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In Vivo Spectral Absorption Analysis Enabling the Classification of Pigmented Cutaneous Lesions: Investigating System Design and the Role of Faculative Melanin in the Spectral Determination of Skin Type Classification

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IN VIVO SPECTRAL ABSORPTION ANALYSIS ENABLING THE CLASSIFICATION OF PIGMENTED CUTANEOUS LESIONS: INVESTIGATING SYSTEM DESIGN AND THE ROLE OF FACULATIVE MELANIN IN THE SPECTRAL DETERMINATION OF SKIN TYPE CLASSIFICATION

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Bachelor of Science in the School of
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of the Rochester Institute of Technology

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COLLEGE OF GRAPHIC ARTS AND PHOTOGRAPHY

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Submitted to the
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at the Rochester Institute of Technology

ABSTRACT

A spectroradiometer was designed and built to record in vivo absorption characteristics of the lateral elbow. An analysis of variance of spectral characteristics between 400 and 1100 nanometers of faculative melanin to skin types one two and three was performed. The hypothysis that skin type could be differentiate by spectral recordings of in vivo faculative melanin was rejected. Further research is required to correlate constitutional melanin to skin type classification, in order to form a reference for pigmented cutaneous lesion classification.

ACKNOWLEDGEMENTS

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I would like to acknowledge the love and friendship of; Ken Riehl, Ariel Shaw, Chris Edwards, Don Marsh, Theresa Ciccone, Chris Vasko, John Francis, Dave Wolf, Jutta Middel, Todd Pegelow, Patty Grimes, Paul Butterfield, Chris Curtis, and Ken Carlson; all of whom have become family that kept me going these four years. They will all be missed very deeply upon graduation.

Last, but not least, my parents, Rhoda and Joel Mahran, who have given me the most valuble gift of all; their love, understanding and support.

Dedicated to all those who have suffered and those who may avoid suffering through persistant research.

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I say "try"; if we never try, we shall never succeed.

Abraham Lincoln

1. INTRODUCTION

A. HISTORY

The ability to differentiate and classify various pigmented lesions is recognized as one of the most difficult tasks in medicine.[1]

Due to their proliferating nature and possible fatal consequences (5 year survival rate after the diagnosis of Melanoma; 53% for males and, 67% for females) [2], it becomes imperative that malignant lesions be identified as quickly and accurately as possible. Treatments for malignant tumors are quite different from that of other pigmented lesions, thus the need for proper diagnosis is apparent. [3]

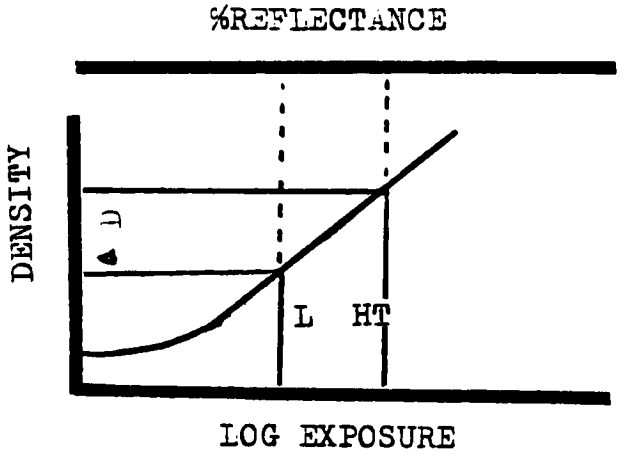
There has been much work conducted in the area of diagnosing and classifying suspected malignancies. [4,5,6] Experimentation by R.J. Marshal at the University Hospital of Wales involved the implementation of infrared, ultraviolet, and visible photography to classify suspicious lesions as either malignant Melanoma or non-malignant Melanoma. [7,8,9,10]

Three negatives of one lesion were exposed in the infrared (700-900nm), ultraviolet (300-400nm), and the visible (400-700) regions of the spectrum. Through the use of photometric techniques, as illustrated in figure 1, Marshal related the densities on the negatives to the

reflectance of the actual lesion. [11]

He then ranked the results as shown in table 1

Figure 1



MARSHAL'S PHOTOMETRIC TECHNIQUE

Table 1

ABSORBTION	CLASS	RANK
IR>PA>UV	IR POSITIVE	1
IR>UV>PA	IR POSITIVE	2
PA>IR>UV	IR POSITIVE	3
UV>PA>IR	IR NEGATIVE	4
UV>IR>PA	IR NEGATIVE	5
PA>UV>IR	IR NEGATIVE	6

MARSHAL'S METHOD OF CLASSIFICATION

IR=INFRARED UV=ULTRAVIOLET PA=VISIBLE

The classification of 'IR positive' and 'IR negative' were a result of previous photographic experimentation. [13] Marshal observed an increase in infrared absorption (between 740nm and 880nm) of melanoma type lesions with a corresponding decrease in ultraviolet absorption (between 300nm and 400nm) when compared to surrounding healthy tissue or other benign pigmented lesions. [14]

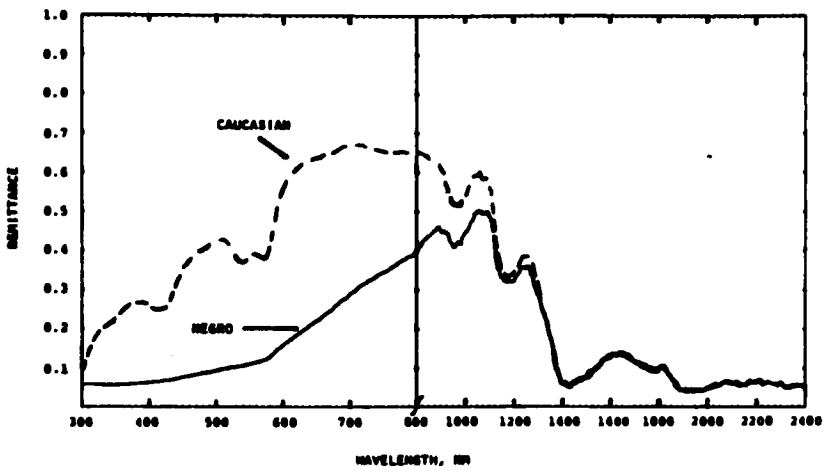
Quantifying his results, it can be shown that a significant difference appears to exist between the mean reflectance of Melanoma type lesions and non Melanoma type lesions, 23.5% and 43.7%, respectively. [15] According to this process, a lesion found to be 'IR positive' would be classified as malignant melanoma and classified as non malignant melanoma if found to be 'IR negative'. Marshal was able to achieve 80% classification accuracy with this simple photographic technique.

In a study performed by J.A. Jacquex, et at., it has been shown that the spectral reflectance of human skin to 1200 nanometers varied as much as 20 percent among White American males, 15 percent among Negro American males, and nearly 40 percent between White and Negro American males, although the characteristic shapes remained relatively the same. [16]

The study revealed that no significant difference in spectral characteristics existed above 1200 nanometers, which is due mainly to absorption bands of water. [17] It

did show large variations below 1200 nanometers that were attributed to the melanin content present in the skin. [18] See figure 2.

Figure 2



Jacquex Spectral Curves of Skin

B. OBJECTIVE

At the onset of the thesis project it was the sole intention of the author, the University of Rochester's School of Medicine and other minor parties to conduct a series of experiments based on Marshal's observations. A diagnostic mainframe (better referred to as a Computer Aided Diagnostic System, nicknamed MADSAC, by the author) would enable real time classification of various pigmented lesions. Further explanation of the technique would be in violation of possible future patent rights.

The initial phase of this major project has been an investigation into the possible correlation between skin types (explained below) and spectral reflectance characteristics of faculative melanin in non-photoprotected area. Faculative melanin is produced upon ultraviolet exposure. (See Appendix A)

C. SKIN TYPE CLASSIFICATION

In the field of Dermatology, four caucasian skin classifying categories are used. These are generally referred to as Skin types one, two, three and four.[19] (See appendix A)

Phototoxic exposures, most commonly in the ultraviolet, can result in complex biochemical reactions in the skin, causing erythema, cell mutation or even death.[20]

It is known that melanin and other chromophores act as defense mechanisms, absorbing energy from otherwise harmful radiation.[21] The ability of various skin types to absorb this incident radiation , and their reaction to it, is the basis of the skin classifications.[22] The classifications are clinically differentiated by certain visual and historical parameters that are judged by the patients complexion and history.[23] Skin type classification is essential in Therapeutic photomedicine.

