LIGHTING FOR A VISUAL INSPECTION TASK

BY

SUDHAKAR MISRA

B.Tech. (MECH.), Jawaharlal Nehru Technological University, Hyderabad, India, 1977

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Corwin A Bennett

Major Professor

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INTRODUCTION

Light and vision are essential for seeing. They may be considered as a partnership in which one is essential to the usefulness of the other. To understand the relationship of light to sight and its final result, seeing, some understanding of the structure of the eye is needed.

The eye is one of the most delicate and miraculous organs in the human body. It is very often compared to a camera having a compound lens (the cornea and the lens combine to help focus the light), a shutter (the iris), a black-box (the eye-ball), and a photographic plate (the retina). Even though eyes are absolutely essential for seeing, one does not see with the eyes, but with the brain. The image on the retina is the picture that the brain sees. The eye converts light waves and transmits them as electric impulses which become the images one sees, after the brain sorts them out.

Light is a form of radiant energy which is transmitted as a transverse wave motion from the source to the receiver and travels through space in the form of electro-magnetic waves. All electro-magnetic waves have a common property that they are propagated through space at the same rate and the only differences are in their wavelengths and amplitude. The visible spectrum is only a small portion of the energy emitted by a glowing solid. Seeing results only when radiant energy within the limits of the visible spectrum enters the eye. It is of interest to note the extremely limited range associated with vision (see Figure 1.). Pinder (1959) summarized the most important facts

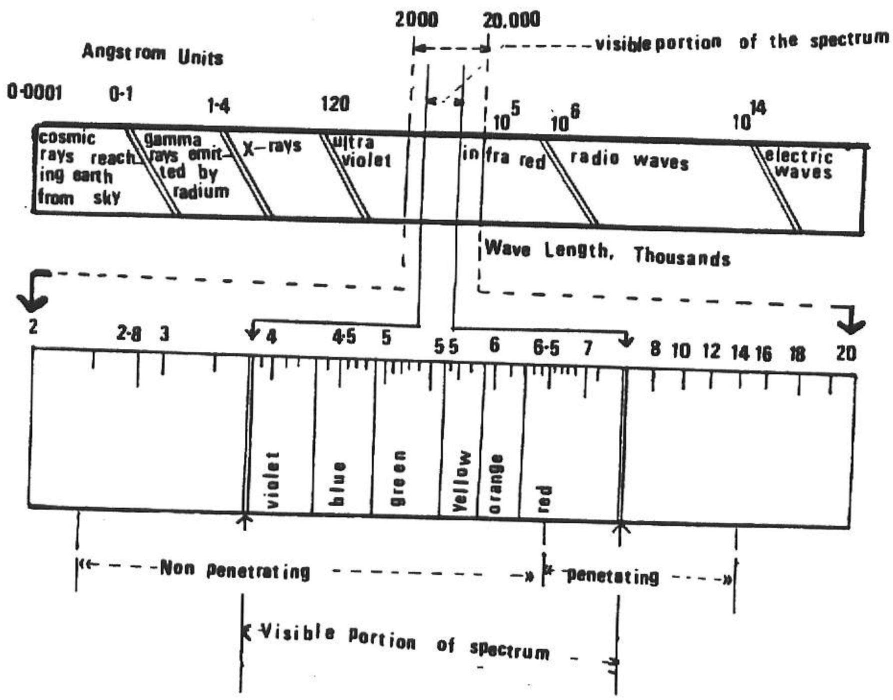

FIGURE 1 The electromagnetic or ether spectrum

concerning light and its relation to vision (see Table 1.).

Industrial Lighting

The past four decades have witnessed a phenomenal increase in the lighting possibilities. Manufacturers have put forth a wide variety of lightsources and control materials, and this gives greater flexibility to the illuminating engineer of today, as compared to the 1930s when only two light sources were available: The incandescent tungsten-filament lamp, and the Cooper-Hewitt mercury lamp.

"The purpose of industrial lighting is to provide energy efficient illumination in quality and quantity sufficient for safety and to enhance visibility and productivity within a pleasant environment", according to The American National Standards Institute (1979). In designing of industrial lighting systems, much emphasis has always been placed on the supply of sufficient task illumination for safe human performance with a *minimum seeing effort.* Recent years however, have seen the tendency on the part of designers to use light not only to enhance the safety and productivity but also to create more attractive work places. The American National Standard Practice for Industrial Lighting (1979), gives a list of twelve recommendations that are based on human needs and energy concern, to be included in any industrial lighting design (see Table 2.). The design of a lighting scheme also depends to a very great extent on the task characteristics, and visual tasks, unlimited in number may be classified according to certain common characteristics of the visual tasks. The American National Standard Practice for Industrial Lighting (1979),

TABLE 1

<u>Important Facts concerning Light and its relation to Vision</u>

(Source: Plant Engineering Handbook, McGraw-Hill Book Company, New York, 1959).

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1. Light is the agent that excites the sensation of sight.
2. Light must fall upon the objects themselves if they are to be seen. Illuminating the eye does not give it the power to see objects from which light is excluded. In order that a body may be seen, light must pass from it to the eye.
3. Light in the visible range of the spectrum can be reflected by ordinary smooth surfaces, brought to a focus by concave mirrors, or refracted and brought to a focus by lens shaped transparent objects.
4. The ray of light falling on the (spectrally reflecting) object, is reflected on the angle at which the incoming light strikes the object (Angle of incidence is equal to the angle of reflection).
5. Shadows are formed by objects that intercept or cut-off the rays of light and represent in their outline the object creating the shadow.
6. Illumination obeys a cosine law which means that the energy emitted in any direction is proportional to the cosine of the angle which that direction makes with the horizontal (plane perpendicular to incidence of light).

TABLE L (cont.)

Important Facts concerning Light and its relation to Vision

(Source: Plant Engineering Handbook, McGraw-Hill Book Company, New York, 1959).

7. Illumination from a light source decreases with distance according to an inverse square law. (At twice the distance from the light source the illumination is about one fourth, for a small light source).

TABLE 2

ANSPIL* recommendations for Design and Use of Lighting

(Source: ANSI/IES RP-7-1979).

---

1. Design lighting for expected activity (light for seeing tasks with less light in sorrounding non-working areas).
2. Design with more effective luminaires and fenestration.
3. Use efficient light sources (higher lumen per-watt output).
4. Use more efficient luminaires.
5. Use thermal-controlled luminaires.
6. Use lighter finish on ceilings, walls, floors, and furnishings.
7. Use efficient lamps.
8. Turn off lights when not needed.
9. Control window brightness.
10. Utilize daylighting when practicable.
11. Keep lighting equipment clean and in good working condition.
12. Post instructions covering operation and maintainence.

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* = American National Standard Practice for Industrial Lighting

has given a classification of visual tasks such as manufacturing, inspection, engraving, and other industrial activities, and the lighting techniques to be used for each specific activity. Table 2 gives the lighting technique to be used and the classification, description of lighting requirements and the luminaire types to be used for visual tasks involving transparent materials.

Visual Inspection Tasks

Harris and Chaney (1969), defined three basic categories of inspection tasks: Those involving scanning, measurement, and monitoring. In inspection tasks, search or scanning is required when, for some reason, a fault cannot be located immediately. Bloomfield (1975), described three main types of tasks involving scanning: the inspection of simple items, multi-part items, or sheets. A multi-part item is generally a single complex object and in inspection of multi-part items an inspector has to search for those features of the object that are faulty. They may be very different in character from each other, and the inspector looks at these heterogenous features, checking them for damage, dimensions, and location. The American National Standard Practice for Industrial Lighting (1979) has ranked inspection tasks from ordinary to most difficult and recommended illuminance levels on the tasks (see Table 4.). They have also recommended illuminance on task required for glass works of varying visual requirements (see Table 5.). This study deals with inspection of a multi-part glass object, the fluorescent tube ends for lamps manufactured by Westinghouse Electric Corporation.

TABLE 3

Classification of Visual Task and Lighting Technique

(Source: ANSI/IES RP-7-1979).

Classification of of Visual Task	Description	Lighting Requirement S-1*	Location of Luminaire
Transparent materials with specular surface.	Bottles, glassware- empty or filled with clear liquid.	To emphasize surface irregularity, cracks, chips, and foreign particles.	To be directed obliquely to objects.

S-1* ——— directional: includes all concentrating units.

Examples: Reflector spot lamps; Luminaires with concentrating reflectors or lenses.

TABLE 4

Recommended Illuminance on different types of Inspection tasks

Area and Task	Illuminance on Task	
	Footcandles	Lux
Inspection		
Ordinary	50	540
Difficult	100	1100
Highly Difficult	200	2200
Very Difficult	500	5400
Most Difficult	1000	11000

TABLE 5

Illumination requirements for Glass works

Area and Task	Illuminance on Task	
	Footcandles	Lux
Glass works		
Mix and furnace rooms, pressing and lehr, glass blowing machines.	30	320
Grinding, cutting, silvering.	50	540
Fine-grinding, beveling, polishing	100	1100
Inspection, etching, decorating.	200	2200

Westinghouse Electric Corporation has a facility at Salina, Kansas, where they make fluorescent lamps. The company manufactures two types of lamps, a four foot long 40 watt model, and an eight foot long 75 watt "Slimline" model. The glass tubes for the lamps are manufactured at the facility and so are the fluorescent tube ends (reffered to as "mounts" hereafter).

Westinghouse has been understandably concerned about the quality of its outgoing product, as well as the percentage of salvageable defective products. One area where the Quality Evaluation Systems Department has been concentrating its efforts, is the manufacture and inspection of the mounts. The 40-watt lamps are produced on two highly automated production lines (HAP 1 and HAP 2), at the rate of about 2600 lamps per hour. The "Slimline" model is manufactured at the rate of about 1500 lamps per hour, on two other assembly lines called Unit 3, and Unit 4 respectively (Peterson, 1980). Each assembly line is supplied by two different mount manufacturing lines, making two types of mounts. One is a non-tubular mount which is sealed, and the other is a tubular mount, with an evacuation tube to remove the air and to allow for filling of inert gas and mercury before sealing. Basically the mounts are inspected for the same features.

Manufacturing is done in two shifts. The day shift starts at 6:00 A.M. and lasts till 6:00 P.M., and the night shift begins at 6:00 P.M. and continues till 6:00 A.M. Further, the shift inspectors work for three days and are off the next four days, then work for four days and are off the following three days. The shifts are divided into eight teams, one team for each mount manufacturing line.

Each team is made up of four persons who rotate from tubular inspection to assisting, to non-tubular inspection, to rest break, on a pre-arranged schedule about every twenty minutes. This shift arrangement necessiates the involvement of thirty-two individuals just for the inspection of the 40-watt lamps. In addition there are eighteen other individuals associated with the manufacture and inspection of the "Slimline" model.

A Review of all the Inspection Stations

Every lamp manufactured at Westinghouse passes through seven automated and three manual inspection stations, before it is shipped out to the customer. These are:

1. The "Automount", or the mount sealing machine (automated).
2. The Manual Inspection Station (manual 1, and manual 2).
3. Automated Leaky Tube Station.
4. Automated No Light Station.
5. Automated No Base Inspection Station.
6. Automated Bottom Pan Station.
7. Automated Top Pan Station.
8. Final Manual Packing/Inspection Station.

Of all the inspection stations, the two manual inspection stations are the most important from "increasing the efficacy" point of view. The other inspection stations check the mounts during the various phases of manufacture of the mount and the lamp. The manual inspection station is the place where a mount is inspected after being fully assembled and before it is inserted in the lamp tube. At this station the inspectors face an input conveyor (coming from the mount manufacturing line), inspect the mount for defects, and transfer the good mounts on to a demand conveyor (going to the sealing machine). On the "Slimline" model, inspectors have to supply the demand conveyor with about 75% of the mounts received by them, storing the remaining mounts in trays that hold twenty-five mounts each, for future use. This activity requires a mean inspection and transfer time of about 2.5 seconds per mount. The 40-watt lines move at a faster rate, and even though the inspectors perform the very same functions as those performed for the "Slimline" model, the mean inspection and transfer time works out to about 1.4 seconds per mount, according to Joshi (1980), and Peterson (1980).

Previous Studies about the Westinghouse Problem

Joshi (1980) looked at the training and inspection procedures at the Westinghouse facility, and by recommending workplace redesign and training procedures suggested the possibility of increasing the productivity by 19%. Peterson (1980), also looked at the same problem of inspector performance at Westinghouse, and found that the illumination level at the inspection station was 550 lux. By increasing the illumination level to 1000 lux, Peterson found that the inspection performance improved by 7%. In another test conducted by Peterson, it was found that the provision of a constant off-white background at the work-station resulted in better contrast between the task and the surrounding, and an improvement in inspection performance by 4%.

The company lists 40 possible defects of the mounts (see Appendix 1). Joshi (1980) classified the defects as major, minor and critical defects.

Peterson (1980) grouped the defects by the components of the mount to which they belonged, and measured the overall detection rate. He found the overall detection rate to be 80%. His results are given in Table 6. He then conducted two tests, in which he changed the level of illumination and provided the inspectors with an off-white background against which they were to perform the inspection task. The results of his tests are given in Table 7. It is interesting to note the nature of the defects that could be detected more easily as a result of the changes Peterson made in the existing set-up, and as such a brief description of the mount and the defects is in order.

The non-tubular mount (see Figure 2), differs from the tubular one (see Figure 3), in only one respect in that it does not have the evacuation tube. The mount is made up of a glass flare 33.5mm in diameter, through which two lead wires are passed. The outer lead wires are 51mm in length and are connected to the inner lead wires (22 mm in length) by a dual metal wire called the dumet, which is 3mm in length. The inner lead wires are curved at the ends and a coil 16.5mm to 17.5mm in length, is clamped between the ends. The evacuation tube for the tubular mount is 5.58mm in diameter and is 94mm long. The dumet is welded to the inner and outer lead wires and the neck of the flare is pressed to enclose the dumet in what is called the press area of the mount. The mounts are heat treated during manufacture and if exposed to the flame longer than necessary, or if the temperature of the flame is higher than required, the dumet develops defects that are a consequence of over heating. If slightly over heated the dumet

TABLE 6

Summary of defects as found by Peterson

Defect	(1) # from mount inspection station	(2) # from lamps at "Bottom Pan"	(3) % Detected (1)/(1)+(2)
Tubular			
Dumet	13	24	35%
Coil	65	11	85%
Clamp	63	27	70%
Emission	35	1	97%
Misc.	144	10	93%
Total	320	80	80%
Non-Tubular			
Dumet	13	18	42%
Coil	53	10	84%
Clamp	42	9	82%
Emission	7	1	87%
Misc.	91	10	90%
Total	206	53	79%

TABLE 7

Summary of improvements in detection of defects with Peterson's experiment

(Source: Peterson, G. P., Improvement of inspection performances, unpublished Master's Thesis, Kansas State University, 1980)

Defect	(1) # from Mount Inspection Station	(2) # from lamps at "Bottom Pan".	(3) % detected before experiment	(4) % detected after experiment	(5) change (3) - (4)
Tubular (Improved Background)					
Dumet	13	22	35%	37%	2%
Coil	53	4	85%	93%	8%
Clamp	59	16	70%	91%	21%
Emission	34	5	97%	87%	-10%
Misc.	116	6	93%	95%	2%
Total	275	53	80%	84%	4%
Non-Tubular (Improved Lighting)					
Dumet	17	10	42%	63%	21%
Coil	63	10	84%	86%	2%
Clamp	37	7	82%	82%	0%
Emission	11	2	87%	85%	-2%
Misc.	110	8	90%	93%	3%
Total	238	37	79%	86%	7%

