A mining research contract report
October 1983

PSYCHOPHYSICAL INVESTIGATIONS OF DISCOMFORT AND DISABILITY GLARE FROM UNDERGROUND COAL-MINE ILLUMINATION SYSTEMS

Contract J0308090
Bituminous Coal Research, Inc.

OFR
86-74

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

DISCLAIMER NOTICE

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U.S. Government.

The use of manufacturers' names or trade names in this report is for purpose of identification only and does not imply endorsement by either Bituminous Coal Research, Inc., or the U.S. Bureau of Mines.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No.

4. Title and Subtitle Psychophysical Investigation of Discomfort and Disability Glare from Underground Coal Mine Illumination Systems

5. Report Date October 1983

6.

7. Author(s) K. L. Whitehead, P. Lindahl, R. Vincent, C. Crouch

8. Performing Organization Rept. No. L-1370

9. Performing Organization Name and Address

Bituminous Coal Research, Inc.
350 Hochberg Road, P.O. Box 278
Monroeville, PA 15146

10. Project/Task/Work Unit No. 2286

11. Contract(C) or Grant(G) No. (C) J0308090 (G)

12. Sponsoring Organization Name and Address

U.S. Department of the Interior
Bureau of Mines
Washington, DC

13. Type of Report & Period Covered Final Report May 1980-November 1982

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

A literature search was conducted to identify current light-control technology and hardware that may be applicable on underground lighting systems to minimize disability and discomfort glare. No research dealing specifically with mine lighting was found, but abstracts on research considered potentially applicable are included in the report. Information on several commercial light-control products for use in controlling glare are also included.

Vision tests conducted on 137 mine personnel to determine their discomfort and disability glare sensitivity indicate their sensitivity to disability glare is about the same as the general population. Miners' sensitivity to discomfort glare is 40% greater coming off-shift than when going on-shift.

Tests on currently available mine lighting hardware showed none were satisfactory with respect to glare potential.

Reflectivity measurements showed the average reflectivity of mine surfaces were 4% for coal, 7.9% for the roof, and 4.2% for the floor.

17. Document Analysis a. Descriptors

Coal Mines
Disability Glare
Discomfort Glare
Mine Surface Reflectivity
Light Control Technology

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group 08/09

18. Availability Statement	19. Security Class (This Report) Unclassified	21. No. of Pages
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

FOREWORD

This report was prepared by Bituminous Coal Research, Inc., Monroeville, Pennsylvania, under U.S. Bureau of Mines Contract J0308090. The contract was initiated under the Minerals Health and Safety Technology Program. It was administered under the technical direction of the Pittsburgh Mining Research Center, with Mr. William Lewis acting as Technical Project Officer. Mr. Patrick Neary, Section of Procurement, Pittsburgh, Pennsylvania, was the Contracting Officer for the Bureau of Mines. This report is a summary of the work completed as a part of this contract during the period May 1980 to November 1982. This report was submitted by the authors in October 1983.

No patentable inventions resulted from this contract.

ACKNOWLEDGEMENTS

BCR, IERI, and Mr. C. L. Crouch wish to acknowledge the cooperation and assistance of the following groups in fulfillment of this contract:

1. Management and labor personnel of Maple Meadow Mining Company and Westmoreland Coal Company for providing test facilities and for their participation in discomfort and disability glare tests of underground mining personnel.

2. The administrative personnel of the National Mine Health and Safety Academy for making arrangements to conduct glare sensitivity measurements of Academy personnel and students.

3. The Westmoreland Coal Company for the use of their lighting laboratory facilities at Big Stone Gap, Virginia, to conduct tests of the glare potential of machine-mounted mine lighting systems.

4. Dr. Sylvester K. Guth, an expert in discomfort glare, provided extensive help in the discomfort glare measurements, experimental setup, data analysis, and final report.

5. Dr. H. Richard Blackwell and staff at the Institute for Research in Vision at the Ohio State University who provided extensive help with equipment, data analysis, and final report.

6. The manufacturers of underground lighting equipment who lent hardware for testing the glare effects from currently available equipment.

7. The Chairman and members of the IERI Technical Advisory Committee on Light and Vision for their valuable input in preparation of this project, as well as reviewing its progress.

8. IERI research team members: Miss Beverly J. Vincent and Mr. William Bailey, who provided capable data collection at the various mine sites under unusual working

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(concluded)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(continued)

LIST OF FIGURES
(concluded)

I. INTRODUCTION

This report is divided into three parts, as follows:

Part I. Literature Search to Obtain Information on Available Anti-glare Materials and Techniques

Part II. Psychophysical Studies of Disability and Discomfort Glare for Underground Coal Miners

Part III. Reflectivity of Underground Coal Mine Surfaces

Part I was conducted by Bituminous Coal Research, Inc., Part II by the Illuminating Engineering Research Institute, and Part III by Mr. C. L. Crouch, an independent consultant. This report is, therefore, a compilation of the reports prepared by the three organizations that conducted the research.

II. SUMMARY

A. Objectives

The objectives of this contract were to:

(1) Conduct a literature search to obtain information on available anti-glare materials and techniques.

(2) Develop data on the glare sensitivity of face personnel in underground coal mines and conduct tests on the glare potential of existing underground lighting systems

(3) Conduct underground studies to evaluate the reflectivity of coal surfaces in an effort to verify the average reflectivity value of 4 percent specified in the MSHA regulations.

(4) Through the Final Report, make this information available to the lighting industry for use in the design and application of low-glare potential luminaires in underground coal mines.

B. Scope of Work

The procedure developed to accomplish the objectives included the tasks described below.

1. Task I - Literature Survey of Glare Investigations and of Anti-glare Materials and Techniques

An extensive literature survey was conducted to collect information on:

(a) Currently available materials that can be used to diffuse or control light output from luminaires, particularly those utilizing point-source lamps.

(b) Lighting techniques used to minimize the glare potential of lighting systems and of individual luminaires.

(c) Investigations conducted on glare with particular emphasis on the human engineering aspects of the work. This information was reviewed to determine its applicability to underground mine lighting requirements.

Details on this work are given in Part I - Literature Survey of Glare Investigations and of Anti-glare Materials and Techniques - Sections A-D. Abstracts of articles describing anti-glare lighting techniques and glare investigations are included as Appendix A to Part I of this report.

2. <u>Task II - Discomfort and Disability Glare Evaluation and Tolerance Level Measurements</u>

Studies have been conducted to determine the light-tolerance levels of people in the general population, but no studies have dealt specifically with underground coal miners. To determine whether the discomfort and disability glare tolerance levels of the miners correspond to the levels exhibited by the general population, two test procedures were conducted by personnel from the Illuminating Engineering Research Institute (IERI).

a. <u>Procedure I - Evaluation of Mining Machine Illumination Systems From the Glare Standpoint</u>

Regardless of the seam height being mined, both the limited space around a mining machine and work procedures require personnel to operate in close proximity to the machines. With luminaires mounted on the machines, the light sources are often directly or within a few degrees of the miner's line of sight. This creates significant glare which can be both uncomfortable and unsafe for the crew members. The severity of the problem depends on the type of light source (incandescent, fluorescent, or high-pressure sodium), the luminaire design, and placement of luminaires with respect to normal work stations. Although shielding and diffusing material over the luminaire lens are used to minimize the problem, glare still remains the most frequent complaint of the miners.

In order to analyze the glare potential of existing lighting hardware, IERI personnel made field measurements on seven MSHA-approved lighting systems mounted on either continuous miners or bolters. The measurements were made in Westmoreland Coal Company's "dark room" facility using a Discomfort Glare Evaluator and a Visual Task Evaluator. The analysis of the field data resulted in a "Vision Comfort Probability" factor which permits the lighting systems to be ranked according to their glare potential. A detailed discussion of the data and results is presented in Part II - Psychophysical Studies of Disability and Discomfort Glare for Underground Coal Miners - Section III, The Study of Disability and Discomfort Glare from Current Mine Lighting Systems.

b. Procedure II - Discomfort and Disability Glare Measurements on Underground Miners

Measurements of the general population have established that factors such as age, eye color, and vision deficiencies do affect the glare sensitivity of individuals. However, no data exist for such specific worker populations as miners, and the possible effect on glare sensitivity of working in an almost totally dark environment is unknown. Inasmuch as the degree of a miner's glare sensitivity could be an important parameter in a lighting system design and in establishing realistic lighting regulations, it is important that this parameter be established. This was accomplished by using the Discomfort Glare Evaluator to evaluate the glare sensitivity of underground personnel at the MSHA Beckley Academy, Maple Meadow Mining Company, and Westmoreland Coal Company. A description of this test procedure is included in Appendix D.

Previous testing by IERI resulted in the development of formulas which relate field luminance or reflected light levels and the "borderline between comfort and discomfort" (BCD) sensation for the general population. Using the field data from Test Procedure II, these formulas were modified to reflect the BCD sensation for underground mining personnel and provide a comparison with the general population's BCD values. Discussion of the analysis and results is presented in Part II - Psychophysical Studies of Disability and Discomfort Glare for Underground Coal Miners - Section IV, The Underground Study of Miners' Sensitivity to Disability and Discomfort Glare.

3. Task III - Evaluate Reflectivity of Coal Surfaces

Federal lighting regulations specify that an average surface reflectivity value of 4 percent shall be used for calculations involving underground coal mine lighting. The validity of this reflectivity value has been questioned by both operators and equipment manufacturers. Since the reflectivity value can have a significant effect on the illumination system design, the Bureau undertook, as part of this contract, to verify the 4 percent value by taking underground surface reflectivity measurements in working faces at mines in different coal seams.

Tests were conducted in seven underground coal mines to collect data on the reflectivity of the face, rib, roof, and floor surfaces in the working place. The results were used to determine if the 4 percent surface reflectivity specified in the federal lighting regulations is a valid average reflectivity value for use in designing mine lighting systems. The surface reflectivity was measured using an Ulbricht sphere modified for use as a reflectometer, specifically for surfaces commonly found in commerce, institutions, and industrial applications. Discussion of the procedure and results is presented in Part III - Reflectivity of Underground Coal Mine Services.

4. Task IV - Development of Conclusions and Recommendations

Field data and information collected during the conduct of Tasks I, II, and III were analyzed to develop conclusions and recommendations related to:

(a) The candlepower distribution for machine-mounted lighting systems to minimize the glare potential for personnel working around the machine.

(b) The investigation and/or application of shields, diffusers, and other light-control techniques examined during this project.

(c) Modifications to the federal lighting regulations to alleviate existing lighting problems while maintaining the intent of the regulations to provide a safer and more efficient mining environment.

C. Summary of Conclusions

Part I - Literature Search to Obtain Information on Available Glare Materials and Techniques

(1) No articles were found that dealt specifically with development of underground mine-lighting techniques to eliminate or minimize glare from machine lighting. This would indicate essentially no research has been done in the development of low-glare, machine-mounted lighting techniques.

(2) Some investigations which involve the general population and/or surface work areas have possible implications to underground lighting. The reports of these investigations, discussed in Part I, Section A, should be reviewed by the Bureau to develop potential research programs to improve underground lighting.

(3) Many products on the market can be used to diffuse or control light. Present practice has been to use diffusing materials to minimize the effect of high-intensity light sources. Based on the information obtained and limited testing performed by BCR, insufficient work has been done in using a combination of diffusing materials and prismatic lenses to minimize glare, particularly with the high-intensity light sources.

Part II - Psychophysical Studies of Disability and Discomfort Glare for Underground Coal Miners

(1) Measurements of disability and discomfort glare of seven currently available lighting systems mounted on a continuous miner and a bolter showed very serious glare effects, resulting in losses of visibility and attendant discomfort.

(2) The average glare sensitivity of the miners tested was about the same as for the above-ground population. However, sensitivity varied widely. As a result, a small percentage of miners who are very sensitive to glare may account for a majority of the complaints which are the basis for the mines' difficulties in achieving a suitable illumination environment.

(3) Field data indicate that age is a factor and eye color a possible factor in glare sensitivity.

(4) Based on results of previous studies presented in CIE Publication No. 19/2, a loss of 50 percent visibility due to lighting systems (average loss of systems tested) might mean a 25 to 30 percent loss of the miners' visual performance.

(5) There appeared to be no significant difference in disability glare sensitivity between miners coming "on" shift and those going "off" shift. However, the miners coming "off" shift showed a 40 percent greater discomfort glare sensitivity than those coming "on" shift.

(6) Miners' disability glare sensitivity was found to be as follows:

(a) 99.86 percent may be expected to have visibility loss equal to or less than 74 percent.

(b) 0.13 percent will have visibility loss equal to or less than 23.9 percent.

(c) 50 percent will have loss equal to or less than 50.71 percent, and 50 percent will have loss greater than 50.71 percent.

Part III. - Reflectivity of Underground Coal Mine Surfaces

(1) Reflectivity measurements for face and ribs varied from 2.3 to 6.6 percent, with an overall average of 4.2 percent.

(2) Reflectivity values for roofs ranged from 5.2 to 11.0 percent, with an average value of 8.3 percent.

(3) Reflectivity values for the floors ranged from 2.8 to 4.6 percent, with an average value of 4.0 percent.

D. Summary of Recommendations

The recommendations resulting from the data analysis are summarized below.

(1) Tests should be conducted to determine the glare reduction achieved by the combination of commercially available diffusion materials and prismatic lenses.

(2) Studies should be conducted utilizing "special-purpose" lighting techniques such as using relatively high light levels on the face or roof where the machine operators must see detail, but, in areas such as the ribs and floor, supply only light adequate to insure good peripheral vision.

(3) In conjunction with all lighting, use more reflective clothing and surfaces; but, in particular, study use of such reflective surfaces in conjunction with the "special-purpose" lighting technique referred to in recommendation (2).

(4) Contrast between a surface or detail and its background is a major factor in a person's ability to see an object. Investigate the use of the "effective relative contrast sensitivity" discussed in the article "Limitation of Disability Glare in Roadway Lighting," as a design tool for analysis of underground lighting requirements.

(5) Investigate the theory discussed in the article "Duration of After-image Disability After Viewing Simulated Sun Reflections" to develop a procedure to measure the duration of after-image disability when viewing a standard light source with and without anti-glare protection. This could be a potential tool for lighting-system designers in choosing the optimum anti-glare materials.

(6) Conduct studies to determine (a) the light uniformity requirements needed to provide a safe environment, and (b) whether lower light levels than specified in the regulations could be used without affecting safety or working conditions.

(7) Conduct studies utilizing both fiber optics and light pipes to provide underground lighting. These may also be useful in designing a non-machine-mounted lighting system that would be easier to advance with the face than a system of luminaires inasmuch as a minimum of light sources would be required.

(8) In view of the relatively high mine roof reflectivity compared to rib, roof, and floor, investigate the design of a machine-mounted lighting system that utilizes the indirect lighting principle to achieve the required light level and distribution.

(9) Test data show an increased discomfort glare sensitivity of miners coming "off" shift as compared to coming "on" shift; lighting systems should be designed to take this factor into account.

(10) Investigate the possibility of developing a procedure that would use the "Index of Sensation," described in Part II, Section C, to evaluate mining machine lighting system designs. Such an investigation would have to consider the following factors:

(a) The procedure would have to be performed in a simulated entry.

(b) A consensus should be reached on what work positions are the most critical for each machine application and should be used in analysis.

(c) What value of index should be established as the design criteria? This could be tied into the visual comfort probability so a given percentage of miners would find the system satisfactory.

(11) If the "Index of Sensation" is used, a program should be initiated to investigate the possibility of developing a computer program as a design tool for determining the index for a given system.

(12) Require increased use of reflective material by personnel and machines to enhance contrast. In conjunction with the use of tape, investigate lowering the .06 footlambert requirement to a level nearer the lower limit required for peripheral vision (.01 fL).

(13) Eliminate the use of underground light level measurements. Require surface measurements under simulated conditions, using incident light measurements in a simualted entry of 4 percent reflectivity on the simulated ribs, floor, and face; and 8 percent on the roof. The underground measurements are inappropriate because results will be influenced by:

(a) The inspector's ability to properly position himself to take accurate readings, i.e., proper distance from surface, not shield luminaires, hold instrument at proper angle.

(b) Condition of luminaires with respect to dirt accumulation, scratched surfaces of lens, age of light source.

(c) Condition and calibration of instrument.

Underground inspection would be limited to checking for approval tag, dirt on lens, condition of lens, and compliance with explosion proof (X/P) or intrinsically safe (I.S.) requirements.

PART I - LITERATURE SURVEY OF GLARE INVESTIGATIONS AND OF ANTI-GLARE MATERIALS AND TECHNIQUES

A. Literature Survey

The literature survey was conducted to identify journal articles, project reports, or other publications that contained information pertinent to underground mine lighting, including glare-control techniques, discomfort and disability glare research, light-control products, lighting design, task and safety lighting, and mine illumination. The primary sources of information were the H. W. Wilson Company "Applied Science and Technology Index" and the Lockheed Missile and Space Company, Inc., "Dialog" information-retrieval system.

The "Applied Science and Technology Index" contains titles and authors of articles published in professional and trade journals including "Coal Age," "Mining Engineering," and "Mining Congress Journal." A total of 199 references were obtained from this source.

"Dialog" is a computerized collection of over 100 data bases, listed in Table 1, which BCR can access by an in-house remote terminal. Using key words and phrases (such as glare, discomfort, and disability), the preselected data bases listed in Table 2 were searched for references to articles considered relevant to mine-lighting control, and produced a total of 137 references.

TABLE 2. DATABASES ACCESSED FOR INFORMATION

National Technical Information Service (NTIS)	- 1964 to present
Engineering Index (COMPENDEX)	- 1970 to present
The Institute of Electrical Engineers (INSPEC)	- 1969 to present

From the 336 references found during the search, 112 articles, listed in Appendix B, were obtained for review. In addition, one article was obtained through contacts at the 1981 CIE Mine Lighting Conference held at the MSHA Academy, Beckley, West Virginia. A summary of these articles, by subject area, is given in Table 3.

TABLE 3. ARTICLES BY SUBJECT AREA

Discomfort Glare	20
Disability Glare	16
Light-control Products	36
Lighting Design	11
Task and Safety Lighting	18
Mine Illumination	12

TABLE 1. DATABASES ACCESSIBLE BY BCR

ABI/INFORM
AGRICOLA 79-present
AGRICOLA 70-78
AIM/ARM
AMERICA: HISTORY & LIFE
APTIC
AQUACULTURE
AQUALINE
AQUATIC SCIENCES & FISHERIES ABS
ARTBIBLIOGRAPHIES MODERN
ASI
BHRA FLUID ENGINEERING
BIOGRAPHY MASTER INDEX
BIOSIS PREVIEWS 1977-present
BIOSIS PREVIEWS 1969-76
BOOK REVIEW INDEX
CA SEARCH 67-71
CA SEARCH 72-76
CA SEARCH 77-79
CA SEARCH 80-present
CAB ABSTRACTS
CHEMICAL INDUSTRY NOTES
CHEMNAME
CHEMSEARCH
CHEMSIS 72-76
CHEMSIS 77-present
CHILD ABUSE & NEGLECT
CIS
CLAIMS™ /CHEM 50-62
CLAIMS™ /CITATION
CLAIMS™ /CLASS
CLAIMS™ /UNITERM 50-62
CLAIMS™ /UNITERM 63-70
CLAIMS™ /UNITERM 71-present
CLAIMS™ /U.S. PATENTS 63-70
CLAIMS™ /U.S. PATENT ABS 71-present
CLAIMS™ /U.S. PAT ABS WEEKLY
COMPENDEX
COMPREHENSIVE DISSERTATION INDEX
CONFERENCE PAPERS INDEX
CONGRESSIONAL RECORD
CRIS/USDA
DIALINDEX
DIALOG PUBLICATIONS
DISCLOSURE
ECER/EXCEPTIONAL CHILD
ECONOMIC ABSTRACTS INTERNATIONAL
EIS INDUSTRIAL PLANTS
EIS NONMANUFACTURING ESTAB
ENCYCLOPEDIA OF ASSOCIATIONS
ENERGYLINE
ENVIROLINE
ENVIRONMENTAL BIBLIOGRAPHY
ERIC
EXCERPTA MEDICA 74-79
EXCERPTA MEDICA 80-present
EXCERPTA MEDICA (IN PROCESS)
FEDERAL INDEX
FEDERAL REGISTER
FOOD SCIENCE & TECH ABSTRACTS
FOODS ADLIBRA
FOREIGN TRADERS INDEX
FOUNDATION DIRECTORY
FOUNDATION GRANTS INDEX
FROST & SULLIVAN DM2
GEOARCHIVE
GEOREF
GPO MONTHLY CATALOG
GRANTS
HISTORICAL ABSTRACTS
INPADOC
INSPEC 1969-77
INSPEC 1978-present
INT'L PHARMACEUTICAL ABSTRACTS
IRL LIFE SCIENCES COLLECTION
ISMEC
LANGUAGE & LANGUAGE BEHAVIOR ABS
LEGAL RESOURCE INDEX
LISA
MAGAZINE INDEX
MANAGEMENT CONTENTS
MEDLINE
MENTAL HEALTH ABSTRACTS
METADEX
METEOR/GEOASTROPHYS ABS
MLA BIBLIOGRAPHY
NATIONAL FOUNDATIONS
NATIONAL NEWSPAPER INDEX
NCJRS
NEWSEARCH
NICEM
NICSEM/NIMIS
NONFERROUS METALS
NTIS
OCEANIC ABSTRACTS
ONTAP CA SEARCH
ONTAP CHEMNAME
ONTAP ERIC
PAIS INTERNATIONAL
PHARMACEUTICAL NEWS INDEX
PHILOSOPHER'S INDEX
PIRA
POLLUTION ABSTRACTS
POPULATION BIBLIOGRAPHY
PSYCINFO
PTS F&S INDEXES 1972-1975
PTS F&S INDEXES 1976-present
PTS INT'L FORECASTS
PTS INT'L TIME SERIES
PTS PREDALERT
PTS PROMT
PTS U.S. FORECASTS
PTS U.S. TIME SERIES
RAPRA ABSTRACTS
RILM ABSTRACTS
SCISEARCH' 1974-77 (subscribers)
(nonsubscribers)
SCISEARCH' 1978-present (subscribers)
(nonsubscribers)
SOCIAL SCISEARCH'
SOCIOLOGICAL ABSTRACTS
SPECIAL EDUCATION MATERIALS
SPIN
SSIE CURRENT RESEARCH
STANDARD & POOR'S NEWS
SURFACE COATINGS ABSTRACTS
TRADE OPPORTUNITIES
TRADE OPPORTUNITIES WEEKLY
TRIS
TSCA INITIAL INVENTORY
U.S. EXPORTS
U.S. POLITICAL SCIENCE DOCUMENTS
U.S. PUBLIC SCHOOL DIRECTORY
WELDASEARCH
WORLD ALUMINUM ABSTRACTS
WORLD TEXTILES

None of these articles contained information on innovative lighting designs or glare-control techniques specifically for mine-lighting applications. Fourteen articles, listed in Table 4, while related directly to mining, do not discuss research and development work. Twelve articles are primarily information on available lighting hardware and its application; one article discusses lighting regulations and one, the critical areas of underground lighting.

Sixteen articles discuss results of lighting studies and were considered potentially relevant to mine lighting. Brief discussions of these articles are presented in Appendix C.

It is significant that only 14 of the 112 articles reviewed were directly related to coal mining, and, as noted, these did not discuss research in mine-related lighting problems. The limited amount of literature available on mine lighting indicates an apparent lack of research and development in coal-mine lighting as compared to the work being done in areas such as roadway, office, and industrial-plant lighting.

B. Survey of Anti-glare Materials and Techniques

1. Organizations Contacted

A survey of anti-glare materials and techniques currently used in general lighting applications was conducted to obtain information on products or techniques with potential value in controlling glare from underground coal mine illumination systems. Table 5 lists 40 organizations--including 32 manufacturers, five distributors, two research organizations, and one optometrist--contacted for information on glare-reducing materials and techniques. A variety of light-control products, as listed in Table 5, were available from the organizations, including complete lighting systems and such components of lighting systems as glare-reducing coatings, plastics, and lenses.

The list of organizations to be contacted was prepared from (1) a search of the Thomas Register of American Manufacturers, and (2) recommendations from lighting manufacturers and the Illuminating Engineering Research Institute. The organizations were initially contacted by phone to obtain the name of the individual most qualified to discuss mine-lighting applications of the organization's product or control technique. As a result of these contacts, 15 companies provided brochures on light-control materials and luminaires, three manufacturers expressed interest in working cooperatively on the development of low-glare coal-mine illumination systems, and seven companies supplied samples of the light-control products listed in Table 6.

2. Anti-glare Materials and Techniques

A review of the products in Table 6 resulted in the following analysis of their usefulness for mine lighting systems. Aluminum reflectors (Items 1, 2, 3) can be used to improve directional lighting efficiency but are considered of no value in reducing glare.

TABLE 4. MINING-RELATED ARTICLES

	Article	Author	Source
1.	Products to Light Underground Workings	Anonymous	Coal Min & Process, Oct. 1976
2.	Illumination of Mining Equipment	Bell, J. R.	Min Cong Journal, Oct. 1979
3.	Lighting Suppliers Work to Cut Glare	Brezovec, D.	Coal Age, May 1980
4.	Underground Mine Lighting; A Look of What's New in Concepts and Equipment	Chironis, N. P.	Coal Age, Aug. 1974
5.	HPS Lights West Virginia Coal Mine	Anonymous	Lighting Design & Appl, Jan. 1977
6.	New Underground Lighting Regulations and How They Apply	Lester, C. E.	Coal Min & Process, Oct. 1976
7.	Overview of Remaining Critical Areas of Underground Illumination	Lester, C. E.	Coal Conference & Expo V, Louisville, KY, Oct. 1979
8.	Companies Take the Initiative on Mine Lighting	Mason, R. H.	Coal Min & Process, Oct. 1976
9.	Polycarbonate Tube Shields Mine Light	Anonymous	Plastics World, Nov. 1978
10.	New Directions for Polycarbonate in Lighting	Reed, J. J.	Lighting Design & Appl, June 1979
11.	Focusing on Tough Illumination Problems Underground	Skinner, C. S., et al.	Coal Conference & Expo V, Louisville, KY, Oct. 1979
12.	How to Implement Mine Illumination	Skinner, C. S.	Coal Min & Process, Mar. 1979
13.	Glare Reduction for Underground Lights	Trotter, D. and Laferriere, L.	Can Min Journal, Sept. 1980
14.	Area Illumination in Room and Pillar Hard Rock Mines	Weakly, L. A.	Min Eng, June 1978

TABLE 5. ORGANIZATIONS CONTACTED FOR INFORMATION ON GLARE-CONTROL PRODUCTS OR TECHNIQUES

	Name of Organization	Type of Organization	Products of Possible Interest
1.	Moldcast Lighting	Manufacturer	Prismatic luminaires
2.	RCA Corporation	Manufacturer	Glare-reducing coatings
3.	3M Company	Manufacturer	Glare-reducing coatings, diffusing tape
4.	Appleton Electric Company	Manufacturer	General lighting products
5.	Sonolite Corporation	Manufacturer	General lighting products
6.	Roflan Company	Manufacturer	Explosion-proof oil refinery luminaires
7.	Alcoa	Manufacturer	Aluminum reflective sheet
8.	Plastic Manufacturers, Inc.	Manufacturer	Custom designed lenses and diffusers
9.	Optical Filter Corporation	Manufacturer	Lenses and optical filters for nautical and space applications
10.	Holophane Division of Johns-Manville Corp.	Manufacturer	Explosion-proof oil refinery and industrial luminaires
11.	American Acrylic Corporation	Manufacturer	Fiberglass reinforced diffusers
12.	KSH, Inc.	Manufacturer	"Acri-tuff" lenses and diffusers
13.	Keene Corporation	Manufacturer	General lighting products
14.	RAB Electric Manufacturing Company, Inc.	Manufacturer	General lighting products
15.	Evaporated Coatings, Inc.	Manufacturer	Heat/light separation and anti-glare films
16.	Lexalite International Corporation	Manufacturer	Custom fabricator of polycarbonate lighting plastics
17.	General Electric Company	Manufacturer	"Lexan" polycarbonate plastics

TABLE 5. ORGANIZATIONS CONTACTED FOR INFORMATION ON GLARE-CONTROL PRODUCTS OR TECHNIQUES (Continued)

	Name of Organization	Type of Organization	Products of Possible Interest
18.	Fiber Optics Technology, Inc.	Manufacturer	Fiber optics illumination systems
19.	Bayhead Products	Manufacturer	Polycarbonate and acrylic lenses and diffusers
20.	Plastic Dynamics Corporation	Manufacturer	Scratch-resistant coatings for polycarbonates and acrylics
21.	Corning Glass Corporation	Manufacturer	Low-glare glass lenses, glass tubes for mine luminaires
22.	American Optical Corp.	Manufacturer	None
23.	United Lighting & Ceiling Corporation	Manufacturer	General fluorescent lighting
24.	Dura-Plastics of New York, Inc.	Manufacturer	Custom fabricator of plastics
25.	ALP Lighting	Manufacturer	Light diffusers, louvers
26.	Exide Corporation	Manufacturer	None
27.	A. W. Carrol Company	Manufacturer	Fluorescent bulb guards
28.	Diffusa-Lite Company	Manufacturer	Light diffusers
29.	Transilwrap Company	Manufacturer	"Transilmatt" polyester diffuser used in bulb guards
30.	Precision Plastics Company	Manufacturer	General lighting plastics
31.	Flexible Lighting, Inc.	Manufacturer	Flexible fluorescent lighting
32.	Optronics, Inc.	Manufacturer	Low-glare headlights
33.	Williams & Company	Distributor	Aluminum reflective sheet
34.	McJunkin Corporation	Distributor	Diffusing tape, bulb guards
35.	Plastic Products	Distributor	General lighting plastics

TABLE 5. ORGANIZATIONS CONTACTED FOR INFORMATION ON GLARE-CONTROL PRODUCTS OR TECHNIQUES (Concluded)

	Name of Organization	Type of Organization	Products of Possible Interest
36.	Flexo-Lighting, Inc.	Distributor	None
37.	Gold Seal Electrical Products	Distributor	Polarized panels
38.	Illuminating Engineering Research Institute	Research	None
39.	Optical Coating Laboratories, Inc.	Research	Glare-reducing optical coatings
40.	Dr. Harry Zeltzer	Optometrist	Low-glare optical lenses

TABLE 6. LIGHT-CONTROL MATERIALS RECEIVED*

	Brand Name	Company	Material	Description
1.	Coilzak Diffuse	ALCOA Corp.	Aluminum	Diffuse finish aluminum reflector
2.	Coilzak Semi-specular	ALCOA Corp.	Aluminum	Semi-specular finish aluminum reflector
3.	Coilzak Specular	ALCOA Corp.	Aluminum	Specular finish aluminum reflector
4.	Para-lite 1	ALP Lighting Products	Acrylic	Parabolic louver; controls high-angle brightness to 45 degrees
5.	Louverlux	Diffusa-Lite Co.	Acrylic	Cell louver; controls high-angle brightness to 40 degrees
6.	White 1000-SOS LUMAsite	American Acrylic Corp.	Acrylic	White diffuser; excellent glare control
7.	Frost .006 LUMAsite	American Acrylic Corp.	Acrylic	Fiberglass reinforced diffuser
8.	Frost .009 LUMAsite	American Acrylic Corp.	Acrylic	Fiberglass reinforced diffuser
9.	GE 9038-112 LEXAN Protect-A-Glaze	General Electric Co.	Polycarbonate	Translucent diffuser, high-impact and temperature resistant
10.	KSH-12	KSH, Inc.	Acri-Tuff Acrylic	Standard lens; high efficiency

*Inclusion of these products does not represent an endorsement or recommendation by the USBM or BCR.

TABLE 6. LIGHT-CONTROL MATERIALS RECEIVED*
(Continued)

	Brand Name	Company	Material	Description
11.	KSH-701	KSH, Inc.	Acri-Tuff Acrylic	Rectangular pattern lens; good light distribution
12.	KSH-3E	KSH, Inc.	Acri-Tuff Acrylic	Asymmetric lens; reduces veiling glare
13.	White Matte	KSH, Inc.	Acri-Tuff Acrylic	White diffuser; excellent glare control
14.	Polarized Panels	Polarized Corp. of America	Acrylic	White diffuser; standard lens and layer of polarizing material
15.	Symmetric 306	Lexalite International Corp.	Polycarbonate	12" x 12" lens; good light distribution
16.	Asymmetric 306	Lexalite International Corp.	Polycarbonate	12" x 12" lens; good light distribution
17.	Red Spot	Lexalite International Corp.	---	Clear flat lacquer, diffuser
18.	Transilmatte .005	Transilwrap Co.	Polyester	Drafting paper, diffuser; heat insensitive

*Inclusion of these products does not represent an endorsement or recommendation by the USBM or BCR.

Louvers (Items 4, 5) can be used to shield light output in a given direction, and control glare in that direction only. They are, however, impractical for mine applications because they reduce lighting efficiency, can significantly affect uniformity of light patterns, require additional space to install, and would be subject to extensive mechanical damage.

Lens and diffusers (Items 6 to 18), made of either clear or white plastic, are designed specifically to control glare by diffusing the light and/or providing directional control. These materials give the best potential for minimizing glare produced by mine lighting systems. When evaluating these lenses, the properties of the plastic must be considered before analyzing the light patterns produced. Table 7 summarizes the properties of the plastics commonly used in the manufacture of lens and of glass used in some luminaires with HID or incandescent light sources. A review of the data indicates that glass is the best lens material because of its chemical stability and relatively good strength and durability. However, glass is more expensive than plastic, which has led to extensive use of plastic lens on mine luminaires, particularly with fluorescent light sources. Of the four plastics included in Table 7, polycarbonate is the best material based on its good chemical stability, particularly flammability characteristics, and excellent impact strength. However, polycarbonate loses its strength and may change color or acquire a haze when exposed to sunlight or certain chemicals. Lumasite has properties similar to polycarbonate, but its lower deflection temperature and "slow-burning" characteristics make it less desirable for mine-lighting application. Therefore, of the currently available plastics, polycarbonate is the best lens material, but some precautions should be observed in its application:

(a) Hydrocarbon fluids and vapors will attack the material, resulting in loss of strength. For example, the fumes given off by the plasticizers in certain wire insulations, and by some solvents, will, over a period of time, attack polycarbonate, causing it to develop a haze and loose strength.

(b) The plastic should be protected from high-temperature heat sources (such as weld spatter, welding torches, and heat from lamp filaments) to avoid localized softening and failure of lens.

(c) There is evidence that the plastic will tend to develop internal cracking or crazing which can lead to impact failure of the lens.

Limited testing of five lenses and two diffusing materials was conducted to evaluate their potential for underground use. The procedure and results of these tests are presented in Section C. The diffusers, listed as items 6 to 9, were not tested either because they were very similar to the tested materials or the sample available was too small. Briefly, the test results indicated that:

(a) Clear, prismatic, plastic lens generally broke up the "hot spot" created by an incandescent or HID light source but often

TABLE 7. PHYSICAL PROPERTIES OF COMMON LENS MATERIALS

Property	Units	Acrylic	LUMAsite*	ACRI-TUF**	Polycarbonate	Tempered Glass****
Specific Gravity	--	1.19	1.35	1.15	1.2	2.3 - 2.6
Light Transmittance 0.125" thick clear plastic	%	92	70 - 84	90	85 - 91	.88 - .92
Rockwell Hardness	--	M-95	M-104	M-92	M-78	N.A.
Impact Strength Izod	ft-lb/ inch	0.4	6	2	14***	3.6
Deflection Temperature at 264 psi	°F	189	233	170	275	415 - 500‡
at 66 psi	°F	210	245	187	280	
Flammability	--	Slow Burning	Slow Burning	Slow Burning	Self-extinguishing	Non-burning
Thermal Shock Resistance	--	Excellent	Excellent	Excellent	Excellent	Good
Effect of Weak Acids	--	None	None	None	None	None
Effect of Weak Alkali	--	None	None	None	Some attack	None
Effect of Sunlight	--	None	None	None	Some embrittlement and color changes	None None
Tensile Strength	lb/in^2	11,000	14,000	5,400	9,500	10,000
Flexural Strength	lb/in^2	17,000	22,000	6,600	13,500	N.A.