Therapeutic photomedicine is one very specific area of medicine that deals with treating cutaneous disorders through the use of nonionizing electromagnetic radiation.[24] Dermatologists often use photomedicine to treat skin disorders such as psoriasis. Therapy usually consists of treatment with ultraviolet exposure to induce cell damage in the affected area. [25] Since the minimal erythema dose for each skin type varies, it becomes necessary to classify patients into categories.[26]

This clinical method of classifying a continuous spectrum of skin types, can lead to classification and subsequently, to treatment errors.[27]

To date this primative method is the only means of classifying skin types.[28] This exemplifies the need for a quantitative method to rank skin types, and became the concern of this thesis study. Knowing the effects of faculative melanin may lead to further understanding of the

techniques needed for lesion classification.

Assuming that melanin is a major constituent attributing to skin type classification, then it would be logical to create an experiment that attempts to quantitatively relate faculative melanin spectral absorption to skin types. This experiment has been designed not to interfere with the physiology , or physically alter the skin samples of interest.

It is known that melanin is a good near infrared reflector,[29] thus correlating infrared reflectance to the associated skin type may be a direct and logical method of investigation.

2. EXPERIMENTAL

A. SYSTEM DESIGN OVERVIEW

The initial stage of experimentation was to design a custom spectroradiometer suited for the needs of the experiment. The system geometry was designed to take comfortable readings of the lateral elbow. The elbow was chosen for its flexibility and adaptability to a variety of system configurations. If it were found necessary to change configurations, it could be done with ease.

The system consisted of three main components;1)Monochrometer, 2)Source and,3)Radiometer. The first component, the monochrometer, was originally a component of an older Beckman Quartz spectrophotometer, model DU. It was of Ebert design, utilizing a single beam, collimating mirror, and a diffraction grating. The modification to the original design follows.

The original system was used for transmission spectrophotometry, the modification entailed designing a reflection type spectroradiometer. This was accomplished by removing the original sample holder and source, replacing a tungsten source at the old exit slit and converting the old entrance slit to the new exit slit. The entrance and exit slits were adjustable to widths ranging from 0.01mm to 2.00mm. The system was calibrated against an industry standard for spectrophotometers, Baryta, barium sulphate

coated on heavy paper. Spectral response of Baryta is nearly flat between 400 and 1100 nanometers , thus making it highly reflective (above 95 percent) and very white in appearence. (see Results section for plot).

The source was originally used for transmission micro-densitometry in an Ansco Model Four scanning microdensitometer. For the required purpose it was held firmly in place by clamps attached to a heavy ring stand and powered by a Hewlett-Packard 6384A D.C. stabilized power supply, running four volts at three amperes, or 12 watts.

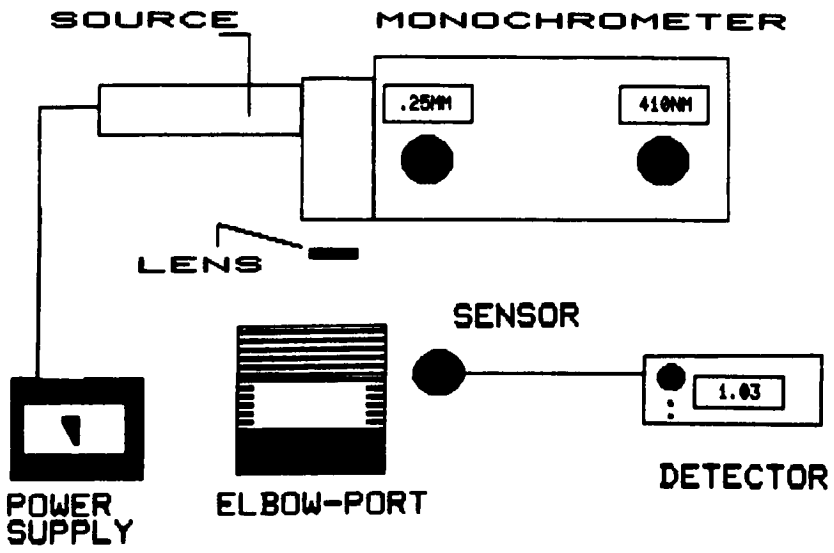
The last major component was the radiometer. The one implemented here was a United Detector Technology's '80X Opto-meter' (referred to as the U-D-T).

The detector was a silicon photovoltaic type having an area of approximately .20 square inches, attached to the meter via a flexible two foot cable. The meter was placed at 45 degrees to the plane of the sample, and the sample was zero degrees, or perpendicular to the exit slit. This common geometry is referred to as 0/45.[30] This was chosen mainly for convenience, and has been proven effective. The output of the meter was read in micro-watts, or some magnitude of micro-watts. It was required to set the meter at its most sensitive position, 10E-2 micro-watts (.00001 watts). Output was in digital form enabling 2000 increments with a least count of .01 units (00.00 to 20.00E-2 micro-watts at the required setting of 10E-2 micro-watts).

This caused two possible problems, the first was noise the second was accuracy, both will be discussed later in this report.

Other components to the system were ;1) 'Elbow-port', essentially a cardboard box used to keep the patients arm still, 2) a black-out cloth to minimize stray light from reaching the subject and sensor, 3) a reducing lens,with a focal length of approximately 10cm, used to focus the exit slit onto the subject, and 4) clamps ,wires and other minor peripherals.

Figure 3



System Schematic

B. USING THE SYSTEM

It took approximately 30 minutes to obtain one sample reading ,ranging from 400 to 1100 nanometers at 10 nanometer increments.

The subject was allowed ten minutes to adjust to room conditions, and then placed his arm in the 'Elbow-port'. After making himself comfortable, to minimize the chances of his arm falling asleep ,the room lights were turned off and recording commenced. Each wavelength was manually dialed into the monochrometer in increments of ten nanometers. At each desired wavelength (400,410,420...1080,1090,1100) the radiometer was allowed to stabilize (approximately a ten second period) and its output recorded, by hand, on paper.(see Results section for examples)

C. DATA MANIPULATION

The data was then typed into a computer (Commodore 64), stored on disc, adjusted for system response, and plotted on paper. The computer algorithms can be found in the appendix.

Each set of data was normalized to a reflectance of one (1.00) at 720 nanometers, this enabled easy comparison of different data sets, and prepared the data for statistical manipulation and interpretation.

D. EXPERIMENTATION AND ASSOCIATED PROBLEMS

The general system operation has been discussed in the previous section, below are problems that occurred during experimentation.

Due to its design, the monochrometer did not disperse the wavelengths equally. This caused increase in the band pass at the exit slit, as the frequency decreased (greater band pass at 1100nm than at 400nm).

Band pass is a significant factor in spectroradiometric resolution. It was measured using an EG&G model 555 Spectroradiometer fitted with a model 555-61 monochrometer Sample repeatability at various wavelengths are shown in table 2. assembly and found to be over 40 nanometers at 700nm with an exit slit width of 0.50mm. This meant that changes in reflection could not be detected at the desired 10 nanometer increment resolution. This was unacceptable and needed immediate attention. (20nm band pass was the maximum acceptable level).

There were three remedies to reduce this problem; either a more powerful source could have been implemented, or a system to decrease the exit slit as the wavelength was increased could have been built, or the slit could remain at a constant width acceptable at the lower frequencies. It was decided that it would be more practical to keep the slit width constant. Constantly changing the width, manually, would make repeatability very difficult and designing a

motor to drive the exit slit in synchrony with the wavelength selector would have been too difficult. Finally, the time lost in obtaining a different source , would have involved further modification to the system, and would have been too time consuming.

Since power was sacrificed for decreases in the band pass, it was necessary to consider signal strength and the sensitivity of the detector when determining the slit width. Optimal conditions would have been an infinitesimally small slit yielding maximum source output at the desired wavelengths. Knowing these condition were impossible to achieve, a compromise was made between band pass and power output. Initially, a width of 0.50mm was used, but after investigation ,this size was found to be unacceptable. To get a first order approximation of the band pass at various wavelengths , the EG& G spectraradiometer was implemented once again. Four wavelengths where chosen, 400nm, 700nm, and 1000nm, representing the low, middle and high regions of investigation, respectively. The results are shown graphically below.