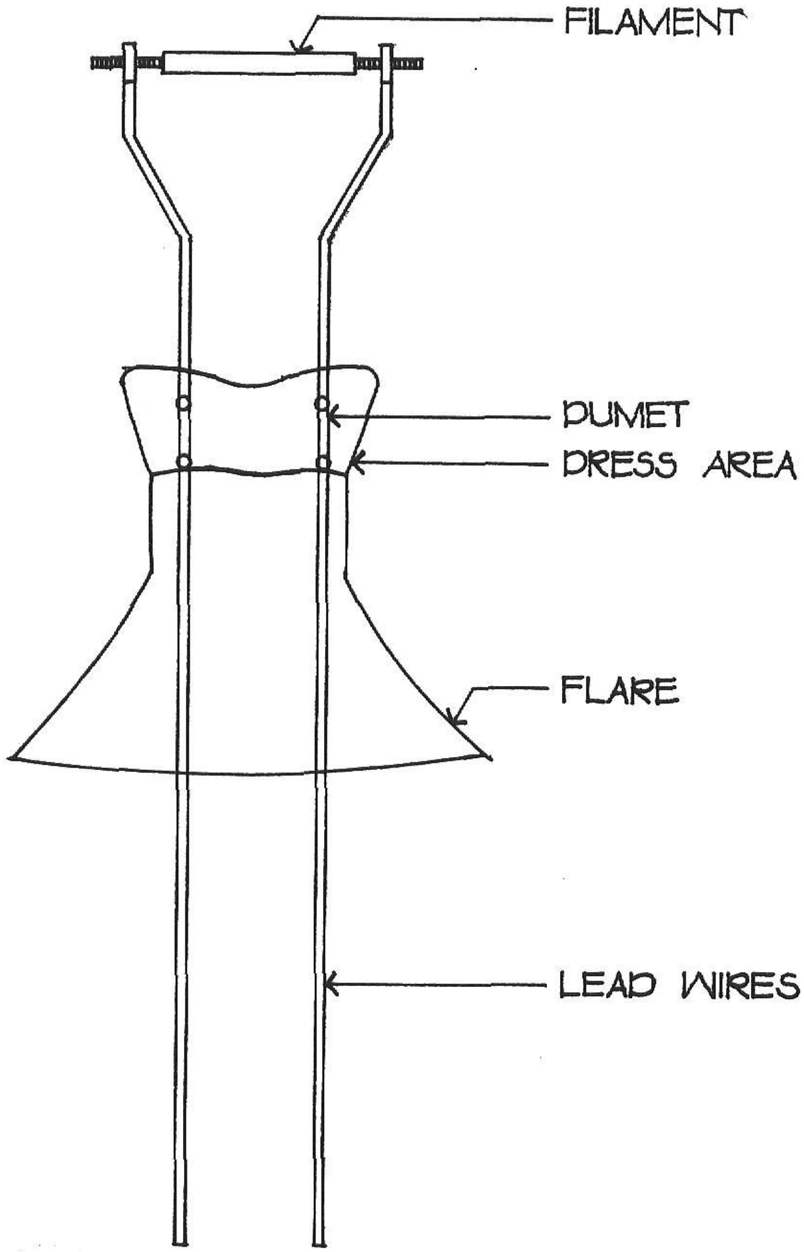

FIGURE 2 Non-Tubular Mount

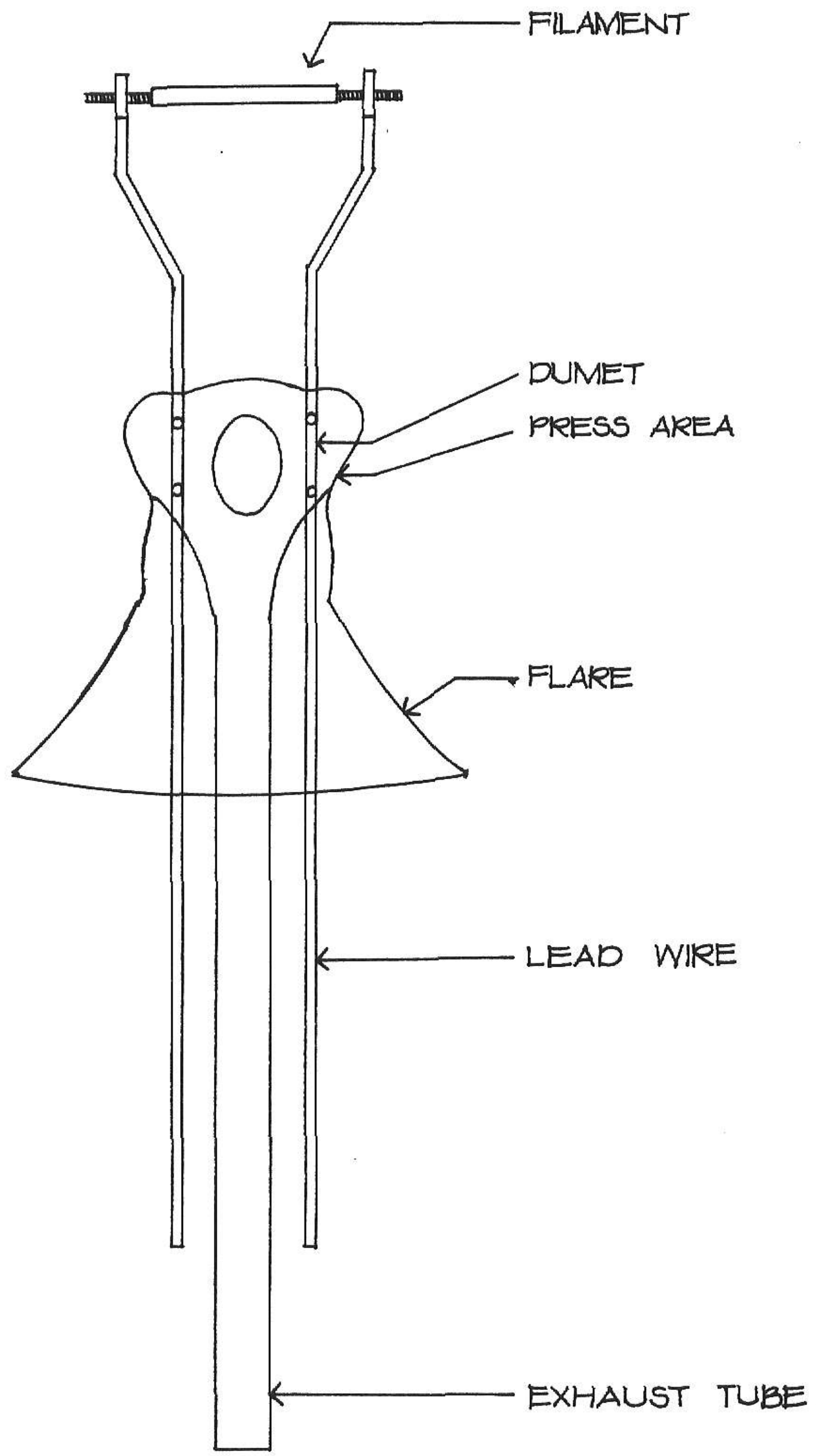

FIGURE 3 Tubular Mount

has a red line on it and is called a "red dumet". If it is very much over heated it turns either deep red, purple or black with a distinct purplish haze on the press area. This defect is called a "burnt dumet".

Illumination and Visual Performance Research

Before the primary question about the optimum light for seeing can be answered, a host of supplementary questions about the nature of the task, its size, color, background etc. demand answers.considerable research effort has been devoted to the question of illumination, by Weston (1935, 1945), Tinker (1939, 1959, 1963), Blackwell (1959), Bodman (1962), and Fry (1962). Various evaluation criteria were used, including visual acuity, heart-rate, and contrast.

Vision according to Pinder (1959), involves four fundamental elements:

1. The Task that one sees (not controllable).
2. The eyes with which one sees (indirectly controllable).
3. The light which makes it possible for the eyes to funtion (controllable).
4. The surroundings or the background, against which the task or object is viewed (controllable to a degree).

Light and Color

"Everything seen is subjugated to two fundamentals- brightness and color", observed Pinder (1959). It is becoming more apparent in recent years that lighting level is important but vision is also dependent on other conditions for perception and visibility. Whenever light strikes an object, some wave-lengths incident on it

TABLE 8

Effect of type of lighting on meats, fruits, and vegetables

(Source: Plant Engineering Handbook, Mc Graw-Hill Book Company, N.Y., 1959).

Test Article	Daylight Fluorescent	White Fluorescent	Deluxe Warm White Fluorescent	Filament 100 watt
Red meats	poor	fair	good	preferred
Dressed chicken	poor	fair	good	good
Butter	poor	good	good	preferred
Chocolate	poor	fair	fair	good
Bread brown crust	fair	good	good	good
Oysters opened	poor	poor	fair	preferred
Parsley	good	good	fair	poor
Carrots	good	good	good	good
Tomatoes	fair	fair	fair	preferred
Red apples	fair	fair	fair	preferred
Onions	poor	fair	fair	fair
Green apples	good	good	fair	preferred
Bananas	fair	good	good	good
Green beans	good	good	fair	fair
Corn	good	preferred	good	good
Plums (reddish purple)	fair	good	preferred	good

are absorbed, some are reflected back, and others may be transmitted. The rays that are reflected back constitute the color that is seen. The effect of different types of lighting on meats, fruits, and vegetables is given in Table 8. Hopkinson and Collins (1970) state that jaundice, a disease that can be diagnosed by a change in the color of the skin, is more readily detectable under light with a high blue content. Friar and Friar (1980) state that "Color differences in red material are emphasized by sources strong in blue light and in blue material by light sources strong in red". This is consistent with Pinder's (1959) observation that "Color appearance of objects depends not only on the reflectance characteristics of the objects themselves but also on the color content of the light with which they are illuminated".

It was obvious from Peterson's study of 1980, that the level of illumination and the background contrast had a significant effect on the performance of the task which is the subject of this study. Therefore it was decided to search for a lighting scheme that would further improve the inspection performance for this particular inspection task, the inspection of mounts at Westinghouse. Efforts were made to find out if inspecting the mounts under colored light against colored background would make the task any easier to perform.

Pilot Study

A pilot study was conducted and the author looked at the mounts for all possible defects a mount could have. The light and background combinations under which this was done are shown in Table 9. Subjective judgements were made about the different color combinations of light and background. It looked to the author as if the following conditions were better than the rest in terms of ease of fault detection and comfort.

Color of Light Source	Color of Background
Blue	Dark Blue
Blue	Pale Blue
Green	Pale Green

The condition of green light and dark green background was better for the dumet defects, but was not very helpful in detecting the clamp and knot defects. The yellow light and yellow background condition was not useful in detecting the emission defects. The red light and red background, and the pink light and pink background condition hampered the identification of mounts with dumet defects. It should be mentioned at this point that this pilot study was not conducted under controlled conditions of illumination, time or any other variable that can affect inspection performance.

As a verification of the subjective judgements of the author, four volunteer subjects were shown eight selected defects. Only mounts having the following eight defects were shown to the subjects.

TABLE 9

Conditions of lighting and background for "Pilot Study".

COLOR OF LIGHT	COLOR OF BACKGROUND
RED.	RED.
GREEN.	GREEN (DARK).
GREEN.	GREEN (PALE).
BLUE.	BLUE (DARK).
BLUE.	BLUE (PALE).
YELLOW.	YELLOW.
PINK.	PINK.
AMBER.	AMBER.
WHITE FLUORESCENT. (COOL WHITE).	WHITE.

Red dumet
Burnt dumet
Emission (the chemical coating for the coil) into Clamp
Coil out of Clamp
Double Coil
Triple Leadwires
Discontinuous coating of Emission on Coil
Heavy Blob of Emission on Coil

The reasons for choosing the eight specific defects were as follows. Defects of the dumet have a good potential as far as the increase in the rate of detection is concerned, as shown by Peterson's experiment. The defects of the clamp and coil were also shown by Peterson, to be susceptible to changes in illumination and contrast-background. Triple leadwires and double coil defects were included as representatives of the move obvious defects, that are detected more easily. The heavy blob of emission is missed by many operators, as was evidenced by the author's visit to the Westinghouse plant. In a tray containing twenty-five mounts, as many as nine mounts exhibited this defect, classified as critical by Joshi (1980). The tray was picked up by the author out of the many that were stored on the racks for future use after having been inspected.

All the four subjects ranked the warm colored light sources viz. Red, Pink, Amber, and Yellow, and their respective backgrounds as poor conditions of illumination for the task. There were tendencies to favor the Blue light - Blue background conditions.

The subjects were then shown the mounts again under the following conditions, and asked to rank them.

1. Blue light-Dark blue background.
2. Blue light-Pale blue background.
3. Green light-Pale green background.
4. Green light-Pale blue background.

Of the four subjects two subjects ranked the blue light-pale blue background as the most comfortable followed by the blue light-pale green background, green light-pale blue background, green light-pale green background, and blue light-dark blue background, in that order. Of the remaining two subjects, one ranked the green light-pale green background as the most comfortable condition, followed by the blue light-pale blue background, green light-pale blue background, and blue light-dark blue background conditions. The fourth and last subject ranked the green light-pale blue background as the most comfortable condition, followed by the blue light-pale blue background, green light-pale green background, and blue light-dark blue conditions.

PROBLEM

Most of the research on illumination and visual performance has involved abstract two-dimensional visual tasks, and there have not been many studies where the quality as well as the quantity of light were used as independent variables affecting performance of an industrial type of inspection task. The purpose of the present research was to determine the relationship if any, between the color of light, the color of the background that provided contrast and performance of a specific industrial task.

Specifically the following hypotheses were made:

(1) Where color discrimination is important, a particular combination of colored light and colored background will increase inspector efficacy.

(2) Blue light will be better for detection of the dumet defects, which are red in color.

METHOD

In this study fourteen subjects performed an inspection task under nine different lighting and background conditions. The objective was to find a relationship between the quality of lighting as pertaining to the colors of light and background, and performance.

Subjects

All the subjects were students of Kansas State University. Of the total of fourteen subjects, four were females. Four of the subjects used corrective lenses, and none of them had any type of color vision deficiency. This information was provided by the subjects before they were allowed to sign up as subjects for the study.

Task

The task involved looking at fluorescent lamp mounts and identifying defective ones from among them. The types of defects looked for were:

1. Red Dumet (See Figure 4.)
2. Burnt Dumet (See Figure 5.)
3. Heavy blob of emission on coil (See Figure 6.)
4. Discontinuous coating of emission on coil (See Figure 7.)
5. Emission into clamp (See Figure 8.)
6. Double coil (See Figure 9.)
7. Coil out of Clamp (See Figure 10.)
8. Triple lead wires (See Figure 11.)