* - LUMAsite is manufactured by American Acrylic Corporation.
** - ACRI-TUF is manufactured by KSH, Inc.
*** - Polycarbonate gradually looses impact strength when exposed to sunlight, chemicals, etc.
**** - General range for glass; will vary for specific types.
‡ - Upper limit range for mechanical considerations only.
N.A. - Not available.

produced small, high-intensity images, dispersed over the surface of the lens.

(b) Diffusion material with smooth surfaces greatly reduced the "hot spot" of the light source and produced a large surface of relatively low intensity.

(c) Diffusion material with a prismatic lens design on one surface further reduced the hot spot and gave a generally more uniform light distribution.

Based on these very limited tests, there appears to be considerable potential for the use of diffusion material with a lens pattern to reduce the glare potential of underground luminaires.

3. Specialized Lighting Equipment

As a result of the literature search, some specialized lighting equipment was identified as having possible use for minimizing the glare potential of mine-lighting systems. Following is a brief discussion of these items, based on information supplied by manufacturers and/or distributors listed in Table 8.

a. Use of parabolic reflector and prismatic lens - Directional control of light can be readily achieved by the use of prism and reflector systems designed to reflect and redirect light to give a desired pattern. One example of a luminaire employing this system is shown in Figure 1A. The reflector controls the light cutoff angle (Figure 1B), while the clear plastic prismatic lens cover provides 180-degree lateral diffusion of the light. This design, which normally uses arc discharge lamps, provides limited light-pattern control and reduced glare potential with high output. Current applications include roadways, streets, and parking lots. A modification of this design to further reduce glare would incorporate a white plastic lens instead of the clear material.

The design principles used in this luminaire may by applicable for lighting specific areas, such as the roof or floor, to a high level while minimizing the glare for personnel working around the machine.

b. Radio-frequency excitation - Fluorescent lamps will produce light if placed in an electrical field of radio frequency. This principle has been used to develop lighting systems incorporating small glass tubes, containing mercury vapor and coated internally with phosphors. These tubes can be placed inside clear, flexible tubing and excited by radio-frequency electrical waves carried by aerial wires oriented axially along the tubes. The advantages of this system are:

(1) The lamps contain no electrodes or filaments and, therefore, have an indefinite life.

TABLE 8. SUPPLIERS OF SPECIALIZED LIGHTING EQUIPMENT*

Source of Equipment	Product
Moldcast Lighting	Paracyl luminaire - sharp cutoff, low-glare luminaire
Flexible Lighting	Radio frequency operated fluorescent luminaires
Optronics, Inc.	Sealed beam, low-glare luminaires
Fiber Optics Technology, Inc.	Numerous custom Fiber Optics' products
L. A. Whitehead, University of British Columbia, Department of Physics	Prism light guide

*Inclusion of these suppliers does not indicate endorsement of the products listed, but is intended only to identify a potential source for the equipment.

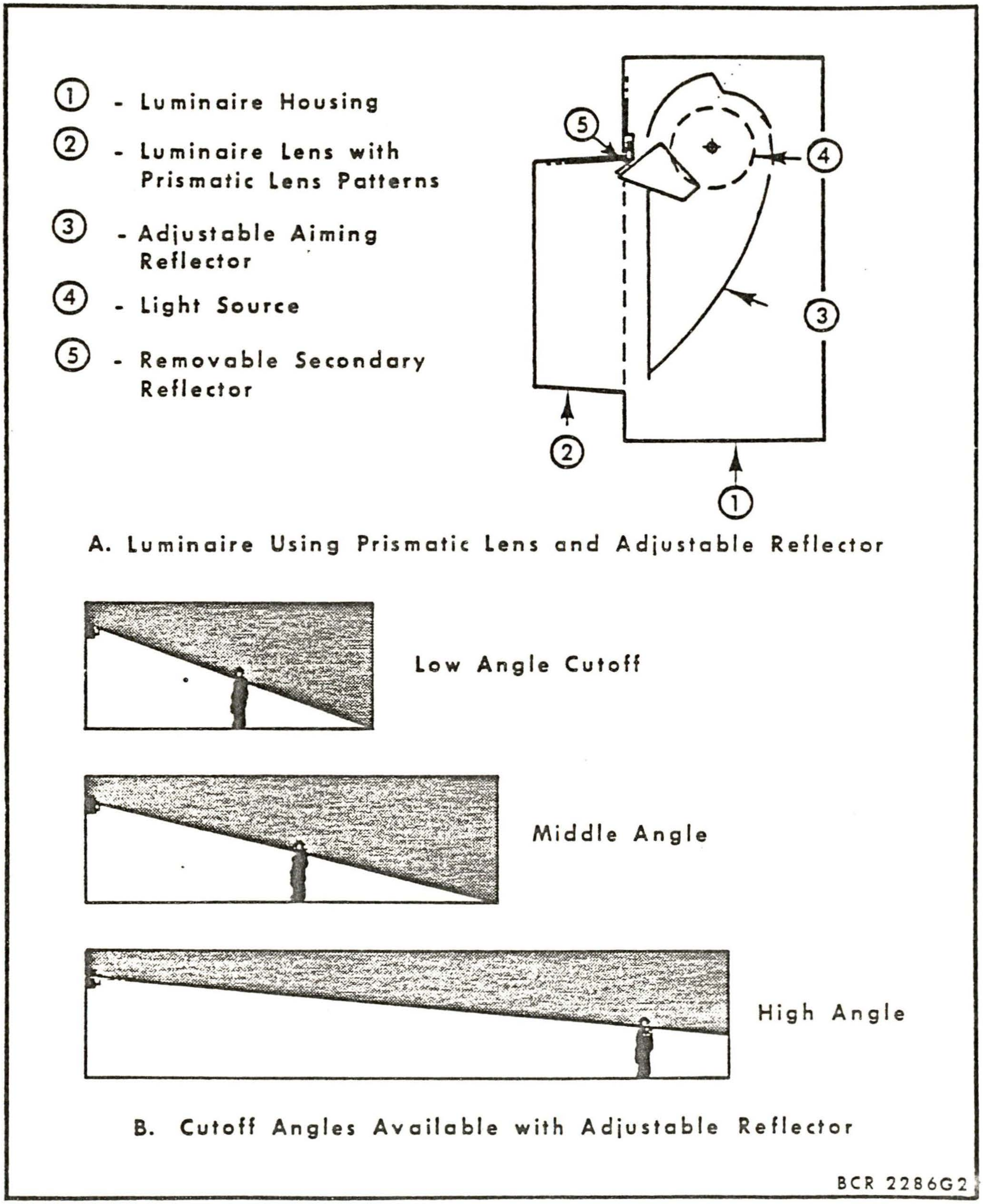


Figure 1. Example of Luminaire Utilizing a Combination of Prismatic Lens and Specialized Reflector

(2) Individual tubes which may be broken can be replaced quickly by inserting new lamps in the plastic tubes.

(3) System output can be changed by varying the size and/or number of tubes.

(4) The system can follow irregular equipment contours to light hard-to-reach surfaces.

(5) Essentially no heat is produced by the lamps.

The disadvantage of the system is that, with present designs, light levels at any point along the plastic tube are low; consequently, attaining the required luminance level (0.06 ft-L) may be difficult. The flexibility and minimum-glare potential of this system should make it attractive for further research and development work and subsequent underground trials on various types of equipment.

c. Low-glare headlights - A sealed beam headlight is available which is designed to suppress glare by essentially eliminating diffuse, scattered light and producing a controlled, high-intensity beam reportedly capable of piercing smoke, rain, fog, and haze. Although surface coverage of the lamp's beam is limited, modifications to the system may be possible to increase its coverage and make it more attractive for underground applications. The reduced glare potential of the lamp should be investigated particularly for applications where personnel, stationed at the front end of the machine, frequently look in the direction of headlights or other luminaires.

d. Fiber optics - The use of glass fiber bundles to transmit light is a well-established technology having many applications in medicine, science, and industry. The main advantage of this system is that light can be carried to one or more locations remote from a single light source. Theoretically, a mining application could use a single, high-wattage incandescent or HID lamp in an enclosed housing with bundles or multistrand cables of glass fibers transmitting light to windows or lenses around the periphery of the machine. This would produce a cool, low-glare system and eliminate the need for the large luminaires now used.

The disadvantages of the system are: (1) because of its low efficiency, a large number of fibers and peripheral outlets would be needed to attain the required light levels; and (2) dissipation of the heat produced by the enclosed light source would be a problem. However, some investigation may be warranted to ascertain the practicality of using fiber optics in mine lighting.

e. Light guides - Light guides, also known as light pipes, are similar to fiber optics in that light is transmitted from a single remote source to the location to be illuminated. The guides are rectangular transparent pipe whose walls have prism-shaped outer facets which act as total internal reflection mirrors. The design has the advantage of total internal reflection combined with low attenuation of light to give an efficient, low-cost method of distributing light. Other advantages, similar to those of light fiber techniques, are the use of a single light source which can be completely shielded from view, cool light-emitting surfaces which eliminate a potential safety hazard, and the potential for carrying light to areas not accessible with luminaires.

A system of light guides should require relatively low maintenance and may also provide a practical system for mounting on the rib or roof.

C. Comparison of Glare-reducing Materials

Current methods to control glare from machine-mounted illumination systems; e.g., partial shielding or applying colored diffusion tape, have not been entirely adequate in providing comfortable illumination for underground mine personnel. To provide information on additional light-control materials for potential underground application, five different plastic lenses, two diffusion materials, and a polarized panel (Table 9) were compared for glare-control characteristics and relative reduction in light output when used with an incandescent light source.

A test box, shown in Figure 2, with an interchangeable black or white interior was constructed to house a 150-watt incandescent lamp. One side of the box was left open to hold a 12-inch by 12-inch sample of lens or diffusing material. Measurements of incident light were taken in a darkroom to compare the distribution and losses of light emitted through the various lens or diffusers with the pattern and output of a bare bulb. A Gossen Panlux incident-light meter was used to record light measurements at distances of 1 foot and 5 feet from the light source, along lines parallel to the open side of the box, and at the level of the lamp filament. Because no convenient method was available to check the photometer calibration, the brightness measurements were used to compare light patterns produced by the various materials and show relative magnitude of "bright spots" in the output. A more precise and detailed evaluation should be conducted to evaluate these materials for underground application.

Figures 3, 4, and 5 show the light distribution pattern and lumen output of the panels tested. These curves indicate the following:

(1) The light distribution curve for a bare luminaire peaks sharply at 8.5 ft-c when intensity is measured opposite the luminaire. From this point, the intensity decreases in approximately a linear pattern up to 5 feet on either side of the luminaire.

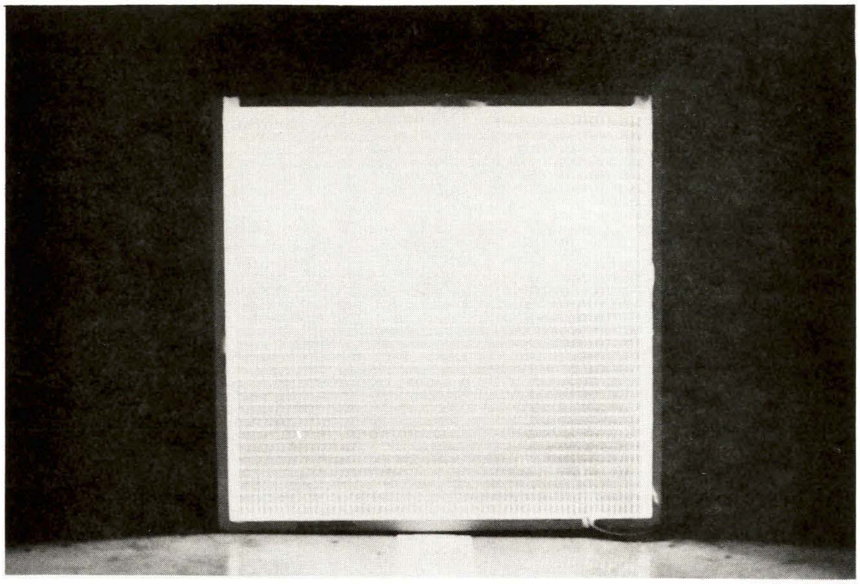
(2) The curves for diffuser materials also peak directly opposite the light source but at a reduced level. In addition, the slope of their curves to the left or right of the hot spot is more gradual than the slope of the curve for the bare luminaire.

(3) The use of prismatic lens materials resulted in a variety of light patterns, some of which produced hot spots equivalent to the bare

TABLE 9. LIGHT-CONTROL MATERIALS TESTED

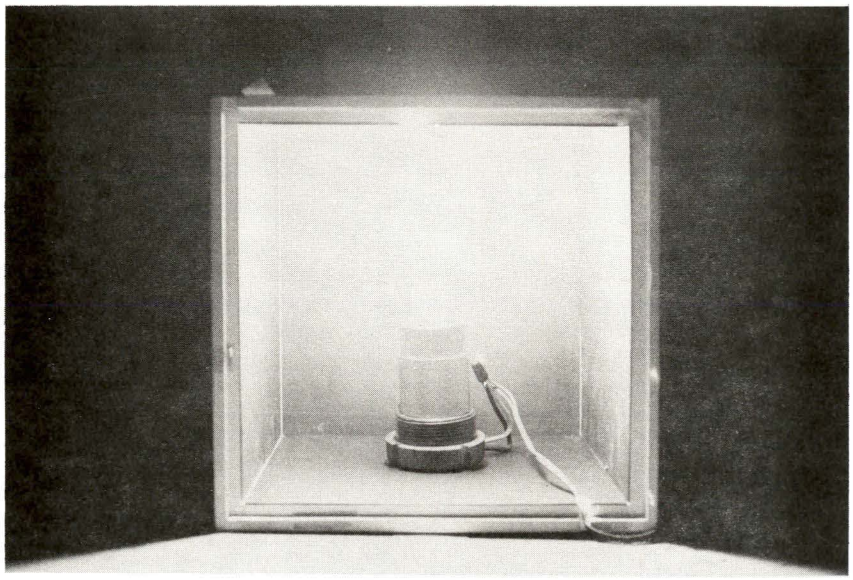
	Brand Name	Company	Material	Description
1.	KSH-12	KSH, Inc.	Acri-Tuff Acrylic	Standard lens; high efficiency
2.	KSH-701*	KSH, Inc.	Acri-Tuff Acrylic	Rectangular pattern lens; good light distribution
3.	KSH-3E	KSH, Inc.	Acri-Tuff Acrylic	Asymmetric lens; reduces veiling glare
4.	White Matte	KSH, Inc.	Acri-Tuff Acrylic	White diffuser; excellent glare control
5.	Symmetric 306*	Lexalite International Corp.	Polycarbonate	12" x 12" lens; good light distribution
6.	Asymmetric 306	Lexalite International Corp.	Polycarbonate	12" x 12" lens; good light distribution
7.	Transilmatte .005	Transilwrap Co.	Polyester	Drafting paper, diffuser; heat insensitive
8.	Polarized Panel	Gold Seal Electric Co.	Acrylic	10" x 10" lens; excellent glare control

*These panels tested for two lens orientations 90 degrees apart.



2276P88

(A) Test Box with KSH-701 Lens to Distribute Light from the 150 Watt Bulb



2276P86

(B) Test Box with 150 Watt Incandescent Bulb and No Lens or Diffuser

Figure 2. Test Box Used to Evaluate Various Lens Designs and Diffusing Material

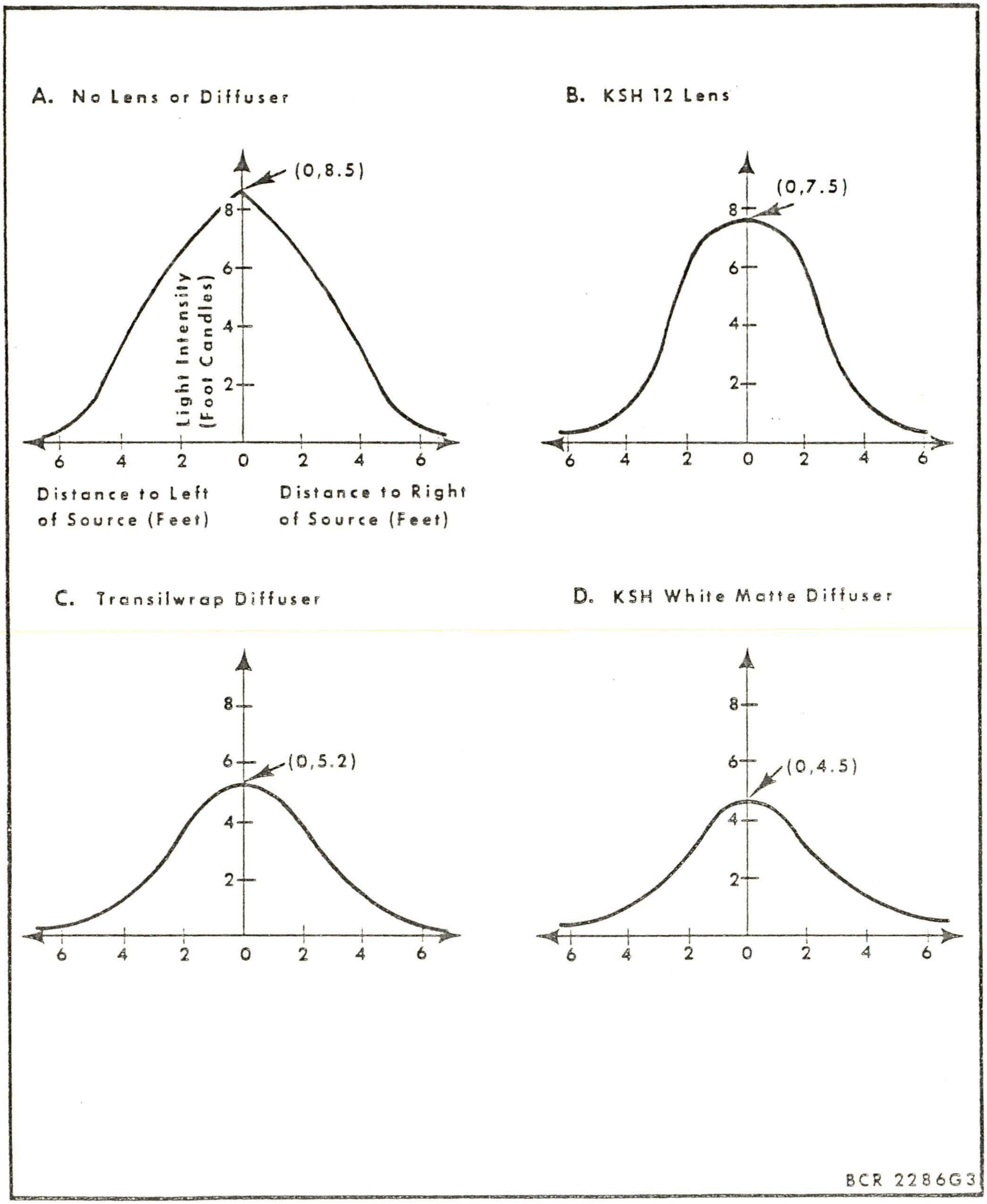


Figure 3. Comparison of Light Intensity and Distribution for Several Lenses and Diffusers

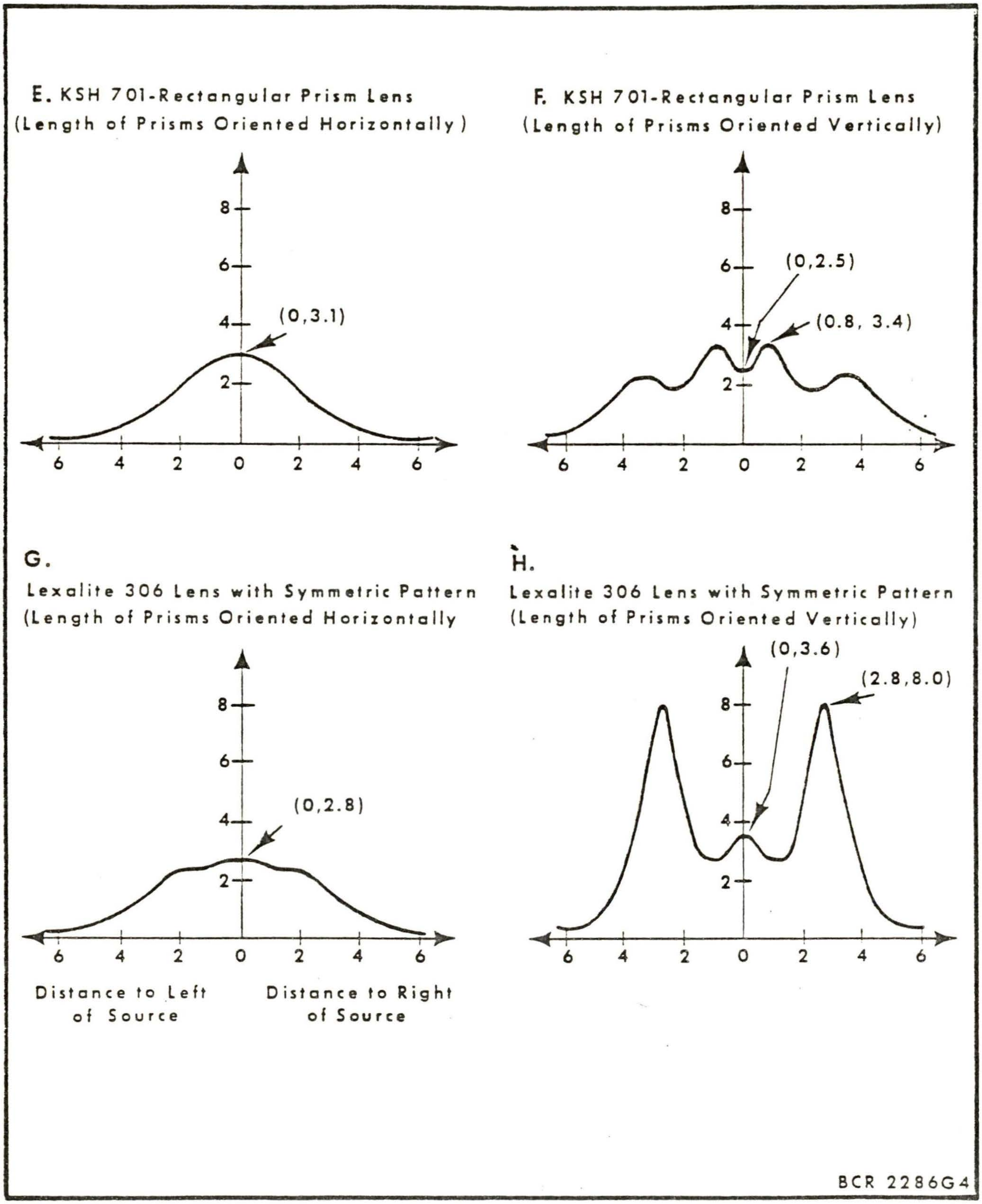
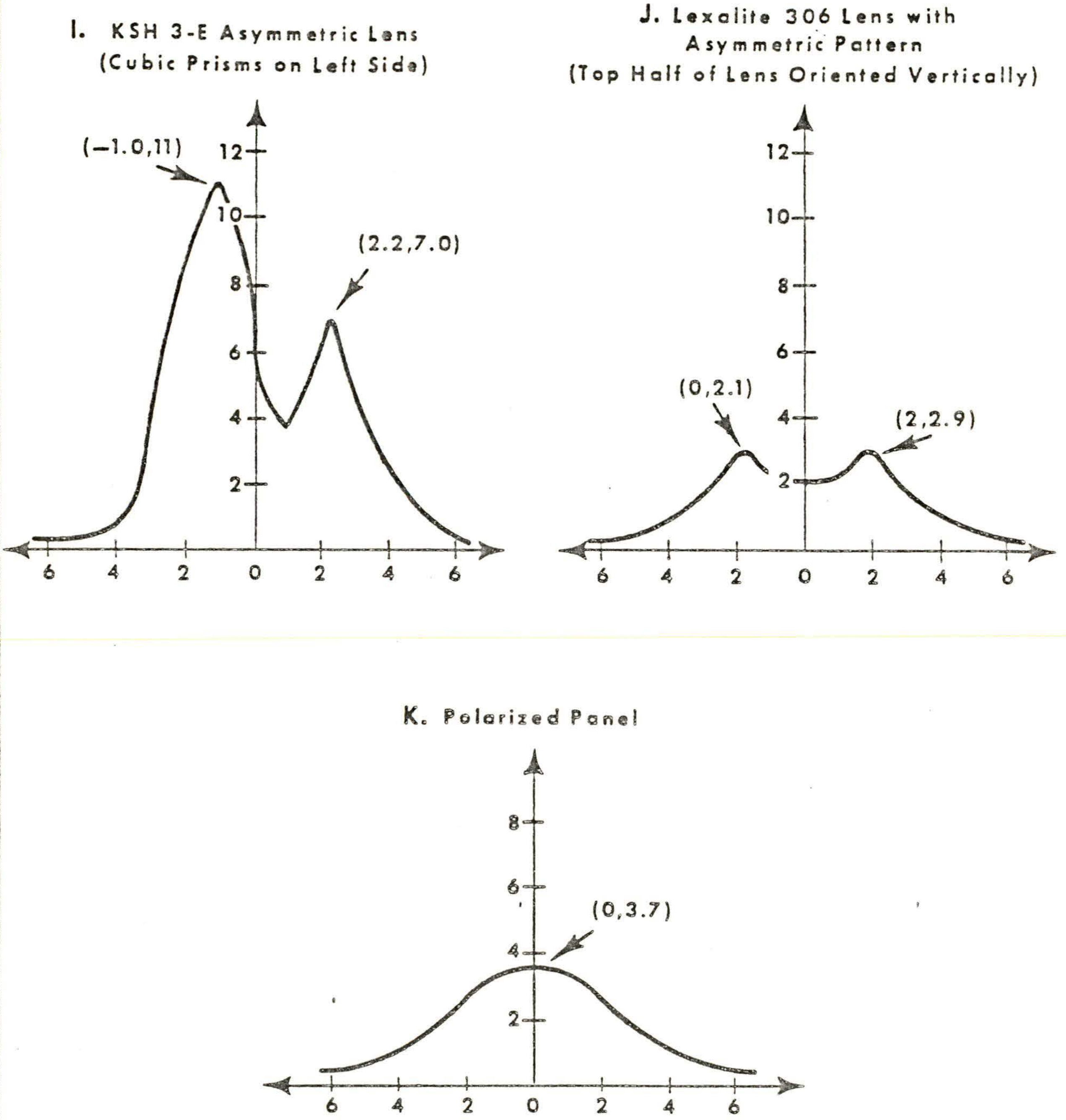


Figure 4. Comparison of Light Intensity and Distribution for Several Lenses and Diffusers



The Data for Curves in Figures 3, 4, and 5 Light Intensity Readings were Taken in a Dark Room at a Minimum Distance of 5 Feet from the Luminaire with the Interior of the Luminaire Box Colored Black

BCR 2286G5

Figure 5. Comparison of Light Intensity and Distribution for Several Lenses and Diffusers

bulb while others produced multiple hot spots. Use of these materials would require careful testing to select an appropriate pattern.

(4) For the eight light-control materials tested, light intensity at distances greater than 4 feet to either side of the source was essentially the same.

(5) When the box interior was black, no more than 0.55 ft-c of illumination was achieved beyond 6 feet to either side of the source for any lens or diffuser tested.

(6) Orientation of the lens pattern can be very critical, as shown by the difference in foot-candle distribution curves for KSH-701 and Lexalite 306 Lens Symmetrical Pattern materials. One orientation produced smooth, bell-shaped curves; however, rotating the panels 90 degrees produced curves with multiple "hot spots" which could increase the glare problem.

The interior of the luminaire box was changed from black to white, resulting in an increase of three to four times the light intensity for most lenses and diffusers tested. However, the increase related to change in box interior color was not as great for the bare lamp. Table 10 shows a comparison of the peak luminaire intensities for the bare lamp, the White Matte diffuser, and the #306 lens with both black and white interiors.

From visual observation, the bare lamp created glare regardless of the color of the box interior. Using a White Matte diffuser over it reduced glare to a minimal level with either a white or black box interior. As shown in Table 10, a higher intensity was achieved with the White Matte diffuser and a white box interior than with a bare lamp and a black box interior. Thus, more illumination with less glare was achieved with proper light control.

From this comparison, it appears that illumination can be significantly improved in a low-reflectance environment by using better methods of light control. Light intensity can be increased by using highly reflective surfaces, while lenses and diffusers can be used to distribute this light and reduce glare resulting from the higher light intensities.

TABLE 10. LUMINAIRE INTENSITY (ft-c) FOR BLACK OR WHITE BOX INTERIORS AT A 5-FOOT DISTANCE

Distance to Left or Right of Light Source, (ft)	Box Interior Color	No Lens or Diffuser	White Matte Diffuser	#306 Lens Horizontal Orientation
0	Black	8.5	4.5	2.8
0	White	20.0	16.0	12.0
2	Black	6.2	2.9	2.4
2	White	15.5	11.0	10.5
4	Black	3.1	1.2	1.0
4	White	8.0	5.0	4.0
6	Black	0.5	0.5	0.3
6	White	3.5	2.0	2.0

D. Task IV - Evaluation of Data and Development of Recommendations

Following are the recommendations developed as a result of information and data collected during the performance of this contract.

1. Anti-glare Materials and Techniques

(1) A project should be undertaken to evaluate and field test the diffusion materials and lens which showed the best potential for glare control. Based on the tests conducted by BCR and the observations made during these tests, the best potential candidate material is the polarized panel, which is a combination of prismatic lens and polarizing diffuser. However, other combinations may offer equal control, and the investigation should not be limited to the polarized panel.

(2) All prismatic lens panels tested were commercial products intended for use in office ceilings or similar applications. Some companies will custom design prismatic panels for specific applications; therefore, it is recommended that the possibility of designing a prismatic lens panel specifically for the mining application be investigated. If this is feasible, panels should be developed and field tested. Potential sources of custom lens panels include Lexalite International Corporation, KSH, Inc., American Acrylic Corporation, Holophane Company, Inc., and Thorn Lighting Ltd.

(3) The "low-glare" headlight design principle should be investigated for possible application to machines where personnel work in front of the luminaires, in particular, the machine headlights. The initial effort could be with the lamp design produced by Optronics, Inc. If results indicate reduced glare, further work could be done to modify the design to give the desired light pattern.

(4) Investigate the use of light pipes for both machine-mounted and rib/roof-mounted lighting systems. This system would have most of the advantages of fiber optics but would be more efficient and could transport a greater quantity of light. The relatively small cross section and rectangular shape of the pipe should lend itself to designing pipes into a machine frame. In addition, pipes should be relatively easy to hang along the rib or roof.

2. <u>Recommendations Based on the Literature Survey</u>

(1) Present regulations require that the luminous intensity of those surfaces in a miner's field of vision which are required to be lighted be not less than 0.06 foot-lamberts and that the surface brightness of floor, roof, coal, and machine surfaces shall not vary more than 50 percent between adjacent surfaces of similar surface reflectivity. The study discussed in the article, "Lighting for Difficult Visual Tasks," indicates that the use of special-purpose lighting may be more beneficial than simply increasing general lighting.

It is therefore recommended that a program be initiated to develop, for each type of mining machine, lighting systems that utilize the "special-purpose" lighting technique. For example, a continuous miner system would provide increased light for the face and only sufficient lighting for peripheral vision for the roof and rib. This should provide personnel with adequate vision to identify movements and objects in their peripheral field while potentially improving their ability to observe details of the cutting operation. Some specific details which would have to be considered include establishing an adequate light level for peripheral vision and insuring that an adaptation problem would not exist between light levels of the "special-lighting" areas and the rest of the working place.

(2) There have been no studies to determine whether the increased lighting in the mine working place has increased production or improved accident records. Therefore, an effort should be made to determine the relationship between light levels and mine productivity and safety so that lighting-system design criteria can be established to achieve appropriate light levels either for increased safety only or for both safety and productivity.

(3) Since contrast between an object and its background is an important vision parameter, a useful tool in designing lighting systems would be a method of evaluating relative contrasts in an environment. The article, "Limitation of Disability Glare in Roadway Lighting," discusses such a method called "the effective relative contrast sensitivity." The derivation and application of this contrast evaluation procedure should be studied to determine its potential application to analysis of the mine environment and use in lighting-system design.

(4) The information in the article, "Duration of Afterimage Disability After Viewing Simulated Sun Reflections," suggests that a method of evaluating light sources and anti-glare techniques could be based on the time required for an observer to recognize an object after exposure to the light source. An investigation should be conducted to determine whether this procedure could be used to rate the glare properties of luminaires and anti-glare materials or techniques. This rating could be used by designers in selecting system components to minimize glare or by hardware designers in identifying the best anti-glare materials.

APPENDIX A

ABSTRACTS OF ARTICLES DESCRIBING ANTI-GLARE LIGHTING TECHNIQUES AND GLARE INVESTIGATIONS CONSIDERED POTENTIALLY RELEVANT TO UNDERGROUND COAL-MINE LIGHTING

Introduction

The articles reviewed indicate that lighting research has concentrated primarily on office, school, roadway, and factory lighting to improve the productivity and/or safety of personnel in these areas. Research and development work done by manufacturers in developing hardware for mine lighting has been directed at producing systems to comply with the federal mine lighting regulations, which are general in their treatment of glare. Title 30, Part 75.1719-2, item (g) states "lighting fixtures shall be designed and installed to minimize discomfort glare." As a result, essentially no research has been done in the development of techniques for low-glare mine lighting.

ILLUMINANCE, DIVERSITY AND DISABILITY GLARE IN EMERGENCY LIGHTING

Simons, R. C. (Thorn Lighting Ltd.), Lighting Research and Technology 7 (2), 125-132 (1975).

A safe minimum level of illumination was determined for escape-lighting systems from a series of experiments with subjects passing through a network of corridors in simulated escapes. This investigation was performed in conjunction with the preparation of a British Code of Practice to establish a generally applicable minimum safe escape illuminance. The major factors considered in defining the quality of illumination were the mean illuminance at the floor level, the diversity in illuminance along an escape route, and the apparent brightness of individual luminaires that could result in observers experiencing disability glare. Discomfort glare was not considered because visual comfort, motivation, and fatigue do not apply in escape situations. In the main experiment, 10 subjects were required to travel a corridor under six levels of emergency lighting. Obstacles were placed in the path of travel in a random manner, and the location of objects was altered for each test. The experiments showed a uniform floor illuminance of 0.28 lux (0.026 ft-c) provided subjects with adequate visibility for carrying out the experimental task. Neither the diversity of emergency luminaires nor apparent brightness were found to affect performance. However, disability glare may be more critical in emergency lighting if an individual is looking toward a light source such as an exit sign, instead of looking down at obstructions as in these experiments.

GLARE REDUCTION FOR UNDERGROUND LIGHTS

Trotter, Donald and Laferriere, Louis (McGill University), Canadian Mining Journal 101 (9), 37-38, 40, 42, 43, 44 (1980).

Some basic theories on visual performance, discomfort glare, and disability glare are presented, and application is made to the underground mine environment. Underground mining personnel generally do not experience serious adaptation problems as most underground areas with permanent lighting have a sufficient illumination level. However, problems of discomfort and disability glare in the low-luminance mine environment are often severe and affect the worker's safety and well-being. The following seven recommendations are given for minimizing the glare potential of underground mine luminaires, and practical applications are discussed for each one.