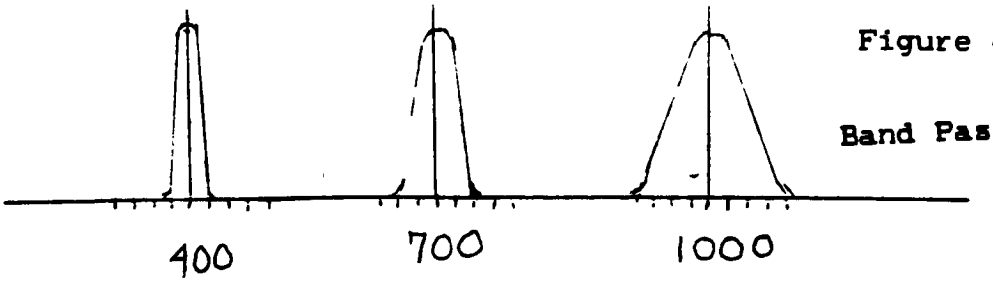


Figure 4

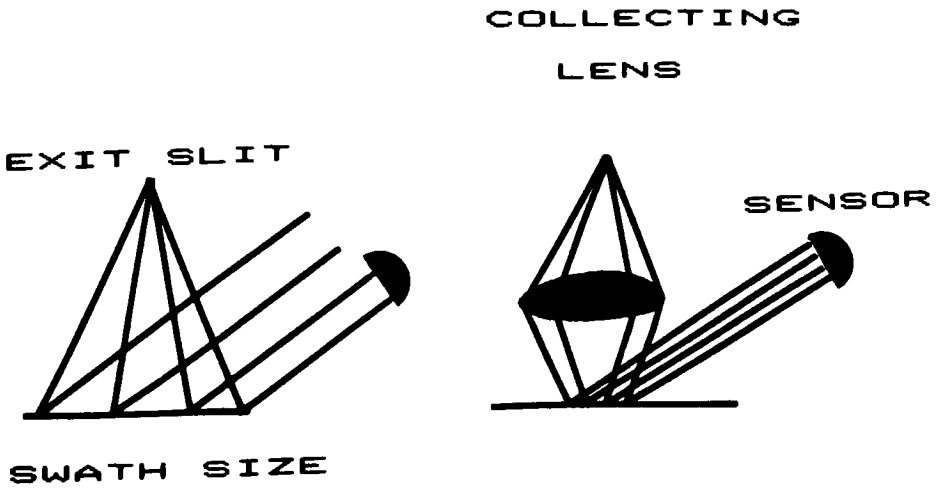
Band Pass

Repeating this technique at .25mm and .10mm, it was determined that the small slit (.10mm) produced acceptable

band pass but at a significant loss of signal strength. Signal strength was sufficient at .25mm and the compromise in band pass, although not optimal ,was 10nm,20nm,40nm at 400nm,700nm and 1000nm, respectively. The resolution obtained was still greater than that of Marshal's photographic system.

Initially the radiation from the exit slit dispersed creating a very large irradiated sample area. The addition of a collection lens , in front of the exit slit ,increased the signal strength by concentrating the energy beam. It also increased the probability of wavelengths reflected off the object to reach the detector. This was caused by the differences in reflection angles (See figure 5, below). Visual inspection suggests this , although a more quantitative analysis supporting this phenomenon would be required to prove this theory.

Figure 5



Addition of Collecting Lens

E. CALIBRATION

Barium sulphate coated on a heavy sheet of paper (Baryta) was used as a reference material. Spectral characteristics of the barium sulphate are well documented in the 400nm to 700nm region [31], and had to be extrapolated beyond this region (see appendix for extrapolation programs). Information regarding the characteristics of barium sulphate beyond 700nm were obtained through Dr. Franc Grum of the Munsell Color Laboratory at Rochester Institute of Technology, making extrapolation possible. Knowing these spectral characteristics, determination of the system response was possible. The barium sulphate was recorded using the system and the results where divided by the known characteristics, yielding a system response. All subsequent sample recordings are divided by the system response to obtain their actual relative spectral response.(see examples in Results section).

F. SKIN SAMPLE RECORDINGS

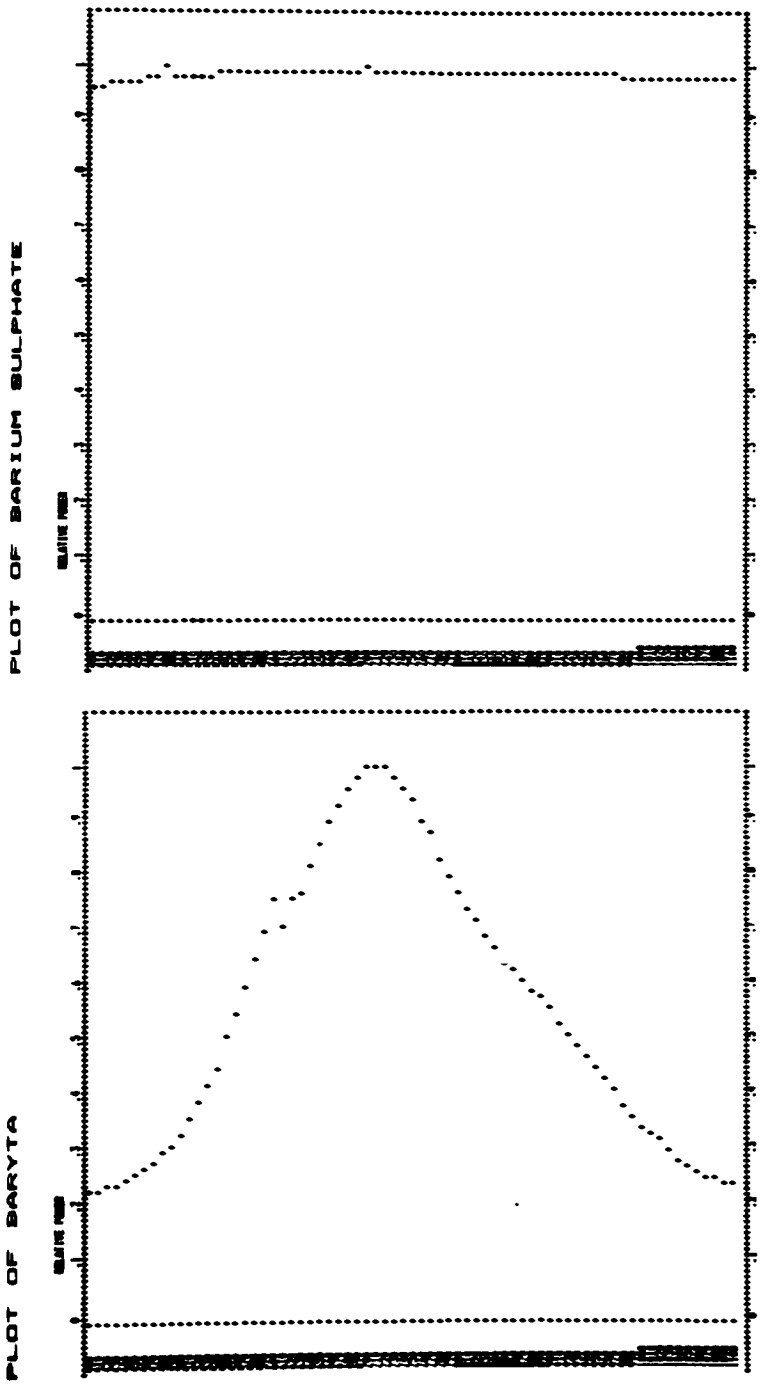
Recording skin samples ,*in vivo*, has been previously found to have many complications.[32] Movement of the patients arm and blood restriction became two problems most noticeable during recording sessions. An 'Elbow-port' was added to aid in keeping the arm static. There were complaints of dysesthesia, so a cushion was added to increase blood flow. This helped, but didn't eliminate the problem. Different recording geometry will be required in the future to fully correct these problems.

Each individual was asked various questions concerning their skin type, and then labeled as either type one, two or three. (see Appendix D for questionnaire sheet) Photodocumentation was also made of each recorded sample.