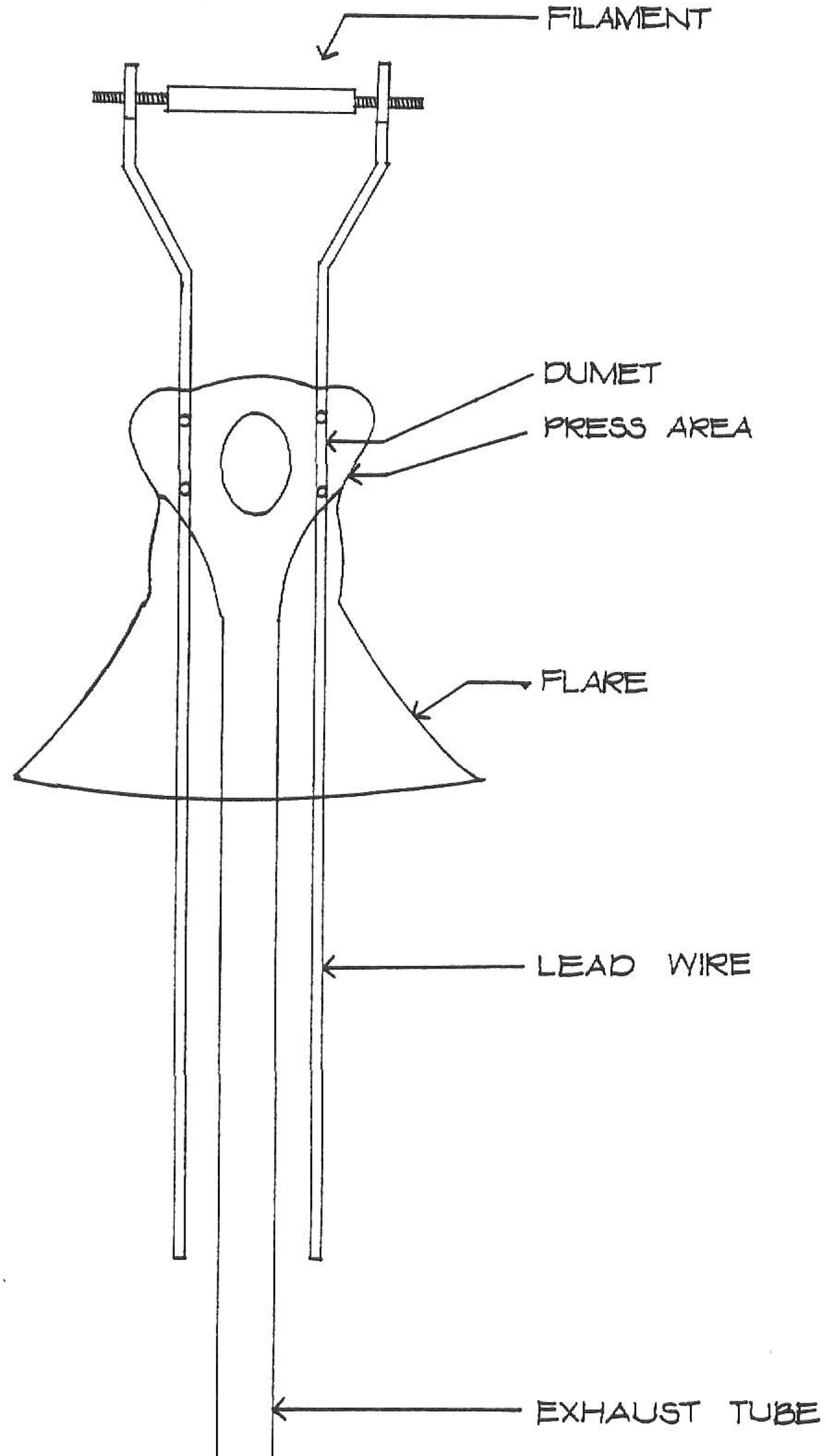

FIGURE 4 Mount showing Red Dumet

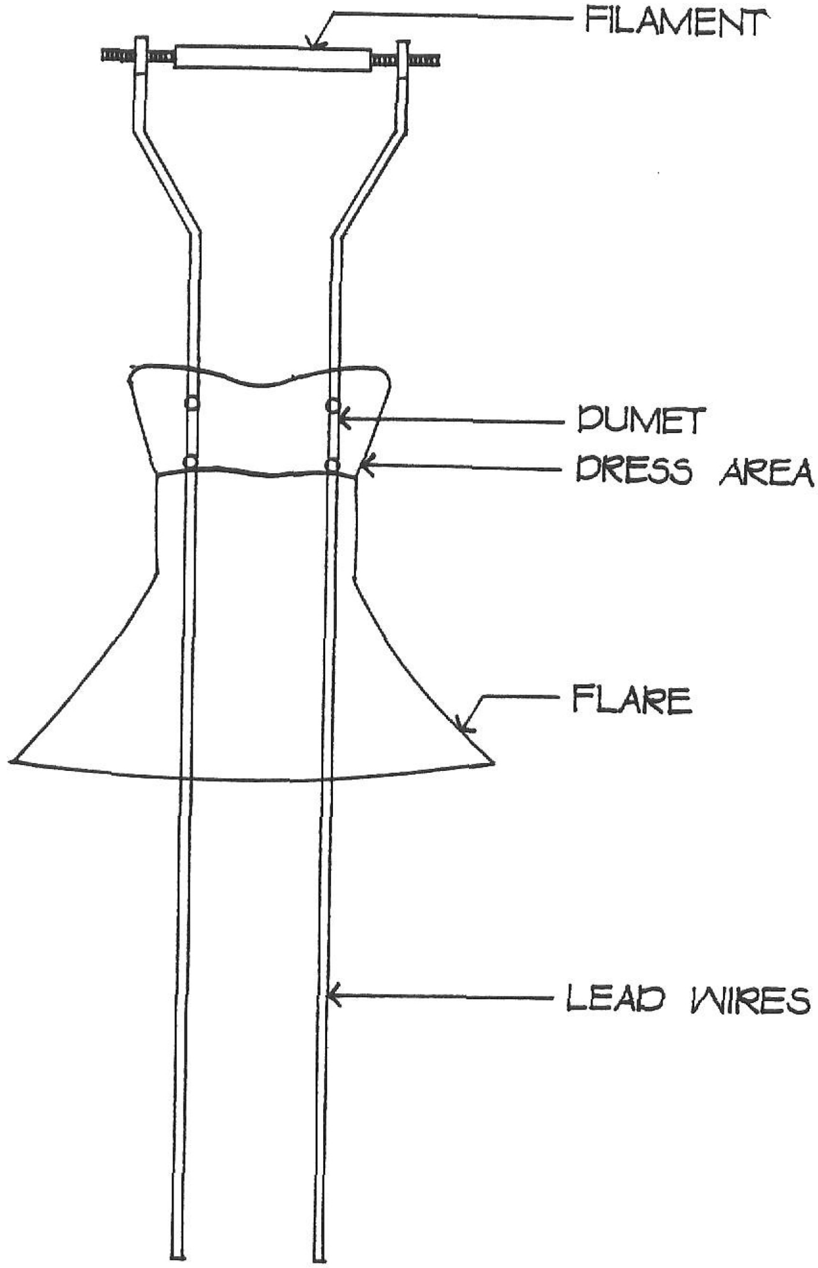

FIGURE 5 Mount showing Burnt Dumet

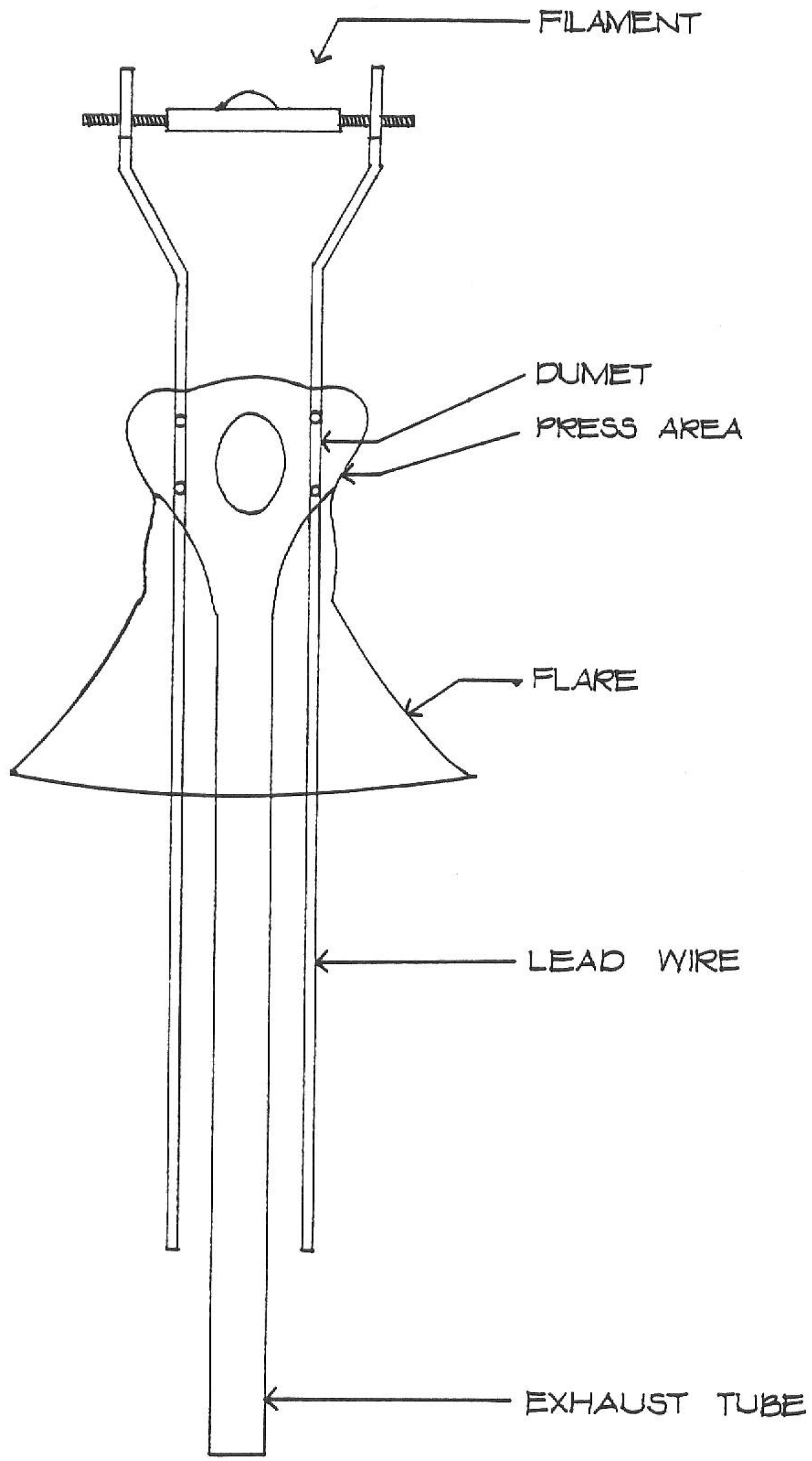

FIGURE 6 Mount showing Blob of Emission on Coil

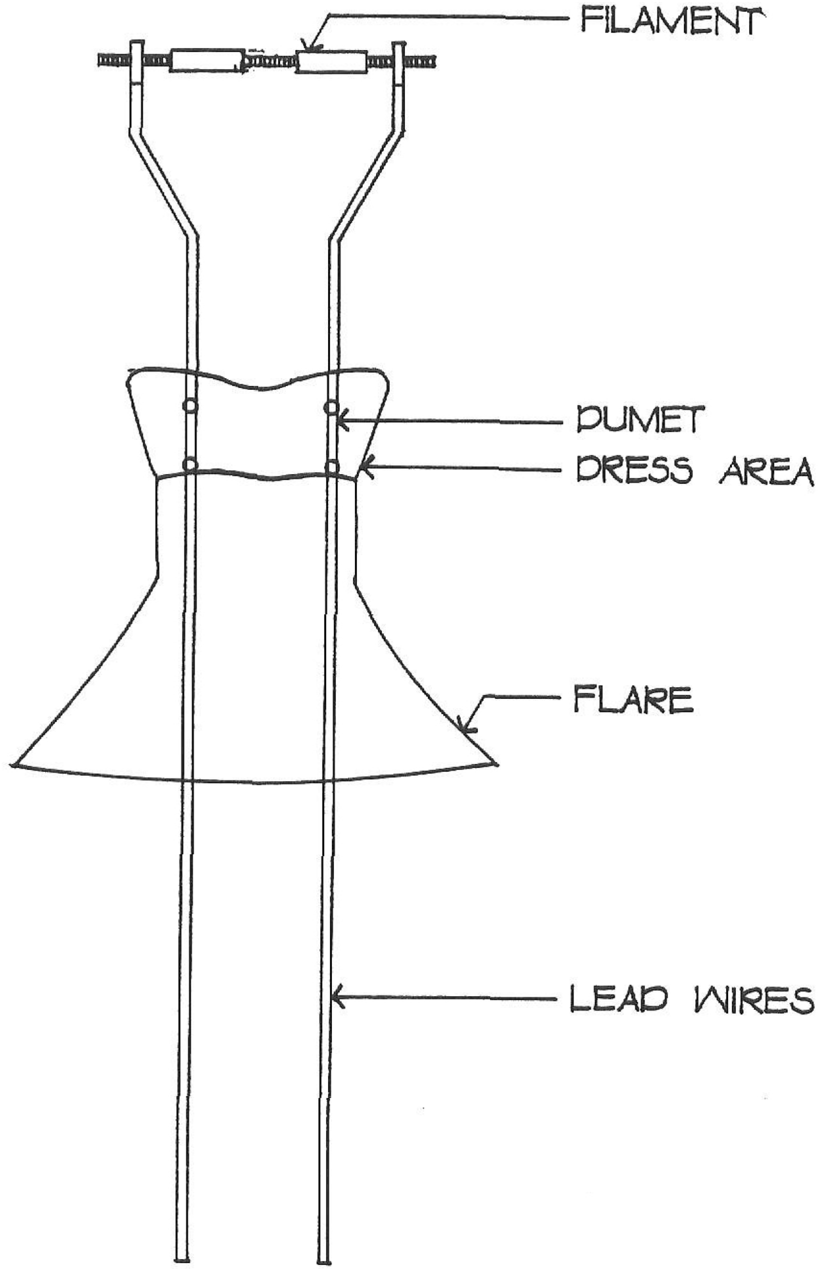

FIGURE 7 Mount showing Discontinuous coating of Emission on Coil

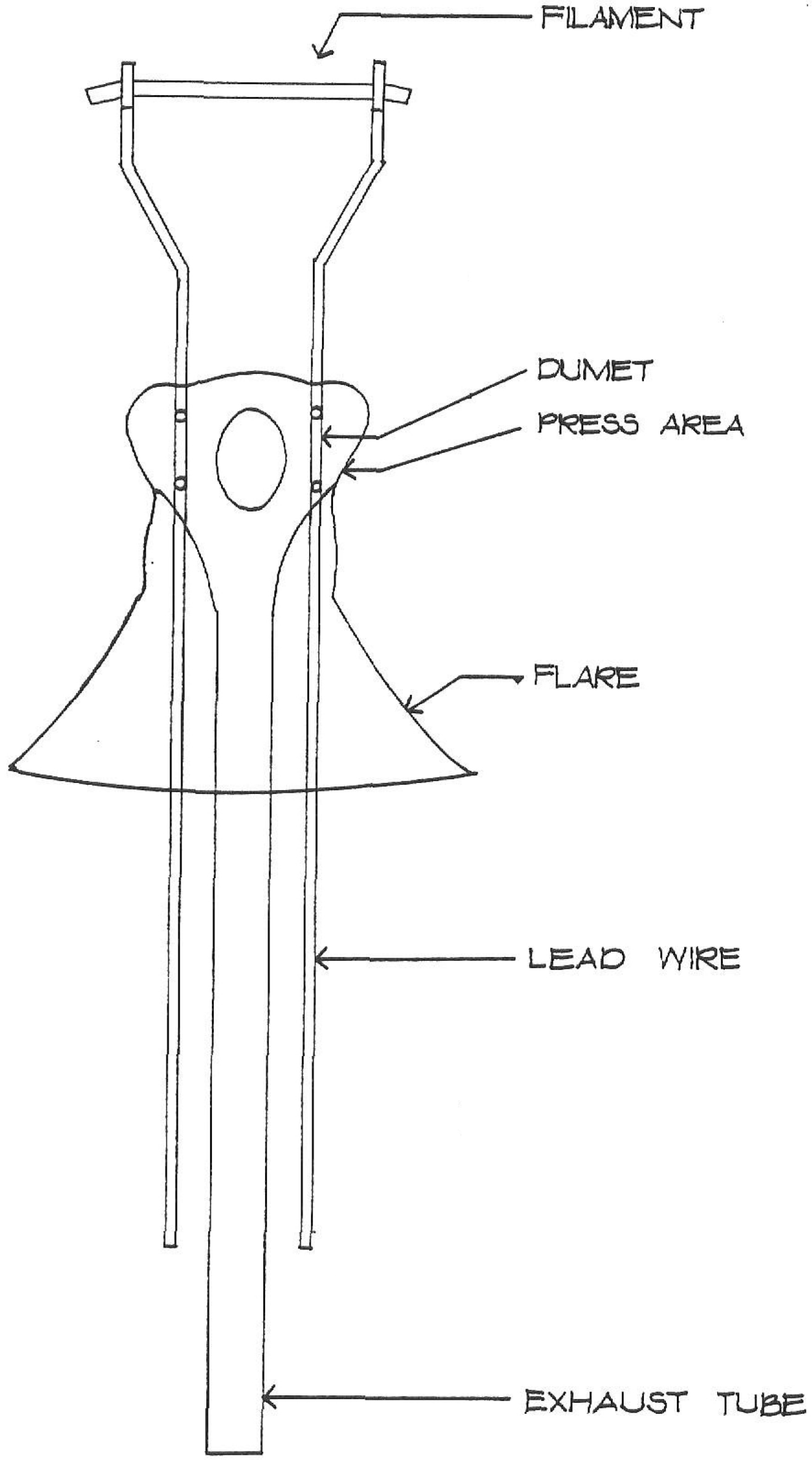

FIGURE 8 Mount showing Emission into Clamp

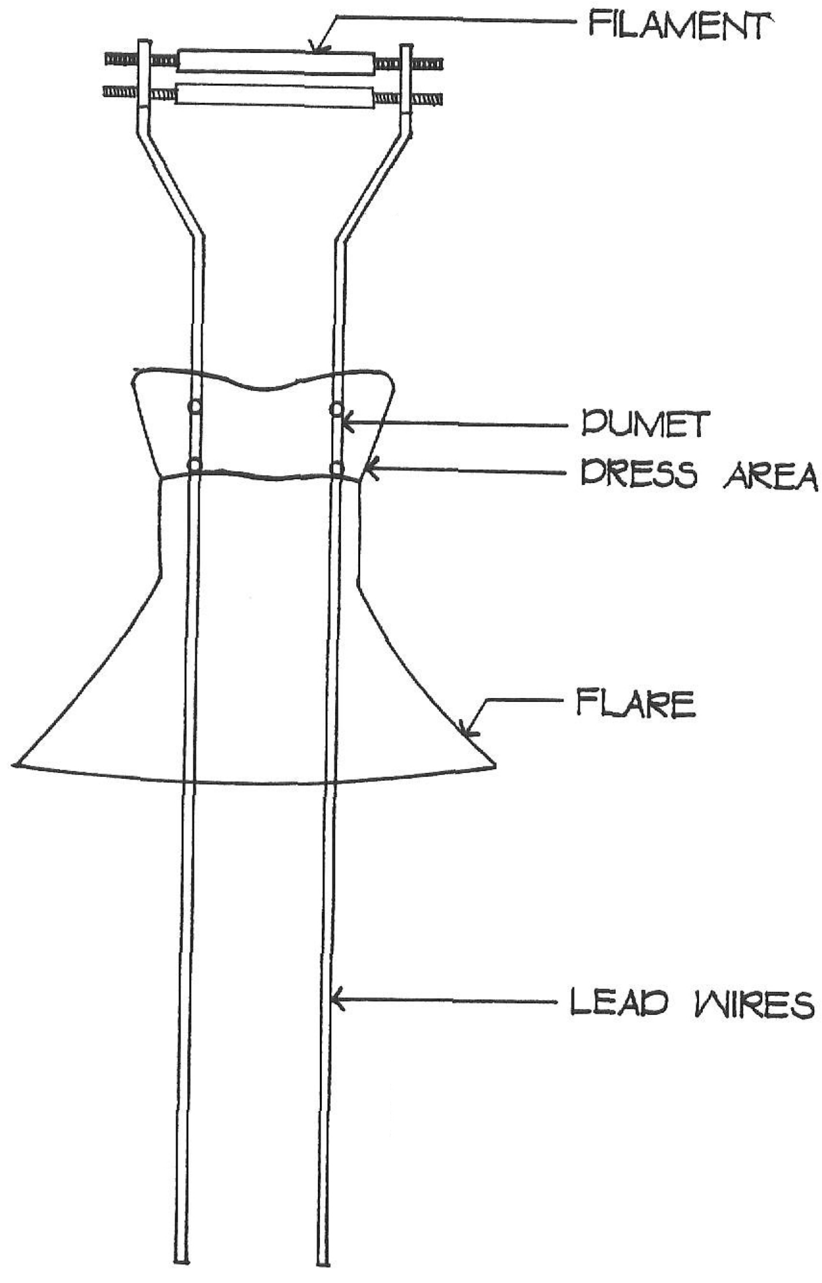

FIGURE 9 Mount showing Double Coil

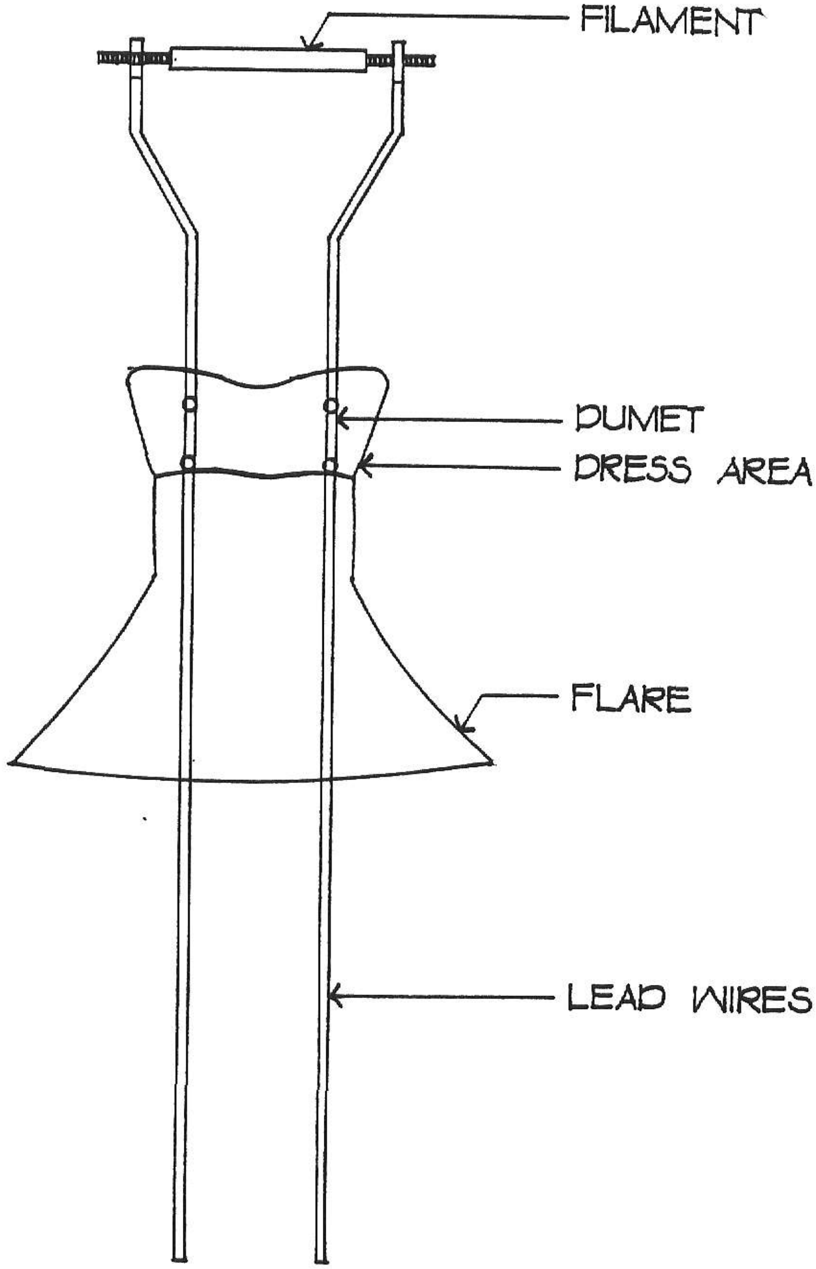

FIGURE 10 Mount Showing Coil out of Clamp

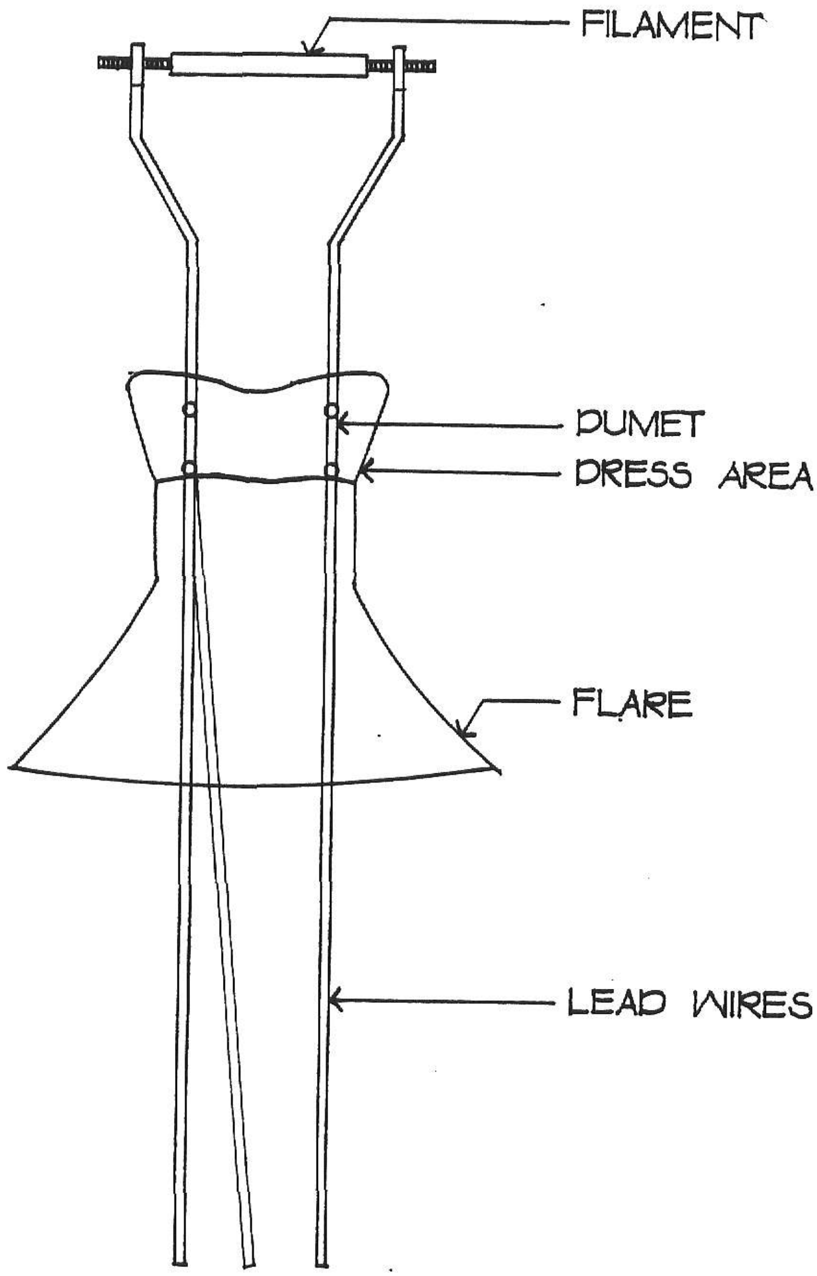

FIGURE 11 Mount showing Triple Lead Wires

Of the eight types of defects selected for the task, the defects numbered one through five required color discrimination for their detection. Defects numbered seven and eight were included as representatives of the more obvious defects that are identifiable with relative ease as compared to other defects. It was hypothesized that where color discrimination was necessary, performance would vary with the variation in the color of the light used to view the task and the background against which it was viewed.

Experimental Design

The mounts were inspected under a total of nine conditions. Of the nine conditions, six were experimental and three were control conditions. In the control conditions, the subjects inspected the mounts against a white background under white light. The experimental conditions were a combination of lights and three different colors and two different colored backgrounds. The subjects had six minutes to do the task in all but one condition, where they had seventy seconds. In this condition an effort was made to simulate the actual working conditions at Westinghouse, where the time to inspect works out to about one and four-tenths of a second per mount. The time of six minutes for the other eight conditions was selected by the author after repeated inspections. In his judgement, it was sufficient time to look for the defects and also call them out for this experiment. Figure 12 lists the conditions used in this study.

The conditions were assigned to the subjects on a random basis using the random order generated by the computer. The order of conditions is given in Appendix 2.

Condition	Light	Background	Time/Tray
1.	Red	Blue	3 minutes
2.	Red	Green	3 minutes
3.	Blue	Blue	3 minutes
4.	Blue	Green	3 minutes
5.	Green	Blue	3 minutes
6.	Green	Green	3 minutes
7.	White-Fluorescent	White	3 minutes
8.	White-Fluorescent	White	35 seconds
9.	White-Incandescent	White	3 minutes

FIGURE 12. The Nine experimental conditions

Procedure

After having read the informed consent form (See Figure 13.) the subjects were given written instructions about the task (See Figure 14.), and upon their acknowledgment of understanding it thoroughly they were given a practice trial to familiarize them with it. The subjects looked at fifty mounts in each condition, presented to them in two trays of twenty-five mounts each. The second tray was given to them after they were finished with the first. Each mounting slot in the tray was numbered, and upon identification of a defective mount the subject called out the number of the slot bearing the defective mount. The subjects were also required to name the defect viz. "Red dumet", "Coil out of Clamp" etc. This information was recorded on the data collection form (See Figure 15.) by the experimentor, and also on a cassette recorder. After performing the task under each condition the subject was asked to rate the condition for the relative perception of effort required to do the task under that condition, on the Borg scale (See Figure 16.).

Apparatus and Physical Set-up

To provide fluorescent white light four cool white F40W Mainlighter lamps made by General Electric were used. For the experimental conditions where colored light was required, one hundred and fifty watt reflector lamps in Blue, Green, and Red colors, made by Sylvania were used. For the condition where incandescent white light was required, one hundred and fifty watt reflector lamp "Movielight Eal", also made by Sylvania was used. Colored matte-boards were joined together to form a trapezoidal section to provide the background. The trapezoidal shape ensured that the subjects had no other color in their field of vision except the one under test.