1. Avoid small sources of high luminance.

2. Use large sources of low luminance.

3. Mount luminaires out of the field of view.

4. Screen or shield source from direct view.

5. Use diffusing lenses or filters.

6. Keep difference in luminance between visible sources and backgrounds small.

7. Keep background and surround luminances high.

VISUAL PERFORMANCE DATA FOR 156 NORMAL OBSERVERS OF VARIOUS AGES

Blackwell, O. Mortenson and Blackwell, H. Richard (Ohio State University), Illum. Eng. Soc. J. 1, 3-13 (Oct. 1971).

A study conducted on the visual-performance potential of 156 "normal" observers from ages 23 to 68 provides an approximation of the real world population in this age range. Observers were tested for the threshold of visibility while viewing a flashing disk of variable brightness, thus measuring the effect of disability glare. These tests were conducted at both fixed and changing background luminances, ranging from 0.001 to 500 ft-L. In the analysis of the data, observers were grouped by age in 10-year spans: 20-30, 30-40, 40-50, 50-60, and 60-70. The threshold contrast and task contrast were plotted against age at various background luminances. Results showed that large differences in visual performance capability exist among individuals in the same age group and between the averages of different age groups. As expected from previous studies, visual performance decreases with increasing age. Future research work needed in visual performance capability is outlined.

THE DEMOGRAPHIC VARIABLES OF DISCOMFORT GLARE

Bennet, Corwin A., Ph.D. (Kansas State University), Lighting Design & Application 7, 22-24 (Jan. 1977).

Two studies were conducted where observers made several judgments on the borderline between comfort and discomfort (BCD) of a light source with variable brightness to relate some demographic variables to discomfort glare. The first study was conducted in 1972 at Kansas State University (KSU) with 162 observers and was the basis for eliminating several demographic variables that were thought to be related to glare sensitivity. These were sex, hair color, wearing of glasses, having a light occupation, and the "sunniness" of one's residential location. The second study was carried out at Kansas State University with 199 observers, but the only demographic correlations made were age, eye color, indoor/outdoor occupation, and residential population classification. Observers participating in the study were primarily high school students, parents, and other interested individuals viewing exhibits at an annual KSU Engineering Open House. The following correlations were drawn from this study:

1. Older people are more sensitive to discomfort from overly bright lights than younger people, in direct proportion to their age.

2. Blue-eyed people are slightly more sensitive to discomfort glare from lighting than brown-eyed people.

3. Indoor workers are slightly more sensitive to discomfort glare from lighting than outdoor workers.

4. People living in large population areas are equally as sensitive to discomfort glare as residents of small population areas.

LIGHTING FOR DIFFICULT VISUAL TASKS

Faulkner, Terrence W. and Murphy, Thomas J. (Eastman Kodak Company), Human Factors 15, 149-162 (April 1973).

Visibility of difficult visual tasks can be improved by changing the task, increasing the light level, or altering the character of light. The visual task may be changed by such methods as magnifying the task or applying a different finish to it. However, when it is not possible to change the task, because of product design requirements, time limitations, etc., a change is required in the illumination of the task. Light levels may be increased to levels of 1000 ft-c or more, but a resulting improvement in visual performance will only occur when the task contrast is very low, approaching the threshold of visibility. High-contrast tasks seldom show any improvement in performance at light levels above 10 to 20 ft-c, while low-contrast tasks show improvement up to 50 or 100 ft-c. In practice, improvements in task visibility from use of special-purpose lighting are substantially greater than improvements achieved through increases in light level. Seventeen types of special-purpose lighting are described, and applications of each system are given. Inspection lighting is one of the most common forms of special-purpose illumination. Experience with designing lighting systems for inspection work has shown that the quantity of light directed on a difficult visual task is less important than the type of light selected. In some cases additional increases in general illumination may actually present a hindrance to performing a difficult visual task.

THE PUPILLARY RESPONSE AND DISCOMFORT GLARE

Fry, Glenn A. and King, Vincent M. (Ohio State University), Illum. Eng. Soc. J. 4, 307-324 (July 1975).

A four-part study was conducted to investigate pupillary fluctuations as an index of discomfort glare. The authors refer to a previous work by Fry and Fugate where discomfort glare from a flashing light was attributed to stimulation of nerve endings in the irides. The major objective in this investigation was to develop a method for analyzing the components of pupil fluctuations. This paper attempts to trace discomfort-glare activity in the sphincter muscle of the iris which manifests itself in minor fluctuations in the diameter of the pupil. Human and artificial pupils are analyzed for their response to steady, momentary, intermittent, and alternating stimuli. Results of this work show: (1) although increased light levels reduce the size of the pupil, fluctuations in the size of the pupil generate discomfort glare more than size alone; and (2) in practice, environments that require rapid adaptation to varying light levels will result in increased discomfort glare, regardless of the average level of illumination.

LIGHTING, PRODUCTIVITY, AND THE WORK ENVIRONMENT

Hughes, P. C. and McNelis, J. F. (General Electric Co.), Lighting Design & Application 8, 32-40 (Dec. 1978).

A study was conducted to determine the effect of different light levels on the work performance of younger and older office workers. Two visual tasks performed were similar to those done by clerical workers in an office environment. The first task performed by a group of 12 office workers consisted of searching three-digit tabular material for 10 numbers. Lighting levels were 50, 100, and 150 ft-c. In a second task, completed by nine office workers, two columns of letters and numbers were compared for similarities, again under light levels of 50, 100, and 150 ft-c. In addition, all personnel completing either task gave subjective reactions to the three lighting levels based on the following criteria: effort needed to perform the task, distinctiveness of print, eye comfort, brightness, stimulation, and satisfaction. Average gains in productivity were five percent when light levels were increased from 50 ft-c to 100 ft-c and nine percent, when they were increased to 150 ft-c. Older workers realized greater increases in productivity than younger workers as levels of illumination increased. Also, older workers found lower illumination levels (50 ft-c) more objectionable than younger workers. Both older and younger workers indicated the quality of the lighted environment improved with increasing levels of illumination. A mean improvement of 31 percent and 46.9 percent was realized by increasing the light level from 50 to 100 and 50 to 150 ft-c, respectively.

LIMITATION OF DISABILITY GLARE IN ROADWAY LIGHTING

Jung, F. W. (Ontario Ministry of Transportation and Communications), Ont. Min. of Transp. and Commun., Record No. 628, 33-37 (1977).

"Safety and comfort while driving at night depend on the visual detection of objects, which is based on contrast. The performance of this visual task is related to the relative contrast sensitivity of the lighting system provided, which is a function of the roadway or background luminance and is adversely affected by disability veiling brightness or glare." A method of designing roadway lighting systems to limit disability glare is proposed; it specifies a minimum value of effective relative contrast sensitivity for a particular road class. When glare sources are present, the relative contrast sensitivity of a task being viewed is decreased by disability glare and eye adaptation, resulting in an effective relative contrast sensitivity with a smaller value. "A simple formula has been derived for the effective relative contrast sensitivity of a lighting system by using curve-fitted standardized data. Glare control by limiting the relative contrast sensitivity can be achieved by a permissible glare formula or a diagram. The method is demonstrated by examples."

NEW CONCEPTS IN DIRECT GLARE CONTROL

Lewin, Ian (Holophane Company, Inc.), Illum. Eng. Soc. J. 2, 209-215 (April 1973).

A simplified technique for assessing Visual Comfort Probability (VCP) of light fixtures was formulated, and a new lens with high efficiency and high VCP was developed. The Equal Area Equal Glare System (EAEGS) can be used to assess visual comfort based on the premise that, in a given room, light fixtures are viewed at different angles, each contributing to the overall glare effect. Overhead light fixtures viewed from various angles are weighed according to the amount of glare produced from each, and the products of the luminance and weighting factor for each fixture are added to give a sum which is a measure of the total glare effect. Using this principle, it was shown that fixtures in view at angles less than 70 degrees from the vertical contribute substantially less direct glare than fixtures at angles ranging from 70 to 90 degrees. Although overhead fixtures viewed at 70 to 90 degrees are a greater distance from the observer, these fixtures contribute most of the direct glare because of their close proximity to the horizontal line of sight. The concept of EAEGS was used to determine the photometric distribution required by a luminaire to produce high visual comfort. From these data, a completely new lens was developed that allows passage of light only in the useful zone, ranging from 0 to 70 degrees. A superior combination of efficiency and VCP were achieved by eliminating high angle brightness.

DURATION OF AFTERIMAGE DISABILITY AFTER VIEWING SIMULATED SUN REFLECTIONS

Saur, R. L. and Dobrash, S. M. (General Motors Corp.), Applied Optics 8, 1979-1801 (Sept. 1969).

The view out of an automobile driver's window was modeled with simulated glare reflections from the sun, a roadway, and an identification target appearing to be 96 meters ahead along the roadway. The scene was painted on a matte surface at an actual viewing distance of 91.5 cm. The glare source was located 5 degrees below the target, simulating the sun's reflection from a windshield wiper arm. The 35 observers viewed the glare source for realistic intervals, then the time they required to recognize the target was measured. Curved, mirrorlike surfaces and matte surfaces were compared for control of discomfort glare and afterimage disability. Results show: (1) proper curvature of mirrorlike surfaces reduces afterimage disability and discomfort glare equally, and at least as much as the matte surfaces now specified in Federal Standards on Automotive Safety; (2) the increase in time required to identify the target with a glare source compared to no glare exposure varied from 0.8 to 2.7 seconds; and (3) for those observers licensed to drive, afterimage disability was not affected by age or visual acuity.

THE THRESHOLD OF DISCOMFORT GLARE AT LOW ADAPTATION LEVELS

Putnam, Russell C. and Faucett, Robert E. (Case Institute of Technology), Illum. Eng. Soc. J., 505-510 (Oct. 1951).

"This paper presents a fundamental study of the borderline between visual comfort and discomfort at low adaptation levels and small glare sources. It takes into consideration the adaptation of the eye and the apparent source size as well as the brightness of the source. Fifteen observers were used in the investigation. Relationships are obtained for the borderline between comfort and discomfort in terms of adaptation level and source size. The adaptation levels range from 10 to 0.001 foot-lamberts and the source size from 0.0011 to 0.000001 steradian which approximate the conditions found in street lighting." The primary conclusion presented was that, "considerable brightness can be tolerated without discomfort if the sources are small, whereas the brightness must be kept relatively low for large sources if comfort is to be maintained, assuming other factors are unchanged."

POLARIZED LIGHT IMPROVES VISUAL COMFORT

Tate, R. L. C. (Thorn Lighting Ltd.), Electrical Times 162, 33-34 (Nov. 1972).

In a discussion of polarized light, the author develops a method of reducing veiling (reflected) glare in working areas using partial polarization of light at the source. Light reflected from a glossy or semi-glossy surface lying flat on a desk is normally horizontally polarized; and light which penetrates the surface, revealing the brightness and color contrast beneath, is vertically polarized. Horizontal polarization is greatest when light strikes the surface at the "Brewster's angle," about 58 degrees from the normal. Horizontally polarized light can be eliminated using a polarizing screen. This screen permits only vertically polarized light to pass through, but cuts the light output in half. However, a new plastic material has been developed to provide vertically polarized light at a higher light output ratio than a polarizing screen. Thin flakes of air are imbedded in a clear panel to reflect horizontally polarized light and produce what is known as a "Polarized" panel. Reflected light is re-reflected inside a luminaire or luminous ceiling, depolarized in the process, resulting in additional output of vertically polarized light. These panels are advantageous over other methods to control veiling glare because they are effective from every angle. For example, desks may be arranged in a large open-plan office without regard to the orientation of overhead luminaires equipped with polarized panels.

A DISCOMFORT GLARE CALIBRATING DEVICE: SUBJECTIVE EVALUATIONS IN A STANDARD ENVIRONMENT

McNelis, John F. (General Electric Company), General Electric Company, Cleveland, Ohio, undated (9 pp).

A study was conducted to determine whether the basic research on Visual Comfort Probability (VCP) could provide a unified method to relate current research on discomfort glare in progress at various laboratories and universities in the U.S. and abroad. Basic VCP investigations were conducted with a large sphere about an observer to evaluate the visual comfort of indoor lighting. No visual task was performed except evaluating the comfort of the space. However, current research on discomfort glare is aimed toward controlling glare in outdoor and roadway applications and relating an individual's sensitivity to demographic variables. In this experiment, a group of 50 observers from a heterogeneous population participated in a study using a new discomfort glare calibrating device. They provided 1,000 determinations of the borderline between comfort and discomfort (BCD). The large sphere used in the basic VCP investigations was replaced by a smaller, more practical test box having dimensions of 100 cm wide x 80 cm high x 60 cm wide. Observers in the experiment selected BCD measurements by adjusting a glare source luminance to the point where the light became vaguely objectionable. The new calibrating device provided a measure of discomfort glare experienced by observers equal to the sphere. The new device is easy to construct and provides an effective means of relating new research in lighting and novel environments with a larger body of basic research using the VCP approach.

SHADOW-FREE LIGHTING DESIGN

Frier, J. P. (General Electric Company), Plant Engineering 33, 171-174 (Sept. 20, 1979).

Application criteria normally provided with industrial luminaires for buildings have included a value known as spacing-to-mounting height (S/MH) ratio. Frequently, this ratio has been interpreted as the recommended, rather than the maximum, spacing to supply illumination free of hot spots below a luminaire and dark spots between luminaires. To provide more uniform lighting when obstructions are present, the S/MH ratio should be decreased. In practice, this requires an increase in the number of luminaires and a reduction in the wattage of each.

When lighting areas with obstructions, this paper recommends that each luminaire provide no more than half the light directly beneath it, while other surrounding luminaires provide the rest. An example was given to demonstrate how to determine the relative light contribution of each surrounding luminaire in the area below a given luminaire. In conclusion, this paper points out that increasing the number of luminaires without increasing the overall wattage will normally result in more shadow-free lighting.

FIBER OPTICS: NEW DEVELOPMENTS BRING NEW APPEAL

Aronson, R. B. (Senior Editor, Machine Design), Machine Design 47, 81-85 (April 17, 1975).

Recent technical and economic developments have improved the outlook for utilizing fiber optics in a great number of new applications. Reasons for this increased interest in fiber optics include: the development of fibers which cause little distortion of a light signal; growing interest in mid-loss fibers; the rising cost and scarcity of metals, especially copper; and greater application of optoelectronic systems. The two most common materials used in fiber optics are plastic and glass. Plastic fibers are generally cheaper and frequently used for illumination over short distances, while glass fibers are more expensive and primarily used for data transmission over longer distances. Applications of fiber optics can be grouped into four broad categories: illumination, display, instrumentation, and communication. Fiber optics for illumination are commonly used in lighting inaccessible areas such as interiors of machines or body cavities. Light can be transmitted to the other end of a fiber or "leak" out light at various points along the fiber. Optical fibers have safety advantages because no electrical current or heat is present at the display face. Fiber-optic cables for display may be used to create alpha-numeric characters and pictures from ambient light emitted by the fiber. Application of fiber optics to instrumentation has been primarily with light-sensing heads that must be placed in hostile environments. Finally, fiber optics have found use in current short-distance communication, and probably with long-distance communication in the future.

A NEW EFFICIENT LIGHT GUIDE FOR INTERIOR ILLUMINATION

Whitehead, L. A., Nodwell, R. A., and Curzon, F. L. (University of British Columbia, Department of Physics).

The paper describes the experimental and theoretical studies of a recently patented prism light guide which combines the total internal reflection of optical fibers with the low attenuation of air transmission of light. Since it can be molded from acrylic plastics, the cost of the guide is low enough that large-scale interior illumination with piped light is feasible.

The operation of the prism light guide has been demonstrated experimentally and is in complete agreement with a simple theoretical model. The present quality of pipe produced by press-molding acrylic plastic is high enough to compete favorably with other types of light guides, and further improvements in manufacturing techniques will make it possible to use prism light guides for piping light to provide general interior illumination in buildings.

APPENDIX B

ARTICLES OBTAINED FOR REVIEW

1. ACRYLIC LIGHT DIFFUSERS IMPROVE FIRE RETARDANCY, ACOUSTICS AT TELEPHONE OFFICE, Lighting Design & Application 5, 54-55 (July 1975).

2. Ahmed, I. and Bennett, C. A., DISCOMFORT GLARE: DURATION-INTENSITY RELATIONSHIP, Illum Eng Soc J 8, 36-39 (Oct. 1978).

3. Allphin, W., MINIMIZING VEILING REFLECTIONS IN LIGHTING INSTALLATIONS, Plant Eng 26, 62-63 (June 1, 1972).

4. ALUMINUM REFLECTORS MEET DIVERSE LIGHTING REQUIREMENTS, Lighting Design & Application 5, 29 (Dec. 1975).

5. Amick, C. L., APPLYING THE 12 RECOMMENDATIONS, Lighting Design & Application 3, 37-41 (June 1973).

6. Anon, PRODUCTS TO LIGHT UNDERGROUND WORKINGS, Coal Min Process 13, 76-80, 104-105 (Oct. 1976).

7. Aronson, R. B., FIBER OPTICS: NEW DEVELOPMENTS BRING NEW APPEAL, Machine Design 47 (9), 81-85 (Apr. 17, 1975).

8. Bell, J. R., ILLUMINATION OF MINING EQUIPMENT, Min Cong J 65, 23-28 (Oct. 1979).

9. Bellchambers, H. E., RELATIONSHIP BETWEEN TWO SYSTEMS OF GLARE LIMITATION, Lighting Research & Technology 7, 106-112 (1975).

10. Bennett, Corwin A., Ph.D., THE DEMOGRAPHIC VARIABLES OF DISCOMFORT GLARE, Lighting Design & Application 7, 22-24 (Jan. 1977).

11. Blackwell, H. R., ANALYSIS OF INDIVIDUAL DIFFERENCES IN VISUAL PERFORMANCE TO BE EXPECTED WITH THE CURRENT IES METHOD FOR PRESCRIBING ILLUMINATION, Illum Eng Soc J 6, 3-9 (Oct. 1976).

12. Blackwell, H. Richard, DEVELOPMENT OF PROCEDURES AND INSTRUMENTS FOR VISUAL TASK EVALUATION, Illum Eng Soc J 70, 267-291 (April 1970).

13. Blackwell, O. M. and Blackwell, H. R., VISUAL PERFORMANCE DATA FOR 156 NORMAL OBSERVERS OF VARIOUS AGES, Illum Eng Soc J 1, 3-13 (Oct. 1971).

14. Boyce, P. R., CURRENT KNOWLEDGE OF VISUAL PERFORMANCE, Lighting Research & Technology 5, 204-212 (1973).

15. Brezovec, D., LIGHTING SUPPLIERS WORK TO CUT GLARE, Coal Age 85 (5), 192-193, 196-197, 200-201, 204-205, 208-209, 212, 215-216 (May 1980).

16. Brown, Malcom G. Jr., et al. (to RCA Corp.), CATHODE-RAY TUBE HAVING LITHIUM SILICATE GLARE-REDUCING COATING WITH REDUCED LIGHT TRANSMISSION AND METHOD OF FABRICATION, U.S. Pat. 3,898,509 (Aug. 5, 1975). 6 pp.

17. Burkhardt, W. C., HIGH-IMPACT ACRYLIC FOR LENSES AND DIFFUSERS, Lighting Design & Application 7, 12-20 (April 1977).

18. Canty, J. M., HYPERBARIC CHAMBER LIGHTING, ASME paper n 73-Pet-9 for meeting September 16-20, 1973.

19. Carl, E. M. and S. S. Williams, Texas Highway Dept., HIGH-LEVEL INTERCHANGE LIGHTING IS EFFECTIVE, Transmission & Distribution 22 (8), 30-34 (Aug. 1970).

20. Chironis, N. P., UNDERGROUND MINE LIGHTING; A LOOK AT WHAT'S NEW IN CONCEPTS AND EQUIPMENT, Coal Age 79, 66-74 (Aug. 1974).

21. Clark, D. A. B., Rank Precision Industries Ltd., FIBRE OPTICS, Light & Lighting 64 (4-5), 133-135 (Apr./May 1971).

22. Clark, G. W., DESIGNING FOR THE VISUAL ENVIRONMENT, Lighting Design & Application 2, 34-37 (Nov. 1972).

23. Crouch, C. L., TASK LIGHTING - THE DEBATE CONTINUES, Lighting Design & Application 8, 12-13 (July 1978).

24. Deal, Samuel Broughton, et al. (to RCA Corp.), METHOD OF PREPARING HAZE-RESISTANT LITHIUM-SILICATE GLARE-REDUCING COATING, U.S. Pat. 3,940,511 (Feb. 24, 1976). 5 pp.

25. de Boer, J. B., MODERN LIGHT SOURCES FOR HIGHWAYS, Illum Eng Soc J 3, 142-152 (Jan. 1974).

26. DiLaura, D. L., VISIBILITY, HUMAN PERFORMANCE, AND LIGHTING DESIGN; INTRODUCTION AND OVERVIEW, Lighting Design & Application 8, 46-47 (Jan. 1978).

27. DiLaura, D. L., VISIBILITY, HUMAN PERFORMANCE, AND LIGHTING DESIGN; EQUIVALENT CONTRAST AS A PRELUDE TO VISIBILITY LEVEL, Lighting Design & Application 8, 8+ (Feb. 1978).

28. DiLaura, D. L., VISIBILITY, HUMAN PERFORMANCE, AND LIGHTING DESIGN; THE CHOICE AND USE OF A VISIBILITY LEVEL, Lighting Design & Application 8, 58-59 (June 1978).

29. Dorsey, R. T. and Blackwell, H. R., PERFORMANCE-ORIENTED APPROACH TO LIGHTING SPECIFICATION, Lighting Design & Application 5, 13-27 (Feb. 1975).

30. Einhorn, H. D., ORIENTATED LIGHTING, Lighting Research and Technology 2 (4), 246-248 (1970).

31. Faulkner, T. W. and Murphy, T. J., LIGHTING FOR DIFFICULT VISUAL TASKS, Human Factors 15, 149-162 (April 1973).

32. Flynn, J. E., A STUDY OF SUBJECTIVE RESPONSES TO LOW ENERGY AND NON-UNIFORM LIGHTING SYSTEMS, Lighting Design & Application 7, 6-14. Discussion, Scutt, D. 14-15 (Feb. 1977).

33. Flynn, J. E. and Spencer, T. J., EFFECTS OF LIGHT SOURCE COLOR ON USER IMPRESSION AND SATISFACTION, Illum Eng Soc J 6, 167-179 (April 1977). Discussion 7, 63-64 (Oct. 1977).

34. Flynn, J. E., IES APPROACH TO RECOMMENDATIONS REGARDING LEVELS OF ILLUMINATION, Lighting Design & Application 9, 74+ (Sept. 1979).

35. Flynn, John E. and Spencer, Terry J., Ph.D., THE EFFECTS OF LIGHT SOURCE COLOR ON USER IMPRESSION AND SATISFACTION, Illum Eng Soc J 6, 167-179 (April 1977).

36. Fouassier, M., et al., RESISTANCE A L EBLOUISSEMENT DES TUBES INTENSIFICATEURS D IMAGES A GALETTE DE MICROCANAUX ET A DOUBLE FOCALISATION DE PROXIMITE, Acta Electronica 20, 369-378 (1977) (in French).

37. Franklin, J. Stuart, SEMI-DIRECTIONAL FIXED LIGHTING FOR ONE-WAY HIGHWAYS, Illum Eng Soc J 71, 14-20 (Oct. 1971).

38. Frier, J. P., SHADOW-FREE LIGHTING DESIGN, Plant Eng 33, 171-174 (Sept. 20, 1979).

39. Fry, G. A. and King, V. M., PUPILLARY RESPONSE AND DISCOMFORT GLARE, Illum Eng Soc J 4, 307-324 (July 1975).

40. Fry, G. A., SIMPLIFIED FORMULA FOR DISCOMFORT GLARE, Illum Eng Soc J 6, 10-20 (Oct. 1976).

41. Fryer, F. E. (Optical Instrumentation, Carpentersville, IL) and Goldberg, O. (Scottsbluff, NE), KOHLER ILLUMINATION USING FIBER OPTICS, Microscope 26 (1), 69-71 (1978).

42. GLARE BARRIER CUTS ACCIDENT RATES, Pub Works 106, 88-89 (March 1975).

43. Goodbar, I., et al., APPLYING VEILING REFLECTION FACTORS TO PRACTICAL FIELD USE AND MEASUREMENT, Lighting Design & Application 4, 45-53 (May 1974).

44. Guth, S. K. and McNelis, John F., A DISCOMFORT GLARE EVALUATOR, Illum Eng Soc J 59, 398-406 (June 1959).

45. Guth, S. K., A METHOD FOR THE EVALUATION OF DISCOMFORT GLARE, Illum Eng Soc J 63, 351-364 (May 1963).

46. Guth, Sylvester K., BCD BRIGHTNESS RATINGS IN LIGHTING PRACTICE, Illum Eng Soc J 52, 184-194 (April 1952).

47. Guth, Sylvester K., COMFORTABLE BRIGHTNESS RELATIONSHIPS FOR CRITICAL AND CASUAL SEEING, Illum Eng Soc J 51, 65-75 (Feb. 1951).

48. Guth, Sylvester K., COMPUTING VISUAL COMFORT RATINGS FOR A SPECIFIC INTERIOR LIGHTING INSTALLATION, Illum Eng Soc J 66, 634-642 (Oct. 1966).

49. Guth, Sylvester K. and McNelis, John F., FURTHER DATA ON DISCOMFORT GLARE FROM MULTIPLE SOURCES, Illum Eng Soc J 61, 46-57 (Jan. 1961).

50. Hartmann, E. and Ucke, Ch., Univ. of Munich, EFFECT OF SIZE OF GLARE SOURCE ON DISABILITY GLARE AT SMALL GLARE ANGLES, for Leo Kanner Associates, Redwood City, CA, May 1974. 11 pp.

51. Hemion, R. H., Southwest Research Inst., San Antonio, TX, DISABILITY GLARE EFFECTS DURING A TRANSITION TO POLARIZED VEHICLE HEADLIGHTS, for the U.S. Dept. of Transportation, Bureau of Public Roads, Federal Highway Administration, Jan. 15, 1969. 18 pp.

52. Herst, D. J. and Ngai, P. Y., RANKING SYSTEM BASED ON VISUAL PERFORMANCE POTENTIAL AND VISUAL COMFORT, Lighting Design & Application 8, 45-47. Discussion 47-52 (Aug. 1978).

53. HPS LIGHTS WEST VIRGINIA COAL MINE, Lighting Design & Application 7, 30-31 (Jan. 1977).

54. Hughes, P. C. and McNelis, J. F., LIGHTING, PRODUCTIVITY AND THE WORK ENVIRONMENT, Lighting Design & Application 8, 32-40 (Dec. 1978).

55. Jaffer, R. P., Robert P. Jaffer, Inc., Tampa, FL, RETROFIT RELIGHTING SAVES ENERGY, MONEY, Specifying Engineer 41 (4), 82-84 (April 1979).

56. Jung, F. W., Ontario Ministry of Transportation and Communications, LIMITATION OF DISABILITY GLARE IN ROADWAY LIGHTING, Transportation Research Record No. 628, 1977. pp 33-37.

57. Kaloudis, J. D., SIGNIFICANCE OF REFLECTED GLARE IN DESIGNING ILLUMINATION, Archit Rec 153, 146 (March 1973).

58. STEEL GLARE BARRIER REDUCES NIGHTTIME ACCIDENTS, Pub Works 105, 77 (Feb. 1974).

59. Kaufman, J. E., LIGHTING FOR SAFETY, Lighting Design & Application 3, 6-8 (March 1973).

60. Kudryavtseva, A. G., ANTI-REFLECTION COATING OF THE OPTICAL ELEMENTS OF MICRO-OBJECTIVES, Sov J of Opt Technology 42, 533-534 (Sept. 1975).

61. Lemons, Thomas M. and Robinson, Anne V., EXPLORING INDIRECT LIGHTING, Lighting Design & Application 9, 37-43 (Dec. 1979).

62. Lester, Cecil E., NEW UNDERGROUND LIGHTING REGULATIONS AND HOW THEY APPLY, Coal Min & Process 13, 66-69, 100 (Oct. 1976).

63. Lester, C. E., OVERVIEW OF REMAINING CRITICAL AREAS OF UNDERGROUND ILLUMINATION, presented at Coal Conference & Expo V, Symposium on Underground Coal Mining, Louisville, KY, by Coal Age, Oct. 23-25, 1979. pp 68-71.

64. LeVere, R. C., LIGHTING DESIGN FOCUSES ON VISIBILITY, Elec World 185, 76-78 (Feb. 15, 1976).

65. Lewin, I., NEW CONCEPTS IN DIRECT GLARE CONTROL, Illum Eng Soc J 2, 209-215 (April 1973).

66. Lewin, I., THE EFFECT OF ILLUMINATION SYSTEMS UPON VISUAL PERFORMANCE, Natl Bur Standards 3, 483-490 (May 2-5, 1972).

67. Lewin, I., VISUAL COMFORT PROBABILITY; FOR ALL LUMINAIRES, Lighting Design & Application 3, 54+ (March 1973).

68. Lewis, A. L., EFFECTS OF ILLUMINATION AND CONTRAST ON VISUAL PROCESSES AFFECTING COMFORT AND PERFORMANCE, Lighting Design & Application 6, 16 (Jan. 1976).

69. LIGHTING EQUIPMENT, Elect Constr & Maint 78, 74-76 (Oct. 1979).

70. LIGHTING PROGRESS 1976, Lighting Design & Application 6, 12-29 (Dec. 1976).

71. LIGHTS PROVIDE LOW-GLARE OPTICAL PERFORMANCE, Design N 33, 44 (Dec. 1977).

72. Long, George, E., et al. (to RCA Corp.), LITHIUM SILICATE GLARE-REDUCING COATING AND METHOD OF FABRICATION ON A GLASS SURFACE, U.S. Pat. 3,635,751 (Jan. 18, 1972). 5 pp.

73. Long, George, E., et al. (to RCA Corp.), SPRAY METHOD FOR PRODUCING A GLARE REDUCING COATING, U.S. Pat. 3,689,312 (Sept. 5, 1972). 4 pp.

74. Lovett, J. D., PROGRESS IN INDUSTRIAL LIGHTING, Electronics & Power 20 (11), 454-457 (June 13, 1974).

75. LOW LEVEL DISPLAY LIGHTING, Design and Components in Engineering 13, 22-29 (July 2, 1969).

76. Luckiesh, Matthew and Guth, S. K., BRIGHTNESS IN VISUAL FIELD AT BORDER-LINE BETWEEN COMFORT AND DISCOMFORT (BCD), Illum Eng Soc J 49, 650-670 (Nov. 1949).

77. Lumsden, W. K., EFFECTIVE TASK LIGHTING USING POLARIZED LIGHT, Light & Lighting Environ Des 69, 160-164 (July - Aug. 1976).

78. Martin, S., REDUCTION OF VEILING GLARE IN OPTICAL INSTRUMENTS BY THE USE OF LENS ELEMENTS OF ABSORBING GLASS, Applied Optics 9, 10 (Oct. 1970).

79. Mason, Richard H., COMPANIES TAKE THE INITIATIVE ON MINE LIGHTING, Coal Min Process 13, Oct. 1976. pp 72-74, 101, 104.

80. MATERIALS USED IN LIGHT CONTROL, Illuminating Engineering Society, IES LIGHTING HANDBOOK, Baltimore, Waverly Press Inc., 1972. pp 6-14 thru 6-21.

81. McNamara, A. C. and Willingham, Andy, THE CONCEPT OF VISUAL COMFORT PROBABILITY, Plant Engineering 29, 141-144 (June 12, 1975).

82. McNelis, John F., A DISCOMFORT GLARE CALIBRATING DEVICE: SUBJECTIVE EVALUATIONS IN A STANDARD ENVIRONMENT, General Electric Company, Lamp Business Division, Nela Park, Cleveland, Ohio, undated.

83. McNelis, J. F., HUMAN PERFORMANCE; A PILOT STUDY, Illum Eng Soc J 2, 190-194. Discussion 195-196 (April 1973).

84. Nelson, S. D. and Zimmer, S. J., STREETLIGHT SAVES ENERGY REDUCES GLARE, Electrical World 188, 70-71 (Oct. 15, 1977).

85. NEW SCREEN PREVENTS GLARE FROM ANY ANGLE, Pub Works 107, 79 (March 1976).

86. Ngai, P. Y., TASK CONTRAST AND VISIBILITY, Illum Eng Soc J 6, 52-58 (Oct. 1976).

87. Nicoll, Frederick H., et al. (to RCA Corp.), METHOD OF PRODUCING LOW GLARE COATINGS, U.S. Pat. 2,486,431 (Nov. 1, 1949). 4 pp.

88. Nicoll, Frederick H. (to RCA Corp.), LOW REFLECTING GLASS, U.S. Pat. 2,707,899 (May 10, 1955). 4 pp.

89. Patterson, C. T., USAMC Intern Training Center - USALMC, Texarkana, TX, DISABILITY GLARE AND CONTRAST ON THE SNELLEN EYE CHART IN GENERAL PRACTICE, submitted to the Industrial Engineering Dept. of Texas A&M Univ., May 1969. 52 pp. NTIS: AD-738940.

90. Patterson, W. C., OBTAINING QUALITY ILLUMINATION USING A PREFINISHED ALUMINUM REFLECTOR SHEET, Lighting Design & Application 7, 33-35 (Aug. 1977).

91. Plankenhorn, J. H., LIGHTING FIXTURE DESIGN FOR INDOOR APPLICATIONS, Specif Eng 41, 82-86 (March 1979).

92. POLYCARBONATE TUBE SHIELDS MINE LIGHT, Plastics World 36, 16 (Nov. 1978).

93. Pratt, C. F., SELECTING PLASTICS FOR TOUGH WORKING ENVIRONMENTS, Plastics Eng 34, 28-31 (Aug. 1978).

94. Putnam, Russel C. and Faucett, Robert E., THE THRESHOLD OF DISCOMFORT GLARE AT LOW ADAPTATION LEVELS, Illuminating Engineering, 505-510 (Oct. 1951).

95. Reed, J. J., NEW DIRECTIONS FOR POLYCARBONATE IN LIGHTING, Lighting Design & Application 9, 52+ (June 1979).

96. Ross, D. K., TASK LIGHTING; YET ANOTHER VIEW, Lighting Design & Application 8, 37-43 (May 1978). Discussion, Crouch, C. L. 8, 12-13 (July 1978).

97. Saur, R. L. and Dobrash, S. M., DURATION OF AFTER-IMAGE DISABILITY AFTER VIEWING SIMULATED SUN REFLECTIONS, Applied Optics 8, 1799-1801 (Sept. 1969).

98. Schmidt-Clausen, H. J., ASSESSMENT OF DISCOMFORT GLARE IN MOTOR VEHICLE LIGHTING, Lighting Research & Technology 6, 79-88 (1974).

99. Shelton, J. A., Yarsley Research Lab., PLASTICS IN OPTICAL APPLICATIONS, Polymer Age 6 (9), 236-237 (Sept. 1975).

100. Simmons, R. C., Thorn Lighting Ltd., Enfield, England, ILLUMINANCE, DIVERSITY AND DISABILITY GLARE IN EMERGENCY LIGHTING, Lighting Research and Technology 7 (2), 125-132 (1975).

101. Skinner, Charles S., HOW TO IMPLEMENT MINE ILLUMINATION, Coal Min & Process 16, 83-84, 86 (March 1979).

102. Skinner, C. S., Hahn, W. F., Ryba, S. J., Friedl, W. M., and Bockosh, G. R., FOCUSING ON THE TOUGH ILLUMINATION PROBLEMS UNDERGROUND, presented at Coal Conference & Expo V, Symposium on Underground Coal Mining, Louisville, KY, by Coal Age, Oct. 23-25, 1979. pp 72-82.