3. RESULTS

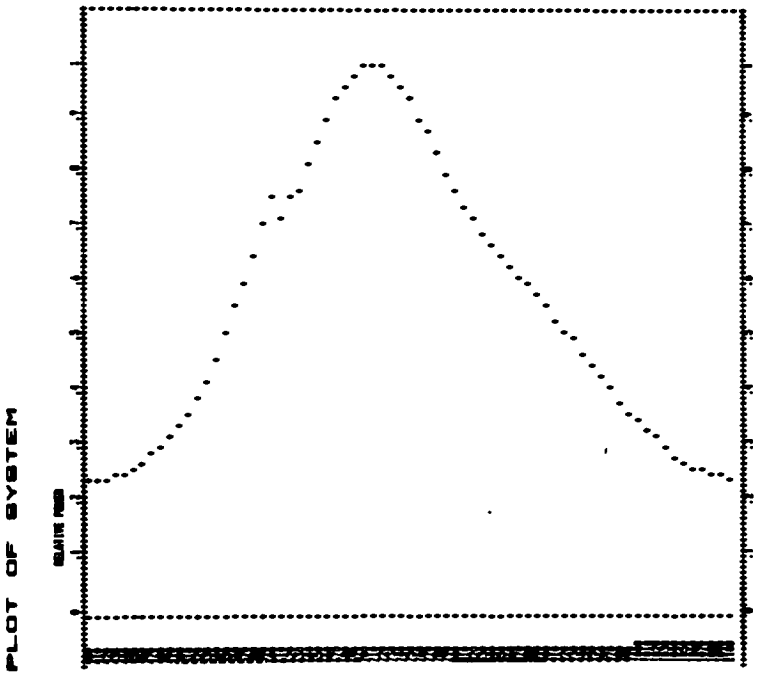
Baryta recorded with the system and known spectral output of barium sulphate.

Figure 6



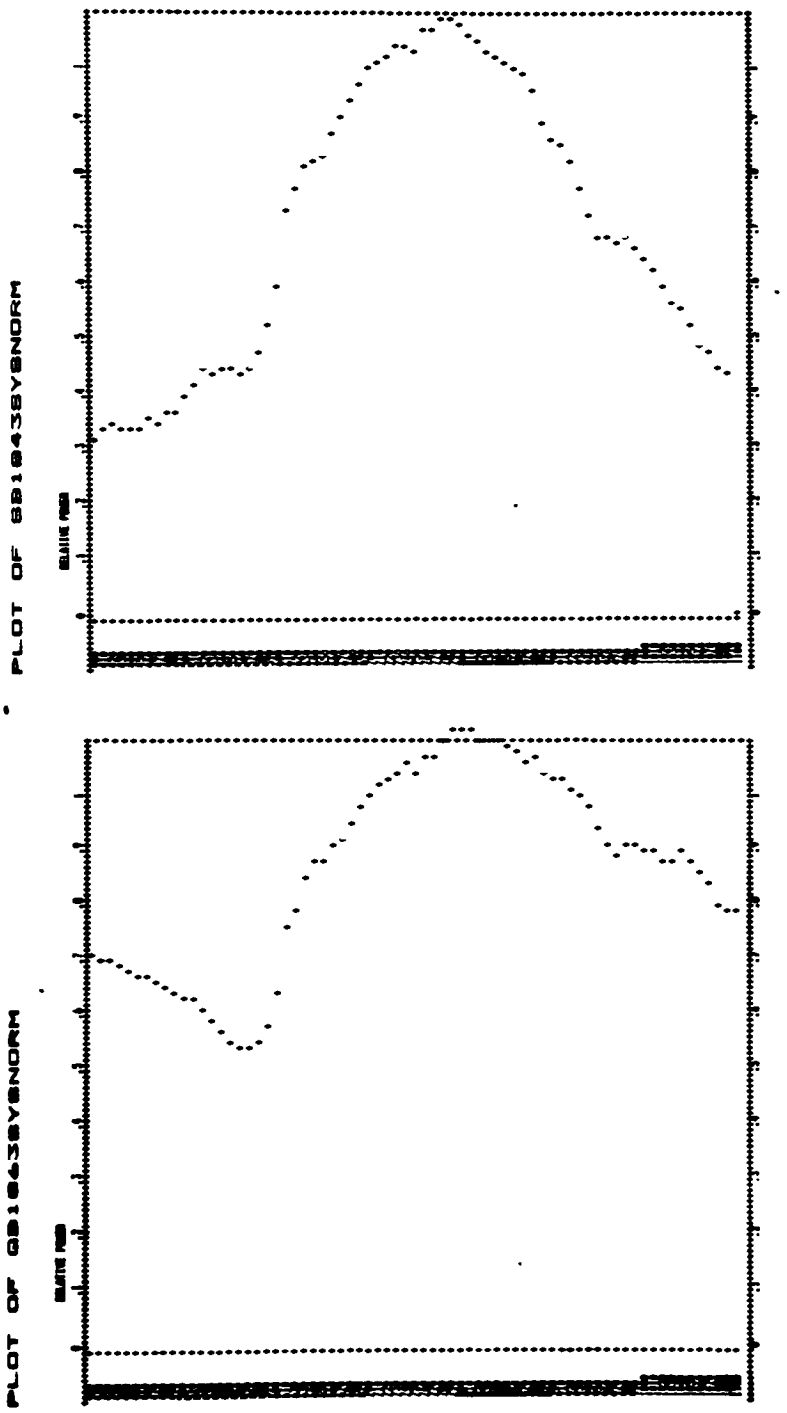
The System response curve below was generated by dividing the Baryta curve by the barium sulphate curve found on the previous page