INFORMED CONSENT FORM

I have read the instructions, and after reassuring myself that there are no risks or hazards involved, I hereby agree to be a subject in the research entitled "Lighting for a Visual Inspection Task".

S.No.	Signature	Age	Sex	Date

FIGURE 13 Informed consent form

INSTRUCTIONS FOR SUBJECTS

This research is being done to find out the relationship between lighting conditions and visual performance. You are asked to look at the fluorescent lamp "mounts" and inspect the same for defectives. The task will be performed nine different times under different lighting and background conditions. There are eight possible defects that a mount can have. You will be familiarized with all possible defects and a practice trial will be given. If you have any questions I will be glad to answer them.

After completing the task under each condition, rank the condition according to the scale provided. While ranking please consider how easy or hard it was to perform the task under the condition in consideration. There are no hazards or risks involved in the experiment. I hope that you will complete the experiment. However you are free to leave anytime you wish. Now if you are ready for the experiment, please sign the consent form provided.

Please start immediately after the experimenter asks you to, and stop when you are asked to. When you identify a defective mount, call out the number of the slot in the tray from where you picked up the defective mount. Also identify the type of defect. You have three minutes to look at the mounts in each tray. However in one of the conditions you will have less time. You will be told about this at the appropriate time.

Thank you for your co-operation. Now, if you are ready, let's begin the practice trial.

FIGURE 14 Instructions for subjects

The eight possible defects are as follows:

1. Red Dumet

   The fluorescent mount is classified as a defective if the small wires (3mm in length) connecting the outer lead wires to the inner lead wires, inside the press area, are red at least half its length.

2. Burnt Dumet

   The mount is defective if the dumet mentioned in 1, above, is either black, deep purple or reddish purple. The press area also gets a purplish haze when this defect is present.

3. Heavy blob of emission on coil

   Emission is the whitish coating seen on the coil. The mount is defective if there is a heavy blob of emission on the coil.

4. Discontinuous coating of emission on coil

   For the mount to be accepted, it should have an even and continuous coating of emission on the coil. If the coating is discontinuous the mount is to be rejected as defective.

5. Emission into clamp

   If the emission on the coil continues throughout the length of the coil and into the clamp, on one or both ends of the coil, the mount is to be rejected as defective.

FIGURE 14 Instructions for subjects (cont.)

6. Coil out of clamp

   If the coil is not properly fastened in the clamp or if it is out of the clamp, the mount is to be rejected as defective.

7. Double Coil

   If the mount has more than one coil fastened in the clamp, the mount is defective.

8. Triple lead wires

   If the mount has three or more lead wires, the mount is defective.

FIGURE 14 Instructions for subjects (cont.)

DATA COLLECTION FORM

<u>Subject</u> <u>Corrective lenses</u> <u>Colorvision Deficiency</u> <u>Treatment</u>

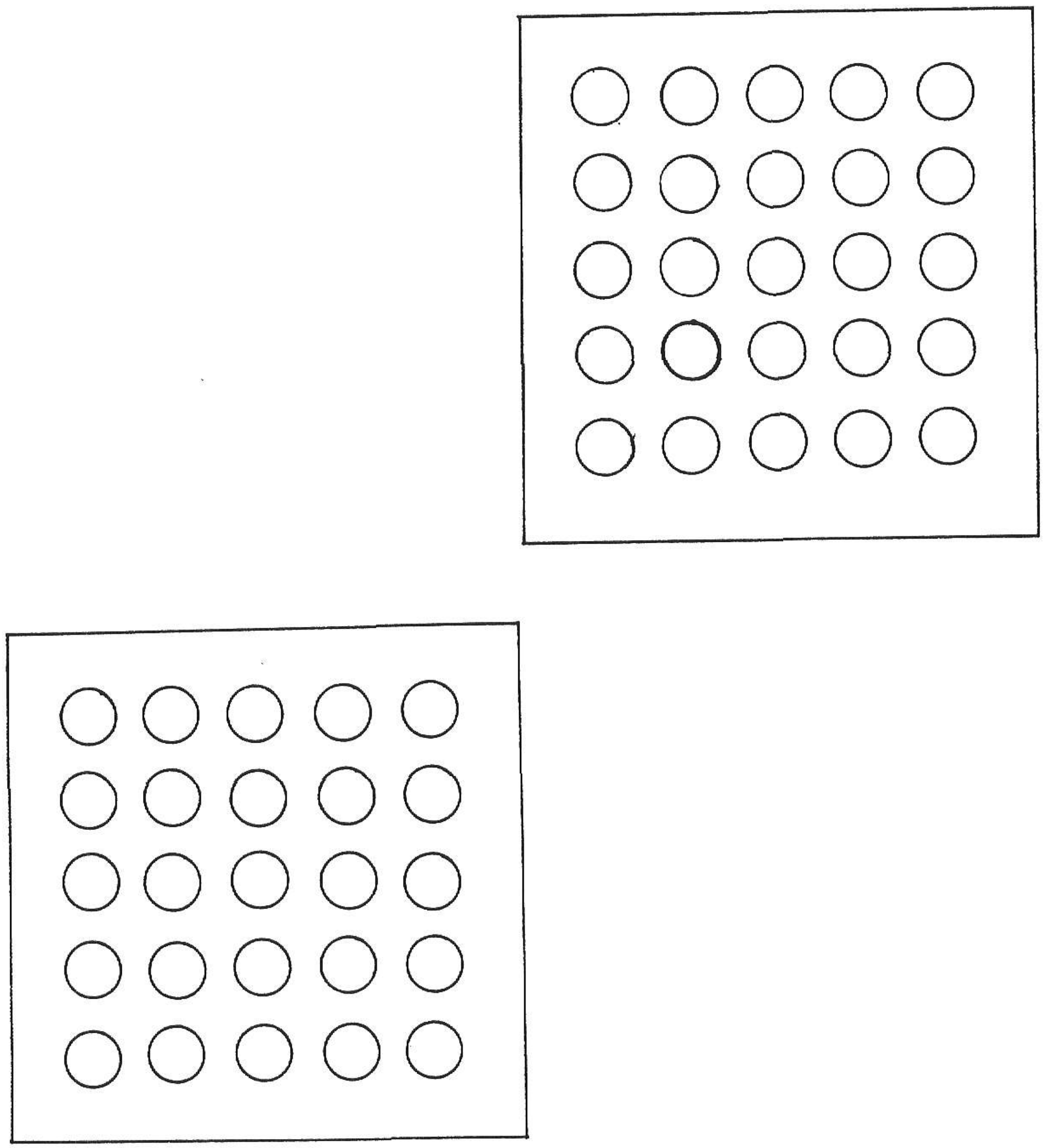

FIGURE 15 Data Collection Form

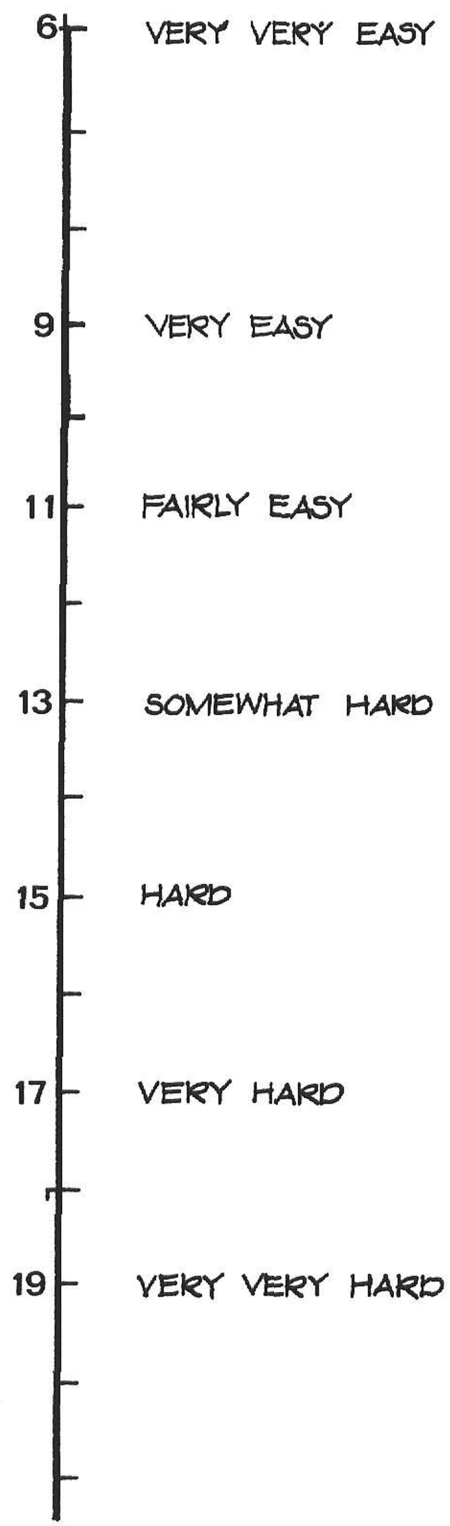

FIGURE 16 Borg Perceived Exertion Scale

The subjects sat on a chair seventeen inches high, facing a table twenty-nine inches high on which the task was performed. The fluorescent lamps were fixed and were at a height of thirty four and one-half inches, the fixture being fixed to the table twenty four inches on the right hand side of the subject. The reflector lamps were used with adjustable lamp holders on two stands which were positioned eighteen inches on the left hand side of the subject in line with his body. The height at which the lamp holders were positioned was varied to provide 1000 lux on the task. This level of illumination was kept constant for each of the nine conditions. The physical set-up of the experiment is shown in Figure 17.