103. Smith, S. W., PERFORMANCE OF COMPLEX TASKS UNDER DIFFERENT LEVELS OF ILLUMINATION, Illum Eng Soc J 5, 235-242 (July 1976).

104. Stark, R. and Cossyphas, H., A SECOND LOOK AT LOW-PRESSURE SODIUM, Lighting Design & Application 2, 13-18 (April 1972).

105. STEEL GLARE BARRIER REDUCES NIGHTTIME ACCIDENTS, Public Works 105, 77 (Feb. 1974).

106. Stone, P. T. and Harker, S. D. P., INDIVIDUAL AND GROUP DIFFERENCES IN DISCOMFORT GLARE RESPONSES, Lighting Research and Technology 5, 41-49 (1973).

107. Swiech, R. E. and Webster, J. C., DESIGN PROCEDURE FOR PROVIDING OPTIMUM ILLUMINATION, Specif Eng 40, 94-98 (Oct. 1978).

108. Tate, R. L. C., POLARIZED LIGHT IMPROVES VISUAL COMFORT, Electrical Times 162, 33-34 (Nov. 30, 1972).

109. Thornton, W. A., HIGH VISUAL EFFICIENCY OF PRIME COLOR LAMPS, Lighting Design & Application 5, 35-39. Discussion 40-41 (Nov. 1975).

110. Trotter, D. and Laferriere, L., GLARE REDUCTION FOR UNDERGROUND LIGHTS, Canadian Mining Journal 101 (9), 37-38, 40, 42-44 (Sept. 1980).

111. Weakly, L. A., AREA ILLUMINATION IN ROOM AND PILLAR HARD ROCK MINES, Min Eng 30, 674-678 (June 1978).

112. Yonemura, G. T., TASK LIGHTING; ANOTHER VIEW, Lighting Design & Application 7, 27-30 (Nov. 1977).

APPENDIX C

DISCUSSION OF ARTICLES POTENTIALLY RELEVANT TO MINE LIGHTING

1. "Visual Performance Data for 156 Normal Observers of Various Ages"

Blackwell, O. Mortenson and Blackwell, H. Richard

Test results discussed show that large differences in visual performance capability exist among individuals in the same age group and between averages of different age groups, and that visual performance decreases with increasing age.

The tests described in this article were conducted under "ideal" lab conditions and confirmed that, for the "normal" population, age and visual acuity do affect an individual's sensitivity to disability glare, older persons being more sensitive. The differences that exist in the normal population also exist in the underground miner population and may be accentuated by the working environment. This was the basis for the tests of underground miners in this report.

2. "The Demographic Variables of Discomfort Glare"

Bennet, Corwin A., Ph.D.

The project resulted in correlations between demographic variables and discomfort glare which showed that (1) older people are more sensitive than younger people to discomfort from overly bright lights, (2) blue-eyed people are more glare sensitive than brown-eyed people, (3) indoor workers are slightly more sensitive than outdoor workers, and (4) urban and rural residents are equally glare sensitive.

These results confirm the findings that age affects discomfort glare sensitivity, and includes eye color and environment as additional factors. Of particular interest is the indoor/outdoor relationship, which indicates "indoor" workers are more sensitive to discomfort glare than "outdoor." Miners should obviously be classified as "indoor" workers and therefore should be more sensitive to disability glare. However, their relationship to light sources, very close and often in their line of sight, may alter the expected result.

3. "Lighting for Difficult Visual Tasks"

Faulkner, Terrence W. and Murphy, Thomas J.

Study results presented in this paper indicate that special-purpose lighting will have more significant positive results than a general increase in light level. In some cases, increasing general illumination may actually hinder performance of a difficult task. Therefore, two approaches are suggested. One is to apply special high-level lighting to specific areas; i.e., the face for continuous miners and the roof for bolters; and/or use low-level general lighting but make objects more visible by using luminous colors; for example, luminous jackets and caps for personnel and stripes on wires, hoses, etc.

4. "The Pupillary Response and Discomfort Glare"

Fry, Glenn A. and King, Vincent M.

In the tests described in this article, results indicate that, in practice, environments that require rapid adaptation to varying light levels will result in increased discomfort glare regardless of the average level of illumination.

The mine work place is required to be uniformly lighted; therefore, after the initial adaptation period, face personnel should not have problems with discomfort glare due to rapid adaptation requirements. However, face personnel are continually alternating their observations between the "uniformly" low-level lighted coal surfaces and the non-uniform, machine-mounted illumination system, having several high-intensity point sources and relatively dark background surfaces. This does represent a situation involving rapid adaptation, with its potential discomfort glare problems, and indicates a need for further development of lighting systems which minimize this condition.

5. "Lighting, Productivity, and the Work Environment"

Hughs, P. C. and McNelis, J. F.

Results of this and other studies have indicated that increased productivity can be achieved by increasing light levels, particularly among older workers. However, the study discussed in this article was done for clerical work requiring observation of detail such as typed figures. This is vastly different from mine work and performed under significantly different conditions. Although this study may indicate a potential for increased productivity with mine lighting, other studies would be necessary to confirm this.

6. "Limitation of Disability Glare In Roadway Lighting"

Jung, F. W.

This article discusses the development of a simple formula for the effective, relative contrast sensitivity of a lighting system. This can be used in roadway-lighting systems to control glare by limiting the relative contrast sensitivity as determined by use of a permissible glare formula or diagram.

Since most surfaces in the mine working place quickly become covered with coal dust, contrast between objects being observed and their background is very low. If the "effective relative contrast sensitivity" discussed in this article can be adapted to the mine environment, it may offer a means of evaluating the low-contrast conditions that exist in underground coal mines. In addition, the technique of high visibility surface preparation to increase contrast between equipment surfaces, personnel, etc., and the coal surfaces could be assessed.

7. "New Concepts in Direct Glare Control"

Lewin, Ian

The project described in this article resulted in a procedure to measure the total glare effect of luminaires in a subject field of view. Results of this work show that fixtures in view, at angles less than 70 degrees from the vertical, contribute substantially less glare than fixtures at angles ranging from 70 to 90 degrees.

This study again verifies that the design of a successful mine-lighting system is difficult since the light sources are generally in the 70 to 90-degree angle from the vertical and, therefore, close to the personnel's line of sight. This would be particularly true in lower coal seams where most lights are essentially at eye level. This emphasizes the need to conduct further studies in the judicial use of shielding and diffusing and in use of novel light sources such as fiber optics and light pipes.

8. "Duration of Afterimage Disability After Viewing Simulated Sun Reflections"

Sour, R. L. and Dobrash, S. M.

The results of this project indicate that the concentrated light from highly reflective surfaces can create discomfort glare and afterimage disability problems. Specifically, the time required by an observer to recognize an object can be increased from 0.8 to 2.7 seconds as a result of such reflections. This is apparently independent of the subject's age or visual acuity. In the mine, these reflective surfaces could be equated to the high-intensity surfaces or point sources of the luminaires used in lighting systems. Mine personnel must frequently look at these sources in much the same way as the project test subjects viewed the reflective surfaces; consequently, the test results may be applicable to the mining situation. The increased recognition time could affect a miner's productivity and safety by requiring him to hesitate in his activity to allow the afterimage to clear up.

This suggests that one method to evaluate the effectiveness of an anti-glare material or technique would be to measure the duration of afterimage when using a light source both with and without it.

9. "The Threshold of Discomfort Glare at Low Adaptation Levels"

Putnam, Russell C. and Faucett, Robert E.

The primary conclusion of the work discussed in this paper was that considerable brightness can be tolerated without discomfort if the sources are small, whereas the brightness must be kept relatively low for large sources if comfort is to be maintained, assuming other factors are unchanged.

These results emphasize the difficulty of designing mine lighting systems with currently available hardware. In an open environment, mine-lighting fixtures could probably be used with little difficulty because they could be mounted further away from observers and would be a relatively small light source. However, in the confined environment of the working face, even the smallest luminaire becomes relatively large because of its close proximity to the observer. It then has a high potential as a glare source. This again emphasizes the need to study mine lighting to determine whether modifications can be made in the requirements that will permit the use of smaller and/or lower intensity sources.

10. "Polarized Light Improves Visual Comfort"

Tate, R. L. C.

Investigations have shown that light produced by a polarizing screen can reduce glare but the light output is cut in half. This article describes a new material to provide vertically polarized light at higher output ratios than a polarizing screen.

The use of materials that partially polarize the luminaire output have been shown to reduce glare and should be evaluated for use as diffusers on mine luminaires. These materials are available in plastic sheets or panels that eliminate horizontally polarized light and provide only vertically polarized light at a higher output ratio than a polarizing screen. This may reduce the glare potential of currently available hardware, particularly point-source luminaires.

11. "A Discomfort Glare Calibrating Device: Subjective Evaluations in a Standard Environment"

McNelis, John F.

The results of this study confirm that valid discomfort-glare data can be obtained by using a smaller, modified version of the large sphere used for glare studies at various laboratories and universities in the U.S. and abroad. This supports the position that glare data collected during the tests described in Section IV of this report would be comparable to data from tests conducted in the more sophisticated spheres, and conclusions and recommendations based on these data should be valid.

12. "Shadow Free Lighting Design"

Frier, J. P.

This paper deals with lighting levels achieved when varying the number, spacing, and wattage of luminaires. The conclusion states that increasing the number of luminaires without increasing the overall wattage will normally result in more shadow-free lighting.

This conclusion points out the problem with the uniformity requirement of the lighting regulations. Better uniformity requires more luminaires of lower output. This is counter-productive since mining equipment is not designed for the mounting of many luminaires. In addition, each luminaire, regardless of the wattage, is a potential glare source. Therefore, this provides some bases for reconsidering the uniformity requirements to minimize both the number of fixtures and the wattage required.

13. "Fiber Optics: New Developments Bring New Appeal"

Aronson, R. B.

As noted in this article, the use of fiber optics is becoming more attractive due to recent advances in materials and techniques used in the transmission of light by fibers. The basic concept of fiber optics is also attractive in mine lighting since, theoretically, a single light source, hidden from operator view, could supply illumination by a system of fiber cables strategically located on the machine. Based on these reported advances, a feasibility study should be considered to study the use of fiber optics and related systems such as light pipes.

14. "Illuminance, Diversity and Disability Glare in Emergency Lighting"

Simons, R. C.

The article's conclusion that 0.026 ft-c provided adequate lighting in escape-lighting situations suggests that the current MSHA standard of at least 0.06 ft-L of light in all active working places may be higher than the minimum light level needed to see potential slipping and tripping hazards. Even if the floor reflectivity in this experiment approached 100 percent, the floor luminance level needed to see the hazards would be only 0.026 ft-L. This indicates that a reevaluation of the minimum standards for underground coal mine face illumination may be warranted.

15. "Glare Reduction for Underground Lights"

Trotter, Donald and Laferriere, Louis

In this paper, some basic theories of visual performance, discomfort glare, and disability glare are presented, and application is made to the underground mine environment.

The discussion suggests that improved visibility in underground mines can be achieved with proper control of discomfort and disability glare from mine luminaires. Seven suggested recommendations are given which can be applied directly to the design of new mine luminaires, or to retrofitting currently existing luminaires with improved light-control techniques. This paper indicates that research on the effects of discomfort and disability glare is needed to provide a basis for mine luminaire design.

16. "A New Efficient Light Guide for Interior Illumination"

Whitehead, L. A., Nodwell, R. A., and Curzon, F. L.

The authors describe experimental and theoretical studies of a recently patented prism light guide which combines the total internal reflection of optical fibers with the low attenuation of air transmission of light. The pipes are molded from acrylic plastic; consequently, the cost of the guide is low enough to make commercial application feasible.

Within limitations, the guides can be made in a range of rectangular sizes, which may be practical for machine mounting. Advantages of the system would be that only a single source would be required and the exposed pipe would be cool and impact resistant. The relative ease of installation and use of a single light source may make the system practical for rib or roof-mounted systems.

PART II. - PSYCHOPHYSICAL STUDIES OF DISABILITY AND DISCOMFORT GLARE FOR UNDERGROUND COAL MINES AND MINERS

By

C. L. Crouch, P.E. and Richard L. Vincent

I. INTRODUCTION

In recent years the system of lighting mines has changed from only caplamps to both caplamps and general lighting with luminaires mounted on machines. In general these luminaires consist of diffusing-type equipment both incandescent and fluorescent. The fluorescent luminaires consist of fluorescent lamps enclosed in diffuse cylindrical housings. This introduction of general lighting luminaires has greatly changed the visual environment, and in general has received favorable reaction of the miners even though there are a number of complaints. A survey of their reaction has indicated in general that they would not want to revert to the former system of caplights only. Seventy-eight percent of the miners interviewed had complaints or questions regarding the lighting systems from the viewpoint of discomfort glare, disability glare, veiling reflections, and after-images. These complaints resulted in a serious concern on the part of the Mine Safety and Health Administration, MSHA, of the U.S. Government and the U.S. Bureau of Mines. The Bureau of Mines wished to correct the situation and instituted a study of both discomfort and disability glare, first from current underground lighting systems and second, the sensitivity of miners to the two forms of glare. The Bituminous Coal Research, Inc., and The Illuminating Engineering Research Institute have collaborated in making a study of these two phases.

GLOSSARY

In the analysis and discussions presented in the report, there are terms used that are unique to the field of lighting and vision. The following is a glossary of these terms to help (readers, users) better understand the report contents.

A. Terms Associated with Disability Glare

1. Disability Glare - glare which results in a reduction of visibility. It is caused by scatter of rays of light from bright areas or light sources as they enter the eye from the periphery of the field of view causing a veil of light overlaying the details to be seen.

2. Disability Glare Factor (DGF) - is defined as the visibility of a task seen under a given lighting system compared with the visibility of the same task seen under reference uniform and practically no glare lighting conditions. DGF measures any reduction in visibility due to disability glare.

3. Disability Glare Constant (K) - is the constant in the disability glare equation which accounts for scatter of light in the eye of the average observer in a reference population of observers.

4. Disability Glare Ratio (DGR) - is the ratio of the contrast of a given seeing task measured under uniform non-glaring conditions divided by the contrast of the same task measured under a calibrated glare condition.

5. Background Luminance (L) - is the non-glaring luminance which serves as contrasting background to the detail to be seen.

6. Effective Background Luminance (L_e) - is background luminance plus any superimposed luminance produced by the scattered light from glare sources in the field of view. It is the total effective luminance to which the eyes are adapted.

7. Veiling Luminance (L_v) - a luminance superimposed on the retinal image which reduces its contrast. It is this veiling effect produced by bright sources or areas in the field of view that results in decreased visibility.

8. Luminance of Uniform Surrounding Field (L_s) - is the uniform luminance surrounding the seeing task being measured.

9. Relative Contrast Sensitivity (RCS) - is a function of the eye's sensitivity to contrast varying with the background luminance expressed as a percentage of the value found under a given level (100 cd/m^2) of diffuse task illumination.

10. Visibility Level (VL) - is measure of how far above threshold seeing conditions a task is being seen. Threshold seeing being the probability that a given task will be seen is 50% of the time being presented; therefore, VL = 1 is considered threshold.

11. Visual Task Evaluator (VTE) - is a contrast threshold meter used to measure visibility of objects above their threshold of being seen in the working environment.

B. Terms Associated with Discomfort Glare

1. Discomfort Glare - glare which produces discomfort. It does not necessarily interfere with visual performance or visibility.

2. Borderline Between Comfort and Discomfort (BCD) - the concept of a sensation between comfort and discomfort as one goes from comfort to the border of discomfort.

3. Relative BCD - is the ratio of luminances, where comparable luminance COMP (L_c), the luminance judged by an observer to produce the same sensation as a lighting system being evaluated, is divided by BCD (L_{bo}), the luminance of a calibrated test source judged to be at the borderline between comfort and discomfort by the same observer.

4. Field Luminance (F) - is the luminance equivalent to the total of sources in the field of view to which the observer is adapted.

5. Index of Sensation (M) (of a source) - a number which expresses the effects of source luminance, solid angle factor, position index, and the field luminance on discomfort glare ratings.

6. Discomfort Glare Rating (DGR) - is a numerical assessment of the capacity of a number of sources of luminance, such as luminaires, in a given visual environment for producing discomfort. It is the net summation effect of the individual values of index of sensation for all luminous areas in the field of view.

7. <u>Visual Comfort Probability</u> (VCP) - the rating of lighting system expressed as a percent of people who, when viewing from a specified location and in a specified direction, will be expected to find it acceptable in terms of discomfort glare.

8. <u>Discomfort Glare Evaluator</u> (DGE) - is the instrumentation used to determine the acceptability of lighting systems in terms of discomfort glare, as well as to determine the rating of glare sensitivity of individual observers.

9. <u>Discomfort Glare Adjective Scale Rating</u> - a descriptive adjective scale which has been found to correlate with discomfort glare ratings and used to indicate the degree of discomfort being produced.

II. SUMMARY OF FINDINGS

A. General

Measurements of disability and discomfort glare from currently available lighting systems showed very serious glare effects in losses of visibility and attendant discomfort.

Sensitivity of miners to disability glare was about the same on the average as the aboveground population. However, there is considerable variation in sensitivity and by looking at the frequency curve plotting, one sees that there is a small percentage of miners who are very sensitive to glare which may account for the complaints and those miners' difficulties in finding a suitable illuminated environment. The measurements indicate an age factor and a possible color of eyes factor. There appeared to be no significant factor between on- and off- shifts. Loss of 50% visibility (the average from the systems tested) might well mean a 25-30% loss of visual performance according to the CIE Publication No. 19/2[1]. In general the data confirms the results of laboratory studies which constitute the basis of formulation in CIE 19/2. It is recommended that this formulation and its development in Appendix E be used for the design of lighting in mines and that visibility measurements of actual objects to be seen in mines be made to carry out visual performance analysis for the mine environment.

Sensitivity of miners to discomfort glare could be less dependent on the field brightness for the mining population than for the aboveground population by 41% due to the change in effect of the luminous environmental field factor from $F^{.44}$ for interiors, to $F^{.32}$ for mines. However, this is more than compensated for by the higher constant in the overall glare formula.

There is a 40% greater sensitivity of miners coming "off" the shifts in the mines than their readings as they go into the mines. If one is to design for the greater sensitivity apparently developed in the mine environment, then one should take this into account.

B. Phase I - Findings of Disability and Discomfort Glare from Current Mine Lighting Systems

1. Disability Glare

CONTINUOUS MINER: Using current formulas from the aboveground population, measurements of disability glare under conditions from seven different currently available lighting systems showed greatly reduced visibility due to disability glare. From Table D1, and Figure 6, one sees not only great losses but also great variations occuring at different positions of view around the continuous miner. The variation is from no

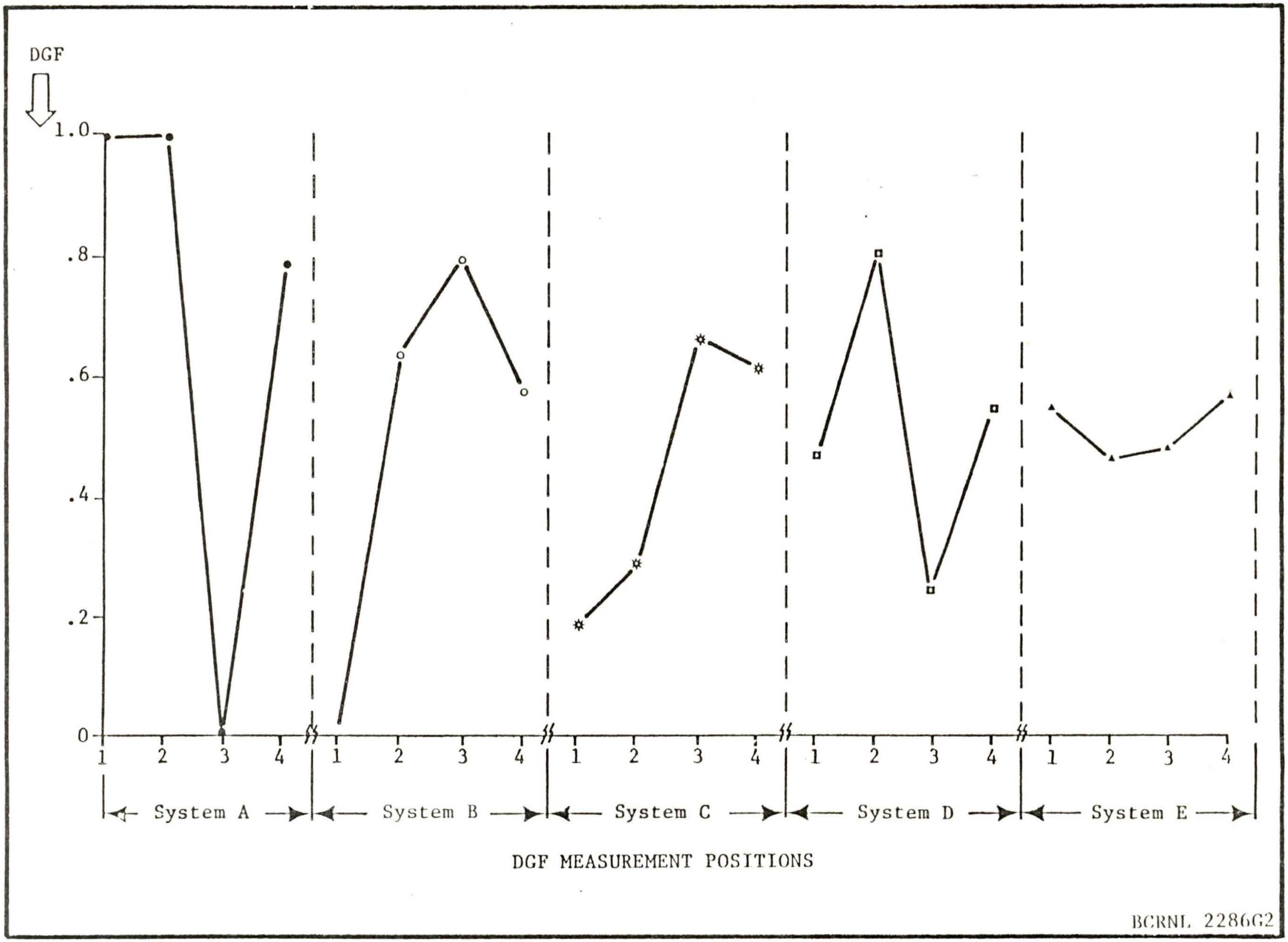


Figure 6. DGF for Lighting Systems on Continuous Miner

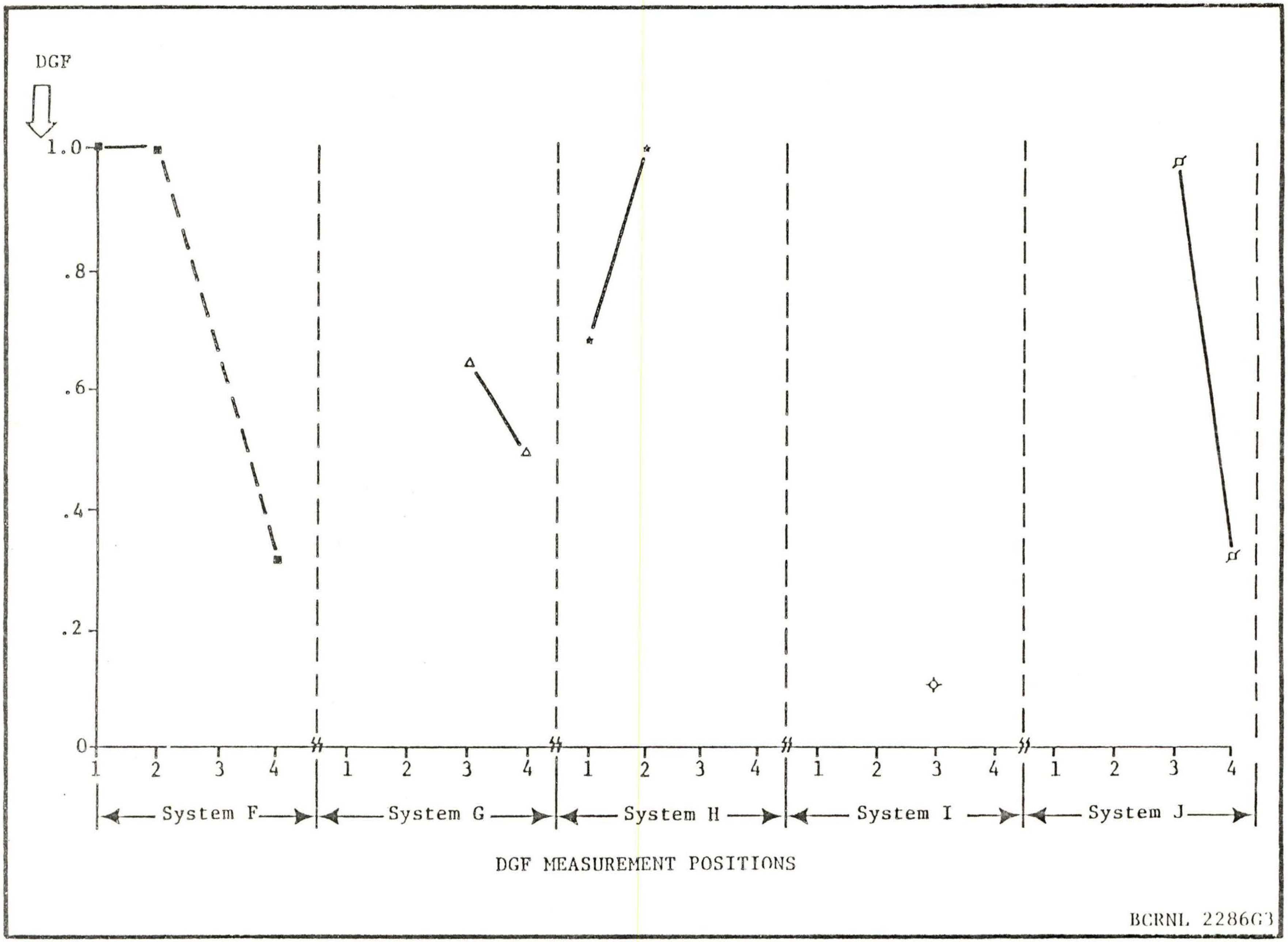


Figure 6. DGF for Lighting Systems on Continuous Miner (continued)

glare, DGF = 1.000 to extreme glare, DGF = 0.018 (1.8% visibility remaining after glare loss). Of course these losses of visibility change from position to position of viewing the systems around the continuous miner. Some lighting units, especially the incandescent, have greater shielding than the fluorescent, both from the geometry of the housing and the mounting arrangement, with parts of the mining machine occluding the view.

BOLTER: The values of DGF for the bolter appear in Table D2 and Figure 7. The magnitude of these values is the same as those for the continuous miner. The losses of visibility are serious and even severe in some cases for all systems.

2. Discomfort Glare

CONTINUOUS MINER: Two positions around the continuous miner were used with one being by the machine cab and the other on the opposite side of the machine. From the Guth analysis, Table E1, he points out, "...the main conclusion is that all the lighting systems are very glaring." In general the ratings varied from approximately "perceptibly uncomfortable" to "intolerable." The Visual Comfort Probability, VCP, (the percentage of observers that would be satisfied) varied from 0% to 28% (with the exception of one having a VCP of 50%).

The ratings on the opposite side of the miner as shown in Table E2, were in general lower but still largely in the discomfort glare category. They varied from the "borderline of comfort and discomfort" to "intolerable" and a VCP of 0% to 50% (with one being 65%).

An observer skilled in discomfort glare evaluations rated the systems from "barely uncomfortable" to "intolerable" as shown in Table E4, and corresponding verbal descriptions given in Table E3.

BOLTER: Three positions around the bolter were used for rating discomfort and represented strategic locations from the worker's viewpoint. The ratings shown in Table E5, were similar to those for the continuous miner although there appeared to be less discomfort glare from Systems 6 and 7. Not all the systems were tested because there was considerable similarity among several systems.

C. Phase II - Findings of studies of the Sensitivity of Miners to Glare

1. Disability Glare

a. Greater Sensitivity of Some Miners: A total of 110 miners were tested for their reaction to a given degree of disability glare. Some individuals were tested twice so that 144 responses were made. The overall

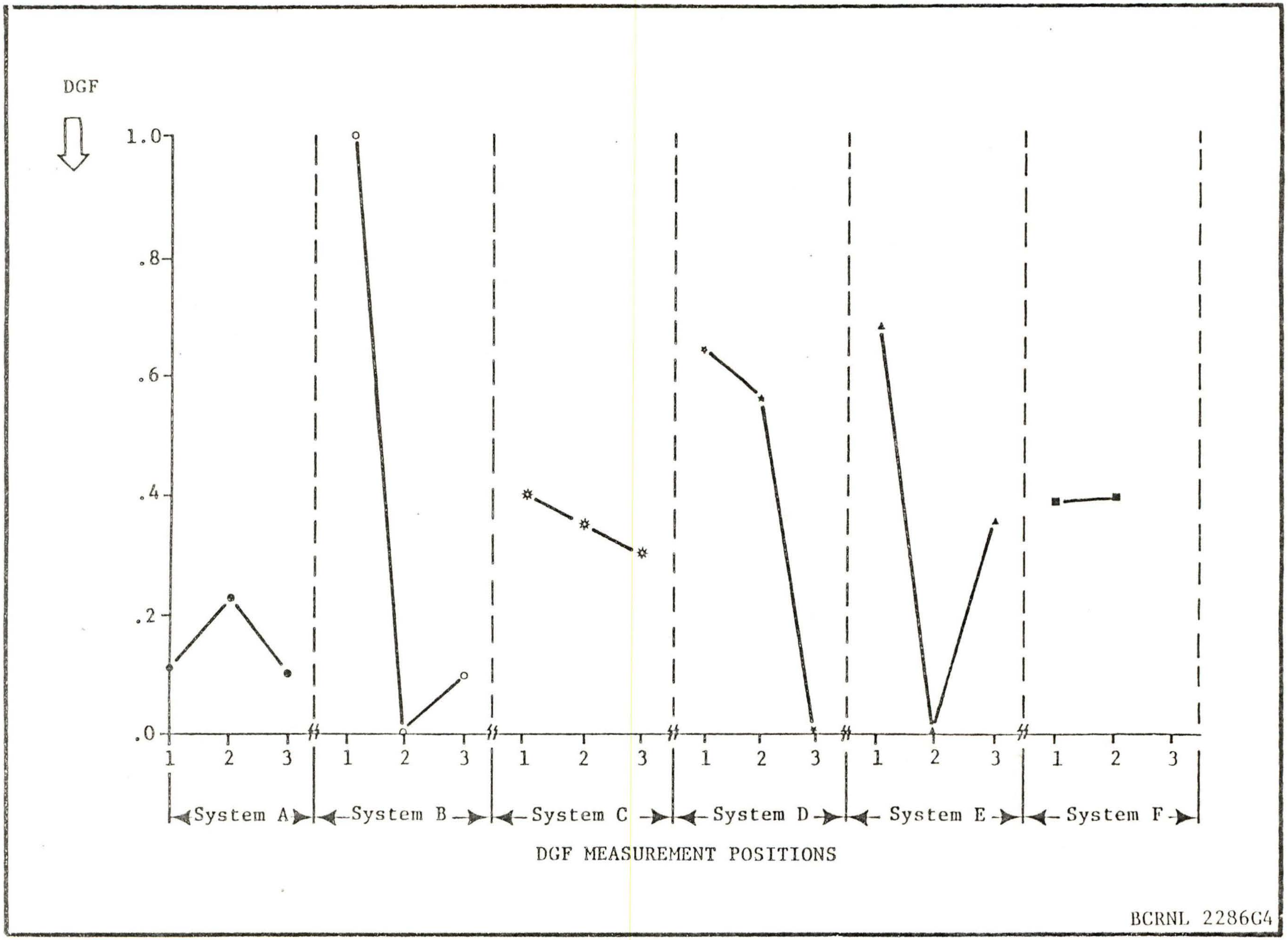


Figure 7. DGF for Lighting Systems on Bolter

results show a general shape of frequency curve as illustrated in Figure 8. This is a generalized curve derived from a probability graph as shown in Figure 9. From the left of Figure 8 cited above, one sees that there are a few miners who are very sensitive to disability glare. Since disability glare is a direct reduction of visibility, this would lead to the conclusion that under the low luminance conditions of mines, these particular miners might well be blinded by glaring lighting systems, particularly from certain viewing positions. This fact may well contribute to the unhappiness reported by the survey cited in the introduction.

By a similar argument, one can see from the righthand side of Figure 8 that a few are rather insensitive to disability glare.

Since Dr. H. Richard Blackwell, Director of the Institute for Research in Vision, Ohio State University, Columbus, has made extensive studies of disability glare[9], both in reference to a normally sighted population and taking account of the effects of age, the data from the 110 miners was transmitted to him for his analysis. His analysis given in Appendix E indicates the following:

1. The visibility losses due to the mean disability glare as measured from currently used lighting systems varied from 19.4% to 82.9%.

2. A visibility loss less than or equal to 74% will be experienced by 99.86% of the mining population, while 0.13% will have a loss of 23.9% or less.

3. Half of the mining population may be expected to have a visibility loss less than or equal to 50.71% and 50% will have a visibility loss greater than or equal to 50.71%.