Figure 7



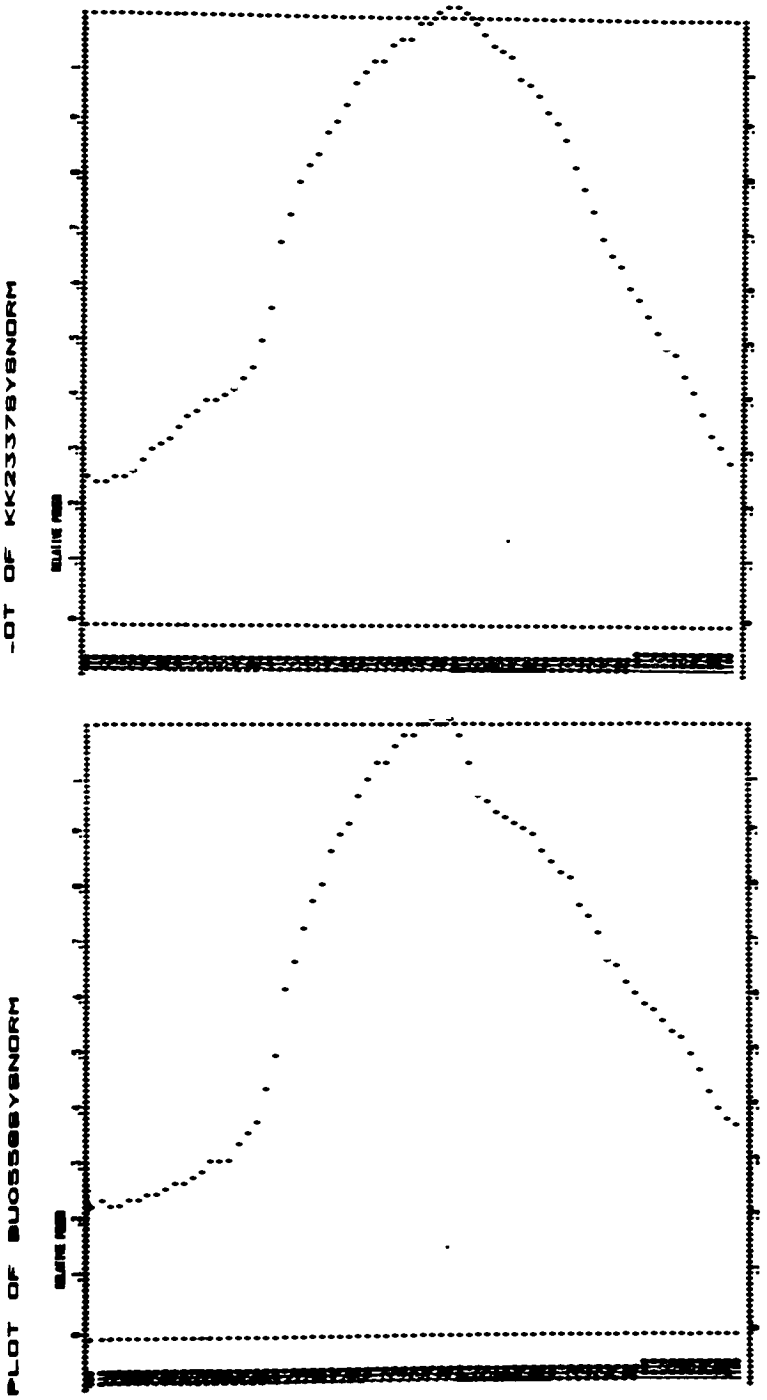
Recordings of skin type one

Figure 8



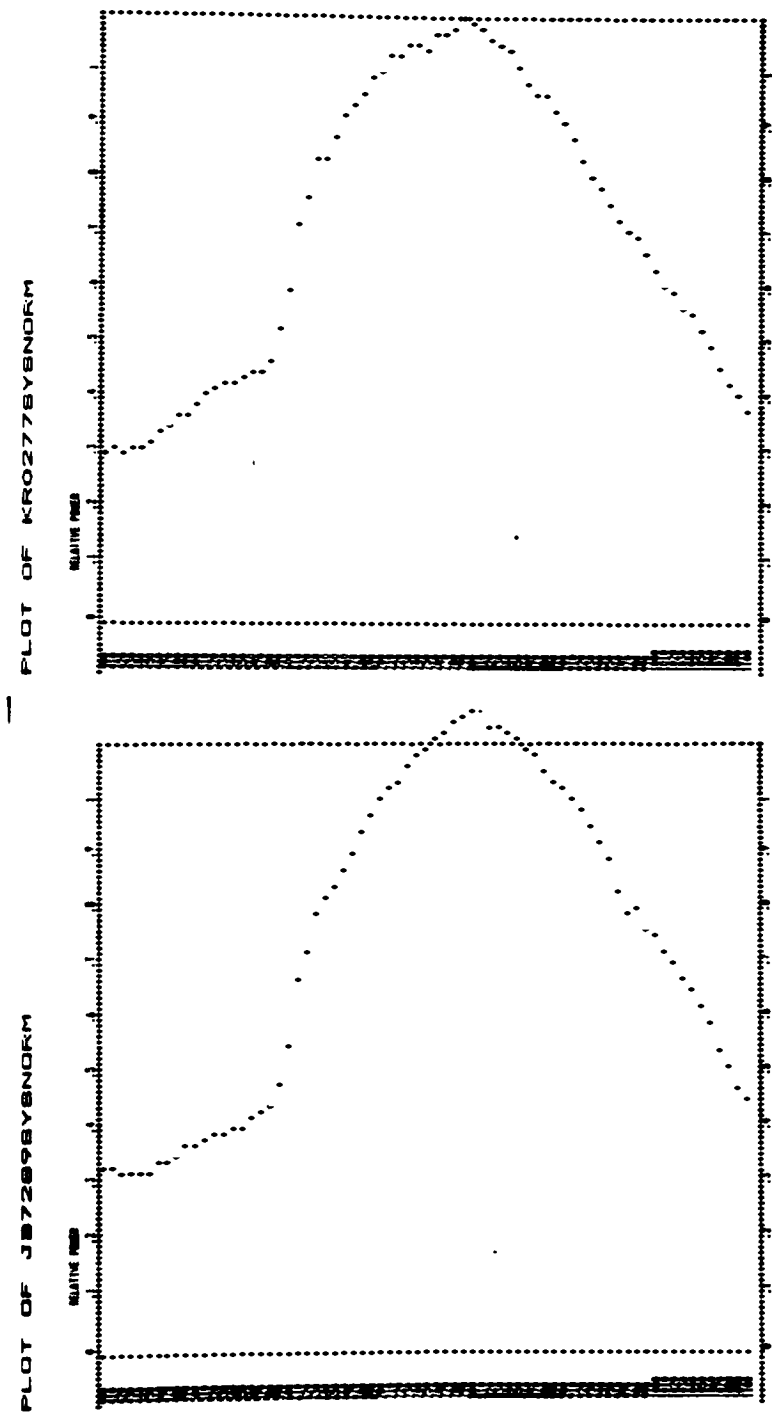
Recordings of skin type two

Figure 9



Recordings of skin type three

Figure 10



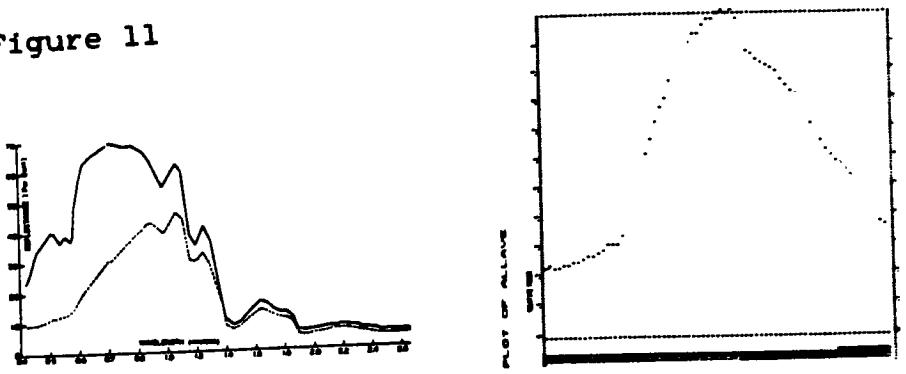
4. DISCUSSION OF RESULTS

A. COMPARISON OF SYSTEMS

The use of barium sulphate as a reference material was optional during the experimentation. Through its use, a general system response was found. This was useful in that it enabled a method in which sample recordings could be compared with sample recordings from other previous investigations.

A comparison between recordings can be seen in the figures below.

Figure 11



System Comparison

It should be noted that the recordings made during this investigation were values normalized to 1.00 at 720nm, relative to barium sulphate, not absolute values, used in previous studies. The general shapes of the curves are similar, although resolution was degraded using this system.

Problems associated with the sensitivity of the detector have been briefly discussed in the Experimental. Here error found in the system will be discussed.

B. SYSTEM ERROR

A rigorous mathematical analysis of the error propagated through the system is beyond the scope of this paper. It should be stated ,however, that system repeatability was tested. It was noticed that system variance at 700 nanometers was five percent of the total recorded power. Repeatability was performed without disturbing the position of the Baryta reference material. To determine repeatability on a day-to-day basis, four recordings of the same subject were made in a twenty day period. The results were found to have a two to ten percent difference in the 700-900 ranges, and as high as a 70 percent difference at the very low (400nm) and very high (1100nm) regions. To avoid problems in analysis, all values below 700nm and above 900nm were truncated. These large deviations have been attributed to system sensitivity failure, or 'undercutting' of the detector. Undercutting can be described as signal strength below the minimal detectable level the radiometer is capable of. Information is lost as the signal to noise ratio is decreased and the limits of the detector are reached.

C. TESTING THE EFFECTS OF FACULATIVE MELANIN

In regards to the alternate hypothysis that skin type may be determined by infrared reflectance of faculative melanin ,it can be seen in the two-way ANOVA (see Appendix C) that the null was not rejected for the interaction of skin type and spectral reflectance. The minimum rejection value to determine whether the interaction between the two was 1.59 at 95 percent confidence. [33] The importance of the calculated Fo(interaction) value, -.0217, indicates that no significant interaction between skin type classification and spectral reflectance exists. To assist in the interpretation of the results, it was helpful to examine the parallelism of the average response of each skin type. In general, the lack of significant interaction is indicated by the parallelism observed in the curves (see Appendix B) A rejection of the null would have indicated that faculative melanin in non-photoprotected areas may play a significant role in skin type classification. The analysis of variance indicates a failure to reject the null or as already stated, faculative melanin has no significant contribution to skin type classification. Consideration of possible reasons for failing to reject the null may be attributed to two possible causes; 1)instrument sensitivity failure, or 2) the physiology of faculative melanin in the role of skin type classification.

Instrument failure is a possible cause, but close examination into the physiology of faculative melanin appears to reveal the actual cause.

It is possible for various skin types to produce different quantities of faculative melanin that when added to constitutional melanin are equal in total melanin content. It is evident that in such a case, a quantitative analysis would reveal no correlation in IR spectral characteristics. The effects seen in this study are indicating that skin type classification is independent of faculative melanin content. A further investigation is required to establish the role of constitutional melanin in the classification of skin type.