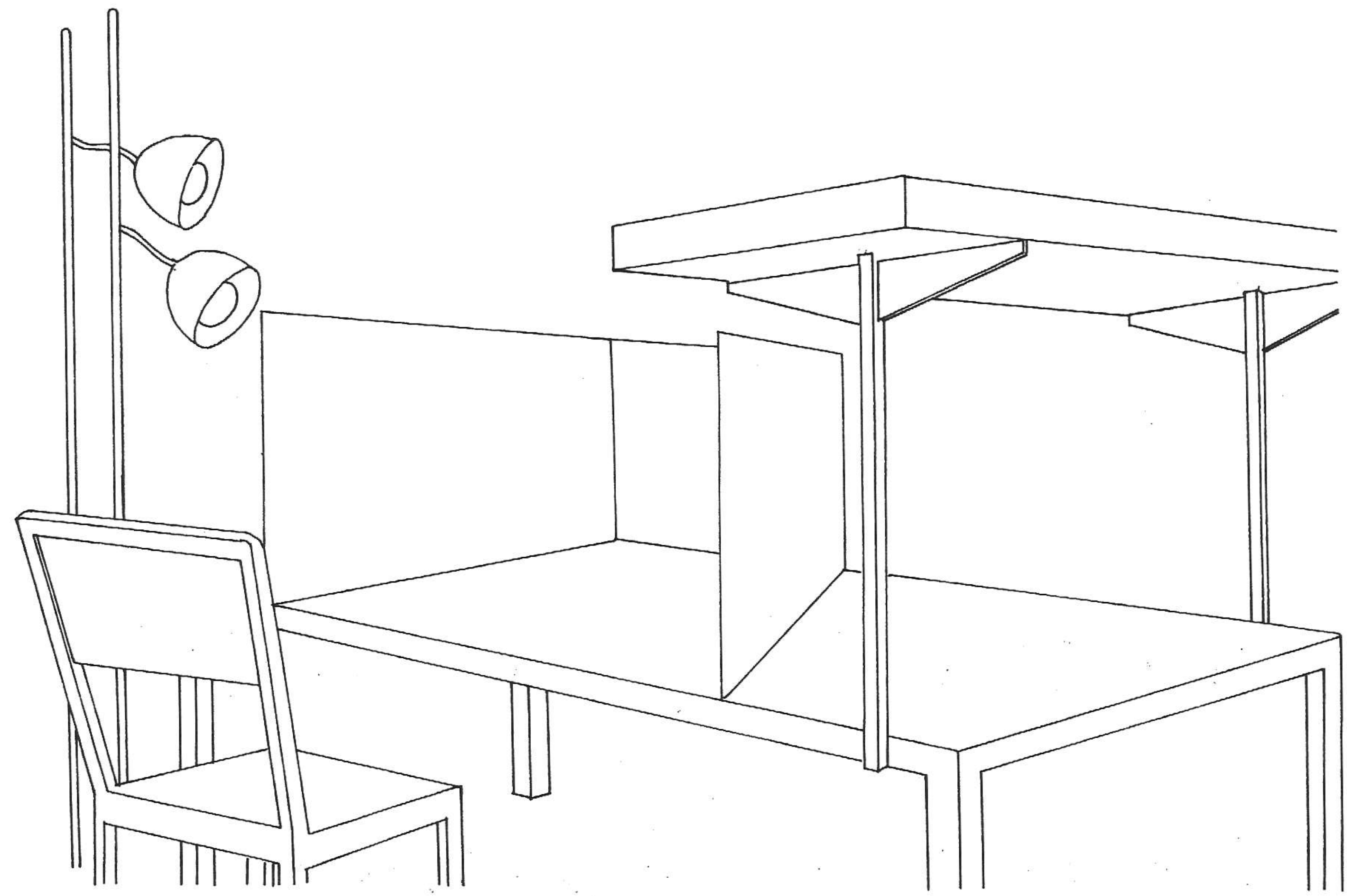

FIGURE 17 The Physical Set-Up of the experiment

RESULTS

The data (See Appendix 2) obtained from this study were analyzed using an IBM computer. A Statistical Analysis Systems package was used to do the analyses of variance.

A one way analysis of variance was done to determine if the treatment effects were significant at the alpha level of 0.05. A two way analysis of variance was done for the six experimental conditions to see if the interaction between the colors of light and the colors of the backgrounds had any significant effect on performance. A Duncan's multiple range test was done to separate the means.

Treatment effects were found to be significant at the alpha level of 0.05 for "Total Hits", "Red Dumet Hits", and "The relative Perception of Effort".

In the one way analysis, the analysis of variance was done for the dependent variables "Total Hits", "Total False Alarms", and the "Relative Perception of Effort" on the Borg scale. Analysis of variance was also done on the "Hits" and "False Alarms", for each of the eight defects individually.

Table 10 shows the summary of the analysis of variance for "Total Hits". The treatment effects were found to be significant at the alpha level of 0.05. Table 11 gives the Duncan's multiple range test for this analysis. Treatment #3, the blue light-blue background condition had the highest mean, with an average detection rate of 76%

Table 12 the summary for the analysis of variance for "Total False Alarms". The treatment effects were found to be not significant.

Table 13 gives the summary of the analysis of variance for "Red Dumet Hits". The treatment effects were significant at the alpha level of 0.05.

TABLE 10

One way analysis of variance for "Total Hits"

ONE WAY RANDOMIZED BLOCK ANALYSIS ON TOTAL HITS AND FALSE ALARMS 5

22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: TOTH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	22869.23988965	1089.01142332	11.39	0.0001	0.696938	16.5403
ERROR	104	9944.61700552	95.62131740		STD DEV		TOTH MEAN
CORRECTED TOTAL	125	32813.85689921			9.77861531		59.12037937

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUBJ	13	3879.70245476	3.12	0.0006
TRT	8	18989.53743492	24.82	0.0001

TABLE 11

<u>Duncan's multiple range test for "Total Hits"</u>

ONE WAY RANDOMIZED BLOCK ANALYSIS ON TOTAL HITS AND FALSE ALARMS

22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TOTH

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05 DF=104 MS=95.6213

GROUPING		MEAN	N	TRT
	A	75.905000	14	3
	A			
B	A	69.190714	14	6
B				
B		66.831429	14	4
B				
B	C	63.956429	14	5
	C			
D	C	58.139286	14	7
D	C			
D	C	57.951429	14	1
D	C			
D	C	56.111429	14	9
D				
D		53.801429	14	2
	E	29.953571	14	8

TABLE 12

One way analysis of variance for "Total False Alarms"

ONE WAY RANDOMIZED BLOCK ANALYSIS ON TOTAL HITS AND FALSE ALARMS 6
22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: TOTFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	25022.54008569	1191.54952808	11.55	0.0001	0.699906	84.5858
ERROR	104	10728.73670844	103.16092589		STD DEV		TOTFA MEAN
CORRECTED TOTAL	125	35751.27679813			10.15681652		12.00770635

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUBJ	13	23695.85356351	17.67	0.0001
TRT	8	1322.68652578	1.60	0.1329

TABLE 13

One way analysis of variance for "Red Dumet Hits"

ANALYSIS ON RED DUMET DEFECTS USING ONE-WAY RANDOMIZED BLOCK DESIGN 13
22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: RDH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	87046.09041508	4145.05192453	8.89	0.0001	0.642169	46.3089
ERROR	104	48503.99470635	466.38456448		STD DEV		RDH MEAN
CORRECTED TOTAL	125	135550.08512143			21.59593861		46.63452381

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	69629.38647143	18.66	0.0001
SUBJ	13	17416.70354365	2.87	0.0015

Table 14 gives the Duncan's multiple range test for this analysis.

Table 15 gives the summary of the analysis of variance for "Red Dumet False Alarms". The treatment effects were found to be stastically not significant at the alpha level of 0.05.

Tables 16 through 29 give the summaries of the analyses of variance for "Hits" and "False Alarms" respectively, for the defects "Burnt Dumet", "Emission into Clamp", "Coil out of Clamp", "Double Coil", "Triple Lead Wires", "Discontinuous Coating of Emission on Coil", and "Blob of emission on Coil:. The even numbered Tables give the results for "Hits" and the odd numbered Tables give the results for the "False Alarms". Treatment effects for neither the "Hits", nor the "False Alarms" for any of these defect types were found to be stastically significant.

Table 30 shows the results of the two way analysis of variance for the dependent variable "Red Dumet Hits". It was found that the color of the light had a stastically significant effect on performance but neither the color of the background nor the interaction between the color of the light and the color of background had any significant effect. Table 31 gives the Duncan's multiple range test for this analysis. Table 32 shows that neither the color of the lights, the colors of the backgrounds, nor the interaction between them had any significant effect on the performance for the dependent variable "Red Dumet False Alarms". Table 33 gives the means for the "Red Dumet Hits", and the "Red Dumet False Alarms", for the six experimental treatment combinations of Red, Blue, and Green lights, and Blue and Green colored background.

TABLE 14

Duncan's multiple range test for "Red Dumet Hits"

ANALYSIS ON RED DUMET DEFECTS USING ONE-WAY RANDOMIZED BLOCK DESIGN 15
22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE RDF

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05 DF=104 MS=466.385

GROUPING	MEAN	N	TRT
A	75.790714	14	3
A			
A	73.567857	14	4
A			
A	67.361429	14	6
A			
A	65.347857	14	5
B	40.617143	14	9
B			
B	35.113571	14	7
B			
B	33.759286	14	1
B			
B	23.053571	14	2
C	5.059286	14	8

TABLE 15

One way analysis of variance for "Red Dumet False Alarms"

ANALYSIS ON RED DUMET DEFECTS USING ONE-WAY RANDOMIZED BLOCK DESIGN 14

22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: RDFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	1506.03249127	71.71583292	1.84	0.0233	0.271009	183.8872
ERROR	104	4051.09254444	38.95281293		STD DEV		RDFA MEAN
CORRECTED TOTAL	125	5557.12503571			6.24121887		3.39404762

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	532.94930000	1.71	0.1046
SUBJ	13	973.08319127	1.92	0.0356

TABLE 16

One way analysis of variance for "Burnt Dumet Hits"

BURNT DUMET DEFECTS- ANALYSIS USING ONE WAY RANDOMIZED BLOCK DESIGN

22:21 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BDH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	100496.02174603	4785.52532124	3.89	0.0001	0.439937	93.0374
ERROR	104	127936.50793651	1230.15873016		STD DEV		BDH MEAN
CORRECTED TOTAL	125	228432.53968254			35.07361872		37.69841270

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	15396.82539683	1.56	0.1445
SUBJ	13	85099.20634921	5.32	0.0001

TABLE 17

One way analysis of variance for "Burnt Dumet FalseAlarms

BURNT DUMET DEFECTS- ANALYSIS USING ONE WAY RANDOMIZED BLOCK DESIGN 19
22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BDFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	43.51708333	2.07224206	1.26	0.2213	0.202563	441.2427
ERROR	104	171.31492063	1.64725885		STD DEV		BDFA MEAN
CORRECTED TOTAL	125	214.83200397			1.28345582		0.29081302

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	25.82896825	1.96	0.0588
SUBJ	13	17.68811508	0.83	0.6326

TABLE 18

One way analysis of variance for "Emission into Clamp Hits"

EMMISSION INTO CLAMP DEFECTS- ANALYSIS USING ONE WAY RCB DESIGN

23

22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: EICH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	73958.41860835	3521.82945745	3.73	0.0001	0.429318	59.4037
ERROR	104	98311.29607619	945.30092381		STD DEV		EICH MEAN
CORRECTED TOTAL	125	172269.71468254			30.74574643		51.75730159

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	27941.38516825	3.69	0.0008
SLBJ	13	46017.03343810	3.74	0.0001

TABLE 19

<u>One way analysis of variance for "Emission into Clamp False Alarms"</u>

EMMISSION INTO CLAMP EFFECTS- ANALYSIS USING ONE WAY RCB DESIGN

24
22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: EICFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	146.28594365	6.96599732	4.54	0.0001	0.478522	282.4535
ERROR	104	159.41760635	1.53286160		STD DEV		EICFA MEAN
CORRECTED TOTAL	125	305.70355000			1.23808788		0.43833333

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	23.82797143	1.94	0.0612
SUBJ	13	122.45797222	6.15	0.0001

TABLE 20

One way analysis of variance for "Coil out of Clamp Hits"

COIL OUT OF CLAMP DEFECTS-ANALYSIS USING ONE WAY RCB DESIGN 28

22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: COCH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	38079.56349206	1813.31254724	1.98	0.0127	0.285880	37.5584
ERROR	104	95121.42857143	914.62912088		STD DEV		COCH MEAN
CORRECTED TOTAL	125	133200.99206349			30.24283586		80.43650794

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	21556.34920635	2.95	0.0052
SUBJ	13	16523.21428571	1.39	0.1763

TABLE 21

One way analysis of variance for "Coil out of Clamp False Alarms"

COIL OUT OF CLAMP EFFECTS-ANALYSIS USING ONE WAY RCB DESIGN

22:27 TUESDAY, JANUARY 13, 1981 29

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: COCFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	82.82245079	3.94392623	1.27	0.2111	0.204385	398.2503
ERROR	104	322.40521270	3.10005012		STD DEV		COCFA MEAN
CORRECTED TOTAL	125	405.22766349			1.76069552		0.44206349

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	17.66832063	0.71	0.6800
SUBJ	13	65.15413016	1.62	0.0918

TABLE 22

One way analysis of variance for "Double Coil Hits"

DOUBLE COIL DEFECTS-ANALYSIS USING ONE WAY RCB DESIGN   22:27 TUESDAY, JANUARY 13, 1981   33

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: DCF

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	23075.39682540	1098.82842026	2.43	0.0017	0.329182	23.6057
ERROR	104	47023.80952381	452.15201465		STD DEV		DCF MEAN
CORRECTED TOTAL	125	70099.20634921			21.26386641		90.07936508

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	2420.63492061	0.67	0.7175
SUBJ	13	20654.76190476	3.51	0.0002

TABLE 23

One way analysis of variance for "Double Coil False Alarms"

DOUBLE COIL EFFECTS-ANALYSIS USING ONE WAY RCB DESIGN 22:27 TUESDAY, JANUARY 13, 1981 34

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: DCFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	38.38662857	1.82793469	1.58	0.0680	0.242008	345.7775
ERROR	104	120.23045714	1.15606209		STD DEV		DCFA MEAN
CORRECTED TOTAL	125	158.61708571			1.07520328		0.31095238

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	10.71194286	1.16	0.3316
SUBJ	13	27.67468571	1.84	0.0459

TABLE 24

One way analysis of variance for "Triple Lead Wires Hits"

TRIPLE LEAD WIRES-ANALYSIS USING ONE WAY RCB DESIGN   22:27 TUESDAY, JANUARY 13, 1981   38

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: TLH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	21904.85449921	1043.08830949	1.21	0.2613	0.195900	37.5484
ERROR	104	89911.64639365	864.53506148		STD DEV		TLH MEAN
CORRECTED TOTAL	125	111816.50089286			29.40297709		78.30690476

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	6261.03267857	0.91	0.5152
SUBJ	13	15643.82181063	1.39	0.1752

TABLE 25

One way analysis of variance for "Triple Lead Wires False Alarms"

TRIPLE LEAD WIRES ANALYSIS USING ONE WAY RCB DESIGN 22:27 TUESDAY, JANUARY 13, 1981 39

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: TLFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	0	0	99999.99	0.0000	0.000000	99999.9999
ERROR	104	0	0		STD DEV		TLFA MEAN
CORRECTED TOTAL	125	0			0		0

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	0	.	.
SUBJ	13	0	.	.

TABLE 26

<u>One way analysis of variance for "Discontinuous Coating of Emission on Coil"</u>

DISCONTINUOUS EMMISSION COATING-ANALYSIS USING ONE WAY RCB DESIGN

43
22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: DISCH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	32095.63008413	1528.36333734	2.98	0.0001	0.375760	30.0786
ERROR	104	53319.62565673	512.68870826		STD DEV		DISCH MEAN
CORRECTED TOTAL	125	85415.25574286			22.64263033		75.27809524

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	11733.77698572	2.86	0.0065
SUBJ	13	20361.85309841	3.04	0.0008

TABLE 27

One way analysis of variance for "Discontinuous Coating of Emission on Coil False Alarms"

DISCONTINUOUS EMMISSION COATING-ANALYSIS USING ONE WAY RCB DESIGN 44

22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: DISCFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	9438.83193413	449.46818734	11.37	0.0001	0.696628	163.7500
ERROR	104	4110.48341587	39.52391746		SID DEV		DISCFA MEAN
CORRECTED TOTAL	125	13549.31535000			6.28680503		3.83811333

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	238.64362857	0.75	0.6432
SUBJ	13	9200.18830556	17.91	0.0001

TABLE 28

One way analysis of variance for "Blob of Emission on Coil Hits"

BLOB ON COIL DEFECTS-ANALYSIS USING ONE WAY RCB DESIGN
48
22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BLCBH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	67366.52541572	3207.92978265	5.93	0.0001	0.544964	40.9735
ERROR	104	56263.51053016	540.99529356		STD DEV		BLCBH MEAN
CORRECTED TOTAL	125	123630.03596587			23.25930553		56.74674603

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	18442.65035873	4.26	0.0002
SUBJ	13	48923.87507699	6.56	0.0001

TABLE 29

One way analysis of variance for "Blob of Emission on Coil False Alarms"

BLOB ON COIL DEFECTS-ANALYSIS USING ONE WAY RCB DESIGN 49

22:27 TUESDAY, JANUARY 13, 1981

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BLCBFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	3396.80765714	161.75274558	2.57	0.0009	0.341836	238.5040
ERROR	104	6540.14349206	62.88599512		STD DEV		BLCBFA MEAN
CORRECTED TOTAL	125	9936.95114921			7.93006905		3.32452063

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TRT	8	352.57226349	0.70	0.6901
SUBJ	13	3044.23539365	3.72	0.0001

TABLE 30

Two way analysis of variance for "Red Dumet Hits"

ANALYSIS OF RED DUMET DEFECTS

ANALYSIS OF VARIANCE PROCEDURE

22:26 TUESDAY, JANUARY 13, 1981 4

DEPENDENT VARIABLE: RDP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	49318.86520238	2739.93695569	5.11	0.0001	0.585784	41.3689
ERROR	65	34874.04355357	536.52374658		STD DEV		RDP MEAN
CORRECTED TOTAL	83	84192.90875555			23.16258226		55.59130952

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	33256.50751667	30.99	0.0001
BKGRD	1	452.63214405	0.84	0.3618
LIGHT*BKGRD	2	396.20060238	0.37	0.6927
SUBJ	13	15213.52493529	2.18	0.0201

TABLE 31

Duncan's multiple range test for "Red Dumet Hits"

ANALYSIS OF RED DUMET DEFECTS 22:26 TUESDAY, JANUARY 13, 1981 6

ANALYSIS OF VARIANCE PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE RDH

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05 DF=65 MS=536.524

GROUPING	MEAN	N	LIGHT	
A	74.679786	28	2	Blue
A				
A	64.864429	28	3	Green
B	28.428214	28	1	Red

TABLE 32

Two way analysis of variance for "Red Dumet False Alarms"

ANALYSIS OF RED DUMET DEFECTS — 22:26 TUESDAY, JANUARY 13, 1981 — 5

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: RDFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	1243.03277381	69.05737632	1.35	0.1866	0.272570	161.5176
ERROR	65	3317.38640115	51.03671386		STD DEV		RDFA MEAN
CORRECTED TOTAL	83	4560.41517500			7.14399845		4.42250000

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	52.51145000	0.51	0.6002
BKGRD	1	144.57814405	2.83	0.0971
LIGHT*BKGRD	2	43.85638810	0.43	0.6526
SUBJ	13	1002.06679167	1.51	0.1374

TABLE 33

Means averaged over all the subjects for "Red Dumet Hits" and "Red Dumet False Alarms"

ANALYSIS OF RED DUMET DEFECTS 22:26 TUESDAY, JANUARY 13, 1981 10

ANALYSIS OF VARIANCE PROCEDURE

MEANS

LIGHT *	BKGRD **	N	RDH	RDFA
1	1	14	23.0571429	2.46000000
1	2	14	33.7952857	6.97142857
2	1	14	13.5678571	4.03071429
2	2	14	15.7907143	6.39000000
3	1	14	64.3850000	2.84071429
3	2	14	65.3478571	3.84214286

*

1 — Red

2 — Blue

3 — Green

**

1— Green

2— Blue

Tables 34 through 47 give the summaries of the two way analyses of variance for the "Hits" and "False Alarms", for the defects "Burnt Dumet", "Emission into Clamp", "Coil out of Clamp", "Double Coil", "Triple Lead Wires", "Discontinuous Coating of Emission on Coil", and "Blob of Emission on Coil". Treatment effects for none of these dependent variables were found to be stastically significant, at the 0.05 alpha level.