Dr. Blackwell points out that the Crouch-Vincent data included a very few individuals whose age exceeded 50 years. When taking into account the age data available on the United States working population, ages 20-70 years, the following results were obtained: 98.86% of the new assumed population would have a visibility loss of 78.03% or less; only 0.13% would have a 24% loss or less; 50% would have a loss of 54.33% or less; and 50% would have a loss of visibility greater than or equal to 54.33%.

b. <u>Miners' Field Measurements Confirm Laboratory Findings:</u> Dr. Blackwell, analyzing all the data and comparing them with his laboratory studies and the data of Prof.-Dr. Werner K. Adrian (formerly of the University of Karlsruhe, Germany and now at the University of Waterloo, Canada), came to the conclusion that the measurements at the Derby and Prescott mines, consisting of 54% of the total, very nicely fit the pattern of the combined laboratory data confirming and supporting the whole,

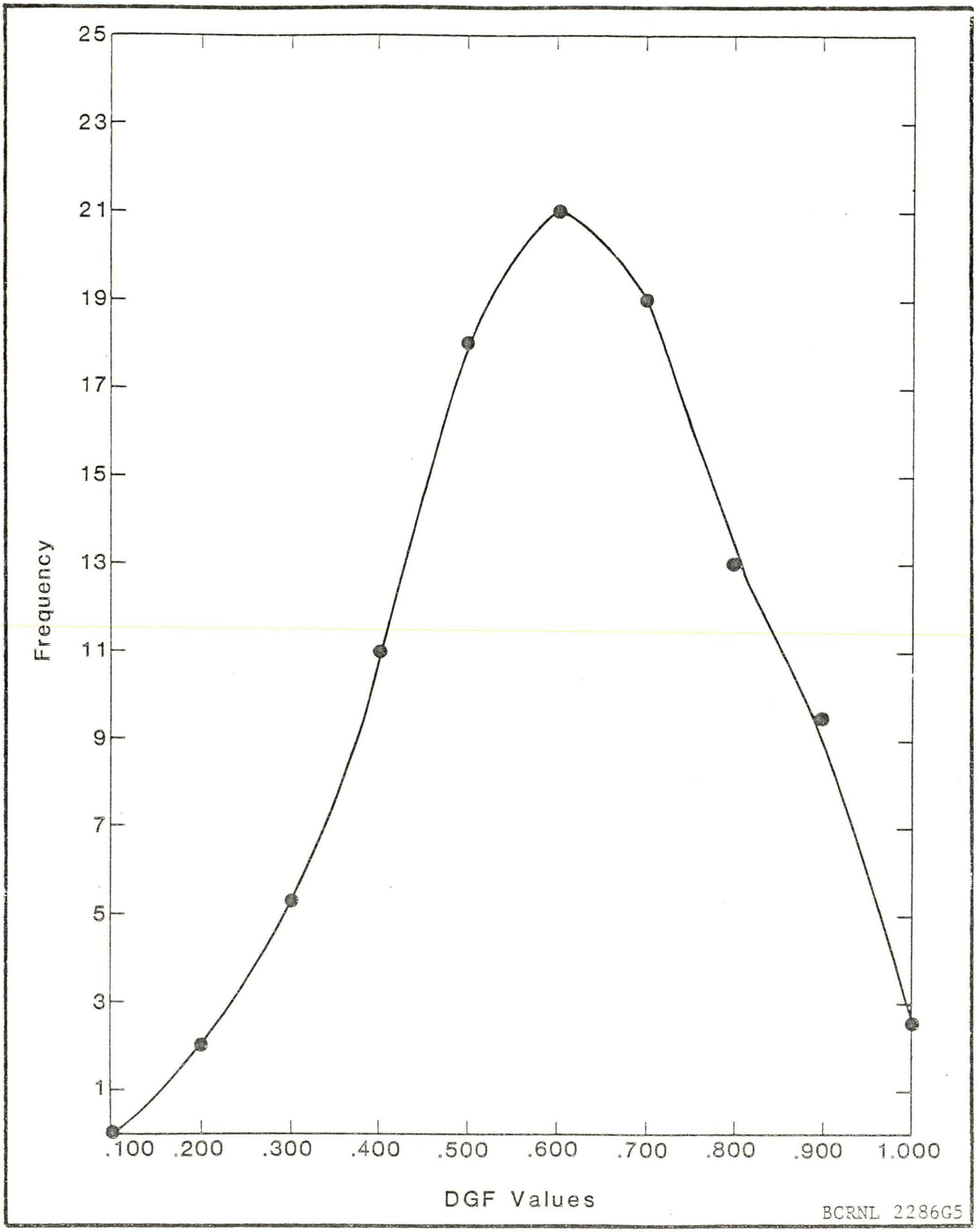


Figure 8. Normal Distribution of Low Luminance DGF's. All Miners, from a Relative Cumulative Frequency Plot

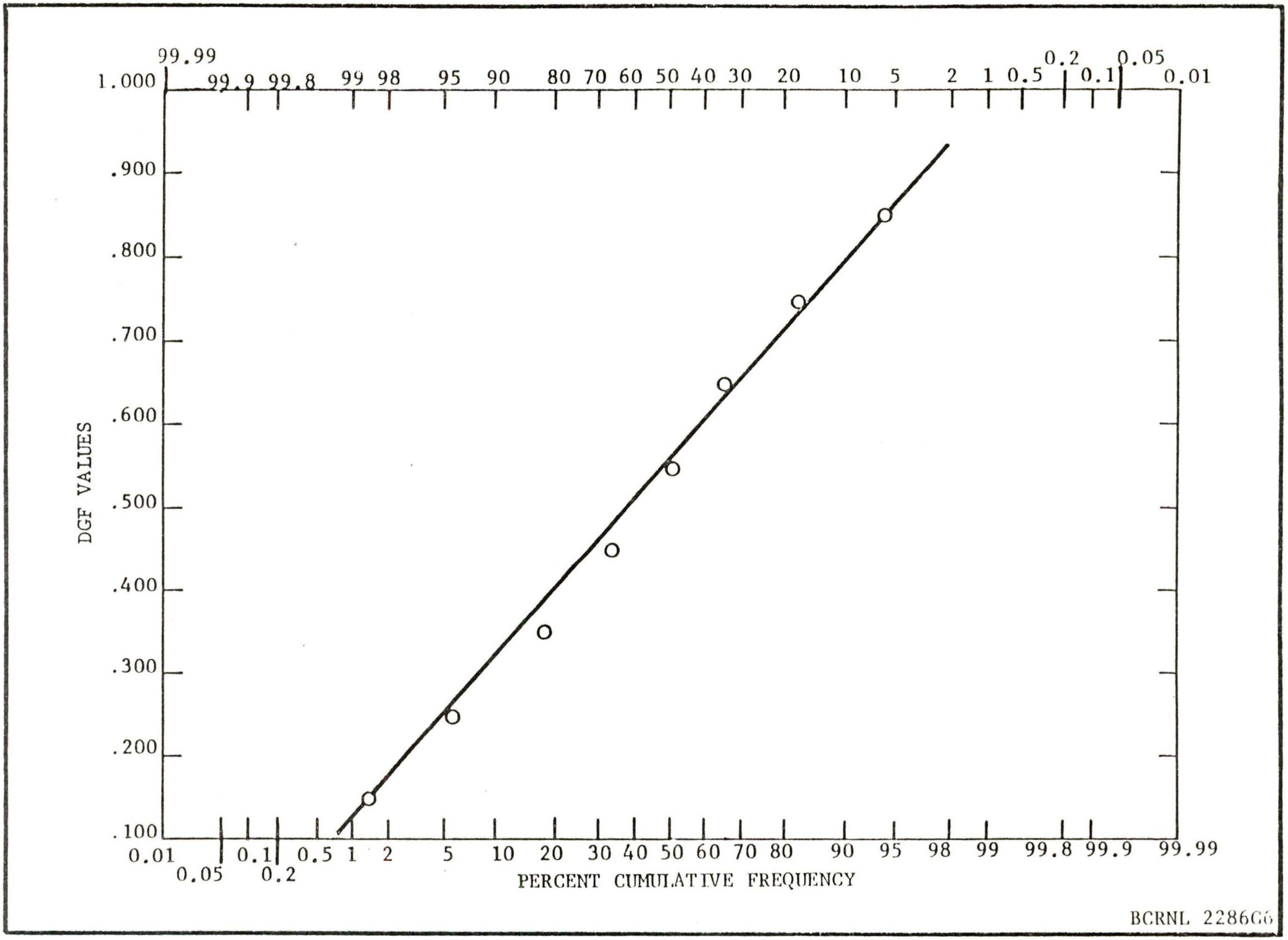


Figure 9. Relative Cumulative Frequency Plotting of Low Luminance DGF Values for All Miners at All Mine Sites

consisting of a grand total of 2,462 observers. All the data form the basis of the model for evaluating disability glare as presented in Appendix E. Disability glare is quantified by the disability glare factor, (DGF) as defined in the Introduction".

Dr. Blackwell in his extensive laboratory studies of the variation of disability glare with age found a very definite age effect (reference 9). The range of age covered by Blackwell was from 25 years old to 75 years old. This field study went from 21 years to 59 years old. The overall effect of age from this study is shown in Figure 10. Since Blackwell's studies were conducted under more carefully controlled laboratory conditions, with a wider range of age and a larger population sample than the study in the mines, it is reasonable to expect that the field study results would not be as significant; however, from the formulation developed by Blackwell the field results for 110 miners were analyzed in accordance with age. The results plotted in Figure 10 and based on Figures 11-13, while not significant, tend to be in the direction of Dr. Blackwell's findings. The straight mean value of DGF for each decade of age is shown below.

Age in Years	DGF
21-30	.575
31-40	.520
41-50	.512

A further analysis of the data to determine if eye color, light eyes vs. dark eyes, made a difference in response to disability glare showed an insignificant difference in the straight mean values which from Figure 14 are as follows:

Eye Color	DGF
Light	.540
Dark	.570

Response to disability glare based on coming "on" shift or "off" shift was analyzed with the straight mean values taken from Figure 15 showing no significant difference. Those mean values were:

Shift	DGF
On	.580
Off	.530

Since field measurements are never as precise as in laboratory conditions, it is recommended that the Blackwell formulation described in Appendix E be used. In general the field measurements were confirmatory of the laboratory results.

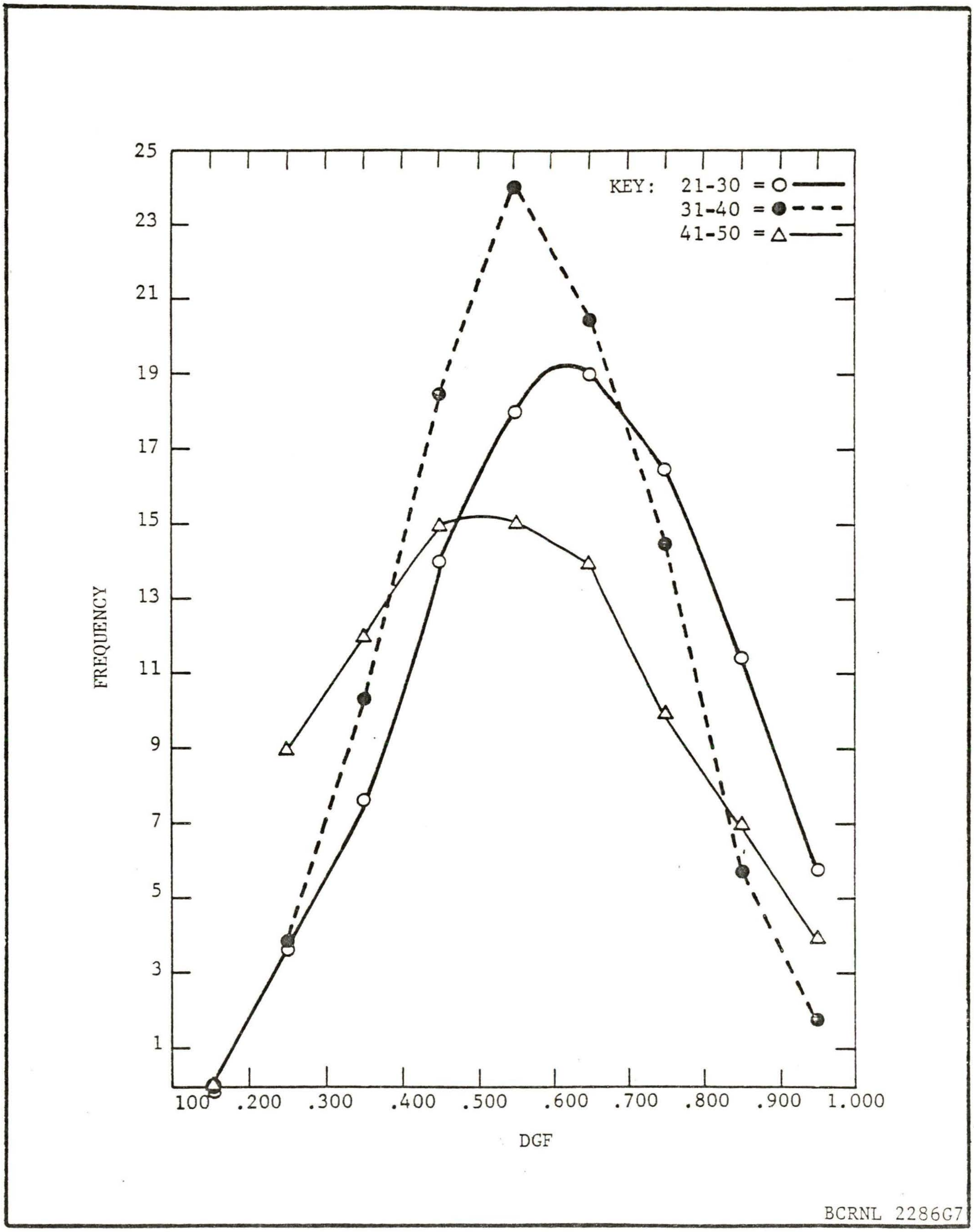


Figure 10. Normalized Distribution of Low Luminance Level DGF's for All 21-30, 31-40 and 41-50 Year Old Miners

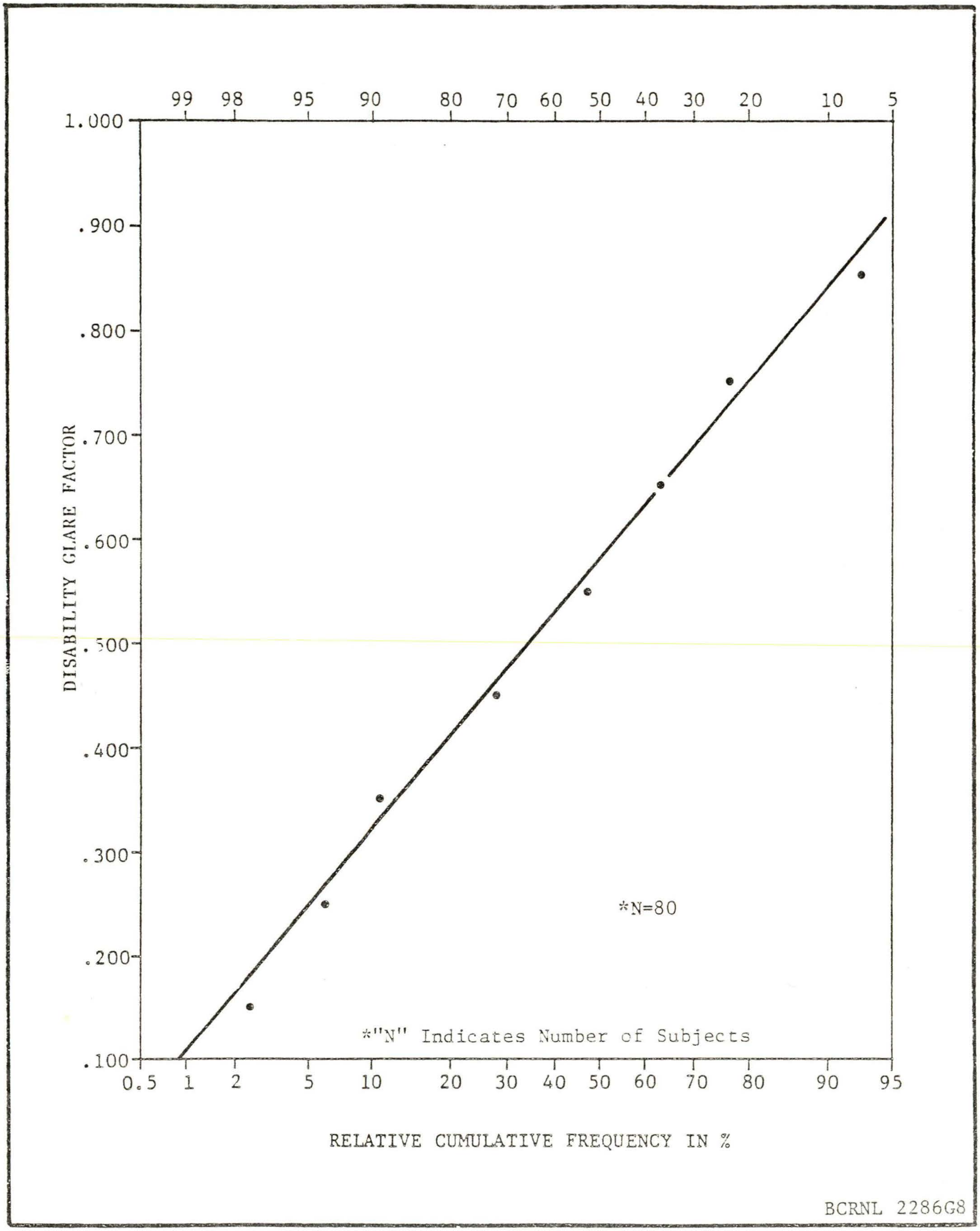


Figure 11. Low Luminance Level Disability Glare Factor:
All 21-30 Year Old Miners

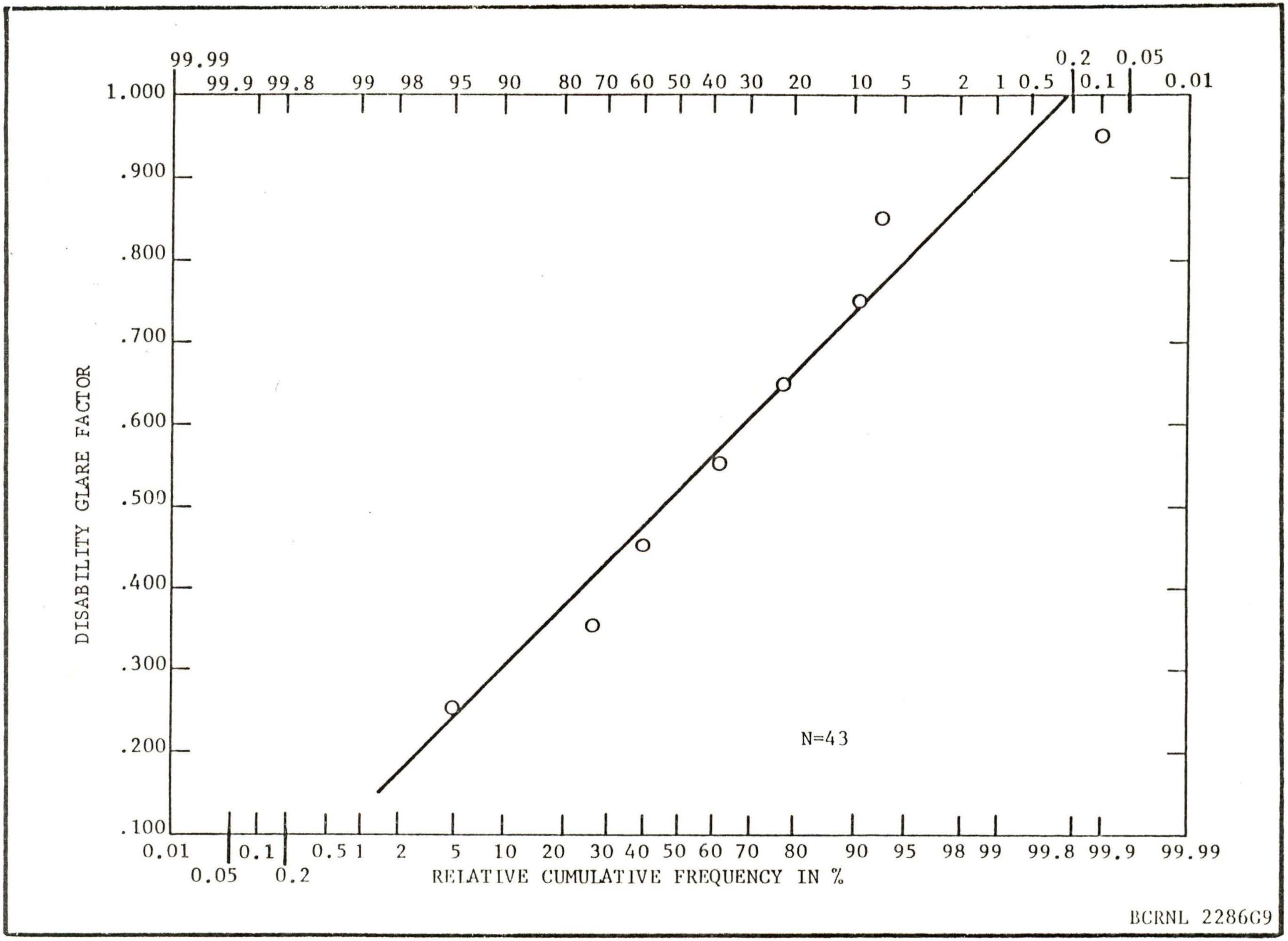


Figure 12. Low Luminance Level Disability Glare Factor: All 31-40 Year Old Miners

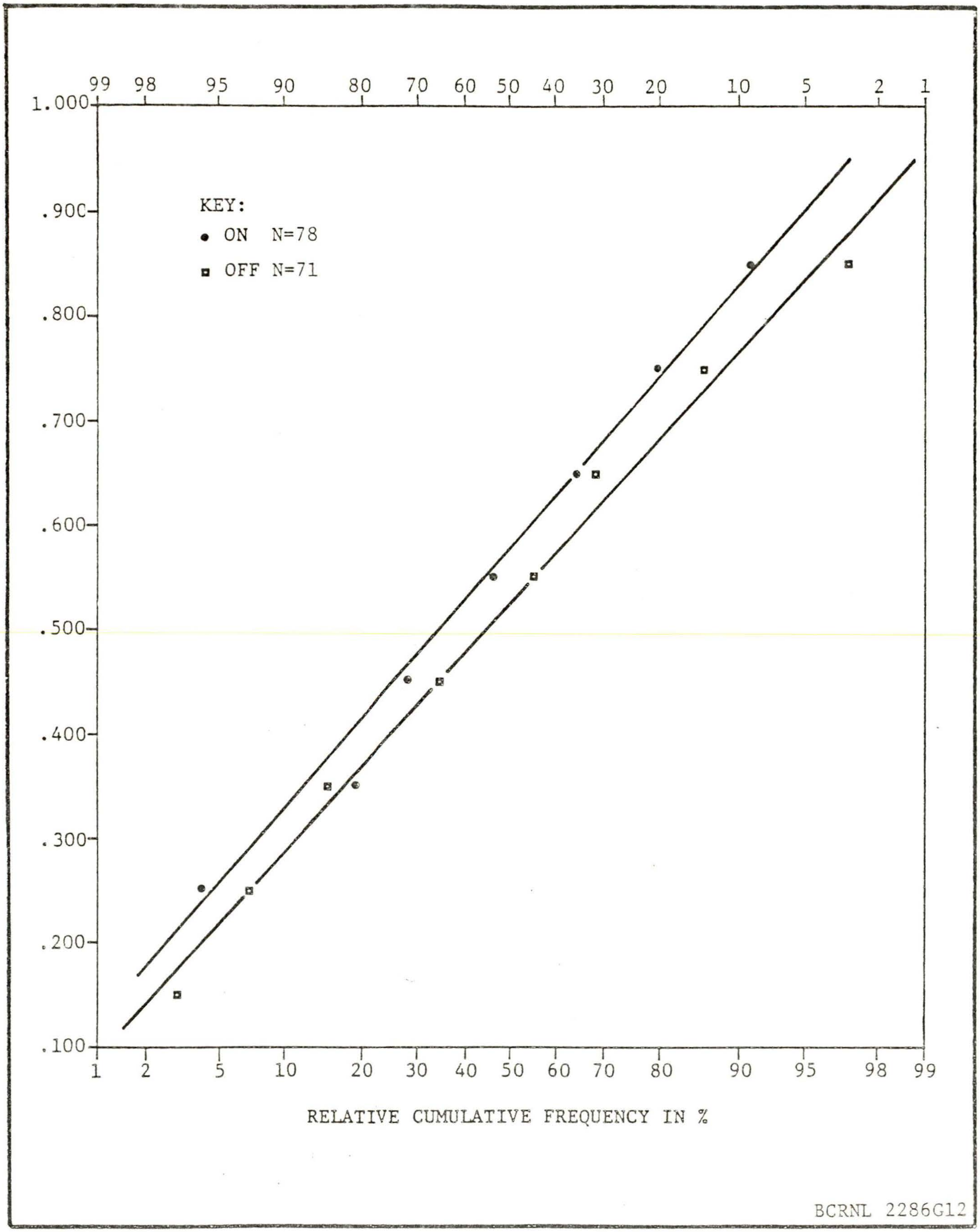


Figure 15. Low Luminance Level Disability Glare Factor: Shift Change; On vs. Off

2. Discomfort Glare

Useful data was obtained from 106 underground miners in relation to their sensitivity to discomfort glare. These were analyzed by Dr. Sylvester K. Guth, a specialist in discomfort glare. His analysis is found in Appendix F.

a. Sensitivity of Miners: If discomfort glare readings by the miners for a field luminance, F = 0.1 fL are treated like those for disability glare, in terms of a frequency distribution per 100 measurements to form a smooth curve, one arrives at the skewed curve shown in Figure 16. From this it can be seen that a rather large part of the miners were very sensitive to low luminances (less than 200 fL). Further there were some who were insensitive in relation to the value at the peak of the frequency distribution, Figure 16.

b. Effect of Field Luminance: Dr. Guth finds that the exponent of the field luminance (F) is 0.32 for miners, $F^{.32}$ instead of 0.44, $F^{.44}$ which has been found to apply to interiors and aboveground populations. Since the "borderline of comfort and discomfort", (BCD) luminance varies inversely with F this means that the glare value is less dependent upon the environmental brightness than for the aboveground interior lighting. If the field luminance currently required for mining situations is used, F = 0.06 fL, then $F^{.44}$ = 0.29 fL and $F^{.32}$ = 0.406 fL, then since the index of sensation, M for discomfort glare for a single luminaire equals the luminance of the source divided by F^x, then the M values for interior lighting would be 40% more than for mine lighting based on $F^{.44}$ for interiors and $F^{.32}$ for mines. However this is more than compensated for by a higher constant as based on Figure F9, as follows:

Discomfort Glare Luminance, L

Interiors: $L = 355\ F^{.44}$

Mines: $L = 614\ F^{.32}$

Dr. Guth has prepared the change in formula due to $F^{.32}$ and has presented the further formulation and graphs for application for design and field use in his report in Appendix F, Figures F6 and F12.

c. Sensitivity in the Mines: Dr. Guth has analyzed the miners' measurements in relation to whether they were taken as the miners came on or off their shift for all three shifts, as shown in Table F8.

In each of the shifts there was a difference with those coming off shift being more sensitive to glare than those going on shift. Those on Shift 1, (12 am to 8 am), showed the greatest gain of sensitivity, 55% for a field luminance of 0.1 fL. Those on Shift 2, (8 pm to 4 pm), showed a 52% gain in sensitivity with those on Shift 3, (4 pm to 12 pm), showing a 19% gain in sensitivity. Guth states that some of these differences could be due to the average sensitivity of each particular group. However, if one

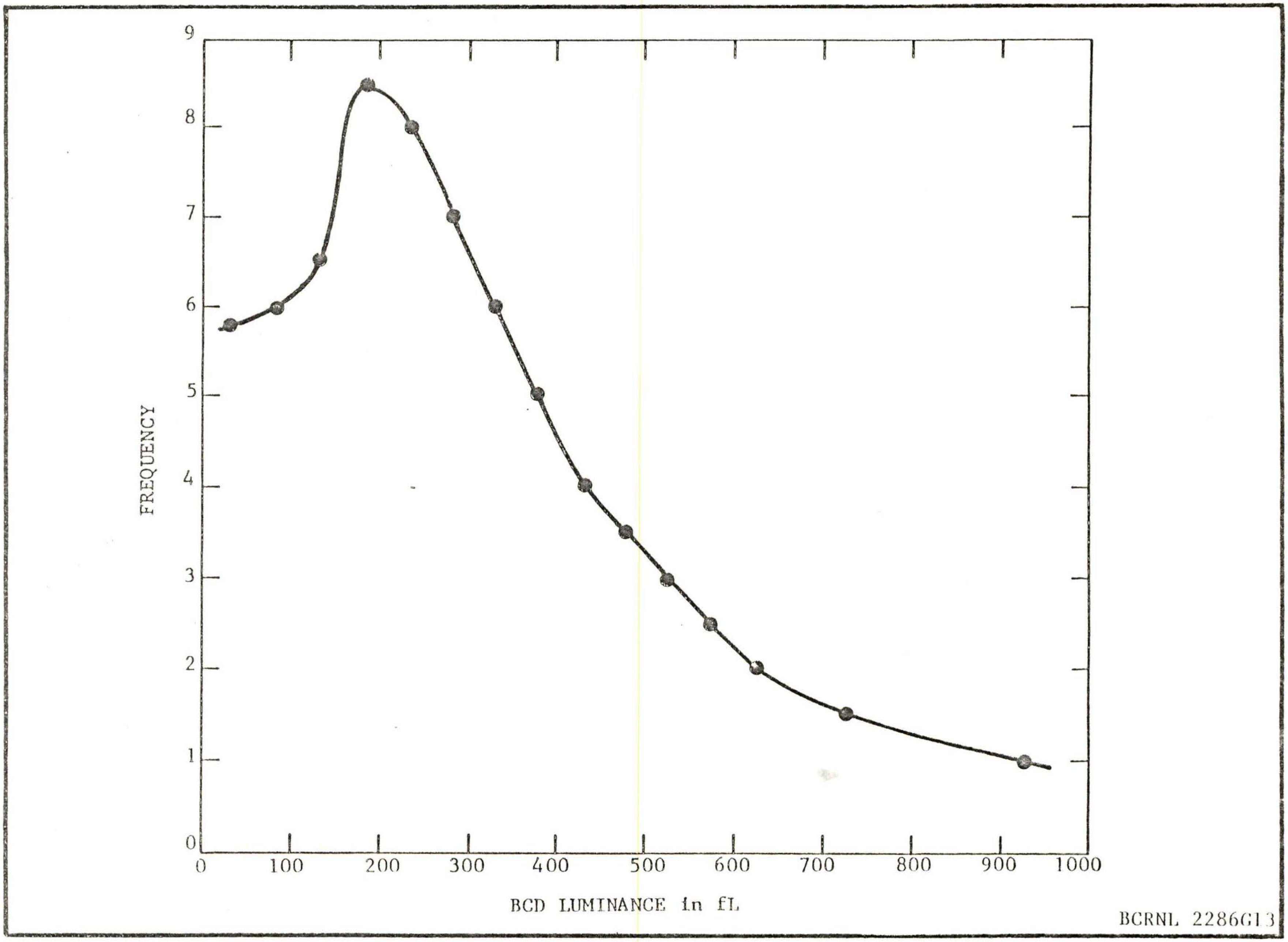


Figure 16. Plotting of Overall BCD Values for All Miners at a Field Luminance = 0.1 fL.

takes all of the "on" values for the three shifts and finds the relative values by dividing the data in each field luminance category by its respective mean value, then a frequency graph can be developed as shown in Figure 17. In looking at this figure one sees that all the values fall on a single curve showing all the groups having the same sensitivity. Then if one averages all the mean BCD values of the on-, and in turn off-, shifts as given in Item IV of Table F8, and averages the change in sensitivity, there is a 40% increase in sensitivity which would mean one should design for 40% less luminance than the geometric "on" luminance or 23% less than the straight mean of all on- and off- shift measurements.

d. Formulation for On, Off, and Combined Data: According to Figure 18 and Table F8, the formula using a geometric mean for a single luminaire in the "on" shift would be $L = 786F^{.32}$ while that for all "on" and "off" shift values would be $L = 614F^{.32}$ and the formula for the "off" values would be $L = 473F^{.32}$.

e. Design for Sensitivity in Mines:

1. Determining Permissable Luminance For Various Sized Light Sources

From the data in Table F8 and plotted in Figures 34 and 35 for "on" and "off" shift values, for field luminance of 0.1 fL, it is noted that between 1 and 400 fL there are 72 observations out of a total of 124 or 58% who are sensitive in this region. From a practical viewpoint, therefore, one could design the lighting for this portion of the more sensitive population. If one takes 200 fL as representing the median between 1 and 400 fL, a lighting unit could be designed with a luminous area to satisfy this portion of the population. The 200 fL represents the luminance obtained at the BCD for the circular luminous area of the test source subtending a solid angle of 0.0011 steradians at the eye of the observer, which is equal to a square light source of 2" x 2" at a five foot distance. One could use any size light source and find the luminance that would be permissable to produce the same glare effect of the 200 fL luminance of the test source occupying 0.0011 steradians. This can be done by developing the index of sensation, M, as given in Appendix F for the test glare source. Then, maintaining the same M value for other sizes of luminous area and using the formula for M, solve for the permissable luminance.

In order to do this it was necessary to prorate the 200 fL downward for a field luminance of 0.06 fL. This is 170 fL. This value is then used in the above formulation for determining the permissable luminance for any size luminous area of a luminaire. These values for differing sizes are shown in the graph, Figure 40. These values are predicated upon direct viewing of a luminaire and the premise that the other luminaires are separated so far away visually that the luminaire under observation is contributing to the total effect. One could therefore measure the average luminance exposed toward the eye of any luminaire and see if it meets the criteria of Figure 40.