It is the opinion of those involved that constitutive melanin may prove to be a significant determining factor of skin type classification. If this is true then pigmented lesion classification may be possible in the near future.

5. CONCLUSION

With the first stage of investigation complete, the following conclusions can be made;

1) Faculative melanin plays a small role if any, in the determination of skin types.

2) System geometry must be altered to provide accurate and comfortable recordings of constitutional melanin in photoprotected areas.

3) System spectral resolution needs to be increased through synchronized slit and wavelength selectors.

4) System repeatability needs to be increased through the use of a more powerful source, a more sensitive detector and an integrating sphere.

The next phase of this study is to modify the existing system for more accurate measurements. The significance that that spectral characteristics of constitutional melanin plays in the determination of skin type classification will follow.

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6. APPENDICIES

APPENDIX A - Glossary of Terms

GLOSSARY

ANOVA	statistical method for the 'ANalysis Of VAriance'
Barium Sulphate	$BaSO_4$ very white in appearence, flat spectral profile
Baryta	Barium sulphate coated on paper used as standard spectrophotometric reference
Constitutional melanin	melanin present at birth and found in photoprotected regions of the body.
Dysesthesia	blood restriction that creates the feeling of 'needles' in the area effected.
Erythema	reddening, inflamation of the skin
Faculative melanin	melanin produced upon radiation exposure
Infrared	IR, area of spectrum beyond 700 nanometers
Lambertian	having equal reflectance at all viewing angles
Melanoma	any tumor composed of melanin pigmented cells
Melanin	pigment found in living organisms. Responsible for radiation protection and skin color in humans.
Minamal Erythema Dose	minimum radiation exposure required to produce phototoxic response.

Monochrometer	instrument that disperese electromagnetic radiation into its components. Visible light is dispersed into its various colors.
Phototoxic	having an adverse effect on the organism, ie. creating inflamation, redness or cell mutation or death
Radiometer	an instrument used to measure electomagnetic radiation, usually measured in micro watts of power.
Skin type Four	upon UV exposure Never burns, always tans
Skin type One	upon UV exposure always burns, never tans
Skin type Three	upon UV exposure Sometimes burns but tans
Skin type Two	upon UV exposure always burns first then tans
Ultraviolet	UV, area of spectrum between 200 and 400 nanometers

APPENDIX B - Plots of Skin Type Averages

Table 2

wavelength	type I	type II	type III
700	.9739	.9680	.9473
710	.9944	.9933	.9731
720	1.0000	1.0000	1.0000
730	1.0012	.9928	1.0170
740	.9866	.9761	1.0188
750	.9629	.9614	.9849
760	.9445	.9467	.9677
770	.9231	.9266	.9573
780	.8978	.8997	.9279
790	.8732	.8715	.8943
800	.8396	.8477	.8534
810	.8048	.8217	.8175
820	.7751	.7976	.7768
830	.6247	.7736	.7413
840	.7125	.7515	.7050
850	.6878	.7278	.6771
860	.6649	.6998	.6590
870	.6433	.6792	.6351
880	.6152	.6651	.6083
890	.5815	.6360	.5795
900	.5562	.6175	.5510

wavelength in nanometers
relative power normalized to 1 at 720nm

Skin Type Averages

Figure 12

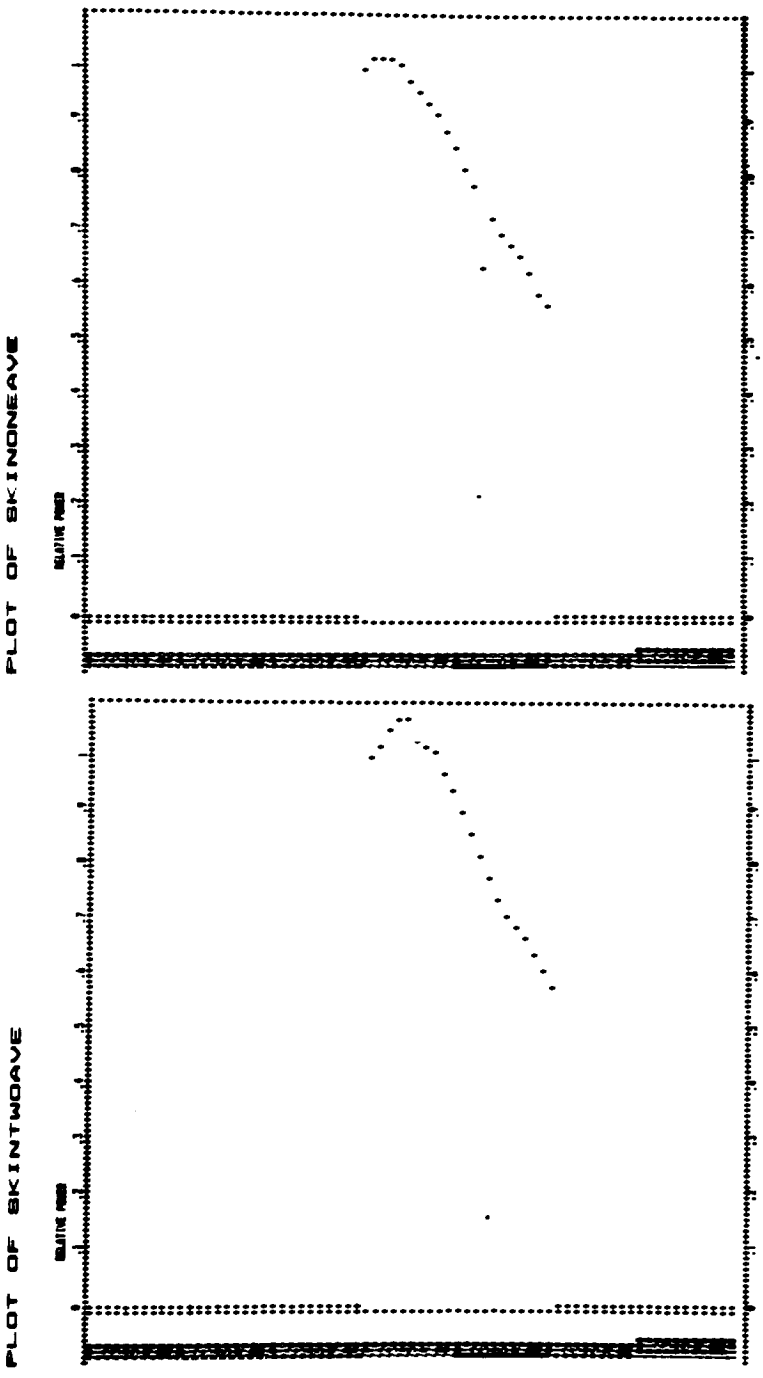
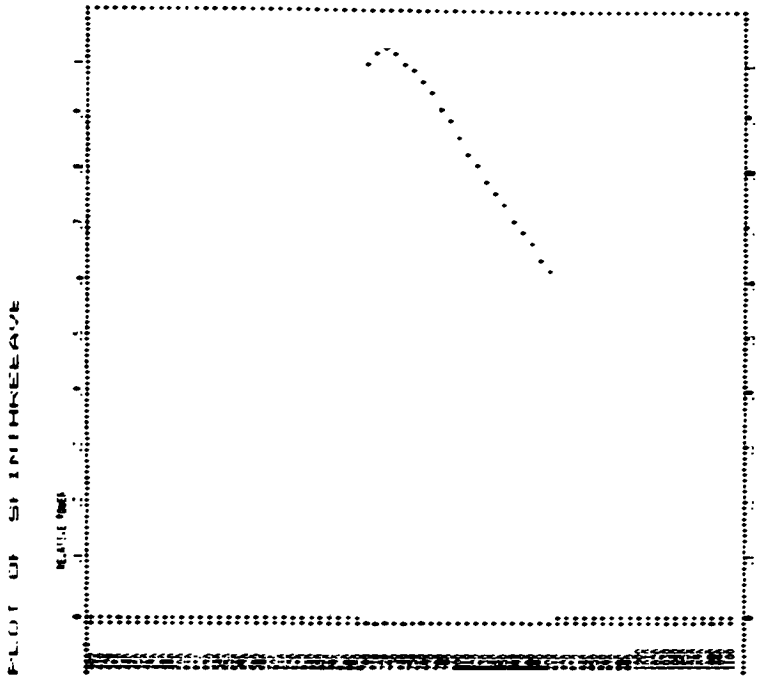
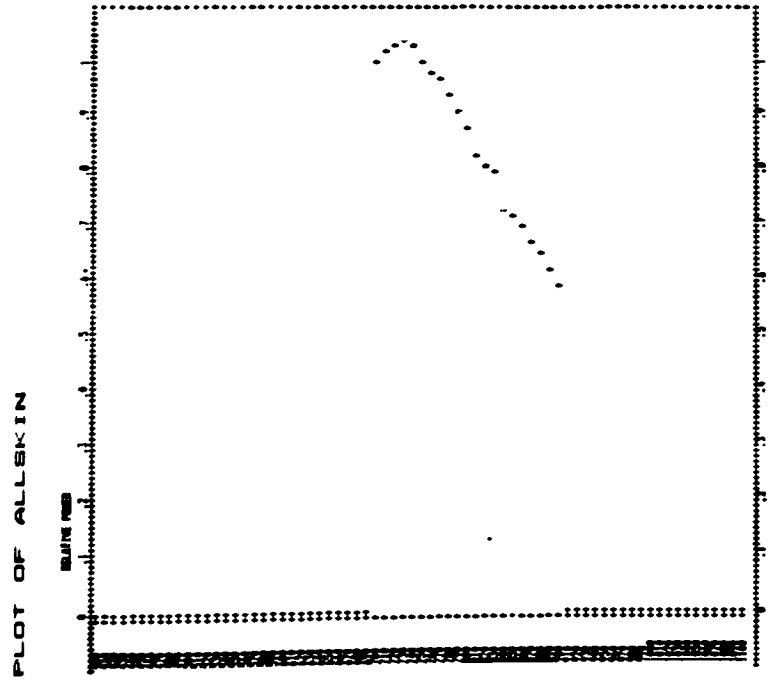


