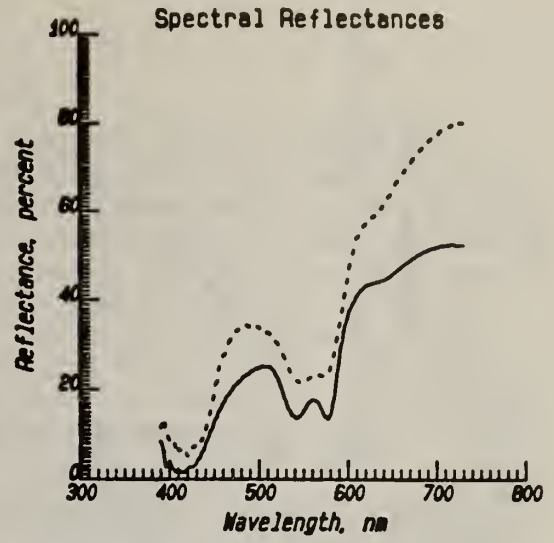


d) Solid: foot, dark area with arthritis.
Dashed: foot, adjacent "normal" area.

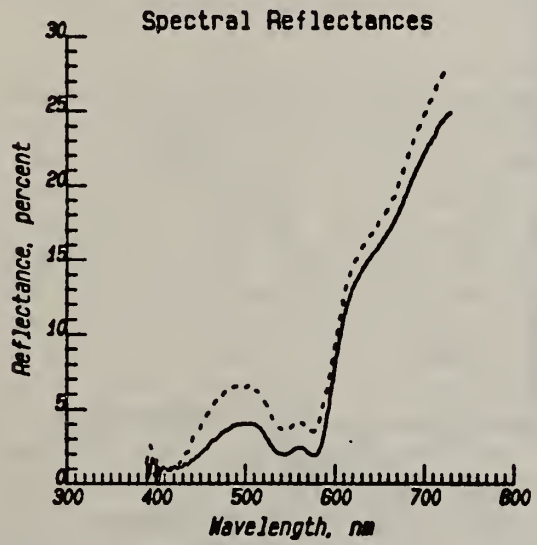
Figure 17. Spectral reflectance measurements of external areas of hog, presented as comparisions of defective areas with "normal" areas.



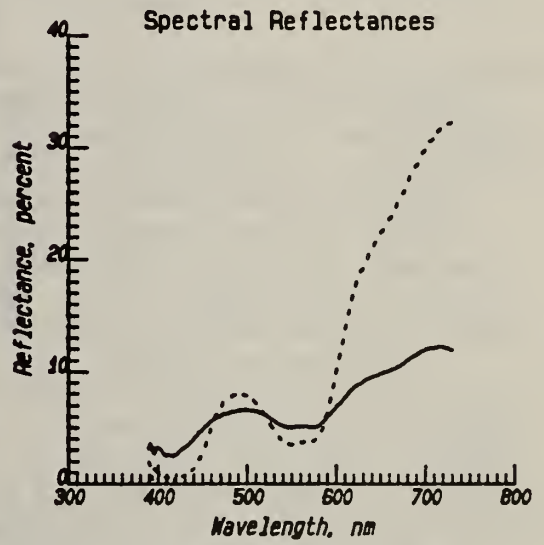
a) Solid: mammary tissue, melanotic lesion.
Dashed: mammary tissue, normal fatty surround.



b) Solid: lung, multiple lesion; yellowish area of abscess.
Dashed: lung, adjacent "normal" area.