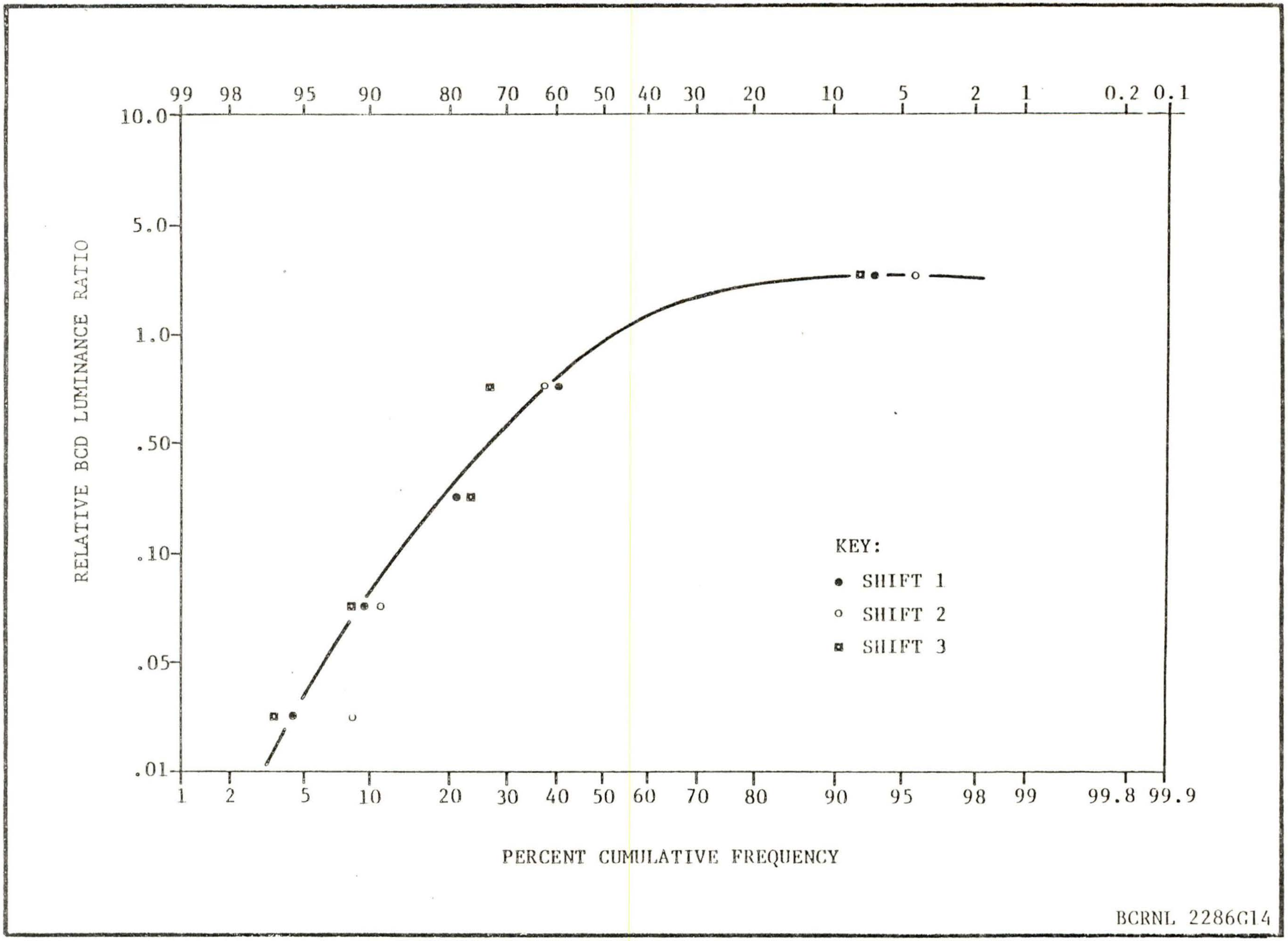


Figure 17. Frequency Plotting of All Discomfort Glare Results of Miners Coming "On" Shifts 1, 2, & 3

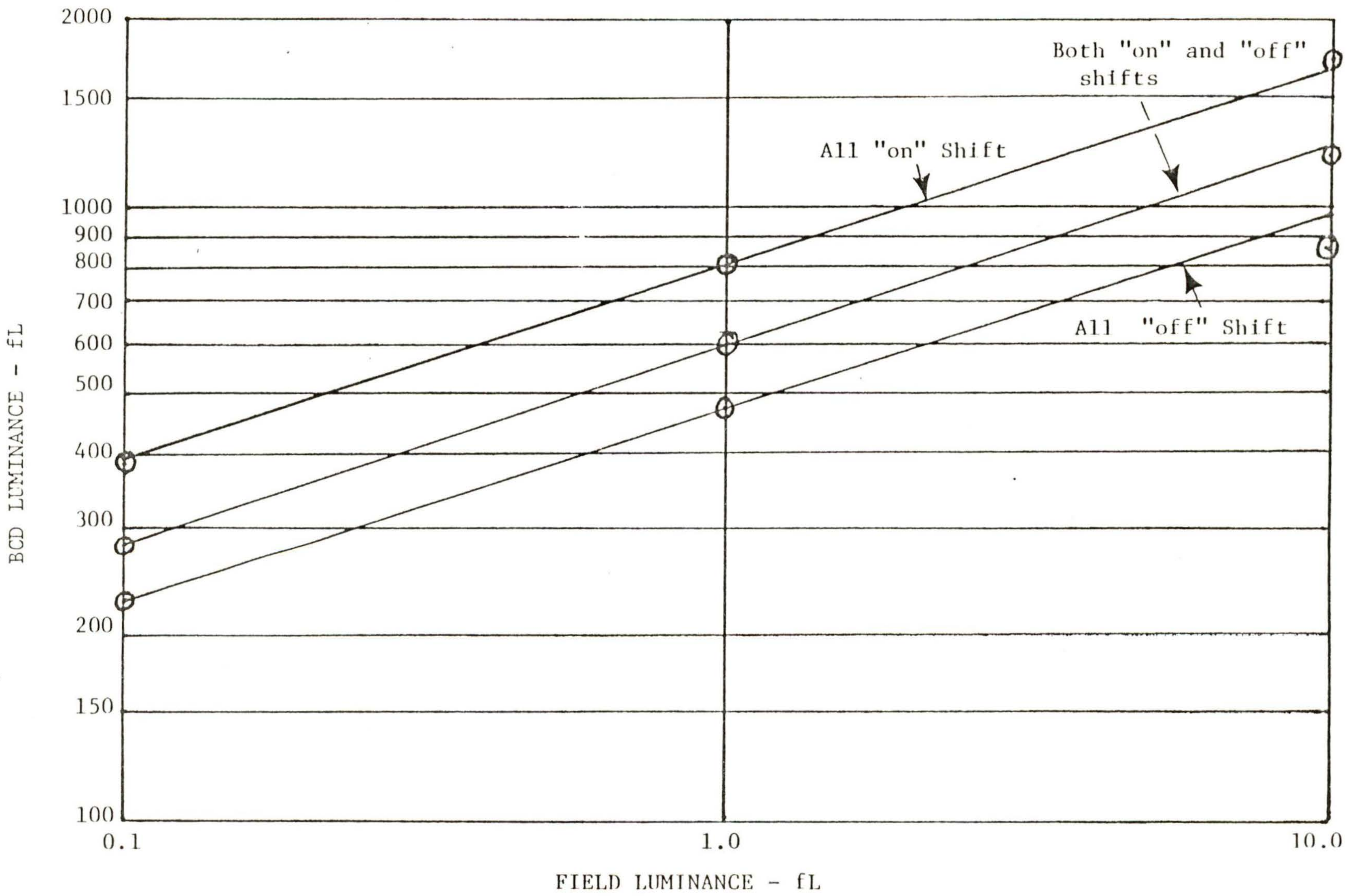


Figure 18. Relationship Between BCD Luminance and Field Luminance for all Underground Miners. Shifts Coming "On", "Off" and an Average for Both Conditions

2. Using the Guth Formulation

The other design method for evaluating discomfort glare is to use the formulation developed by Dr. Guth in Appendix F for M, the index of sensation; DGF, the disability glare rating; and VCP, the visual comfort probability scale, using Figure 19 for combined values of the "on" and "off" shift (the solid line) or for the most sensitive condition, the "off" shift (the dashed line).

As an example applying the Guth formulation, the discomfort glare rating, DGR, and the resulting visual comfort probability, VCP showing the portion of the population satisfied with the lighting system from a discomfort glare response, have been calcuated below for the test glare source, and for the MSHA required field luminance, 0.06 fL.

First calculate the Index of Sensation, M, from the formula:

$$M = \frac{L\overline{K}\omega}{PF^{.32}}$$

Where:
- M = Index of Sensation
- L = $473F^{.32}$, Luminance for the "off" shift condition, L = 192.25 fL^2
- F = Field Luminance, in this example, 0.06 fL, the MSHA requirement.
- P = Position Factor, Use: 1, for on the line of sight
- ω = Solid angle of the glare source in steradians, Use: 0.0011 for the discomfort glare test glare source
- $\overline{K}$ = A modifier of the solid angle selected from Appendix F, Table F12, Use: 306.

Then

$$M = \frac{192.25 \times 306 \times 0.0011}{1 \times 0.406}$$

$$= 159.38$$

In this instance, the Index of Sensation, M, is calculated for one glare source in the field of view; if there is more than one glare source to consider then use the formula:

$$M_t^a$$

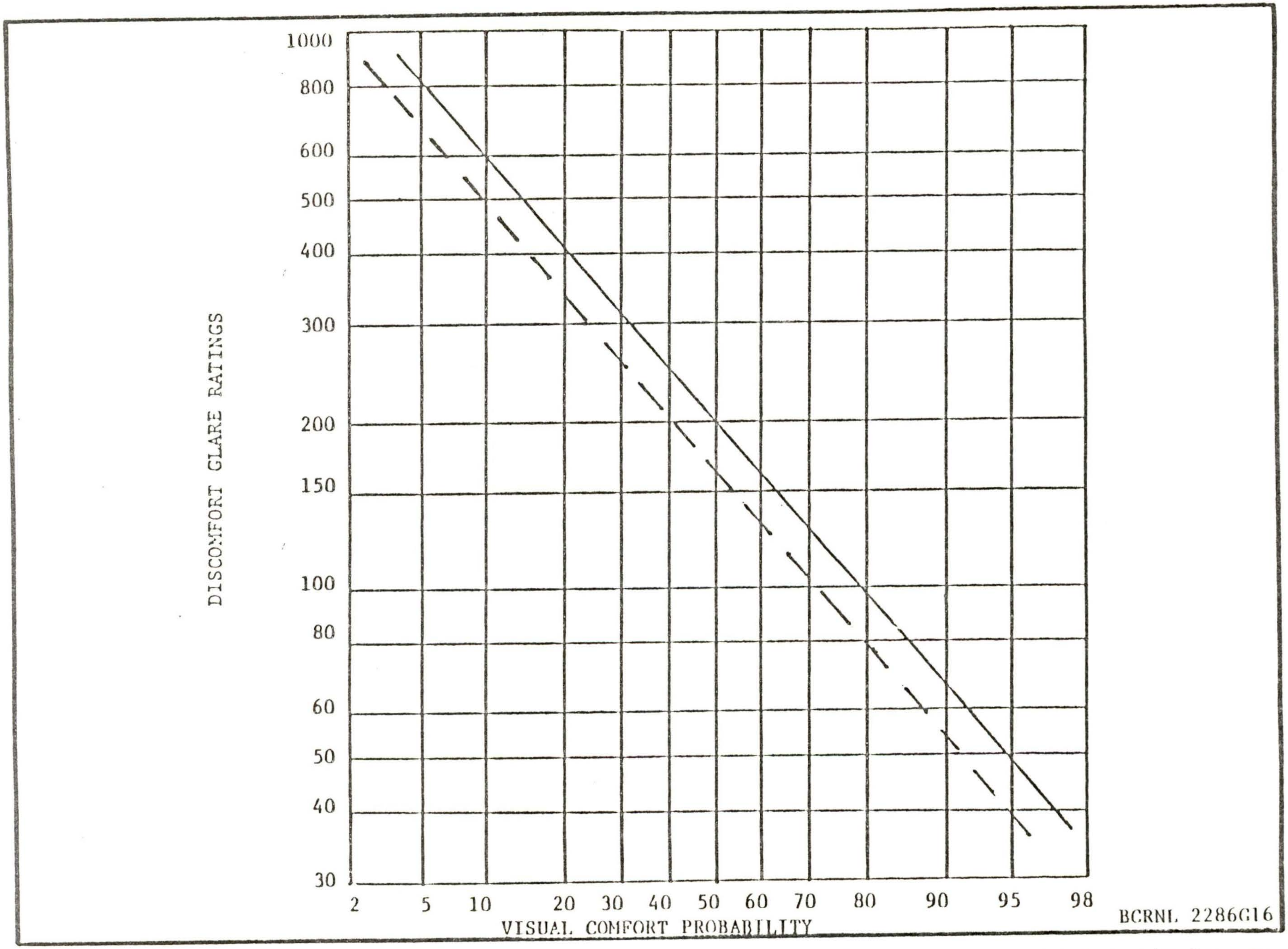


Figure 19. A Chart for Converting Discomfort Glare Ratings to Visual Comfort Probabilities, the Percent of observers Who Would be Expected to Judge a Lighting System to be at or More Comfortable than the Borderline Between Comfort and Discomfort, BCD. Dashed Line is Representative of the Most Sensitive In-Mine Condition.

Where: M_t = the sum of the individual indices of sensation

a = $n^{-0.914}$, and represents a variable exponent

n, is the number of values of M included in M_t

Then, calculate Discomfort Glare Rating, DGR, where:

$$DGR = M_t^a$$

For this example M_t = 159.25 and the exponent, a, = 1.

Therefore, for this example DGR = 159.25, compared with the calculated result of Guth where DGR = 200, which was based on the combined data for both "on" and "off" shift conditions. Using the more sensitive "off" shift, DGR calculation rounded off to 160, and coming across to the dashed line in the graph plotted in Figure 19, the visual comfort probability, VCP = 50%; or 60% VCP for the combined "on" and "off" data (solid line).

III. THE STUDY OF DISABILITY AND DISCOMFORT GLARE FROM CURRENT MINE LIGHTING SYSTEMS

A. Purpose

The first phase of the study was to determine from current glare formulas whether or not current lighting systems used in underground mines caused disability and discomfort glare. It was impractical to study the lighting systems in an active underground mine; therefore, the Westmoreland Coal Company made their research laboratory available to conduct this phase of the investigation. The laboratory was designed to simulate the luminous conditions found in an underground coal mine. The laboratory is located near Big Stone Gap, Virginia.

B. Research Plan

Before beginning this part of the investigation, the research team visited an active underground coal mine in order to better understand the visual and physical conditions encountered by miners while working in and around various mining machines.

After the visit to the mine and before making the disability and discomfort glare evaluations, a joint meeting of the Westmoreland engineers (who were responsible for installation of mine machine lighting systems) and the research team was held. The meeting was to determine where the critical visual locations were located around the continuous miner and bolter which were to be used in the glare evaluations. A critical visual location for example, was an area where the miners had to be able to see in order to assemble roof bolts. From the joint discussions the research team selected several locations around each machine for making the glare evaluations.

Seven different lighting systems were placed on a continuous miner with five of the same systems later being tested on the bolter. The evaluations were first made using the continuous miner which had been placed in the mine simulator. The bolter was then placed in the mine simulator for measurements of glare produced by its unique lighting configuratiens. The mine simulator was painted a special flat black in order to maintain a nominal 0.06 fL wall luminance.

C. Disability Glare

In 1925, Holladay[2] discovered that disability glare reduced the visibility of objects to be seen and that for glaring lighting units, the glare effect could be represented by an equivalent uniform luminance overlaying the object to be seen. In an effort to quantify the effect of disability glare on visual performance, Blackwell[5] developed the concept called disability glare factor, (DGF) which is defined as the visibility of a task seen under a given lighting system compared with the visibility of the same task under reference uniform and practically no glare lighting conditions. Even an unlimited luminous field represents a 7% disability glare loss. The DGF concept modified the original Holladay and Stiles concept by taking into account not only the reduction in image contrast produced by the equivalent uniform luminance, L_v, but also the change in contrast sensitivity of the eye due to adaptation to the sum of the focused light on the task and the stray light in the eye. Blackwell accounts for the change in the eye's sensitivity to contrast by the concept relative contrast sensitivity, (RCS). In general DGF usually represents a loss. To take account of both L_v and RCS, he developed the DGF concept which is given as follows:

$$DGF = \frac{L \times RCS \text{ for } L_e}{L_e \times RCS \text{ for } L} \qquad (1)$$

Where: DGF is the disability glare factor.
RCS is the relative contrast sensitivity.
L is the background luminance of the task without glare.
L_e is the effective background luminance including the glare effect.

The formula for L_e is: $$L_e = \frac{L + L_v}{1 + aK} \qquad (2)$$

Where: L and L_e are the same as above.
L_v is the equivalent veiling luminance.
K is the constant that accounts for the scatter of light in the eye for the average observer in the reference population of 20-30 year old observers.

"a" is the proportionality constant under reference conditions consisting of a uniform surround with an inner limit of 2 degrees diameter and an outer limit of 180 degrees diameter.

The formula for L_v is: $L_v = a_i K_i L_s$ (3)

Where: L_v is the veiling luminance.

a_i is the constant related to the dimensions of an annular source of uniform luminance used to produce stray light. For the Disability Glare Attachment of the Visual Task Evaluator used in the investigation, $a_i = 0.00379$ (when the inner limit of the field is 3.25 degrees in diameter and the outer limit is of 24 degrees in diameter).

K_i is the stray light coefficient of the observer.

L_s is the luminance of the uniform surrounding field.

1. Physiological Basis of Disability Glare

Fry[6] and other researchers found that there was a scatter of the light from the glare sources through the eye media involving the cornea, the lens, the vitreous humor, and the retina itself. This scattering of light caused an internal veiling luminance to be superimposed upon the focused image that the observer was trying to see.

2. Effect of Age

Fisher and Christie[7], in studies related to roadway lighting, found that there is a definite age factor involved in disability glare. Further research[8] determined that the disability glare factor was dependent upon the eye's pupil size which in turn is decreased by both age and luminance of the environment; therefore, the K factor in the above formulas changed with age to a higher value at low levels of illumination such as those involved in roadway and mine lighting as compared with the higher levels used in interior lighting.

Blackwell[9] made very comprehensive tests on various age groups and with both high and low luminance levels to determine the K factor for age. For 100 cd/m^2, $K = 10m_3$. For 1.7 cd/m^2, $K = 10m_4$. The formulas for

"m_3" and "m_4" are as follows:

"m_3" (4)

$$
\begin{aligned}
\text{Age } 20\text{-}44 \text{ years, } m_3 &= 1.000 \\
44\text{-}64 \quad &= 1.000 + .0310(A - 44) \\
64\text{-}80 \quad &= 1.620 + .0725(A - 64)
\end{aligned}
$$

"m_4" (5)

$$
\begin{aligned}
\text{Age } 20\text{-}44 \text{ years, } m_4 &= 1.500 \\
44\text{-}64 \quad &= 1.500 + .0419(A - 44) \\
64\text{-}80 \quad &= 2.338 + .0668(A - 64)
\end{aligned}
$$

Where: A is the age of the observer.

The other age affected factor is RCS[9]. The generalized formula being:

$$RCS = n\left[\left(\frac{S}{tL}\right)^{.4} + 1\right]^{-2.5} \tag{6}$$

$$n = \left[\left(\frac{S}{100t}\right)^{.4} + 1\right]^{2.5} \tag{7}$$

Where: RCS is relative contrast sensitivity.

L is the task background luminance in (cd/m^2).

n is a normalizing constant used to bring RCS to unity at 100 cd/m^2.

S is a constant used to construct the various RCS curves and which is related to the steepness of the curve. As a person ages, the steepness of the RCS curve becomes less.

t is the "relative effective overall transmittance" of the eye of the observer.

3. <u>Visibility Level</u>

Visibility Level (VL) which is defined in Figure 20 as the logarithmic distance between the equivalent contrast line (A) and the threshold contrast line (B) at any point on the graph. Then VL is calculated as:

$$VL = \frac{\tilde{C}}{\bar{C}} \qquad (8)$$

Where: $\tilde{C}$ is the equivalent contrast found using the VTE.

$\bar{C}$ is the threshold contrast of the 4' disc at a given level of luminance.

VL is the visibility level, where a VL = 1 represents threshold seeing conditions and the probability of seeing a given detail is 50%. As the VL is increased, the probability of seeing the detail also increases.

4. <u>VTE Disability Glare Factor Measurements</u>

An important modifier to the basic VL equation (8) is disability glare, which has been quantified by the DGF concept as described above. DGF determines the amount of visibility that will remain after accounting for disability glare.

The DGF is assessed in the field using the Visual Task Evaluator (VTE*) with the optical surround device, the disability glare evaluator, attached. The VTE with the glare attachment, pictured in Figure 21 can be operated using three different fields of view as shown in Figure 22 and described as follows:

<u>MATCHED MODE</u>: Where the annular surround luminance is matched to the background luminance of the task detail being measured. Contrast threshold measurements made in this condition establish the reference condition (which represents a practical no glare condition even though an unlimited field luminous field represents a disability loss due to glare).

<u>REAL WORLD (EXTERNAL) MODE</u>: Where the contrast threshold measurements are made using a 24 degree field of view of the actual illuminated environment as the annular surround for the task being measured. The 24 degree field of view may or may not have glare sources within its field. The ratio of the visibility found in the real world to the visibility in the matched condition determines the DGF value.

*For further explanation of VTE, see Appendix D.

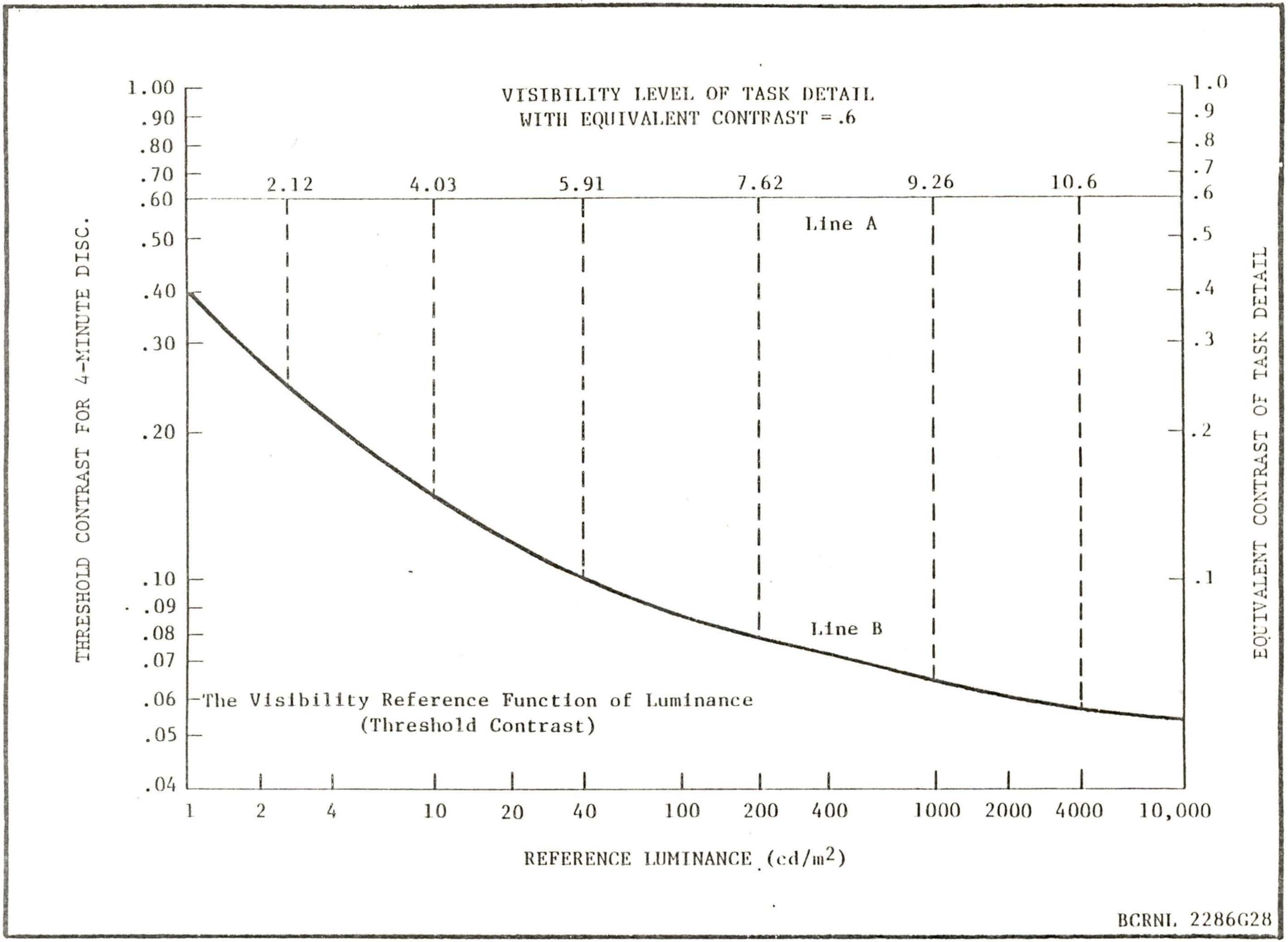
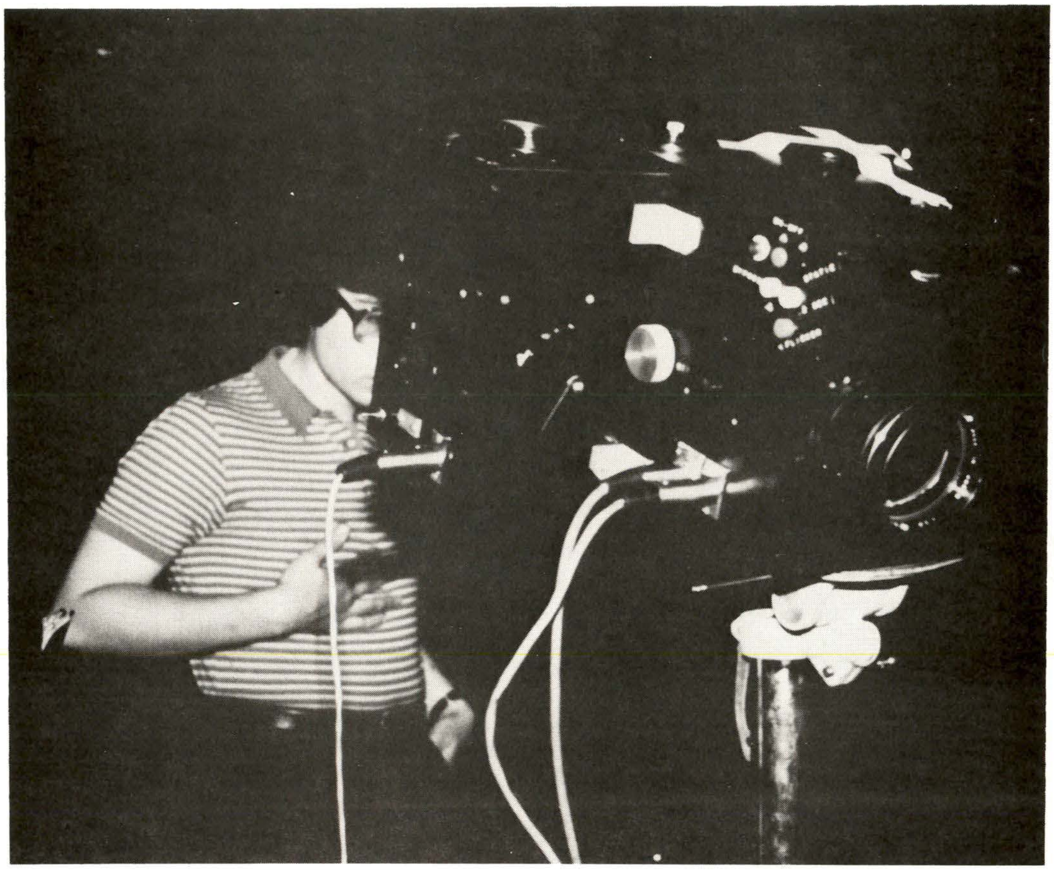


Figure 20. Visibility Level Increases for a Given Object as the Luminance Increases and Threshold Decreases.



2286P13

Figure 21. Operator Using the Visual Task Evaluator with Disability Glare Attachment While Evaluating the DGF for Mine Lighting Systems.

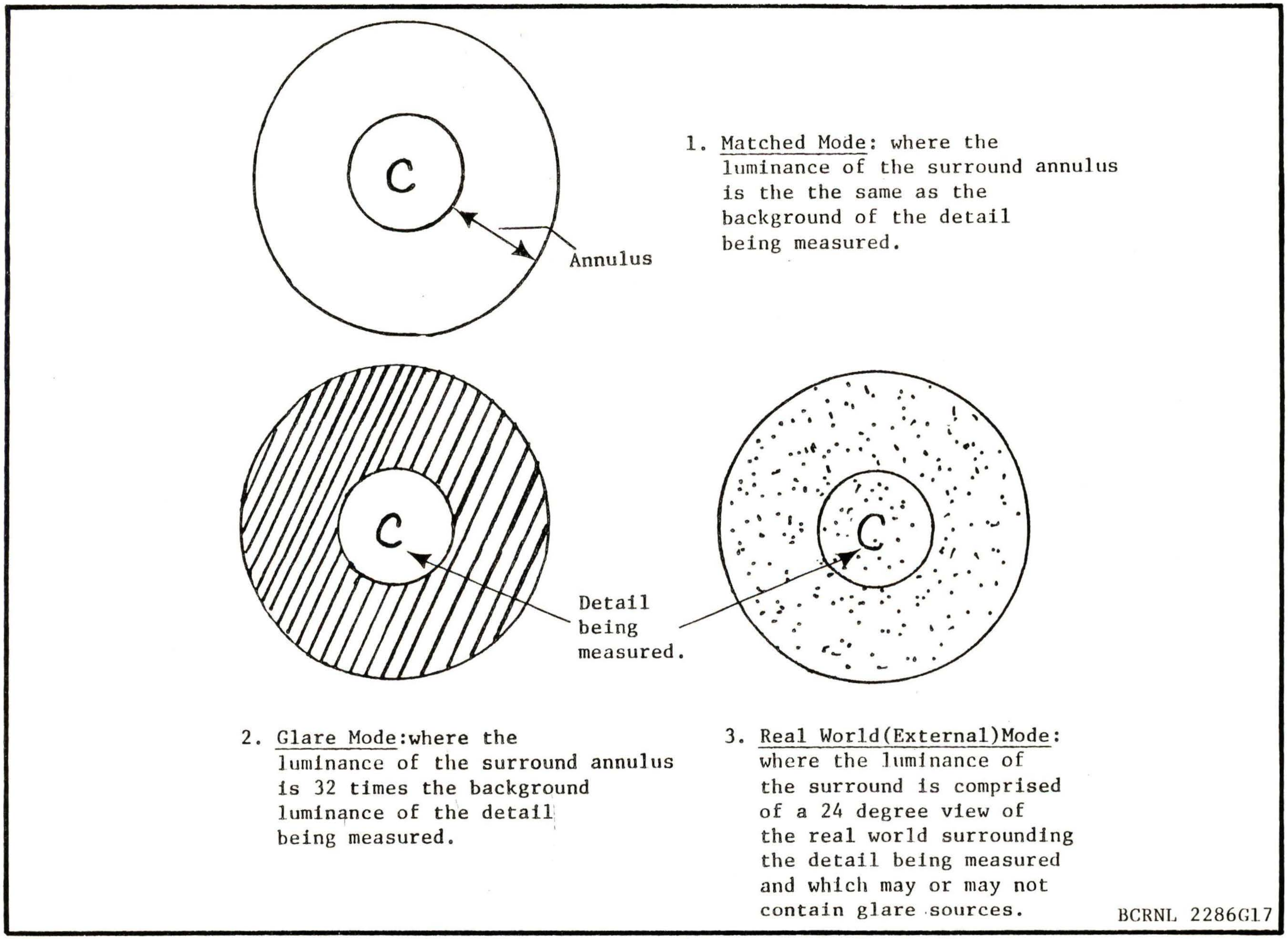


Figure 22. Three Fields of View as Seen Through the Visual Task Evaluator When Measuring Disability Glare from Mine Lighting Systems.

GLARE MODE: Where the annular surround luminance is approximately 32 times the background luminance of the detail being measured. The glare mode threshold measurements are used to determine the individual VTE operator's K factor (which is the constant that accounts for the scatter of light in the eye due to glare).

5. Determining DGF from Field Measurements

Referring to the DGF equation (1) above and Figure 23, one finds that there is both a positive and negative factor to disability glare. The increase of luminance, to which the eyes are adapted due to the introduction of a glare source or sources within the field of view, results in a greater sensitivity of the visual system to the visibility of detail. It has been found that if the surroundings are very low in luminance, the addition of a glare source actually increased the ability of the eye to see detail[13]. However, in most cases of overly bright light, (glare sources), there is an actual decrease of sensitivity or visibility due to the veiling reflections in the eyes. In Figure 23, cited above, one sees that there is a positive contribution to sensitivity, and therefore visibility, which is accompanied by a larger negative loss of sensitivity. The DGF becomes the final net effect of both components. Equation (1) can be broken into these components:

$$DGF = \frac{L}{L_e} \times \frac{\text{RCS for } L_e}{\text{RCS for } L}$$

The first term L/L_e, represents the negative component, the loss in sensitivity. The second term: RCS for L_e divided by RCS for L, represents the positive component, the gain in sensitivity.

From the measurements obtained using the three fields of view described above, one can determine the appropriate DGF. Each person who made threshold measurements in the glare mode had their own sensitivity to glare and degree of scattered lighting in the eye; so, an individual K factor was determined. To make the individual values more useful, it is generally necessary to relate them to a large population of observers tested under more controlled conditions in the laboratory. Through the use of disability glare equation (2) above, the losses obtained by the individual were related to the losses that would be expected if the average observer of the larger laboratory reference population had made the measurements. Once the DGF has been determined it can be used as a modifier to the basic VL equation (8):

$$VL = \frac{\tilde{C}}{\bar{C}} \times DGF$$

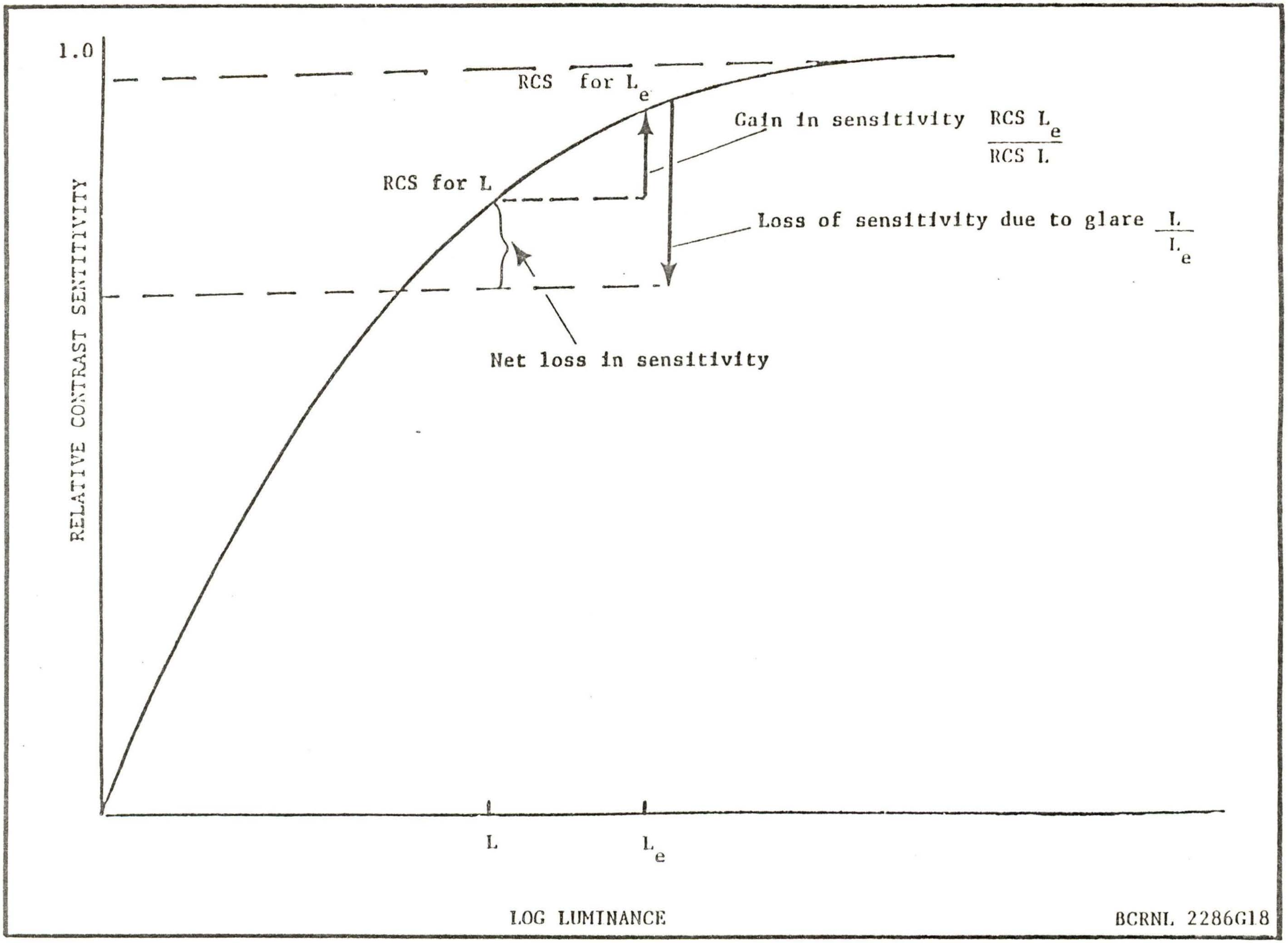


Figure 23. Principle of Disability Glare Reactions

6. Evaluation of Disability Glare from Current Lighting Systems

A highly skilled VTE operator made all the DGF measurements of the different mine lighting systems. The operator had made several thousand VTE measurements in other studies in the past and could thus make these more exacting measurements for this phase of the glare investigation. A skilled operator who was calibrated with the VTE was required since the actual visibility being produced by the several lighting systems was required. Several positions that had been selected by the research team were used to evaluate the DGF's of each of the seven mine lighting systems mounted on the continuous miner as well as the DGF's for five of the same systems mounted on the bolter. The VTE with disability glare evaluator attached, as shown in Figure 21, was positioned seven feet from each machine at the various chosen locations shown in plan view in Figures 24 to 28. Figure 29 illustrates the bolter and lighting system to be evaluated in the dark room. The DGF results for the continuous miner and bolter are shown in Tables D1 and D2 respectively and are discussed in the summary of findings at the beginning of this report and in Appendix E.

D. Discomfort Glare

In 1925, Holladay[2] not only investigated and defined disability glare but also determined a new concept of discomfort glare, the psycho-physiological effect of light sources. He found that there was a "shock" effect when bright light sources are exposed momentarily. He was able to evaluate this effect and develop a formula to denote various degrees of sensation varying from "scarcely noticeable", to "pleasant", to "comfortable" and "the boundary between comfort and discomfort" (BCD). Further he was able to define sensations that varied from "uncomfortable", to "the boundary between uncomfortable and intolerable". Guth (Appendix F) refers to these sensations in his Table F3.