Figure 13





Testing the hypothysis
Ho = skin type I = skin type II = skin type III = 0
Hl = at least one skin type = 0

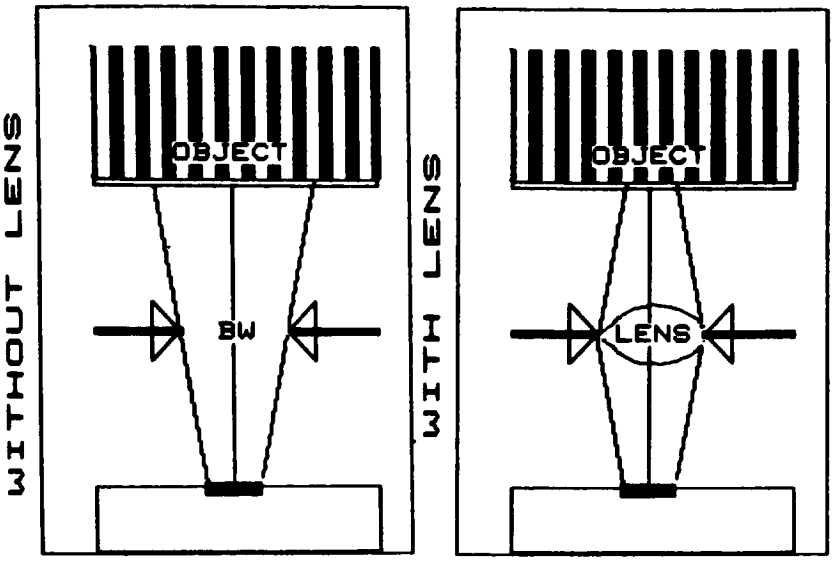
Table 3

wavelength	skin type one	skin type two	skin type three
700	.9713	.9569	.9837
	.9810	.9551	.9538
710	.9334	.9941	.9990
	.9964	.9831	.9876
720	1.0000	1.0000	1.0000
	1.0000	1.0000	1.0000
730	1.0070	1.0039	.9923
	.9964	1.0140	.9932
740	.9779	1.00780	.9837
	.9846	1.01970	.9685
750	.9536	.9902	.9769
	.9632	1.0140	.9459
760	.9470	.9609	.9654
	.9359	1.0084	.9279
770	.9205	.9452	.9500
	.9087	.9888	.9032
780	.8918	.8904	.9289
	.8743	.9635	.8705
790	.8565	.8532	.8962
	.8458	.9494	.8468
800	.8168	.8082	.8846
	.8102	.9129	.8108
810	.7770	.7397	.8664
	.7639	.8904	.7770
820	.7417	.6791	.8576
	.7224	.8539	.7376
830	.7042	.6477	.8433
	.6868	.8118	.7038
840	.6711	.6125	.8385
	.6548	.7753	.6644
850	.6402	.5832	.8250
	.6228	.7416	.6306
860	.6203	.5036	.8039
	.5991	.7191	.5957
870	.6004	.5421	.7885
	.5706	.6938	.5698
880	.5629	.5186	.7750
	.5279	.6657	.5563
890	.5143	.4892	.7529
	.4947	.6376	.5191
900	.4790	.4599	.7394
	.4733	.6063	.4955

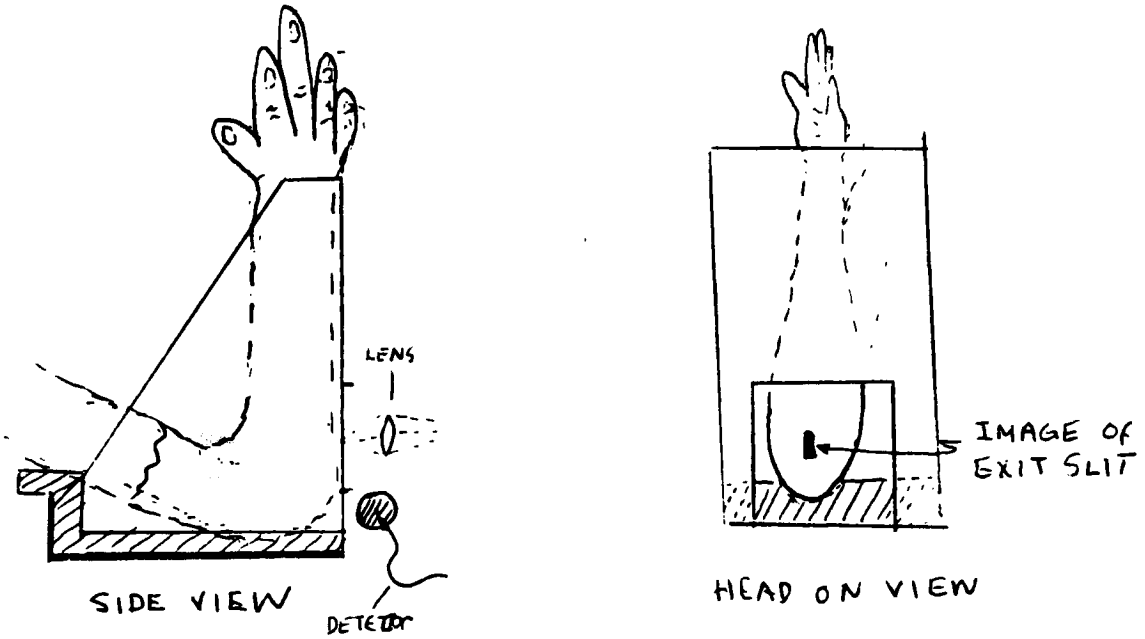
Source of Error	Sum of Squares	Degrees of Freedom	Mean Square	Fo
SSSkin	493.31	2	246.50	36.57
SSSpectral	-69.505	20	-3.4752	0.5155
SSinteraction	5.8464	40	0.1462	-0.0217
SSError	-424.7056	63	-6.7414	
SSTotal	4.9429	125		