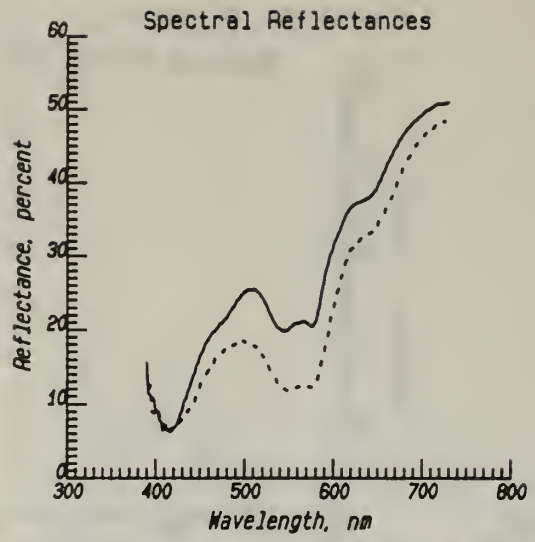


c) Solid: spleen, red spots in splenitis.
Dashed: spleen, adjacent "normal" area.

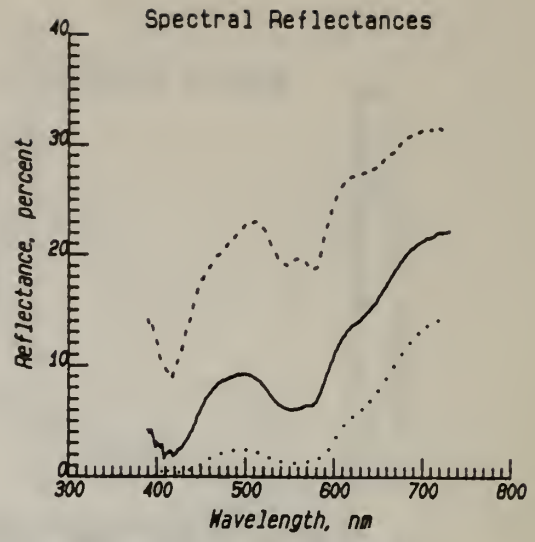


d) Solid: kidney, cyst with urine against background of kidney. The cyst is actually transparent, so its color depends strongly on the geometry of lighting and viewing.
Dashed: normal red area of same kidney.

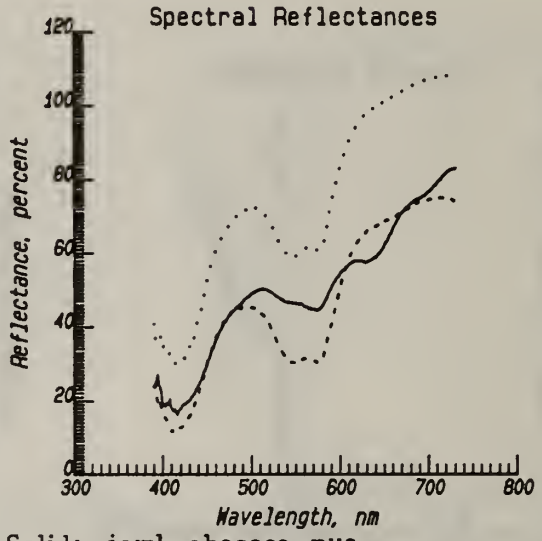
Figure 18. Spectral reflectance measurements of internal organs in hog, presented as comparisons of defective areas with "normal" areas.



a) Solid: mesentery, white tubercular spot in lymph node.
Dashed: mesentery, more normal area in lymph node.



b) Solid: liver with "milk spots," white area.
Dashed: liver with "milk spots," a second white area.
Dotted: liver, adjacent "normal" area.



c) Solid: jowl, abscess, pus.
Dashed: jowl, capsule area of abscess.
Dotted: jowl, normal fatty tissue.

Figure 19. Spectral reflectance measurements of internal areas in hog, presented as comparisions of diseased areas with "normal" areas.

4. CONCLUSIONS

The major analyses performed in the present research project suggest two important conclusions: 1) differences in spectral reflectance between defective and normal tissue exist; and 2) at least two light sources, HPS, and LPS, decrease the inspector's ability to inspect meat and poultry tissue accurately. Thus, the spectral reflectance data indicate that potential color differences--differences in the shapes of the spectral reflectance functions--do exist between defective and adjacent normal tissue for all four species measured. Along with the accompanying lightness differences, color differences appear to play a major role in the successful identification of tissue for condemnation, judging by the results of the psychophysical experiment. Those data indicate that the two sources with the poorest color rendering (HPS and LPS) had some of the poorest performance for the various measures studied. These included pass/reject judgments; accuracy of identification; rated ease of task performance under each source; overall rating of source for the inspection task; and response time. While these results were more pronounced for the poultry study, due perhaps to the greater veracity of the simulation, the trends for the cattle study were in the same direction.