1. Physiological Basis of Discomfort Glare

Further studies[17] showed there is a pupillary opening change when the observer was suddenly exposed to an overly bright light source. From this it was concluded that the sensation of discomfort could be related to the strain in the eye's sphincter muscle which reduces the pupillary opening when exposed to an overly bright light source.

The most comprehensive studies of discomfort glare were carried out over many years by Dr. S. K. Guth[16] who investigated the various elements that contributed to the sensation of discomfort glare and then put them together in suitable formulation, described in Appendix F, labeled, the Borderline between Comfort and Discomfort (BCD). This formulation serves as a basis for determining the acceptability of lighting systems in terms of discomfort glare and also for rating the glare sensitivity of individual observers.

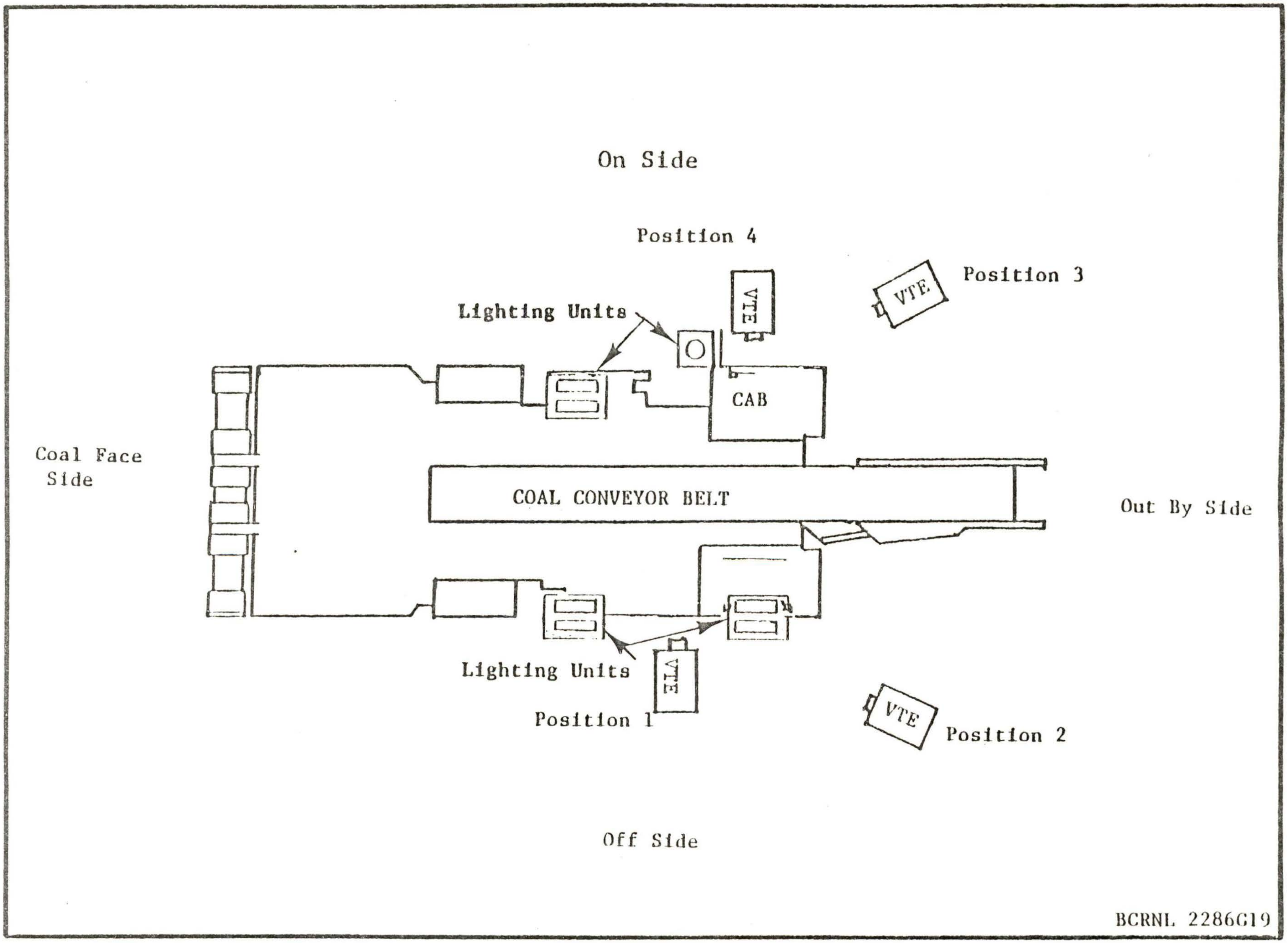


Figure 24. Disability Glare Measurements Using Visual Task Evaluator - Continuous Miner-Plan View - Incandescent Lighting Layout, Rectangular Units.

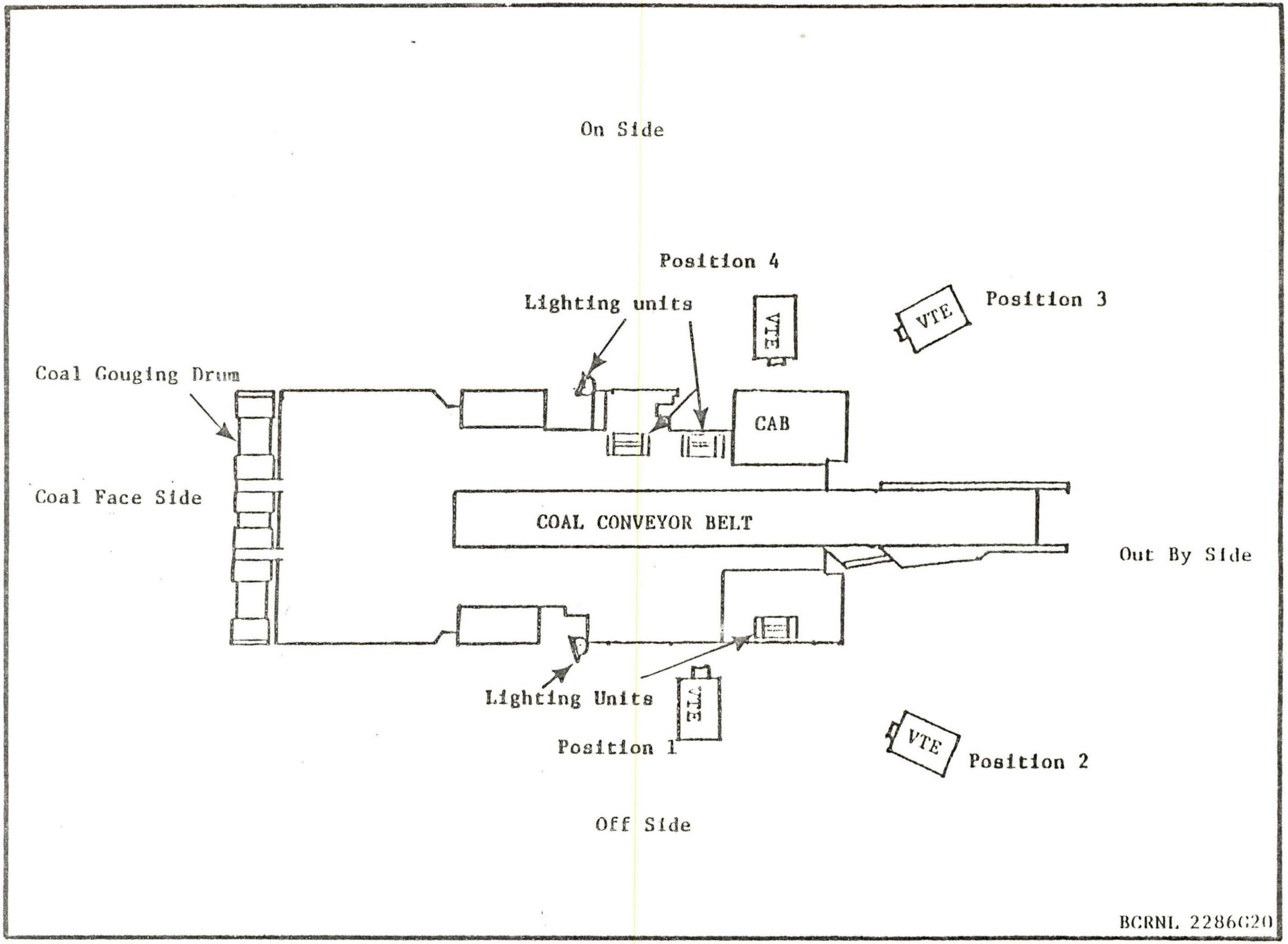


Figure 25. Disability Glare Measurements Using Visual Task Evaluator - Continuous Miner - Plan View - Incandescent Lighting Layout - Triangular Units.

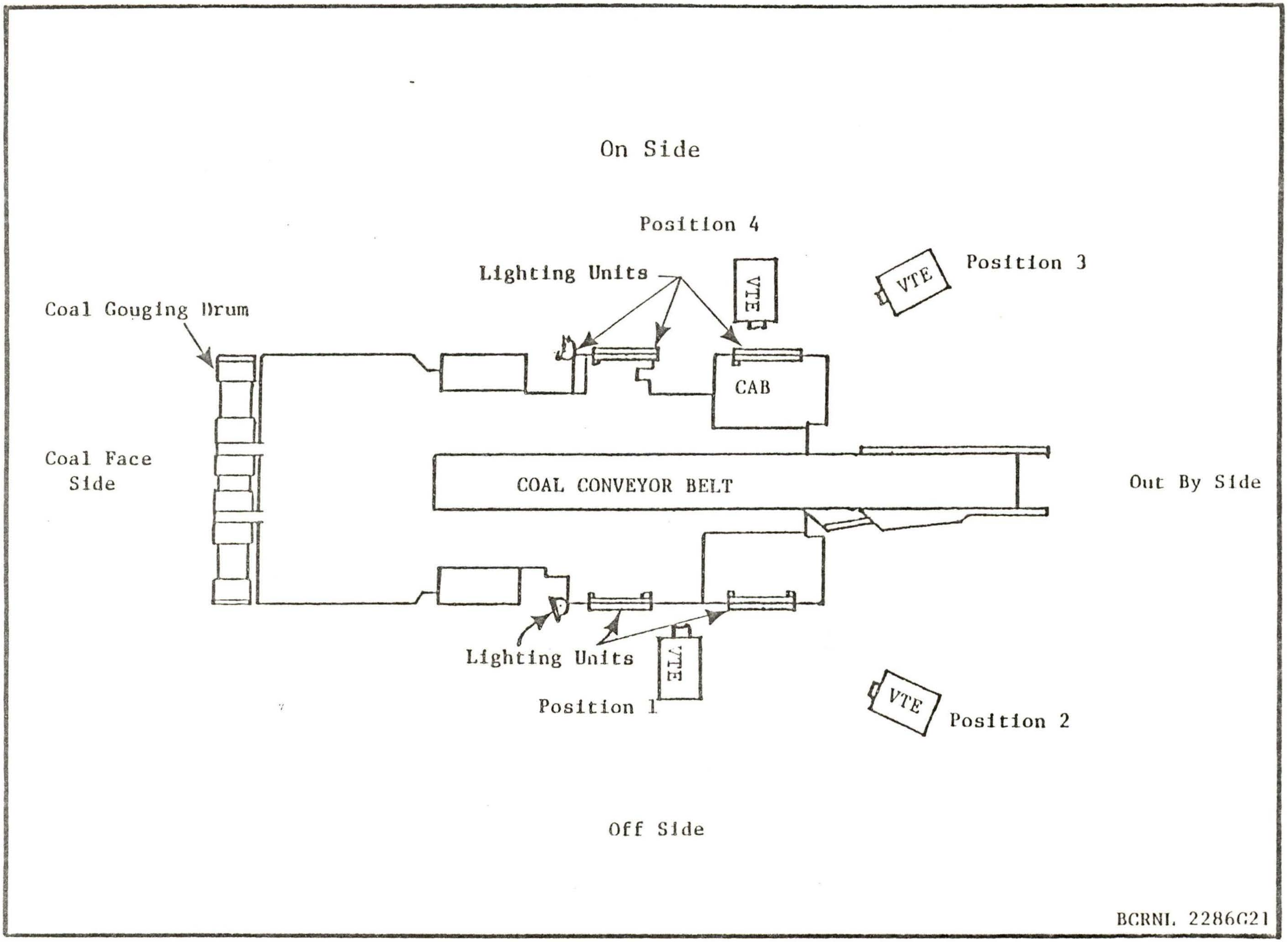


Figure 26. Disability Glare Measurements Using Visual Task Evaluator - Continuous Miner - Plan View - Fluorescent Lighting Layout.

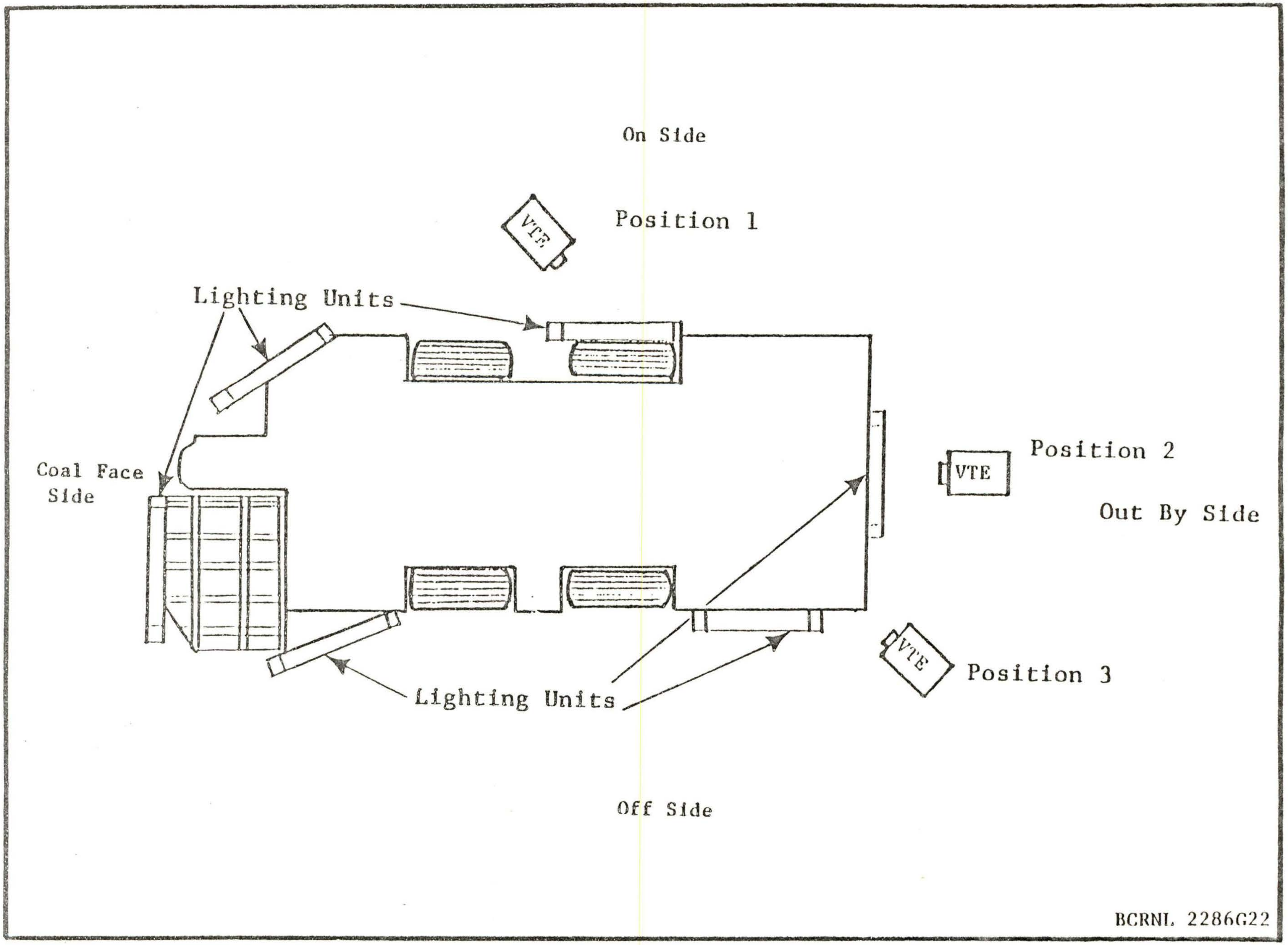


Figure 27. Disability Glare Measurements Using Visual Task Evaluator Acme Bolter - Plan View - Fluorescent Lighting Layout.

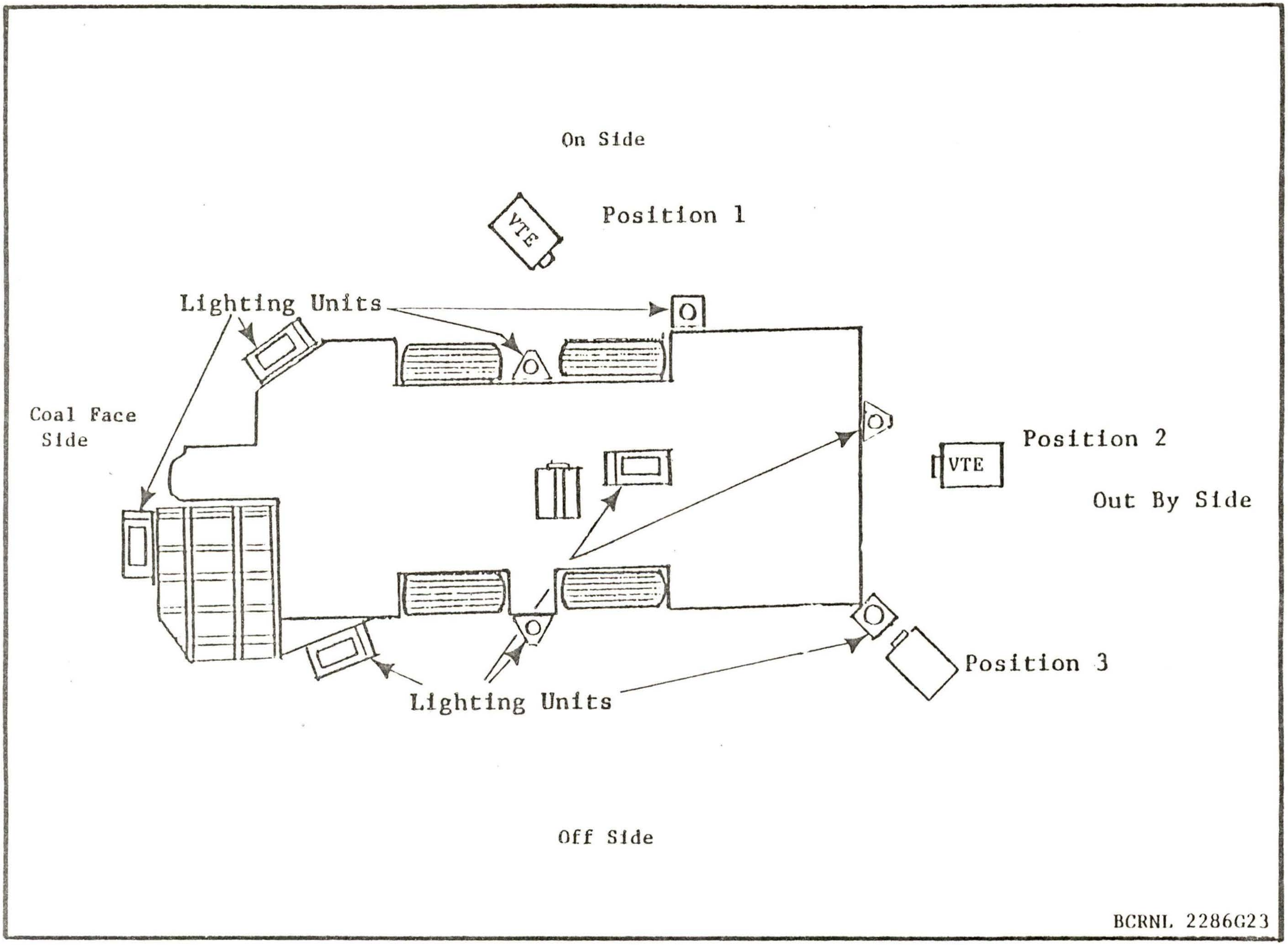


Figure .28 Disability Glare Measurements Using Visual Task Evaluator Acme Bolter - Plan View - Two Incandescent Lighting Layouts.

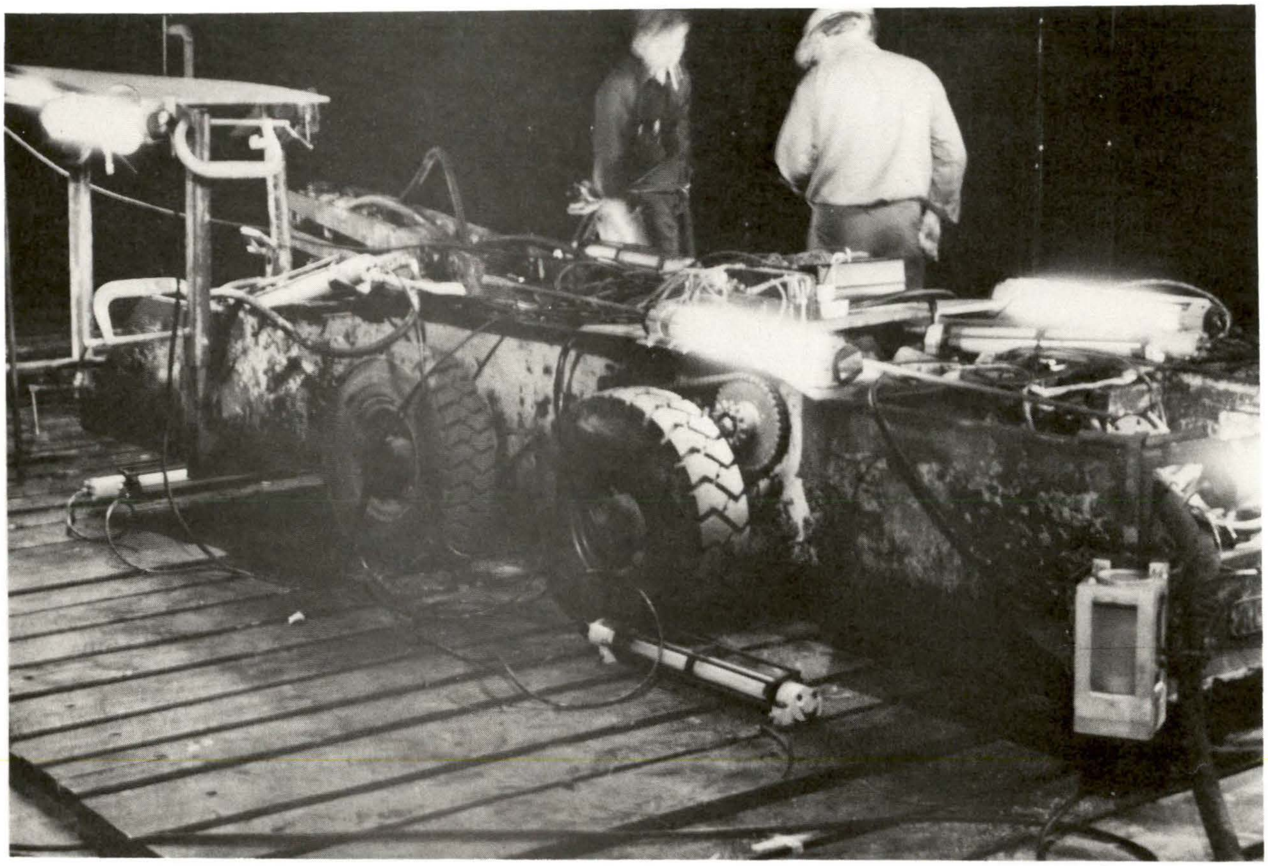


Figure 29. Evalutation of a Fluorescent Lighting System as Placed on a Acme Bolter and as Seen From Position 3 for both Discomfort and Diability Glare. The Picture also Shows the Bolter as it Appeared in the Mine Simulation Testing Room.

2. Instrumentation

Since the BCD sensation serves as a basis for determining the acceptability of lighting systems in terms of discomfort glare and also for rating the glare sensitivity of individual observers, Guth has developed the Discomfort Glare Evaluator (DGE)[19] to measure the BCD sensation. The DGE employed in the present investigation is shown in Figure F1, being used to evaluate an underground lighting system. The components include a head-rest with a moveable shield, a light source and control units for the experimenter and the observer.

When the moveable shield is in the "down" position, all of the test luminaires are excluded from the field of view of the observer. When the shield is rotated upward, the luminaires are included in the field of view.

The circular test source consists of a transilluminated diffusing glass. It is viewed in a small mirror (see Figure F1) located on the line of sight which can be in any direction, depending upon the experimental conditions. A gray mask, the reflectance of which is selected so its luminance approximates that of the area viewed by the observer, surrounds the test source.

A timing mechanism in the operator's control unit governs the exposure sequence of the test-source and the lighting system. When BCD evaluations are made, the moveable shield on the head-rest remains normally in the "down" position, except for the glare condition. The test-source is presented for one-second exposures separated by one-second intervals during which the observer is exposed only to the field luminance. A ten-second cycle is used during which the test-source is presented for subjective evaluations three times, and the remaining short period is allowed for the observer to alter its luminance.

When making comparative evaluations of a lighting system, the source on the line of sight -- now termed the comparison source -- and the luminaires are alternately exposed to view. When the moveable shield rotates upward to expose the luminaires, the comparison-source is turned off. When the shield returns to the "down" position, the comparison source is again turned on. The exposures are of one-second duration, separated by one-second intervals. Each group of three exposures is followed by a five-second period for evaluating the sensation and altering the luminance of the comparison source. The observer is permitted as many cycles as necessary for making an appraisal.

3. Evaluation of Discomfort Glare from Current Lighting Systems

CONTINUOUS MINER: Using the procedure and instrumentation outlined above, discomfort glare evaluations were made from two different observer positions as shown in Figure F2 for all seven lighting systems. A total of eleven people participated in the measurements with the results summarized in Table F1, F2, and F4.

BOLTER: Three observer positions were used in evaluating five of the same systems with a total of four observers participating. The results are shown in Table F5 with the glare evaluation positions shown in Figure F3.

IV. THE STUDY OF UNDERGROUND MINERS' SENSITIVITY TO DISABILITY AND DISCOMFORT GLARE

A. Purpose

The second phase of this investigation was to answer the question of whether or not the underground mining population is more, less or the same in sensitivity to both forms of glare as compared with the sensitivity of the aboveground population in commerce and industry. If they were more or less sensitive then current glare formulas should be changed so that improved lighting designs could be made for mine illumination.

B. Research Plan

Prior to testing the mining population a plan was developed to determine what population characteristics of the miners might have an influence upon the disability and discomfort glare evaluations. It was decided that factors of age, years worked as a miner, shift worked during the test period, eye color (light or dark), whether or not glasses or contacts were used, color vision (normal or deficient) and visual acuity at the time of the test were of possible influence. Standardized tests were used to determine these various factors at each test location. Before any testing was begun at the different mine site locations, two or three research team members met with the mine management to describe the purpose of the investigation, set a date for testing and to determine a schedule for testing the miners as they came on or off their shift and to locate a facility in close proximity to the mine entrance to setup the various testrooms. Each miner participated on a voluntary basis and was paid his hourly wage for each hour of work. Ideally the research team was capable of testing a group of four miners coming on shift and four miners coming off shift with an hour's time required for each group of four miners.

C. Testing the Miners

At each test location the space made available by the mine management was adapted to accommodate the experimental setups. The different test setups were separated from each other either by using different rooms or by dividing a large room into several cubicles by hanging black strips of cloth for curtains. Each group of miners who were tested entered the test area which had been darkened to simulate the mine environment. After a brief description of the purpose of the glare investigations the miners were seated and asked a series of questions to determine their age, number of years worked underground, shift worked, eye color and the need of glasses or contacts. Color vision and visual acuity were then tested.

1. Color Vision Test: The miners were given a color vision test using the American Optical Corporation's test charts: "Pseudo-Isochromatic Plates For Testing Color Perception". The test plate booklet was placed on a Macbeth Easel Lamp Stand at a distance of 30 inches from where the miner was seated. Each miner was instructed to read the number (which had been printed in various shades of color) on each test plate. The number of correct responses determined whether or not the miner had a deficiency in color vision or was normal. If the miner was color deficient it could make him more sensitive to glare.

2. Visual Acuity Test: The objective of this test was to determine the miner's visual acuity at the time of testing. A standard visual acuity test was given using the Snellen eyechart. The eyechart was placed twenty feet from a line marked on the floor by which the miner was instructed to stand. Supplemental lighting was used to light the eyechart. Each miner was instructed to cover his right eye with his right hand cupped and then read the top line on the chart. If more than two or three errors were made he was instructed to try and read the next line below until he came to a line which could be read without error or just one error. The same procedure was repeated for the left eye.

After these factors were determined, the sensitivity of the miners to disability and discomfort glare was tested.

3. Disability Glare Testing: The purpose of this test was to find whether or not the sensitivity of underground miners to disability glare was different when compared with the aboveground population of workers. The degree of disability glare was quantified by the disability glare factor, DGF as described in Section III. In order to make the comparison between the two different populations, the DGF testing was done at two different luminance levels. 6.0 fL being the higher level and 0.06 fL being the lower level. The high luminance level testing of DGF allowed comparison to the data on an aboveground population which had been extensively tested by Dr. Blackwell[9] in his laboratory at Ohio State University. The low luminance level represented the actual luminance level currently being recommended for underground mine lighting; thus, the range of DGF's would be representative of what might be found in an underground mine. At each test site two VTE's with glare evaluator attachments in place were setup to determine the DGF response with one recording the high luminance DGF and the other the low luminance DGF. The setup and procedure was the same for both luminance conditions. A test chart composed of a series of different sized Landolt rings (which are shaped like the letter C) was placed 13.1 inches from the longitudinal center of the front objective lens of the VTE, and supplemental lighting with a dimmer switch was used to light the test chart to the desired luminance. The general arrangement for disability glare testing at both high and low luminance levels is shown in Figure 30. The absorptive properties of the VTE optics were accounted for when determining the light

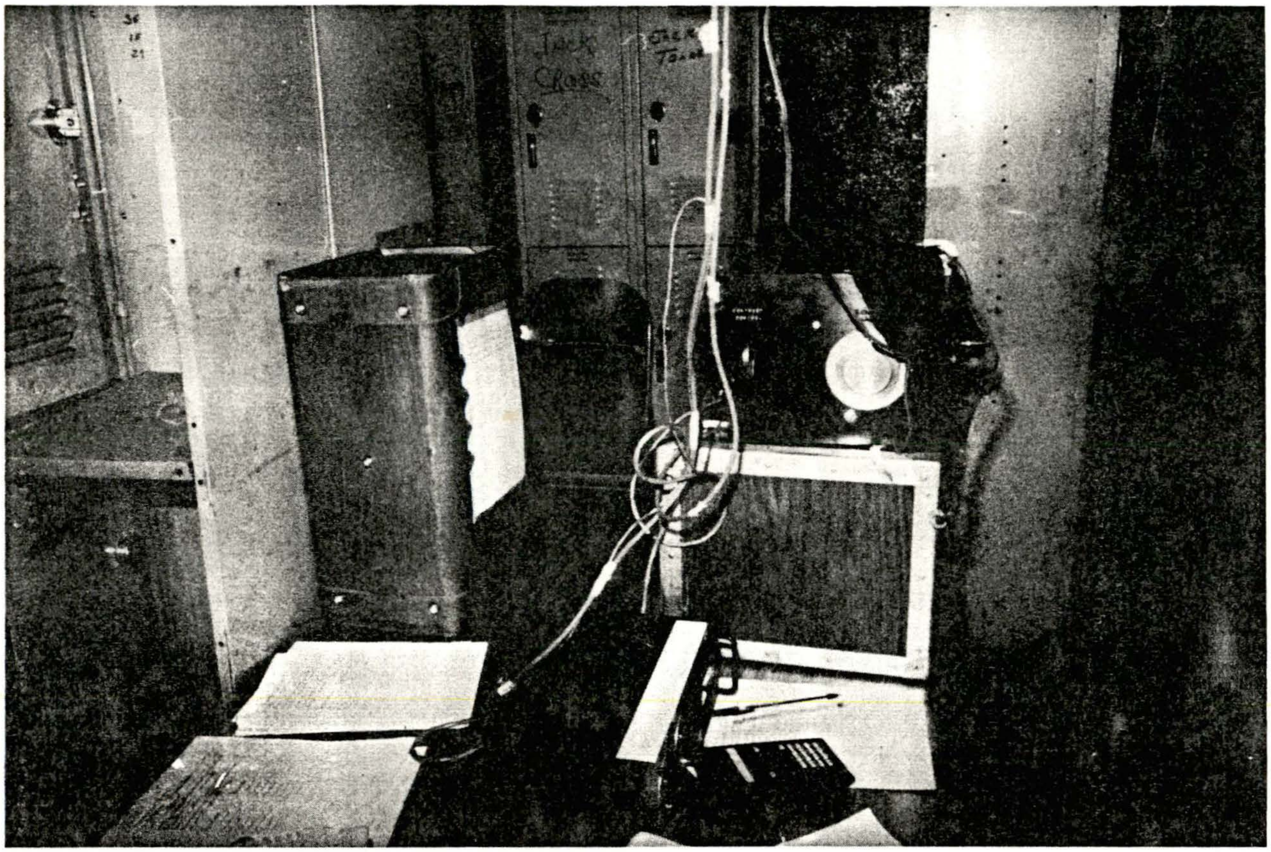


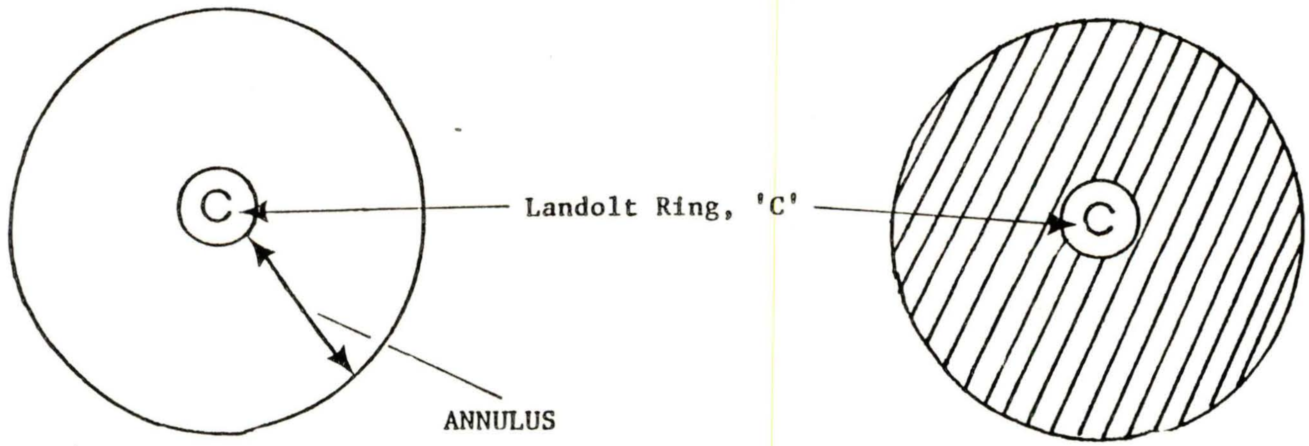
Figure 30. Disability Glare Test at Low Luminance Level: Visual Task Evaluator with Glare Attachment Centrally Positioned in Front of Testchart of Landolt Rings.

level to be maintained on the test chart in order that the luminance levels stated above would represent the amount of light at the eye of the miner.