Table 48 gives the summary of the analysis of variance for the dependent variable "Relative Perception of Effort" on the Borg scale. The effect of the treatments was found to be stastically significant for this variable at the alpha level of 0.05. Table 49 gives the Duncan's multiple range test for this analysis.

TABLE 34

Two way analysis of variance for "Burnt Dumet Hits"

ANALYSIS OF BURNT DUMET DEFECTS 22:26 TUESDAY, JANUARY 13, 1981 12

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BDH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	71726.19047619	3984.78835979	3.75	0.0001	0.509406	96.0828
ERROR	65	69077.38095238	1062.72893773		STD DEV		BDH MEAN
CORRECTED TOTAL	83	140803.57142857			32.59952358		33.92857143

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	2321.42857143	1.09	0.3416
BKGRD	1	267.85714286	0.25	0.6173
LIGHT*BKGRD	2	3750.00000000	1.76	0.1794
SUBJ	13	65386.90476190	4.73	0.0001

TABLE 35

Two way analysis of variance for "Burnt Dumet False Alarms"

ANALYSIS OF BURNT DUMET DEFECTS — 22:26 TUESDAY, JANUARY 13, 1981 11

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BDFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	45.11642857	2.50646825	1.04	0.4291	0.223826	391.3535
ERROR	65	156.45250000	2.40696154		STD DEV		BDFA MEAN
CORRECTED TOTAL	83	201.56892857			1.55143854		0.39642857

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	10.50446429	2.18	0.1210
BKGRD	1	3.40011905	1.41	0.2389
LIGHT*BKGRD	2	8.61751667	1.79	0.1751
SUBJ	13	22.59352857	0.72	0.7358

TABLE 36

Two way analysis of variance for "Emission into Clamp Hits"

ANALYSIS OF EMMISSION INTO CLAMP DEFECTS 22:26 TUESDAY, JANUARY 13, 1981 20

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: EICH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	52732.75585524	2929.59754574	3.38	0.0002	0.483478	48.3813
ERROR	65	56336.93650000	866.72210000		STD DEV		EICH MEAN
CORRECTED TOTAL	83	109069.69239524			29.44014436		60.85023810

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	502.04800552	0.29	0.7495
BKGRD	1	11.75257619	0.01	0.9077
LIGHT*BKGRD	2	1063.27658095	0.61	0.5446
SUBJ	13	51155.67672857	4.54	0.0001

TABLE 37

Two way analysis of variance for "Emission into Clamp False Alarms"

ANALYSIS OF EMMISSION INTO CLAMP DEFECTS 22:26 TUESDAY, JANUARY 13, 1981 21

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: EICFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	100.61140000	5.58952222	3.96	0.0001	0.522788	289.0789
ERROR	65	91.84008095	1.41292432		STD DEV		EICFA MEAN
CORRECTED TOTAL	83	192.45148095			1.18866493		0.41115048

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	7.97126667	2.82	0.0669
BKGRD	1	2.86011905	2.02	0.1596
LIGHT*BKGRD	2	4.02726667	1.43	0.2479
SUBJ	13	85.75274762	4.67	0.0001

TABLE 38

Two way analysis of variance for "Coil out of Clamp Hits"

ANALYSIS OF COIL OUT OF CLAMP EFFECTS 22:26 TUESDAY, JANUARY 13, 1981 29

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: COCH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	32105.52380952	1783.86243386	2.28	0.0081	0.387351	34.1275
ERROR	65	50785.71428571	781.31868132		STD DEV		COCH MEAN
CORRECTED TOTAL	83	82895.23809524			27.95207830		81.90476190

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	188.09523810	0.12	0.8868
BKGRD	1	2742.85714286	3.51	0.0655
LIGHT*BKGRD	2	2450.00000000	1.57	0.2163
SUBJ	13	26728.57142857	2.63	0.0053

TABLE 39

Two way analysis of variance for "Coil out of Clamp False Alarms"

ANALYSIS OF COIL OUT OF CLAMP DEFECTS 22:26 TUESDAY, JANUARY 13, 1981 29

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: COCFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	43.22094286	2.40116349	1.45	0.1411	0.285871	406.6914
ERROR	65	107.96945238	1.66106850		STD DEV		COCFA MEAN
CORRECTED TOTAL	83	151.19039524			1.28882446		0.31690476

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	1.32961667	0.40	0.6718
BKGRD	1	0.92610000	0.56	0.4579
LIGHT*BKGRD	2	3.53766429	1.06	0.3507
SLPJ	13	37.42756190	1.73	0.0745

TABLE 40

Two way analysis of variance for "Double Coil Hits"

ANALYSIS OF DOUBLE COIL DEFECTS — 22:26 TUESDAY, JANUARY 13, 1981 — 36

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: DCH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	9404.76190476	522.48677249	2.08	0.0166	0.365741	17.0588
ERROR	65	16309.52380952	250.91575092		STD DEV		DCH MEAN
CORRECTED TOTAL	83	25714.28571429			15.84032042		92.85714286

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	178.57142857	0.36	0.7019
BKGRD	1	119.04761905	0.47	0.4934
LIGHT*BKGRD	2	59.52380952	0.12	0.8883
SUBJ	13	9047.61904762	2.77	0.0034

TABLE 41

<u>Two way analysis of variance for "Double Coil False Alarms"</u>

ANALYSIS OF DOUBLE COIL DEFECTS 22:26 TUESDAY, JANUARY 13, 1981 37

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: DCTA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	19.20159286	1.06675516	1.39	0.1880	0.272181	433.8034
ERROR	65	51.34550595	0.78993086		STD DEV		DCTA MEAN
CORRECTED TOTAL	83	70.54709881			0.88878055		0.20488095

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	1.76364524	1.12	0.3337
BKGRD	1	0.86214405	1.09	0.3000
LIGHT*BKGRD	2	1.72429810	1.09	0.3418
SUBJ	13	14.85151548	1.45	0.1627

TABLE 42

Two way analysis of variance for "Triple Lead Wires Hits"

ANALYSIS OF TRIPLE LEAD WIRES — 22:26 TUESDAY, JANUARY 13, 1981 44

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: TLH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	22197.52381190	1233.19576733	1.38	0.1725	0.276410	38.1021
ERROR	65	58109.11045833	893.98631474		STD DEV		TLH MEAN
CORRECTED TOTAL	83	80306.63427024			29.89960392		78.47226190

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	656.43783095	0.37	0.6941
BKGRD	1	100.04034405	0.11	0.7391
LIGHT*BKGRD	2	1747.65211667	0.98	0.3817
SUBJ	13	19693.39352024	1.69	0.0830

TABLE 43

Two way analysis of variance for "Triple Lead Wires False Alarms"

ANALYSIS OF TRIPLE LEAD WIRES 22:26 TUESDAY, JANUARY 13, 1981 45

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: TLFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	0.00002143	0.00000119	1.00	0.4715	0.216867	516.5151
ERROR	65	0.00007738	0.00000119		STD DEV		TLFA MEAN
CORRECTED TOTAL	83	0.00009881			0.00109105		0.00011505

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	0.00000238	1.00	0.3735
BKGRD	1	0.00000119	1.00	0.3210
LIGHT*BKGRD	2	0.00000238	1.00	0.3735
SUBJ	13	0.00001548	1.00	0.4620

TABLE 44

Two way analysis of variance for "Discontinuous Coating of Emission on Coil Hits"

ANALYSIS OF DISCONTINUOUS EMISSION COATING DEFECTS 22:26 TUESDAY, JANUARY 13, 1981 52

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: DISCH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	15260.15252857	847.78625159	1.57	0.0554	0.302949	30.2996
ERROR	65	35111.84613809	540.18224878		STD DEV		DISCH MEAN
CORRECTED TOTAL	83	50371.99866667			23.24182111		76.70666667

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	1850.43425952	1.71	0.1884
BKGRD	1	685.71428571	1.27	0.2640
LIGHT*BKGRD	2	668.03135000	0.62	0.5420
SUBJ	13	12055.97303333	1.72	0.0780

TABLE 45

Two way analysis of variance for "Discontinuous Coating of Emission on Coil False Alarms"

ANALYSIS OF DISCONTINUOUS EMMISSION COATING DEFECTS 22:26 TUESDAY, JANUARY 13, 1981 53

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: DISCFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	6719.85924574	373.32551362	4.84	0.0001	0.572628	194.2586
ERROR	65	5015.26418650	77.15791057		STD DEV		DISCFA MEAN
CORRECTED TOTAL	83	11735.12343224			8.78395757		4.52178571

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	258.66283571	1.68	0.1951
BKGRD	1	0.75562976	0.00	0.9539
LIGHT*BKGRD	2	318.93393095	2.07	0.1348
SUBJ	13	6142.00784881	6.12	0.0001

TABLE 46

Two way analysis of variance for "Blob of Emission on Coil Hits"

ANALYSIS OF BLOB ON COIL DEFECTS   22:26 TUESDAY, JANUARY 13, 1981   69

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BLOB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	45708.76014762	2539.37556376	2.40	0.0053	0.399503	50.0615
ERROR	65	68705.29651905	1057.00456183		STD DEV		BLOB MEAN
CORRECTED TOTAL	83	114414.05666667			32.51160657		64.94333333

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	205.13618095	0.10	0.9077
BKGRD	1	573.67693333	0.54	0.4640
LIGHT*BKGRD	2	1095.31706667	0.52	0.5981
SUBJ	13	43834.62856667	3.19	0.0010

TABLE 47

Two way analysis of variance for "Blob of Emission on Coil False Alarms"

ANALYSIS OF BLOB ON COIL DEFECTS 22:26 TUESDAY, JANUARY 13, 1981 61

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BLCBFA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	18	3671.26759762	203.55931058	2.91	0.0008	0.446653	228.9164
ERROR	65	4548.24644405	69.97302222		STD DEV		BLCBFA MEAN
CORRECTED TOTAL	83	8219.51404167			8.36498788		3.65416667

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LIGHT	2	167.32551667	1.20	0.3091
BKGRD	1	2.27701071	0.03	0.8574
LIGHT*BKGRD	2	118.20807857	0.84	0.4344
SUBJ	13	3383.45659167	3.72	0.0002

TABLE 48

Analysis of variance for "Relative Perception of Effort"

ANALYSIS ON RELATIVE PERCEPTION OF EFFORT   22:27 TUESDAY, JANUARY 13, 1981   10

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BRPE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	21	372.03174603	17.71579743	5.15	0.0001	0.509721	16.4825
ERROR	104	357.84126984	3.44078144		STD DEV		BRPE MEAN
CORRECTED TOTAL	125	729.87301587			1.85493435		11.25396825

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUBJ	13	159.87301587	3.57	0.0001
TRT	8	212.15873016	7.71	0.0001

TABLE 49

Duncan's multiple range test for "Relative Perception of Effort"

ANALYSIS ON RELATIVE PERCEPTION OF EFFORT 22:27 TUESDAY, JANUARY 13, 1981 11

ANALYSIS OF VARIANCE PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE URPE

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05 DF=104 MS=3.44078

GROUPING		MEAN	N	IRT
	A	14.428571	14	8
	B	12.428571	14	2
C	B	11.214286	14	4
C	B	11.142857	14	1
C		10.571429	14	6
C		10.500000	14	5
C		10.500000	14	9
C		10.428571	14	3
C		10.071429	14	7

DISCUSSION

As in any research devoted to improving the efficacy of an existing industrial task, the main objective of this study was to devise a lighting scheme for the manual inspection work-station at Westinghouse, that would increase productivity by reducing shrinkage and thus bring down the unit cost of the lamps.

It was observed that a remarkable improvement in the detection of "Red Dumet" defects was possible if the mounts were to be inspected under a blue light. The cost structure of the mounts shows that it is more expensive to accept a defective mount than to reject a good one, according to Joshi (1980). Therefore "Hits", are the more important criterion on which the results of this study should be judged.

"Hits" in this study have been defined as:

The number of defective mounts identified/the total number of defective mounts.

"False Alarms" are defined as:

The number of good mounts called defective/the total number of good mounts.

The overall hit-rate was highest for treatment #3 (The Blue light-Blue background condition), with the "Hits" averaged over all the subjects being 76%. For treatment #6 (The Green light-Green background condition), the overall "Hits" averaged over all the subjects were 69%, a difference of seven percentage points or 10%.

Under treatment #4 (The Blue light-Green background condition), the overall "Hits" averaged over the subjects were 67%, nine percentage points less than under treatment #3 or a decrement of 13%. The difference between treatment #3 and the remaining other treatments was substantial and Table 11 gives the difference in percentage points.

From Table 11 it can be seen that treatment #3 had an edge over treatment #8 of 46 percentage points or 153%. Treatment #8 was a simulation of the actual working conditions at Westinghouse. Joshi (1980), after a laboratory test with actual inspectors from the Westinghouse plant reported that under the existing conditions, the percentage of total hits was about forty. In the light of this observation, the simulation of the actual working performance in this study was pretty accurate.

The time factor seems to be a major reason for the improved performance under conditions other than the control condition 1. To eliminate the effects of the extra time the subjects had under the experimental conditions, a second control condition (Treatment #7) was used. In this condition, the light and background of control condition 1 (i.e. white fluorescent light-white background) were used but the subjects had as much time as in all the other experimental conditions (i.e. three minutes to inspect a tray of twenty five mounts). The percentage of "Hits" averaged over all the subjects for this condition was 58%, which was eighteen percentage points or 31% less than that obtained under treatment #3. Table 50 shows the percentage of "Hits" for each of the defect types and the overall hits, for treatments 3, 7, and 8.

TABLE 50

Comparison of "Hits" under the three significantly different treatments *

Defect	(Blue light- Blue background- 3 minutes per tray). Treatment #3	(White Fluorescent light- White background- 3 minutes per tray). Treatment #7	(White Fluorescent light- White background- 35 seconds per tray). Treatment #8
Overall	76	58	30
Red Dumet	76	35	5
Burnt Dumet	46	50	21
Emission into-Clamp	66	46	19
Coil out of Clamp	93	88	50
Double Coil	96	86	82
Triple Lead	93	79	68
Discontinuous Coating	80	84	49
Blob on Coil	72	55	31

* These three treatments were significantly different from each other.

As can be seen from Table 50, a very substantial improvement of 71 percentage points or 1420% resulted in the detection of "Red Dumet" defect under treatment #3, as compared with the control condition 1 (Treatment #8). Treatment #3 also had an advantage of 41 percentage points or 117% over control condition 2 (Treatment #7). This clearly demonstrates that the color of the light with which the task was illuminated had a consistent with the observation of Pinder (1959) that "The color appearance of objects depends not only on the reflectance characteristics of the objects themselves but also on the color content of the light with which they are illuminated". This also validates the observation made by Friar and Friar (1980), that a light source strong in blue light emphasizes the color difference in red material and accentuates the red. This study showed that the blue light-blue background condition definitely helped in the detection of red dumet defects, but there was no indication whatsoever that it hindered the detection of any other type of defect.

It was observed that none of the nine conditions neither the experimental conditions nor the control conditions had a statistically significant influence on the "False Alarms". Table 51 gives the comparison between treatments 3, 7, and 8 for the total false alarms, and false alarms for each defect individually.

It would seem from Table 51 that the condition of treatment 3 is slightly inferior to treatments 7 and 8, as far as the false alarms are concerned.

TABLE 51

Comparison of "False Alarms" under three different treatments *

Defect	(Blue light- Blue-Background- 3 minutes per tray). Treatment #3	(White Fluorescent light White Background- 3 minutes per tray). Treatment #7	(White Fluorescent light White Background 35 seconds per tray). Treatment #8
Overall	13	7	10
Red Dumet	6	0	2
Burnt Dumet	0	0	0
Emission into Coil	0	0	1
Coil out of Clamp	1	0	0
Double Coil	0	1	0
Triple Lead	0	0	0
Discontinuous Coating of Emission	1	5	4
Blob on Coil	4	1	3

* These treatments were not significantly different from each other.

However the difference is negligible, and can be ignored, since the primary objective of inspection in a situation like the one at Westinghouse is to prevent the acceptance of defective items, and the rejection of good items is relegated to a place in importance.