An alternate interpretation of the data would be that sources of higher color temperature yield higher performance. The independent variables of color rendering and color temperature were not studied independently in the psychophysical study. Our assumption in this report has been that color rendering is the more important variable. The most cautious interpretation would be that both low CRI and low color temperatures should be avoided.

In conclusion, the data obtained in the psychophysical experiment indicate that sources with color rendering indices as low as that of HPS (21) do not allow meat and poultry inspection to be done accurately and reliably. These sources were also characterized by low color temperatures, around 1750 K. Sources with color rendering indices equal to or better than cool white fluorescent (62) appear to cause no problems. (It should be noted, however, that no source, such as improved mercury, with a CRI between 60 and 20 was tested.) The data also suggest that performance is better for sources with higher color temperatures (above the 2800 K of the incandescent lamp used) but the effects of color temperature were not studied independently of CRI. The CRI of cool white fluorescent is lower than might be considered ideal (Worthey, 1982), but since it is the source under which many of the inspectors were accustomed to working, it is, in effect, their reference standard. They were able to perform equally well for sources better than this, particularly incandescent lighting, but not for ones that were markedly "worse" in terms of conventional CRI specifications. Consequently, if recommendations for minimum CRI for USDA meat and poultry inspection were to be made, they would be that sources with CRI below 62, and with color temperatures below 2800 K, are not likely to be adequate.

5. RECOMMENDATIONS FOR FURTHER RESEARCH

A question left unanswered by the psychophysical research is the effect of light sources with CRI better than that of cool white fluorescent, such as cool white deluxe light. The poor performance with this source in the meat study was not well understood. Neither the inspectors' ratings nor their comments indicated that this source caused problems. Comments by the poultry inspectors indicated that they were unused to seeing the "reds" brought out by this source, since the more customary cool white fluorescent tends to dull reds. They associated the red with a chicken killed by scalding (for which the carcass is condemned). As a result, it is conceivable, that after sufficient familiarization, inspection performance might improve if the task were performed under a source such as cool white deluxe with a CRI higher than that of cool white. The performance of a source such as metal halide with a CRI almost equivalent to that of cool white should also be evaluated, because of its high luminous efficacy and relatively high color temperature.

As a result, it appears desirable to conduct a full scale field study under a series of plausible light sources. Instrumenting an actual inspection station, and conducting the study over several days, seems reasonable. This would allow use of actual red meat and poultry samples, thus avoiding the problems of sample size and familiarity noted earlier, as well as providing an opportunity for training inspectors before performance is assessed. It would also allow the inspectors to adapt properly to the light source, and to work under it long enough to report fatigue or strain associated with the light. In addition, it would permit the geometry of the viewing situation, including general plant lighting, to be more realistic.

Other needed research would build on the spectroradiometric data already collected for the four species. These data indicate that differences in spectral composition and lightness characterize almost all sample pairs studied. Further research is needed to determine the extent to which color differences are affected by changes in the spectral composition of the light source. Two researchers, Worthey (1982) and Xu (1983) recently presented some new conceptual approaches to evaluating the color rendering properties of light sources. Both noted that some light sources can systematically reduce object color contrast and decrease overall visual clarity and brightness.

The goal of lighting of meat and poultry inspection should be to transfer the most information about the tissue for the lighting dollar. While Xu (1983) showed that certain lamps have a greater "capacity" for information transfer than others, it is difficult to write an exact formula for "information per chicken" in the inspection context. The discussion in section 1.2.3, comparing the work of Thornton (1972), Worthey (1982), and Xu (1983), suggests that contrast (or differences in color and lightness) can serve as a good proxy for information transfer. In a specific case, if a lesion does not contrast with nearby tissue, then no information can be transferred to the eye about it. If an illuminant reduces many of the color contrasts arising in meat and poultry inspection, relative to what would be seen in daylight, then it gives poor information transfer.