APPENDIX D - Miscellaneous

Collecting Lens Figure 14



Elbow-Port Figure 15



Questionnaire Sheet Figure 16

ID#_____

Name_____ Phone_____ Time_____am__pm

Skin Type __I__II__III

Sex__M__F Height_____ Weight_____

Location of Recording _____

Hair Color_____ Eye Color_____

Time Last Ate_____

Diseases_____ Medication_____

Lotions,Make-up,etc _____

Skin Roughness___coarse___medium___smooth

Hair Density_____

Pore Size_____

Body Temperature_____Room Temperature_____

Room Humidity_____

COMMENTS

200_____	250_____	300_____	350_____	400_____
410_____	420_____	430_____	440_____	450_____
460_____	470_____	480_____	490_____	500_____
510_____	520_____	530_____	540_____	550_____
560_____	570_____	580_____	590_____	600_____
610_____	620_____	630_____	640_____	650_____
660_____	670_____	680_____	690_____	700_____
710_____	720_____	730_____	740_____	750_____
760_____	770_____	780_____	790_____	800_____
810_____	820_____	830_____	840_____	850_____
860_____	870_____	880_____	890_____	900_____
910_____	920_____	930_____	940_____	950_____
960_____	970_____	980_____	990_____	1000_____
1010_____	1020_____	1030_____	1040_____	1050_____
1060_____	1070_____	1080_____	1090_____	1100_____
1200_____	1300_____	1400_____	1500_____	1600_____
1700_____	1800_____	1900_____	2000_____	

Hi-resolution plot Figure 17

```
1 DIMF(75)
5 F=4:C=400
6 POKE53281,0:POKE53280,0
10 PRINT"{CLR}"
20 INPUT"FILE NAME ";F$
30 OPEN2,8,2,"0:"+F$+",S,R"
40 FORI=0TO70:INPUT#2,F(I):NEXT
50 CLOSE2
60 OPEN4,4:CMD4
70 PRINTCHR$(27)CHR$(87)CHR$(I)
80 PRINT"PLOT OF ";F$
90 PRINTCHR$(27)CHR$(87)CHR$(0)
100 PRINTCHR$(27)CHR$(66)CHR$(3)
110 PRINTCHR$(9);CHR$(9);"RELATIVE POWER"
120 FORI=0TO10:READ V:PRINTCHR$(9);V;:NEXT
125 PRINTCHR$(27)CHR$(51)CHR$(7)
130 PRINT"  "
140 FORI=0TO120:PRINT"+";:NEXT
150 PRINT" "
170 FORI=0TO70 :P=F(I)/F(30)*100
180 PRINTC;
190 IFC=1000 THENF=F-1
200 PRINTSPC(F)"+";
210 PRINTSPC(P)"+"
215 PRINTSPC(120)"+"
220 C=C+10
230 NEXTI
233 PRINT" "
235 FORI=0TO120:PRINT"+";:NEXT
236 PRINT" "
237 FORI=0TO10:READ V:PRINTCHR$(9);V;:NEXT
240 PRINT#4,:CLOSE4
300 OPEN4,4:CMD4:PRINTCHR$(27)CHR$(64):PRINT#4,:CLOSE4
1000 DATA 0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1
1010 DATA0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1
2000 PRINT"{CLR}":PRINT"PRESS RETURN FOR MAIN PROGRAM OR 'A' FOR AGAIN"
2020 GETA$:IF A$=""THEN 2020
2030 IF A$<>"A"THEN GOTO 3000
2040 GOTO 5
3000 LOAD"M",8
```

Barium sulphate extrapolation

Figure 18

```
CALCULATED VALUES FOR BARIUM SULPHATE FROM KNOWNS
700 TO 800 GIVE .9934 AND .988
 700              .9934
 710              .99316
 720              .99292
 730              .99268
 740              .99244
 750              .9922
 760              .99196
 770              .99172
 780              .99148
 790              .99124
 800              .991
```

```
10 OPEN4,4:CMD4
20 PRINT"CALCULATED VALUES FOR BARIUM SULPHATE FROM KNOWNS"
30 PRINT"700 TO 800 GIVE .9934 AND .988"
40 FOR X=700TO800STEP10
50 Y=-.024*X+1010.2
60 PRINTX,Y*1E-3
70 NEXT
80 PRINT#4,:CLR4
90 FORX=1000TO1100STEP10
100 Y=-.05*X+1032
110 PRINTX,Y*1E-3
115 NEXT
120 PRINT#4,:CLOSE4

READY.
```

```
CALCULATED VALUES OF BARIUM SULPHATE GIVEN KNOWNS. .991 AT 800NM AND
 .988 AT 900 NM
 800              .991
 810              .9907
 820              .9904
 830              .9901
 840              .9898
 850              .9895
 860              .9892
 870              .9889
 880              .9886
 890              .9883
 900              .988

READY.
```

```
0 open4,4:cmd4
5 print"calculated values of barium sulphate given knowns. .991 at 800nm and"
6 print" .988 at 900 nm"
10 forx=800to900step10
20 y=(-3.0e-2*x)+1015
30 print x,y*1e-3
60 next
70 close4

ready.
```

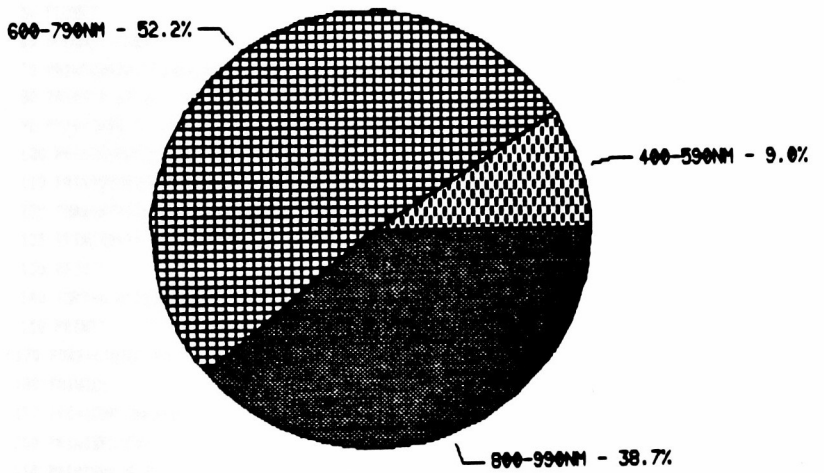
```
CALCULATED VALUES FOR BARIUM SULPHATE GIVEN KNOWN VALUES.
.988 AT 900 AND .982 AT 1000
 900          .988
 910          .9874
 920          .9868
 930          .9862
 940          .9856
 950          .985
 960          .9844
 970          .9838
 980          .9832
 990          .9826
 1000          .982
CALCULATED VALUES USING KNOWNS AT 1000 AND 1500, .982 AND .957
 1000          .982
 1010          .9815
 1020          .981
 1030          .9805
 1040          .98
 1050          .9795
 1060          .979
 1070          .9785
 1080          .978
 1090          .9775
 1100          .977


10 OPEN4,4:CMD4
20 PRINT"CALCULATED VALUES FOR BARIUM SULPHATE GIVEN KNOWN VALUES."
30 PRINT".988 AT 900 AND .982 AT 1000"
40 FOR X=900TO1000STEP10
50 Y=(-.06*X)+1042
60 PRINTX,Y*1E-3
70 NEXT
80 PRINT"CALCULATED VALUES USING KNOWNS AT 1000 AND 1500, .982 AND .957"
90 FORX=1000TO1100STEP10
100 Y=-.05*X+1032
110 PRINTX,Y*1E-3
115 NEXT
120 PRINT#4,:CLOSE4

READY.
```

Figure 19

Pie chart representation of the power distribution of the system. Here it is seen that the majority of power falls between 700 and 900 nanometers.



PERCENTAGE OF TOTAL POWER OUTPUT

Repeatability Table 4

NM	trial 1	trial 2	trial 3	trial 4	mean	sdev
700	11.41	11.39	11.40	11.39	11.398	.0096
710	11.46	11.40	11.47	11.45	11.445	.0311
720	11.51	11.56	11.60	11.45	11.530	.0648
730	11.27	11.27	11.31	11.26	11.278	.0222
740	11.02	11.11	11.02	10.96	11.028	.0618
750	10.82	10.83	10.86	10.83	10.835	.0173
760	10.32	10.32	10.34	10.30	10.320	.0163
770	10.07	10.10	10.06	10.07	10.075	.0173
780	9.57	9.66	9.64	9.58	9.613	.0443
790	9.13	9.20	9.16	9.15	9.160	.0294
800	8.82	8.91	8.89	8.83	8.863	.0443

VITA

Howard was born March 12, 1962 in Brooklyn, New York. He attended Shenendahowa and Oakton High Schools, in Clifton Park, New York and Oakton Virginia, respectively. He has worked for Zenith Radio Corporation in Glenview, Illinois as a Materials and Process Research technician. His goals are to recieve a Master's Degree in Imaging and Photographic Science and then persue a career that would allow him to develop his many ideas.