The third and last criterion in this study was the relative perception of effort, on the Borg scale. Table 48 gives the summary of the analysis of variance. Treatment effects were statistically significant. Table 49 gives the ratings averaged over all the fourteen subjects. Treatment 7 was perceived to be the condition that required the least effort. It received a mean rating of 10.07, which would place it between "Very easy" and "Fairly easy" on the Borg scale. Treatment 3 was given a mean rating of 10.43, and this also would be between "Very - easy" and "Fairly easy" on the Borg scale. In fact as is evident from Table 49, there was not much difference in the perception of effort required for any treatment but treatment #8, where very little time was allowed for inspection. As expected the subjects perceived this condition to be between "Somewhat hard" and "Hard" on the Borg scale. The mean rating for this condition was 14.43.

Further Research

According to ANSI classification, the inspection task at Westinghouse can be classified as a "Highly Difficult" task. This study proved that performance of the task under blue light and the provision of a pale blue background substantially improves the detection of the "Red Dumet" defects, with no deterioration in the detection of any other type of defect. Westinghouse could undertake a study at their plant to see if the provision of a pale blue background and blue light at the manual inspection station improves the performance, when work is done at the pace that is customary for their plant. It would be interesting to see if the results obtained with the blue light source could be duplicated using blue colored glasses and white light. If this could be done, there would be no need to replace the existing lighting installations.

Practical Implications

The results validate the hypothesis that blue light will be better for detection of dumet defects that are red in color. It was in the detection or red dumet defects that the most substantial improvement was achieved. One conclusion that can be made is that the increased inspection time allowed to the subjects was responsible for their better performance. The author spent two days at the Westinghouse plant observing the inspection performance. It was fairly clear that the inspectors were not making a conscientious effort to look at all types of defects possible, but were content with rejecting the more obvious defects like mounts with double coils, mounts with single or triple lead wires etc.

The time at their disposal (1.4 seconds/mount) for inspection and transfer of mounts precludes the possibility of looking for more subtle defects like red dumets, blob of emission on coil, etc. It is in the detection of these types of finer defects that the lighting scheme recommended after this study would help.

In a test conducted in 1980, Peterson found that the percentage of detection of dumet defects for tubular mounts was 35%. By providing an off-white background, Peterson reported a detection rate of 37%, an increase of two percentage points or 6% approximately. For non-tubular mounts, Peterson reported an increase from 42% to 63%, an improvement of 21 percentage points or 50%, by increasing the illumination level to 1000 lux from 550 lux.

Since the time for inspection of mounts was the same for treatments 3 and 7, a comparative analysis of the performance under these two conditions was done. It was found that the percentage of "Total Hits" increased from 58% under treatment 7, to 76% under treatment 3, an improvement of 18 percentage points or 31%. The percentage of "hits" for "Red Dumets", similiarly, increased from 35% to 76%, an improvement of 41 percentage points or 117%. Assuming that this improvement observed in the laboratory could be translated to the industrial situation, the effective saving could be calculated. The following assumptions are made, for lack of actual information:

1. Assume 2% of the incoming mounts to the inspection are defective.
2. Assume the inspectors miss detecting 25% of the defective mounts. (under the existing lighting scheme at Westinghouse, inspectors actually miss about 60% of the defective mounts, as indicated by the studies of Joshi (1980) and Peterson (1980). With student subjects, in this study the rate of detection under the simulation of the actual working condition, it was found the subjects failed to detect 70% of the defective mounts. Therefore it should be noted that this is a very conservative estimation of the real situation).
3. Assume the cost of a rejected lamp is one dollar. This includes the cost of materials and overhead.

Production rate for HAP 1 and HAP 2 is 2600 lamps/hour. It takes two mounts to make one lamp. Therefore minimum number of lamps inspected and forwarded from there on is

2600 x 2 = 5200 mounts/hour. For the entire shift, the total number of mounts is 5200 x 12 = 62400/line.

With a 2% defect rate there are 62400 x 0.02 = 1248 defective mounts - per shift per line.

Inspectors fail to detect 25% of the defective mounts, i.e., 1248 x 0.25 = 312 mounts/shift/line. At one dollar per lamp being the cost of rejection of a lamp, total cost of rejection is 312 x 1 = 312 dollars/shift/line. Thus for two lines the cost is 312 x 2 = 624 dollars/shift.

With an improvement of 31% in detection, the saving per shift amounts to 624 x 0.31 = 193.44 dollars/shift. For 12 shifts/week and 50 weeks a year the total annual savings for HAP 1 and HAP 2 are 193.44 x 12 x 50 = 116064 dollars.

Rate of production for UNIT 3 and UNIT 4 is 1500 lamps/hour. Therefore the minimum number of mounts inspected and put on the line is 1500 x 2 = 3000 per hour. For an eight hour shift, the total number of mounts on the production line is 3000 x 8 = 24000 mounts/line.

With a 2% defect rate there are 24000 x 0.02 = 480 defective mounts per shift per line.

Inspectors fail to detect 25% of the defective mounts, i.e. 480 x 0.02 = 120 mounts/shift/line. At one dollar per lamp rejection cost, dollar value lost is 120 x 1 = 120 dollars/shift/line. For two lines the dollar value lost per shift is 120 x 2 = 240 dollars/shift.

With an improvement of 31% in detection, the saving/shift amounts to 240 x 0.31 = 74.4 dollars. For 10 shifts/week and 50 weeks a year, the annual savings on UNIT 3 and UNIT 4 are 74.4 x 10 x 50 = 37200 dollars.

The combined savings for HAP 1, HAP 2, UNIT 3, and UNIT 4 are 116064 + 37200 = 153264 dollars.

These calculations are based on the improvement in performance resulting from the use of a blue light source to illuminate the task and the use of a pale blue background to provide the contrast, as compared with the white fluorescent light and a white background. The time to perform the task in both the conditions was three minutes for a tray of 25 mounts which works out to be 7.2 seconds per mount. The time allowed for inspection at Westinghouse is 1.4 seconds per mount. The difference in times should be noted. Though the subjects in this study were given three minutes /tray, not all the subjects used that much time for the task. Even though no record of the time taken by the subjects individually to perform the task was kept, it was observed that mostly subjects finished the task much soon than the given three minutes. Perhaps the engineers at Westinghouse could do a time study at their plant and in the light of this research could re-evaluate the time allowed their inspectors and come up with a satisfactory compromise between production and quality goals.

CONCLUSIONS

From the results of this study, following conclusions can be made about the visual inspection task performed in this experiment.

1. Blue colored light is definitely better than light of any other color for the detection of "Red Dumet" defects.
2. Blue colored light does not hinder the detection of any other type of defect included in this experiment.
3. The color of the light does not have a bearing on the "False alarms".
4. Even though the color of the contrast background did not have a statistically significant effect on performance, of the three colors, White, Pale Green, and Pale Blue used in this experiment Pale Blue seems to be the best aid for efficient performance.
5. The time presently allowed inspectors at Westinghouse, is not sufficient for them to do a good job of inspection.

APPENDIX 1

APPENDIX 1

CLASSIFICATION OF DEFECTS (MOUNTING)

CLASS 1

101 - High air line
102 - Exposed inner knot
103 - Broken or cracked glass
104 - Wrong Coil
105 - No blow hole
106 - Coil out of clamp
107 - Bubbled dumet
108 - Red dumet
109 - Multiple coils or wires
110 - Misplaced wire
111 - Oil or grease
112 - Damaged coils
113 - No coil
114 - Burned dumet
115 - Wire or glass adhered to mount
116 - Coil broken

CLASS 2

201 - Emission on wires
202 - Emission length
203 - Scissor clamp
204 - Off center flare
*205 - Crooked or Off-center tube
*206 - Poor dumet seal
*207 - Coil out of clamp pocket
*208 - Coil loose in clamp

CLASS 3

301 - Emission coverage poor
302 - Blow hole small
303 - Blow hole shape poor
304 - Coil off center
305 - Ridged flare
306 - Out of round flare
*307 - Burned dumet
309 - Foreign material on mount

CLASS 4

401 - Clamp thickness wrong
402 - Clamp spacing before stretch wrong
403 - Clamp spacing after stretch wrong
404 - Hook depth wrong
405 - Emission weight wrong
406 - Strain excessive
407 - Flat thickness wrong
408 - Re-entrant angle poor

MOUNTING Q.E.S. INSPECTION CRITERIA

DEFECT IDENTIFICATION

DEFECT #101 - HIGH AIR LINE

A line of air extending all the way through the press along a dumet wire.

DEFECT #102 - EXPOSED INNER KNOT

An outer lead weld knot partially or completely outside of glass.

DEFECT #103 - BROKEN OR CRACKED GLASS

Any broken, cracked or chipped glass in the press, flare or exhaust tube. Half moon chips on the flare edge are not criticizable.

DEFECT #104 - WRONG COILS

Any coil other than specified.

DEFECT #105 - NO BLOW HOLE

No blow hole on tubular mounts.

DEFECT #106 - COIL OUT OF CLAMP

Criticize any coil completely out of the clamp.

DEFECT #107 - BUBBLED DUMET

A continuously connected line of bubbles along the entire length of a sealed dumet section.

DEFECT #108 - RED DUMET

A dark red or purple line along the entire length of a sealed dumet section. Refer to standard.

*DEFECT #109 - MULTIPLE COILS OR WIRES

More than one coil or two wires on the mount.

DEFECT #110 - MISPLACED WIRE

A wire obviously out of position in the press.

DEFECT #111 - OIL OR GREASE ON MOUNT

Any oily or greasy substance on flare, press, wires or coil.

DEFECT #112 - DAMAGED COILS

Any obviously distorted or skeleton coils.

DEFECT #113 - NO COIL

The absence of a coil.

DEFECT #114 - BURNED DUMET

Dumet burned along its entire length.

DEFECT #115 - WIRE OR GLASS ADHERED TO MOUNT

Criticize a mount with any extranious metal or glass adhering to any part of it's glass surface.

DEFECT #116 - COIL BROKEN

Criticize any coil with a broken primary winding.

DEFECT #201 - EMISSION ON WIRES

Any emission on the clamp or outer lead wire.

DEFECT #202 - EMISSION LENGTH

Any coated coil which falls outside the following limit:
1 to 2 mm from clamp - 40 Watt.

½ to 1½ mm - Slimline

DEFECT #203 - SCISSOR CLAMP

Any clamp scissored more than ½ the width of the flattened wire.

DEFECT #204 - OFF CENTER FLARE

The flare is out of alignment with the exhaust tube and wires. Limit to be established.

*DEFECT #205 - CROOKED OR OFF-CENTER TUBE

The flare and wires are in alignment. The exhaust tube is out of alignment. Limit to be established.

DEFECT #206 - POOR DUMET SEAL

Criticize any mount with less than 2 mm good dumet seal. Good dumet is that which is not burned, excessively red, bubbled or otherwise defective.

DEFECT #207 - COIL OUT OF CLAMP POCKET

Any coil secured past the center point of clamp.

DEFECT #301 - EMISSION COVERAGE POOR

A gap in emission coverage of more than 1 sq. mm. Refer to defect #405.

DEFECT #302 - BLOW HOLE SMALL

Limit: ½ the inside diameter of the exhaust tube. Note: see defect #105.

DEFECT #303 - BLOW HOLE SHAPE POOR

Limit to be established.

DEFECT #304 - COIL OFF CENTER

Criticize any coil end which does not extend beyond the clamp.

DEFECT #305 - RIDGED FLARE

Criticize any obvious ridges which may prevent sealing.

*DEFECT #306 - OUT OF ROUND FLARE

Criticize any flare which is out of round more than 1.0 mm.

*DEFECT #307 - BURNED DUMET

A dark or brown spot on the dumet caused by overheating. Criticize any in excess of 1.5 mm in length. Refer to defect #114 and #206.

DEFECT #309 - FOREIGN MATERIAL ON MOUNT

Criticize any foreign substance on any part of a mount. Disregard the white film which is sometimes on the flare as a result of SO_2.
Note: See defect #111 when oil or grease is present.

*DEFECT #401 - CLAMP THICKNESS WRONG

Criticize any clamp thickness outside of specification.

DEFECT #402 - CLAMP SPACING BEFORE STRETCH WRONG

Criticize any mount outside of specification.

DEFECT #403 - CLAMP SPACING AFTER STRETCH WRONG

Criticize any mount outside of specification.

DEFECT #404 - HOOK DEPTH WRONG

Criticize any mount outside of specification.

DEFECT #405 - EMISSION WEIGHT WRONG

Criticize emission weight outside of specification.

DEFECT #406 - STRAIN EXCESSIVE

Criticize any strain in excess of that shown in pictures at polariscope.

DEFECT #407 - FLAT THICKNESS WRONG

Criticize any flat thickness outside of specification.

*DEFECT #408 - RE-ENTRANT ANGLE POOR

Criticize a sharp re-entrant angle between the exhaust tube and stem press, or wire touching side of flare just below entry into the stem press.

APPENDIX 2

APPENDIX 2

STATISTICAL ANALYSIS SYSTEM 22:27 TUESDAY, JANUARY 13, 1981 1

OBS	SUBJ	TRT	TOTH	TOTFA	ARPE	RDH	RDFA	BDH	BDFA	FICH	FICFA	CPCH	CPCFA	DCH	DCFA	TLH	TLFA	DISCH	DISCFA	BLUDH	BLUDFA
1	1	1	53.57	0.000	12	25.00	21.74	0	0.00	60.00	0.00	80	0.00	50	0.00	100.00	0	100.00	0.00	50.00	0.00
2	1	2	74.00	21.740	17	16.67	21.74	0	0.00	100.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	100.00	0.00
3	1	3	77.42	0.000	7	77.78	0.00	50	0.00	80.00	0.00	100	0.00	100	0.00	66.67	0	100.00	0.00	100.00	0.00
4	1	4	84.61	0.000	7	100.00	0.00	0	0.00	100.00	0.00	100	0.00	50	0.00	100.00	0	100.00	0.00	100.00	0.00
5	1	5	77.77	0.000	7	42.86	0.00	100	0.00	100.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	50.00	0.00
6	1	6	85.00	0.000	10	55.56	0.00	100	0.00	100.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	100.00	0.00
7	1	7	75.00	0.000	11	50.00	0.00	100	0.00	100.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	50.00	0.00
8	1	8	23.70	0.000	13	25.00	0.00	0	0.00	40.00	0.00	0	0.00	0	0.00	50.00	0	50.00	0.00	0.00	0.00
9	1	9	67.86	18.180	13	50.00	18.18	100	0.00	60.00	0.00	80	0.00	0	0.00	100.00	0	100.00	0.00	100.00	0.00
10	2	1	44.44	4.350	9	28.57	4.35	0	0.00	0.00	0.00	100	0.00	100	0.00	100.00	0	75.00	0.00	16.67	0.00
11	2	2	44.83	9.520	12	44.44	0.00	0	0.00	0.00	0.00	100	0.00	50	0.00	50.00	0	100.00	4.76	20.00	4.76
12	2	3	55.25	13.040	12	44.44	0.00	100	0.00	100.00	0.00	100	4.35	100	4.35	50.00	0	66.67	0.00	20.00	0.00
13	2	4	75.00	0.000	10	75.00	0.00	50	0.00	50.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	33.33	0.00
14	2	5	56.00	12.000	10	71.43	8.70	0	0.00	50.00	0.00	100	4.00	100	0.00	100.00	0	25.00	0.00	25.00	0.00
15	2	6	62.96	13.040	9	100.00	8.70	50	0.00	50.00	0.00	50	0.00	100	0.00	50.00	0	50.00	0.00	42.85	4.35
16	2	7	45.83	3.830	13	75.00	0.00	50	0.00	50.00	0.00	100	0.00	50	0.00	100.00	0	66.67	0.00	0.00	3.85
17	2	8	40.74	8.700	19	0.00	0.00	100	0.00	0.00	0.00	100	0.00	100	0.00	50.00	0	100.00	0.00	20.00	4.35
18	2	9	57.14	13.640	12	25.00	0.00	50	0.00	50.00	0.00	100	13.64	100	0.00	100.00	0	80.00	0.00	40.00	0.00
19	3	1	62.96	0.000	11	33.33	0.00	0	0.00	100.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	100.00	0.00
20	3	2	58.62	0.000	13	44.44	0.00	0	0.00	100.00	0.00	50	0.00	50	0.00	100.00	0	50.00	0.00	50.00	0.00
21	3	3	80.76	0.000	10	88.88	0.00	0	0.00	100.00	0.00	50	0.00	50	0.00	100.00	0	100.00	0.00	100.00	0.00
22	3	4	65.23	0.000	11	66.67	0.00	0	0.00	100.00	0.00	100	0.00	50	0.00	50.00	0	50.00	0.00	100.00	0.00
23	3	5	84.00	0.000	10	100.00	0.00	0	0.00	100.00	0.00	100	0.00	50	0.00	100.00	0	100.00	0.00	100.00	0.00
24	3	6	74.07	0.000	11	75.00	0.00	0	0.00	71.42	0.00	50	0.00	50	0.00	100.00	0	100.00	0.00	100.00	0.00
25	3	7	55.25	0.000	14	33.33	0.00	0	0.00	50.00	0.00	75	0.00	50	0.00	100.00	0	100.00	0.00	100.00	0.00
26	3	8	25.92	0.000	17	0.00	0.00	0	0.00	20.00	0.00	0	0.00	0	0.00	100.00	0	100.00	0.00	100.00	0.00
27	3	9	50.00	0.000	14	37.50	0.00	0	0.00	40.00	0.00	100	0.00	100	0.00	100.00	0	50.00	0.00	100.00	0.00
28	4	1	55.55	0.000	9	28.57	0.00	50	0.00	50.00	0.00	50	0.00	100	0.00	100.00	0	100.00	0.00	100.00	0.00
29	4	2	58.62	0.000	9	0.00	0.00	50	0.00	100.00	0.00	100	0.00	100	0.00	100.00	0	75.00	0.00	100.00	0.00
30	4	3	74.07	0.000	8	66.67	0.00	50	0.00	100.00	0.00	100	0.00	100	0.00	100.00	0	33.33	0.00	80.00	0.00
31	4	4	76.92	0.000	9	44.44	0.00	0	0.00	50.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	100.00	0.00
32	4	5	80.76	0.000	6	77.77	0.00	0	0.00	50.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	100.00	0.00
33	4	6	56.00	0.000	10	14.28	0.00	0	0.00	50.00	0.00	50	0.00	100	0.00	100.00	0	100.00	0.00	75.00	0.00
34	4	7	68.00	0.000	8	28.57	0.00	0	0.00	50.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	100.00	0.00
35	4	8	37.03	0.000	13	0.00	0.00	0	0.00	0.00	0.00	100	0.00	100	0.00	100.00	0	50.00	0.00	28.57	0.00
36	4	9	67.85	0.000	8	37.50	0.00	50	0.00	100.00	0.00	100	0.00	100	0.00	100.00	0	60.00	0.00	80.00	0.00
37	5	1	77.77	43.470	11	28.57	0.00	100	0.00	50.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	100.00	43.48
38	5	2	58.62	47.620	11	22.22	0.00	0	0.00	50.00	0.00	100	0.00	100	0.00	50.00	0	80.00	4.76	100.00	41.38
39	5	3	92.59	39.100	11	100.00	34.78	100	0.00	50.00	0.00	100	0.00	100	0.00	100.00	0	75.00	0.00	100.00	0.00
40	5	4	64.00	24.000	13	100.00	24.00	100	0.00	0.00	0.00	50	0.00	100	0.00	50.00	0	100.00	0.00	25.00	0.00
41	5	5	55.55	0.000	13	71.43	0.00	0	0.00	50.00	0.00	100	0.00	100	0.00	100.00	0	50.00	0.00	16.67	0.00
42	5	6	74.00	0.000	11	100.00	0.00	0	0.00	50.00	0.00	50	0.00	100	0.00	100.00	0	100.00	0.00	40.00	0.00
43	5	7	53.57	0.000	11	12.50	0.00	100	0.00	100.00	0.00	100	0.00	100	0.00	100.00	0	40.00	0.00	40.00	0.00
44	5	8	34.61	0.000	17	0.00	0.00	100	0.00	0.00	0.00	0	0.00	100	0.00	100.00	0	0.00	0.00	75.00	0.00
45	5	9	44.44	0.000	11	50.00	0.00	100	0.00	0.00	0.00	50	0.00	100	0.00	50.00	0	50.00	0.00	14.29	0.00
46	6	1	46.42	18.180	14	25.00	13.64	50	0.00	50.00	0.00	100	0.00	100	0.00	100.00	0	40.00	0.00	60.00	0.00
47	6	2	48.14	13.040	14	22.22	4.35	50	8.70	50.00	0.00	100	0.00	100	0.00	100.00	0	66.67	0.00	60.00	0.00
48	6	3	75.31	28.570	11	88.88	14.29	0	0.00	100.00	6.89	100	0.00	100	0.00	100.00	0	100.00	0.00	60.00	4.75
49	6	4	87.50	7.690	13	100.00	7.69	0	0.00	100.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	66.67	0.00
50	6	5	48.14	8.690	14	37.50	4.35	0	0.00	100.00	4.35	100	0.00	100	0.00	50.00	0	75.00	0.00	25.00	0.00
51	6	6	65.50	47.620	14	66.67	9.52	0	0.00	100.00	4.76	100	0.00	100	0.00	50.00	0	75.00	14.28	71.43	19.10
52	6	7	56.00	0.000	12	57.14	0.00	50	0.00	0.00	0.00	50	0.00	100	0.00	50.00	0	100.00	0.00	25.00	0.00
53	6	8	22.22	17.390	17	0.00	13.00	0	0.00	50.00	4.35	50	0.00	100	0.00	50.00	0	0.00	0.00	20.00	0.00
54	6	9	57.69	25.000	12	44.44	0.00	0	0.00	0.00	8.33	100	0.00	100	0.00	100.00	0	100.00	0.00	50.00	16.66
55	7	1	54.16	7.691	4	12.50	3.85	100	3.85	50.00	0.00	100	0.00	100	0.00	100.00	0	100.00	0.00	33.33	0.00
56	7	2	61.53	16.660	12	27.72	0.00	50	0.00	0.00	0.00	100	0.00	100	0.00	100.00	0	100.00	4.17	100.00	12.50