The spectral reflectance data already collected for meat and poultry samples could be used to compute the color and black-and-white contrasts which could be seen by an inspector under various light sources. For example, figure 6b, compares the curves for normal chicken skin, and chicken skin stained with gall. The graphs show that there are potential color and lightness differences between these areas. Given the spectral power distribution of a light source, one can compute the luminous reflectance and chromaticity of each area under that light. These values can be transformed to measures that assess the lightness contrast, the chromatic contrast, and the total contrast between the two samples, under the particular light. Through such calculations, light sources could be compared on the basis of their ability to reveal gall stain, as well as other defects for which the spectroradiometric data were taken. The most appropriate color space for this calculation would be a uniform color space that incorporates a correction for the observer's adaptation, such as CIELAB space (CIE, 1978).

This analysis would allow one to predict the effect of a specific light source on the size of the color differences between defective and normal tissue measured in the present study. Such an analysis can provide direction for determining optimal lighting sources which maximize information transfer while minimizing energy costs for meat and poultry inspection.

Finally, another topic for further research, which has not been formally examined in this report although it was hinted at in the inspectors' remarks, is whether lamp color temperature has an important effect on the meat and poultry inspection task. Although illuminant color has an effect on the appearance of objects, this problem is usually kept separate from color rendering. In the CRI calculation, for instance, an infinite family of reference illuminants is defined, one for each color temperature. When one looks at color rendering as a matter of performance, and not just as a matter of normal versus abnormal appearance, however, then the effect of lamp color must be considered.

No experiment has ever been done (to our knowledge) in which an observer's performance was measured, while color temperature and color-rendering were separately and systematically varied. Because of the eye's known ability to adapt to changes in illuminant color (Judd, 1940; McCann, McKee, and Taylor, 1976), it would not be expected that small changes in lamp color would drastically affect performance. However, if a light of low color temperature is used (which emits relatively little blue light), blue-yellow contrasts should be harder to detect, even if luminance is maintained at a reasonably high level. Thus as a light is made yellower--lower in color temperature--it becomes effectively a dimmer and dimmer light as far as stimulation of the blue-sensitive receptors in the eye is concerned. The other receptors, those that respond to red and green light, have spectral sensitivities similar to that of a light meter, so that fixing illuminance with this meter keeps their level of stimulation approximately constant. From this clue, we may infer that lights of very low color temperature can impair perception of blue-yellow contrasts (Ronchi and Stefanacci, 1978). The computational project will provide information on the existence of blue-yellow contrasts in mean and poultry tissues--contrasts which might be affected by lowering color temperature.

Future research in this area should also include an analytical type of experiment in which lamp color and color-rendering properties are varied independently, and psychophysical performance is then evaluated.

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The role of color in lighting for meat and poultry inspection is discussed. A review of literature relevant to the problem of quality of illumination is presented, along with literature specific to agricultural and veterinary problems. A psychophysical study of the accuracy of detecting and identifying selected defects in meat and poultry was conducted under five light sources: incandescent, cool white fluorescent, cool white deluxe, high pressure sodium (HPS), and low pressure sodium (LPS). The results indicated that more errors were made under the latter two sources, and that the inspection task was rated as more difficult under these sources. In addition, spectroradiometric measurements were made of defective and adjacent "normal" tissue to document the kinds of spectral reflectance that exist in four species: chicken, cattle, turkey, and swine. These measurements indicated that differences in spectral reflectance characterized much of the tissue studied. Based on these data, recommendations are made to avoid the use of light sources with poor color rendering qualities in the inspection task.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Chromaticity; color; color appearance; color rendering; energy-efficient light sources; illumination; inspection; meat poultry; spectral reflectance.

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