OBS	SUBJ	TRT	TOTH	TOTFA	BRPE	ROH	ROFA	RCH	RDFA	EICH	EICFA	CCCH	CUCFA	DCH	DCFA	ILH	ILFA	DISCH	DISCFA	BLUNH	PLURFA
57	7	3	80.C0	0.00	11	57.14	0.CC	ICC	0.CC	IC0	0.00	IC0	C.00	100	0.00	50	C	ICC.00	0.00	75.0G	0.0C
58	7	4	62.57	0.00	12	37.50	0.00	100	0.00	100	0.00	50	0.00	100	0.00	100	0	66.67	0.00	60.00	0.00
59	7	5	64.28	0.00	9	50.00	0.00	100	0.00	100	0.0C	100	0.00	100	0.0C	IC0	0	60.00	0.00	20.00	0.0C
60	7	6	81.48	0.00	11	85.71	0.C0	10C	0.00	50	0.00	100	0.C0	100	0.00	100	0	75.00	0.00	66.67	0.00
61	7	7	51.85	4.35	8	28.57	C.00	10C	0.00	5C	C.00	50	0.00	100	4.34	50	0	50.00	0.00	50.00	0.0C
62	7	8	13.79	14.28	13	0.00	0.0C	C	0.CC	50	4.76	C	0.00	50	0.00	0	0	50.00	0.00	0.00	9.52
63	7	9	62.50	15.38	9	25.00	0.00	100	3.85	50	0.00	100	0.00	100	0.00	100	0	IC0.00	11.54	33.33	0.00
64	8	1	40.74	C.00	14	11.11	0.00	C	0.00	50	0.00	0	0.00	IC0	0.00	100	0	66.67	0.00	60.00	0.0C
65	8	2	48.27	0.00	13	33.33	0.00	5C	0.00	100	0.00	50	0.00	100	0.00	100	0	5C.00	0.03	60.00	0.00
66	8	3	54.16	0.00	11	42.85	0.00	0	0.00	0	0.00	50	0.00	100	0.00	50	0	75.00	0.00	75.00	0.00
67	8	4	40.C0	0.00	15	28.57	C.00	C	0.C0	50	0.C0	0	0.00	100	0.00	50	C	75.00	0.00	25.00	0.00
68	8	5	55.55	0.00	13	100.00	0.00	C	0.00	50	C.00	50	0.00	100	0.C0	50	C	75.00	0.00	14.28	0.00
69	8	6	60.71	0.00	11	50.00	0.0C	C	0.C0	IC0	0.00	100	0.00	100	0.00	50	0	60.00	0.00	40.00	0.0C
70	8	7	65.38	0.00	11	77.77	0.00	0	0.00	50	0.00	100	0.00	100	0.0C	IC0	0	66.67	0.00	100.00	0.00
71	8	8	33.33	0.00	9	12.50	0.C0	C	0.00	0	0.00	50	0.00	100	0.00	100	0	33.33	0.00	33.33	C.0C
72	8	9	59.25	0.00	11	71.43	0.00	10C	0.00	50	C.00	100	0.00	0	0.0C	100	0	50.00	0.00	33.33	0.00
73	9	1	65.38	16.70	12	33.33	0.00	C	0.00	50	0.00	100	0.00	100	4.16	100	0	100.00	8.33	100.00	4.16
74	9	2	46.43	9.10	10	12.50	0.CC	C	0.CC	100	0.00	100	9.10	100	0.0C	50	0	60.00	0.00	40.00	0.00
75	9	3	77.80	17.40	11	100.00	17.40	C	0.00	50	0.00	100	0.00	50	0.0C	50	C	IC0.00	0.00	100.00	0.00
76	9	4	66.67	4.35	12	100.00	0.00	10C	0.00	50	0.00	50	0.00	100	4.35	50	0	50.00	0.00	42.85	0.0C
77	9	5	50.00	11.53	11	37.50	0.00	0	0.00	50	0.00	100	0.00	100	0.00	100	0	100.00	11.53	33.33	0.00
78	9	6	65.52	13.70	9	66.67	0.00	0	0.00	50	0.00	100	0.00	100	0.00	0	0	100.00	9.52	80.00	0.00
79	9	7	48.00	4.00	8	28.52	0.0C	C	0.00	0	0.00	100	0.00	100	0.00	50	C	100.00	4.00	25.00	0.00
80	9	8	31.03	23.80	15	0.00	0.00	C	0.00	0	0.00	0	0.00	100	0.00	100	0	66.67	23.80	75.00	0.00
81	9	9	59.25	13.15	10	33.33	C.C0	C	0.00	50	C.00	100	0.00	100	4.35	IC0	0	100.00	8.70	60.00	0.00
82	10	1	51.73	0.00	9	33.33	0.0C	50	0.00	100	0.00	100	0.00	50	0.00	0	0	5C.00	0.00	66.67	0.00
83	10	2	44.00	4.00	13	28.52	4.00	50	0.00	0	0.00	100	0.00	100	0.00	50	0	25.00	0.00	50.00	0.0C
84	10	3	74.10	17.40	11	100.00	8.70	100	0.00	0	C.00	IC0	0.00	IC0	0.0C	100	0	75.00	4.35	33.33	4.35
85	10	4	55.55	7.40	11	55.55	8.70	10C	0.00	0	0.00	0	0.00	100	0.00	100	0	66.67	0.00	40.0C	0.00
86	10	5	62.97	18.52	11	100.00	17.39	ICC	0.C0	50	0.C0	50	0.00	100	0.00	50	0	50.00	0.00	28.57	4.35
87	10	6	83.33	11.54	11	87.50	7.69	100	3.85	50	0.00	100	0.00	100	0.CC	100	0	66.67	0.00	66.67	0.00
88	10	7	68.00	0.00	11	55.55	0.00	5C	0.0C	100	0.00	100	0.00	50	0.0C	0	0	50.00	0.00	66.67	0.C0
89	10	8	35.70	14.54	16	0.00	0.00	10C	0.00	50	C.00	100	4.55	100	0.0C	100	0	C.00	0.00	20.00	0.00
90	10	9	53.57	13.64	9	50.00	4.45	5C	0.00	50	0.00	100	0.00	100	0.00	100	0	40.00	0.00	20.00	9.1C
91	11	1	62.96	30.43	11	100.00	26.10	C	0.C0	100	0.00	100	0.00	100	0.00	50	0	50.00	0.00	16.67	0.00
92	11	2	44.44	0.00	12	42.86	0.C0	C	0.00	100	0.00	100	0.00	50	0.00	0	0	50.00	0.00	33.33	0.00
93	11	3	78.57	4.55	9	88.88	0.00	C	0.C0	50	C.00	IC0	4.55	100	0.0C	100	0	60.00	0.00	60.00	0.00
94	11	4	57.64	4.17	10	55.55	0.00	0	0.00	50	C.00	100	4.17	IC0	0.0C	IC0	C	33.33	0.00	75.00	0.00
95	11	5	73.C7	0.00	11	88.88	0.00	C	0.00	50	0.00	100	C.00	100	0.00	100	0	66.67	0.00	50.00	0.00
96	11	6	50.C0	4.55	9	50.00	0.00	C	0.00	100	0.00	100	4.45	50	0.0C	50	0	40.00	0.00	20.00	0.00
97	11	7	54.17	3.87	9	0.00	0.00	100	3.85	50	C.00	100	0.00	100	0.00	100	0	100.00	0.00	33.33	0.00
98	11	8	25.00	4.55	11	0.00	0.00	C	0.C0	0	0.00	IC0	C.00	100	4.76	50	0	50.00	0.00	0.00	0.00
99	11	9	40.74	4.34	10	0.00	0.00	5C	0.00	50	0.00	50	0.00	100	4.35	100	0	66.67	0.00	40.00	0.0C
100	12	1	59.25	56.52	15	44.44	0.00	5C	0.0C	0	0.00	0	0.00	100	0.00	50	0	100.00	47.82	100.00	8.69
101	12	2	48.77	61.90	11	11.11	0.00	5C	0.00	0	0.00	100	0.00	100	0.0C	0	0	10C.00	19.00	100.00	42.85
102	12	3	88.88	47.82	13	100.00	0.0C	5C	0.00	0	0.00	100	0.00	100	0.00	100	0	66.67	8.69	100.00	39.10
103	12	4	76.C0	68.00	11	100.00	0.00	5C	0.00	0	0.00	C	0.00	100	0.00	50	0	1C0.00	52.00	75.00	12.00
104	12	5	75.86	80.95	13	100.00	19.00	C	0.00	0	0.00	100	0.00	100	0.00	0	0	100.00	28.57	100.00	33.33
105	12	6	77.77	47.82	11	100.00	4.34	10C	0.CC	C	0.00	0	0.00	100	0.00	50	0	100.00	43.47	80.00	0.00
106	12	7	64.28	63.63	9	37.50	0.C0	C	0.00	0	0.00	100	0.00	50	0.0C	IC0	C	IC0.00	61.90	100.00	0.00
107	12	8	37.03	47.82	13	33.33	0.00	C	0.C0	0	0.00	50	0.00	100	0.00	50	0	25.00	17.40	42.85	30.43
108	12	9	87.50	34.61	9	100.00	11.53	100	0.00	0	0.00	ICC	C.00	100	0.00	100	0	ICC.00	23.00	66.67	0.00
109	13	1	58.62	28.57	13	44.44	14.28	C	0.00	50	0.00	100	0.00	100	0.00	50	0	50.00	14.29	100.00	0.0C
110	13	2	58.33	30.76	14	0.00	0.00	100	3.85	IC0	0.00	50	0.00	100	0.0C	100	0	100.00	26.92	66.67	0.00
111	13	3	59.26	4.34	10	16.67	0.C0	10C	0.C0	IC0	0.00	100'	0.00	100	0.0C	50	0	75.00	0.00	42.86	4.35
112	13	4	55.55	8.69	11	66.67	4.35	C	0.CC	5C	0.00	100	0.00	100	0.CC	100	0	75.00	0.00	14.29	4.35

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   22:27 TUESDAY, JANUARY 13, 1981   3

OBS	SUBJ	TRT	TOTH	TCTFA	BRPE	RDH	RCFA	BCH	BCFA	EICH	EICFA	COCH	COCFA	DCH	DCFA	ILH	ILFA	DISCH	DISCFA	BLDBH	BLDBFA
113	13	5	52.00	4.00	9	0.00	0.00	50	0.0	0	0.00	100	0.00	100	0.00	100	0	100.00	4.00	50.00	0.00
114	13	6	58.33	3.85	11	25.00	0.00	100	0.0	50	0.00	100	0.00	100	0.00	100	0	100.00	3.85	0.00	0.00
115	13	7	53.85	20.83	8	0.00	0.00	100	0.0	50	0.00	100	0.00	100	4.17	100	0	100.00	0.00	50.00	16.67
116	13	8	25.92	8.69	15	0.00	0.00	0	0.0	0	0.00	100	0.00	100	0.00	50	0	66.67	8.70	0.00	0.00
117	13	9	33.33	4.35	9	0.00	0.00	100	0.0	0	0.00	0	0.00	100	4.35	50	0	66.67	0.00	40.00	0.00
118	14	1	77.77	21.30	12	25.00	13.64	50	0.0	50	0.00	100	0.00	100	0.00	100	0	40.00	0.00	60.00	0.00
119	14	2	58.62	43.47	13	22.22	4.35	50	8.7	50	0.00	100	0.00	100	0.00	100	0	66.67	0.00	60.00	0.00
120	14	3	86.50	5.52	9	88.88	14.29	0	0.0	100	0.00	100	6.85	100	0.00	100	0	100.00	0.00	60.00	4.75
121	14	4	64.00	24.00	12	100.00	7.69	0	0.0	100	0.00	100	0.00	100	0.00	100	0	100.00	0.00	66.67	0.00
122	14	5	60.00	13.53	10	37.50	4.35	0	0.0	100	4.35	100	0.00	100	0.00	50	0	75.00	0.00	25.00	0.00
123	14	6	74.00	24.00	10	66.67	9.52	0	0.0	100	4.76	100	0.00	100	0.00	50	0	75.00	14.28	71.43	19.10
124	14	7	53.57	0.00	8	57.14	0.00	50	0.0	0	0.00	50	0.00	100	0.00	50	0	100.00	0.00	25.00	0.00
125	14	8	33.33	0.00	14	0.00	13.00	0	0.0	50	4.35	50	0.00	100	0.00	50	0	100.00	0.00	20.00	0.00
126	14	9	44.44	0.00	10	44.44	0.00	0	0.0	0	8.33	100	0.00	100	0.00	100	0	100.00	0.00	50.00	16.66

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LIGHTING FOR A VISUAL INSPECTION TASK

by

SUDHAKAR MISRA

B.Tech. (MECH.), Jawaharlal Nehru Technological University, Hyderabad, India, 1977

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1981

ABSTRACT

Experiments were performed to determine the relationship between the colors of light and background, and performance of a "highly difficult" visual inspection task: the inspection of fluorescent lamp ends called mounts. The experiments were conducted under nine different conditions of lighting and background: blue light- pale blue background, blue light- pale green background, green light- pale blue background, green light- pale green background, red light- pale blue background, red light- pale green background, cool white fluorescent light- white background, incandescent white light- white background, and the control condition where the actual industrial working conditions were simulated. The time allowed for inspection in all but the control condition was three minutes per tray of twenty-five mounts. In the condition where the industrial conditions were simulated, the inspection time allowed was thirty-five seconds per tray of twenty-five mounts. Eight important defects of the mounts were selected for the study. The study was performed under a task illumination level of 1000 lux, which was constant under all the conditions.

Three performance measures were chosen to evaluate the effect of the independent variables. These were "hits", "false alarms", and the relative ranking of each condition by the subjects on the "Borg" scale, for "relative perception of effort".

The treatment effects were stastically significant for the "total hits", "red dumet hits" and the "relative perception of effort". Under the blue light- blue background condition, there as an improvement of

153% in hit-rate for total hits, over the white light- white background condition (control condition 1), and an improvement of 1420% in the hit-rate for "red dumet" defects.

Overall the results of this study show that the blue light- blue background condition helps in the detection of red dumet defects, without adversely affecting the performance for detection of any other type of defect.