4. DGF Procedure: The largest Landolt ring on the test chart was centered in the VTE's field of view. As each miner was seated, he was instructed to look into the VTE's eyepiece and determine whether the 'C' was centered and in focus. If this was not the case the miner adjusted the focus by pulling out or pushing in the eyepiece. Since this phase of the study was to determine only the individual miner's response to disability glare, it was only necessary to use the two fields of view as shown in Figure 31 to determine DGF and the K factor for the miner. Measurements were first made in the matched mode condition where the luminance of the annular surround was the same as the background luminance of the Landolt ring task being measured.

While the miner fixated on the centrally located 'C', the contrast dial on the side of the VTE was turned by the team member taking the data. As the contrast dial was moved the contrast was gradually reduced until the 'C' disappeared, then the dial was turned until the 'C' could just barely be seen. This point of bare seeability is threshold. Once the miner understood the concept of threshold, he was instructed to turn the contrast dial while looking through the VTE at the test letter -- turning the contrast dial until the 'C' disappeared and then back to the point where it could just barely be seen. As each threshold point was reached and indicated by the miner, the number on the contrast dial was recorded by the research team member until a series of seven consistent measurements were obtained. The average of these contrast threshold measurements was used in determining DGF. Then using the same procedure the VTE was placed in the glare mode where the luminance of the annular surround was approximately 32 times the background luminance of the Landolt test letter. Before taking this series of threshold measurements, the miner was instructed to look only at the 'C' and not the brighter surround while his eye adapted to the higher luminance level of the surround. A five minute time period was given for adaptation. From these glare mode measurements, an average value was obtained which together with the matched mode threshold measurements, the DGF and K value for each miner was determined, using the procedure described in Section III.

5. Discomfort Glare Testing: To determine whether or not the underground mining population was different in sensitivity to this form of glare a cubicle was constructed to provide a standard controlled environment.[19] The cubicle, as shown in Figure 32, consisted of a box 199 cm deep, 80 cm high and 60 cm wide. The interior and exterior were painted a light gray to provide a uniform luminance of 0.01, 0.1, 1.0, and 10.0 fL for the interior field luminances. A chin and head-rest were mounted on a sawhorse and positioned at the front opening of the cubicle which located the eyes of the observer even with the front of the cubicle. The cubicle was adapted



A. No Glare Condition, where the luminance surrounding the Landolt 'C' is the same as the luminance of the surrounding annulus.

B. Glare Condition, where the luminance of the surrounding annulus is 32 times the luminance surrounding the Landolt 'C'.

BCRNL 2286G24

Figure 31. Fields of View as Seen Through the VTE When Testing Miners for Disability Glare.

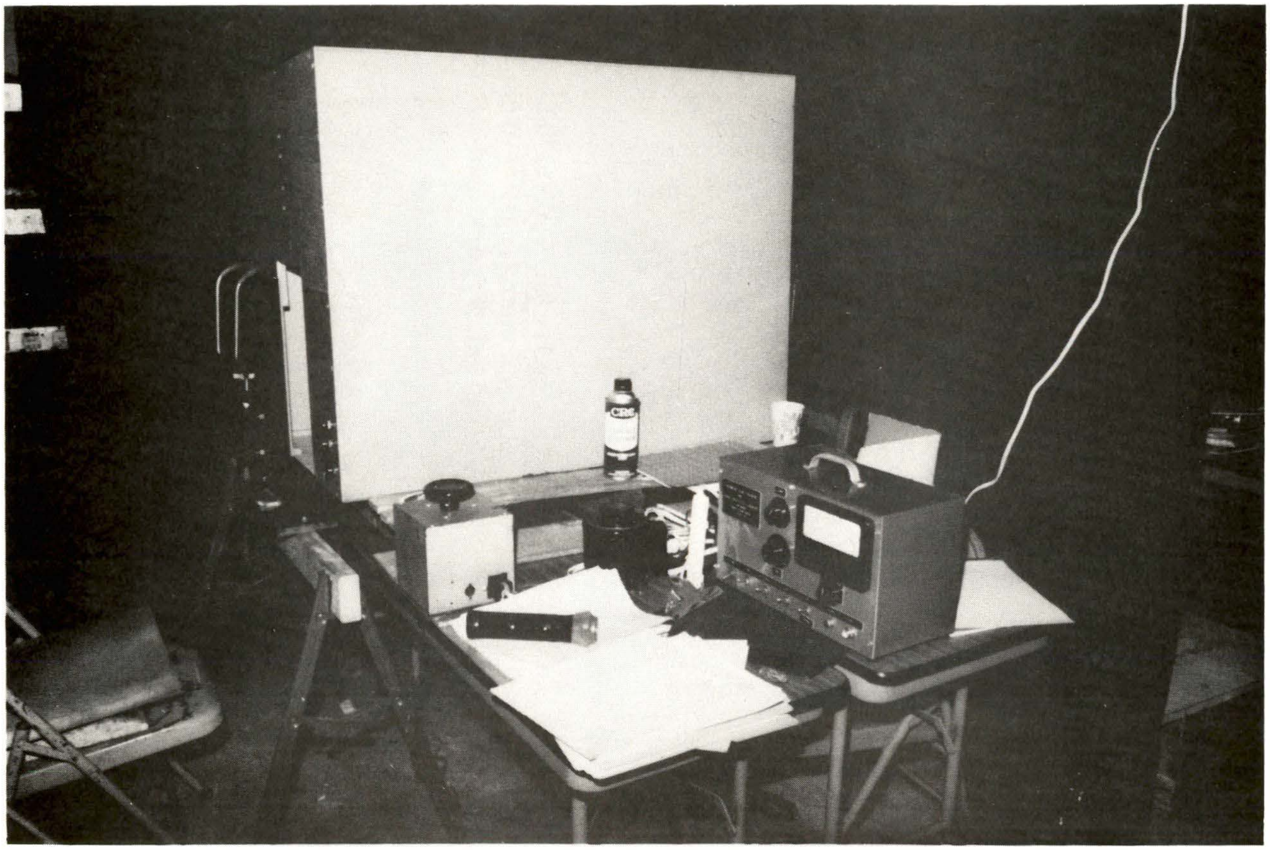


Figure 32. Cubicle Used For Obtaining BCD Judgements.

to allow not only on the line of sight measurements but also 25 degrees above and below the line of sight. The circular aperatures through which the test-source shined subtended a solid angle of 0.0011 steradian.

The source luminance was provided by the luminous element of the Discomfort Glare Evaluator (DGE). This source was reflected toward the observer's eyes by a diagonal mirror located outside the rear of the cubicle. The luminance of the source, which was under the control of the observer, was continually variable from 0 to about 12,000 fL. The arrangement for obtaining the source luminance being external did not measurably affect the internal luminance of the cubicle.

During the testing the observer adjusted the luminance of the test source which momentarily was exposed for a 1-second period, until it was judged to produce a sensation at the borderline between comfort and discomfort, (BCD). The 1-second interval was found to be long enough for the observer to receive the full impact of glare but sufficiently short so that it did not significantly affect adaptation. The latter point is particularly important when the field luminance is low, as in the present investigation.

Each observer made a series of at least five judgements for each field luminance at one sitting or test period. Ideally, at least two such series of measurements should be made by each observer on different days. Because of lack of continued availability of observers and time restrictions, only a few were able to make repeat measurements on different days; yet, many made repeat measurements on the same day. The results obtained are considered valid and useful.

6. <u>Testing at the Mine Safety and Health Administration</u>

The total experimental procedure and setup was first tested at the Mine Health and Safety Administration, MSHA, Academy at Beckley, West Virginia. Observers for this part of the investigation included attendees of the Academy courses as well as personnel from the illumination laboratory on campus plus members of the research team. Although it had been hoped that many underground miners would be attending courses at the Academy during the test period, only a few of those who agreed to be tested had actually been full time miners or had been underground for a period of years; however, data provided on disability and discomfort glare was valid with the results being used to provide a stronger base of reference for the aboveground population. The results provided a base of comparison to the later testing of the miners. This pilot study helped modify and refine the testing procedures used on the underground miners. In all, twenty-three observers were tested with one being excluded for incomplete data. The results of the disability glare testing along with the population characteristics determined from the interview process outlined above are shown in Table D3. The disability glare results as shown in Table D3 show a normal range of values to be expected and substantiate the generalized disability glare model developed by Blackwell as reported in Appendix E. Due to instrument failure of one of the VTE's, low level DGF results could not be obtained. The discomfort glare results are shown and discussed in Appendix F.

D. Measurements at the Mine Sites

Active underground miners were tested at five different mine sites which included: Maple Meadow Mine, Fairdale, West Virginia; Prescott Mines 1 and 2, and Derby Mines 4 and 5, Big Stone Gap, Virginia. A total of 114 miners completed the battery of tests with valid data being obtained for 110 miners for disability glare and 106 miners for discomfort glare. The miners were tested for an hour before or an hour after their shift.

1. Populational Characteristics, Color Vision and Visual Acuity Results

The tabluated results obtained through the interview process are recorded in Table D4, D5, and D6. Of the 114 miners measured, 5.3% had a deficiency in color vision which did not significantly affect the DGF results. Additionally the mining population as a whole had normal 20/20 vision. The populational characteristics were used to determine trends in disability glare and discomfort glare results.

2. Disability Glare Testing

The valid disability glare testing results were used in support of the Blackwell model described in Appendix E. The data obtained on 51 miners at the Maple Meadow Mine at the high luminance level and the 59 miners at the Prescott and Derby Mines at the low luminance level were used by Blackwell in the development of his generalized model of disability glare. Additionally in order to analyze the populational trends, the results of the 51 miners at Maple Meadow Mine tested at the low luminance level were combined with the 59 miners' low level results at the Prescott and Derby Mines. The tabulated summary of results of disability glare are shown in Tables D4, D5, and D6.The conclusions from the disability glare testing are stated in the summary of findings at the beginning of this report.

3. Discomfort Glare Testing

The results from the discomfort glare tests are discussed and shown in Appendix F. Conclusions are discussed in the findings at the beginning of this report.

CONCLUSIONS AND RECOMMENDATIONS

As noted in the Introduction, there were many complaints from miners about the glare from current lighting systems even though there was general agreement that the environment or general lighting was a great improvement over lighting by caplamps only. Tests by evaluating instruments in this report confirmed the reaction of the miners by measuring very large losses of visibility due to Disability Glare and marked degrees of Discomfort Glare. Therefore these data would lead to the conclusion that the conditions should be remedied by suitable general lighting design. It is the considered judgment of the authors as both researchers and application engineers that this can be satisfactorily done.

Before this can be carried out there are some further data that need to be obtained. A thorough basis for the 0.06 footlamberts needs to be established. We now know from psychophysical data that the effect of surrounds has a large impact on the ability to see the tasks at hand. Of course Disability Glare is proving that in this report. However, the general surrounding ambience of light has a large effect. Lythgoe, in 1931, found that dark surrounds profoundly affected visual acuity, the ability to see small detail. This was confirmed by later researchers. Recently, Boynton found that as one looks about in the scanning process and encounters lighter or darker areas, there is an immediate loss of visual sensitivity which means lowered visibility. Thus the luminance (or brightness) of the surroundings should be kept in appropriate balance with the luminance of the task. In interior environments the goal is not to exceed ten to one, i.e. the surroundings be not less than one tenth the luminance of the task or greater than ten times the task. But what is the task or tasks? At the present time we do not know. Only tests with the Visual Task Evaluator can really tell how much light should be on the tasks.

If we assume that the current regulations value of 0.06 footlamberts is correct, then will 0.06 footlamberts be enough for seeing the tasks in coal mines? There would be a strong question in our minds as to whether this would be adequate.

What do caplamps deliver to the tasks and do they make the details plainly visible? All of this could be determined by suitable Visual Task Evaluator measurements. We would recommend that this be done.

Assuming that the environmental field luminance of 0.06 fL combined with the light provided by caplamps will turn out to be satisfactory to adequately illuminate the details to be seen, then the results of this study can be summarized as follows:

Disability Glare

1) There is no difference in the mean sensitivity between the underground mining population and the aboveground population.

2) The frequency curve of disability glare, Figure 3, indicates that some miners are very sensitive to disability glare and some are very insensitive. The very sensitive could account for the reports of unhappiness from some miners with current lighting systems.

3) It is recommended that the formulation developed by Blackwell in Appendix E and CIE Report 19/2 be used to evaluate the effects of various lighting systems on disability glare.

Discomfort Glare

1) The frequency curves for discomfort glare, Figure 33-39 for all levels of field luminance (0.1, 1.0 and 10 footlamberts) shows there was a tendency for most observers to be sensitive to low levels of luminance; however, just as in the case of disability glare there were some quite insensitive to much higher levels.

2) DESIGN TECHNIQUE A: Based on the data for both the "on" and "off" shifts at 0.1 fL field luminance plotted in Figures 34 and 35, the majority of observers (approximately 58%) were at the borderline between comfort and discomfort between the limits of 1 to 400 fL. The limiting luminance for the 0.0011 steradian glare test source (which represents a luminous area of 2 inches by 2 inches at a distance of five feet) is 200 fL. Prorating the 0.1 fL field luminance to the regulated luminance of 0.06 fL results in an index of sensation, M = 141 for the 0.0011 steradian test glare source. Then holding M = 141 as a constant and varying $\overline{K}$ and ω, in the basic glare equation:

$$M = \frac{L\overline{K}\omega}{PF^{.32}}$$

The limiting luminances of other various sized glare sources have been calculated and plotted in the graph, Figure 40.

3) DESIGN TECHNIQUE B: Based on the combined data from all field luminances, the revised formula presented below represents the changed constant value to account for the 40% increase of sensitivity of "off" shift miners over "on" shift miners and the reduced exponent 0.32, which modifies the environmental field luminance, F.

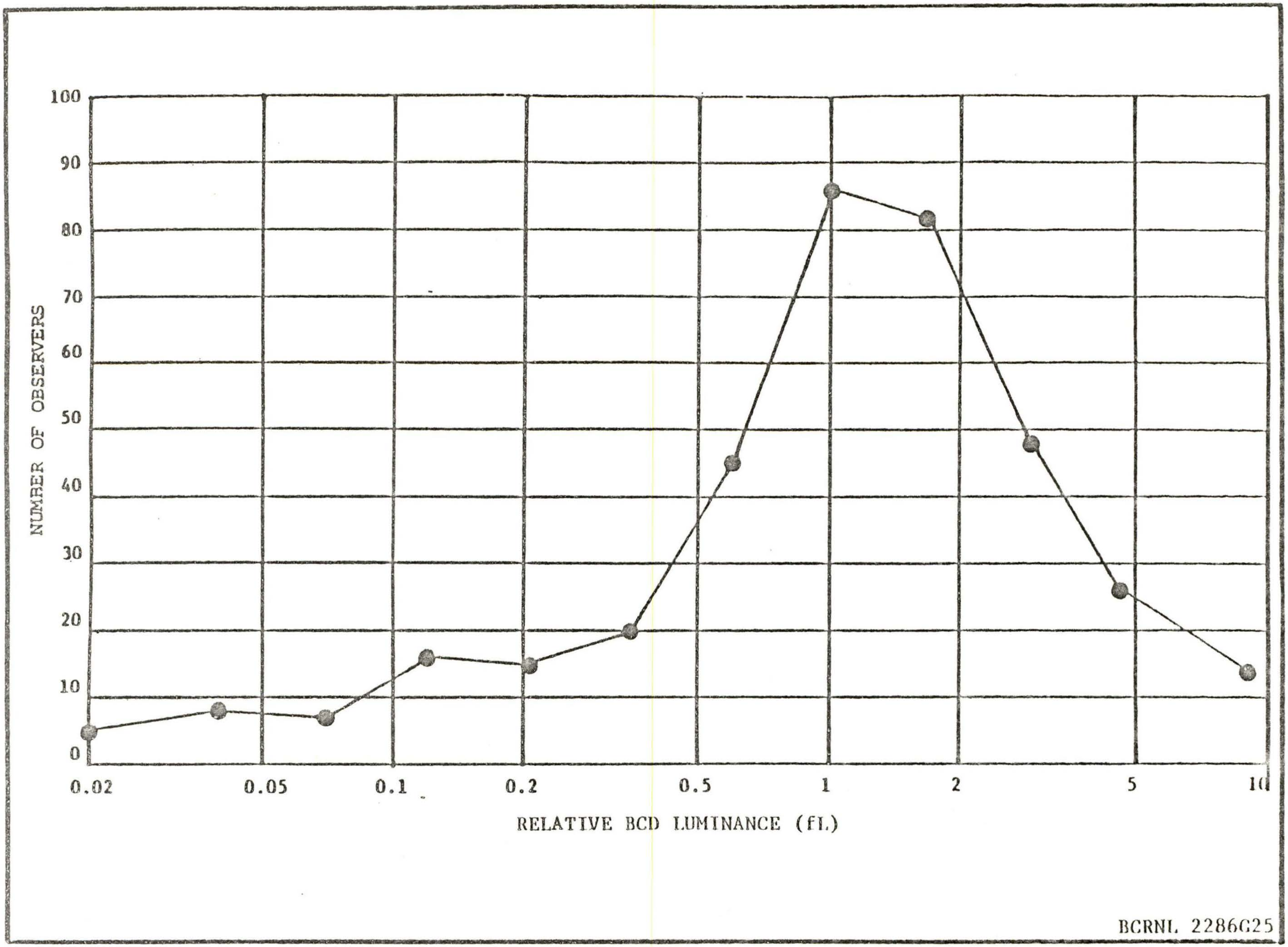


FIGURE 33. Discomfort Glare Frequency Plotting for Combined Data at all Field Luminances

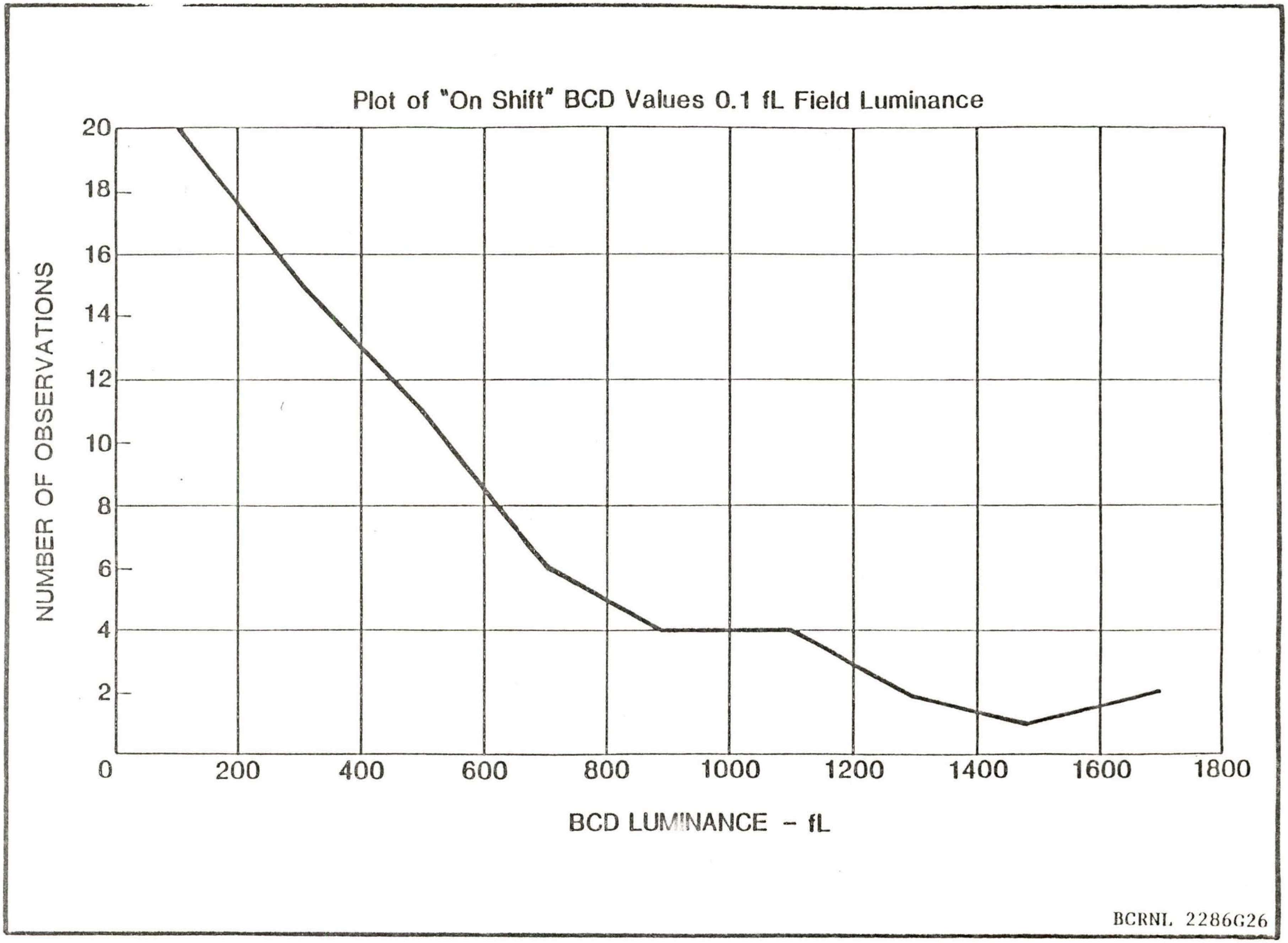


Figure 34. Frequency Plotting for "On" Shift BCD Data at 0.1 fL, Field Luminance.

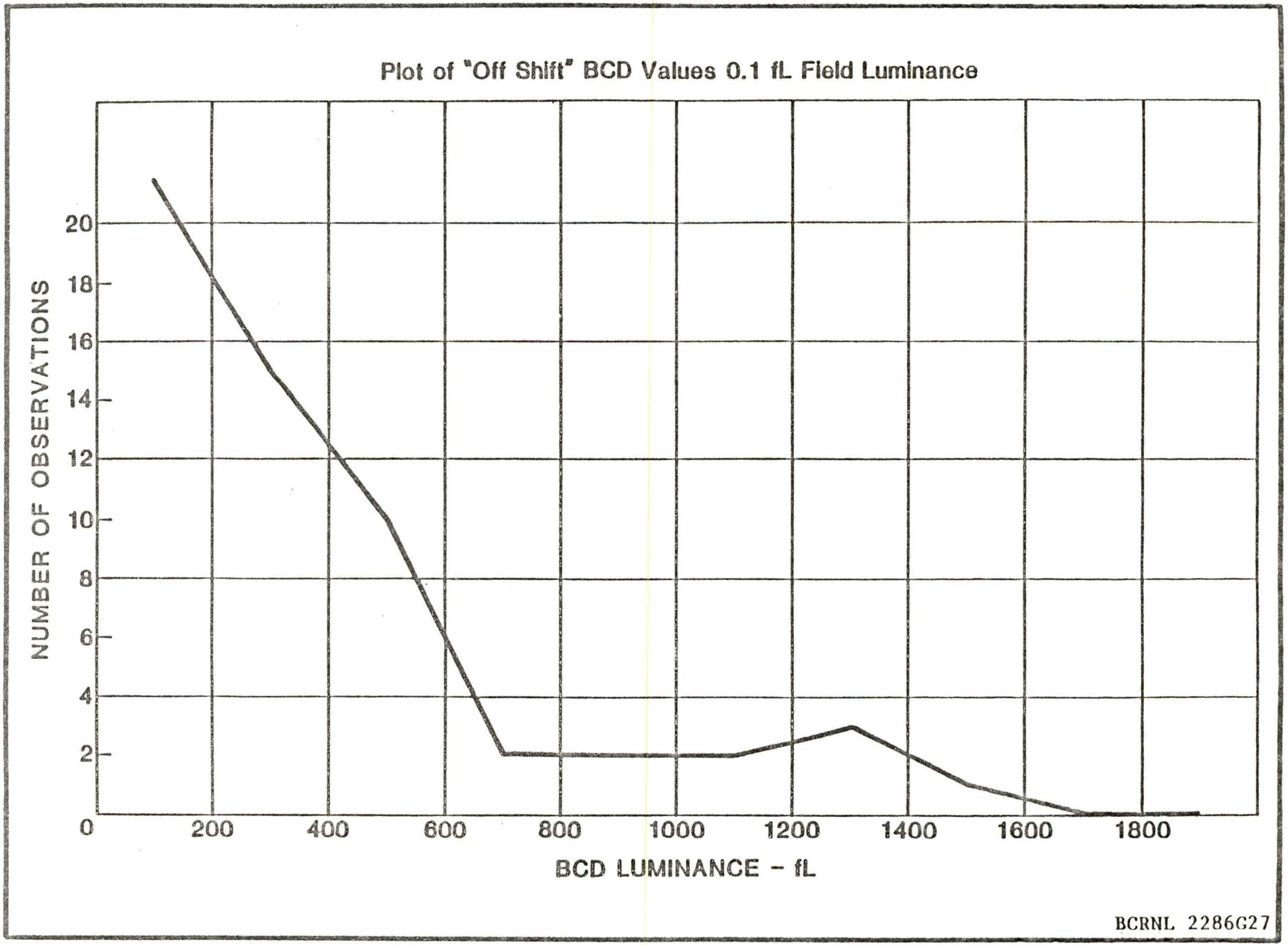
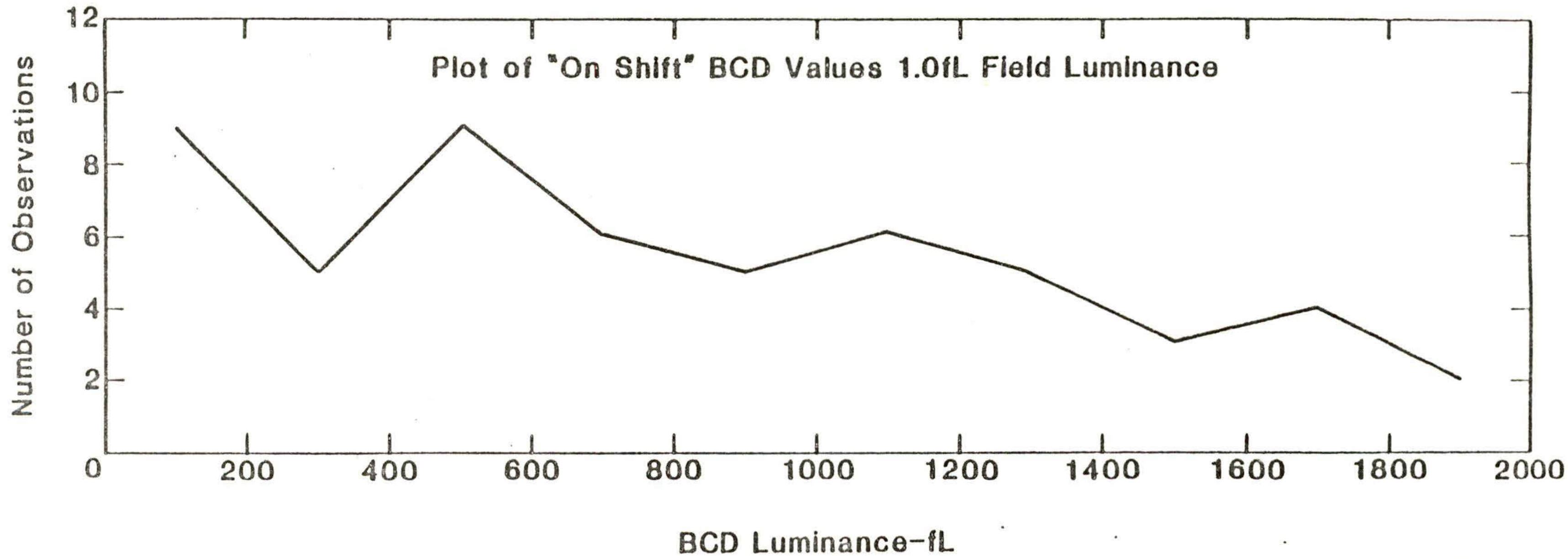


Figure 35. Frequency Plotting for "Off" Shift BCD Data at 0.1 fL, Field Luminance.



BCRNL 2286G29

Figure 36. Frequency Plotting for "On" Shift BCD Data at 1.0 fL, Field Luminance.

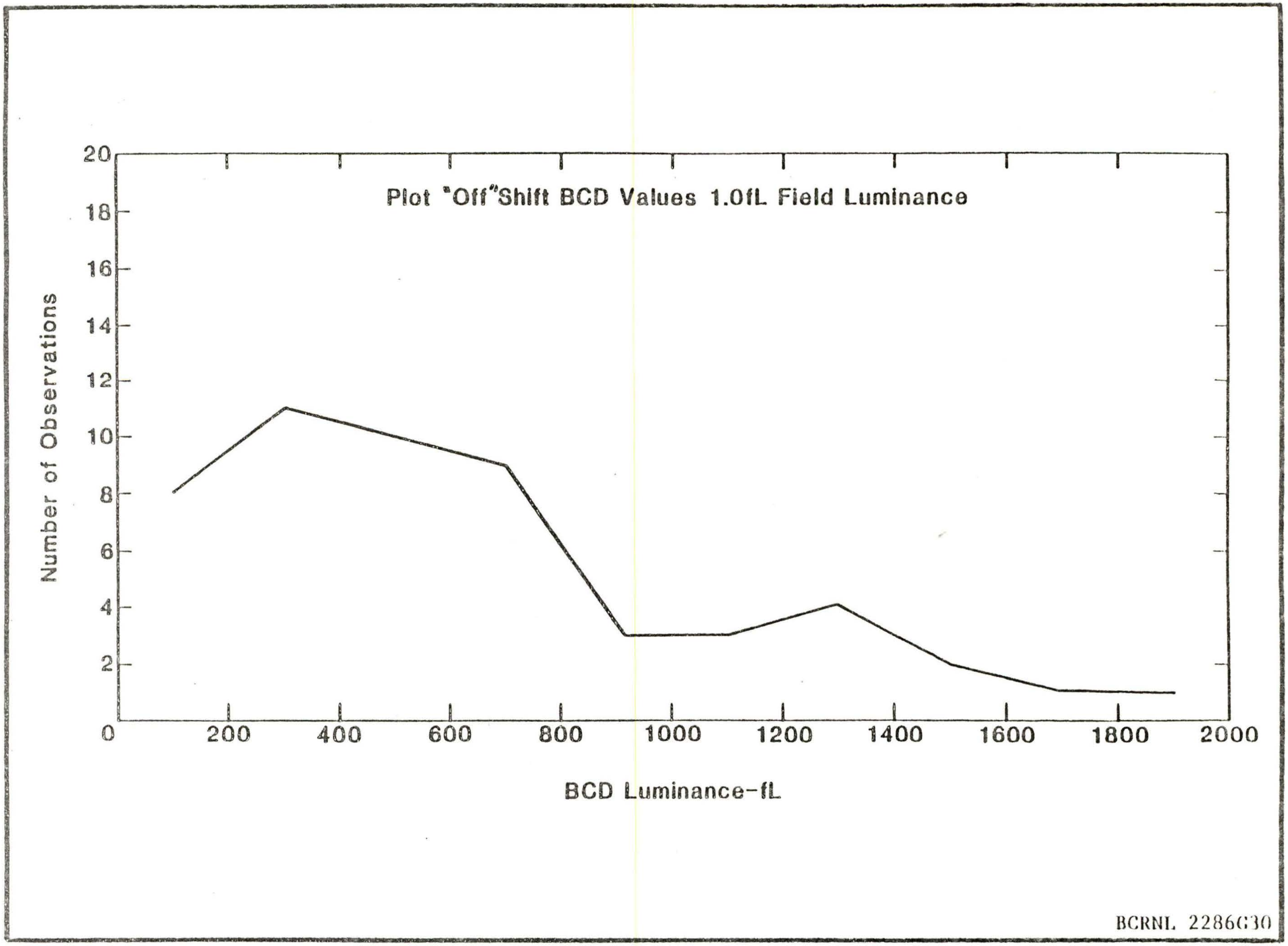
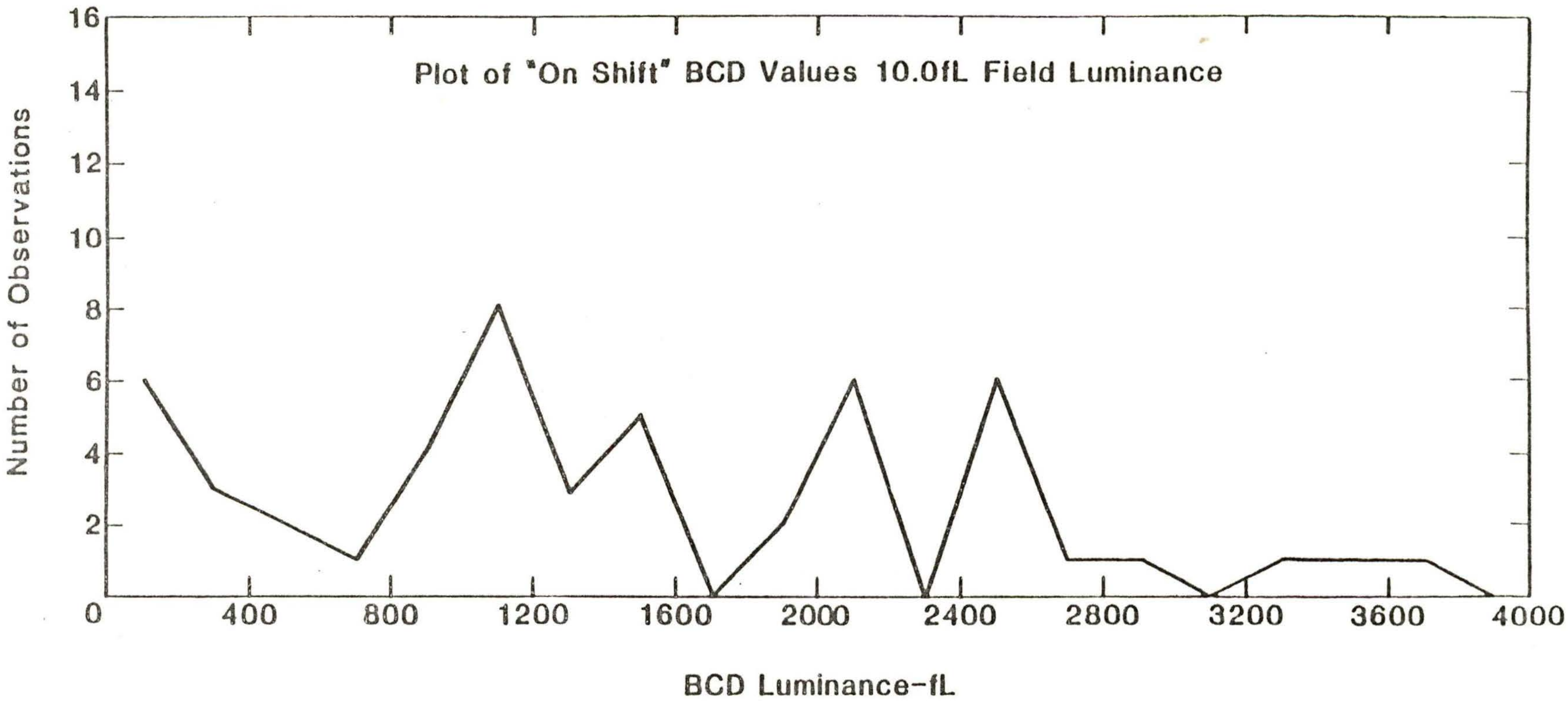


Figure 37. Frequency Plotting for "Off" Shift BCD Data at 1.0 fL, Field Luminance.



BCRNL 2286G31

Figure 38. Frequency Plotting for "On" Shift BCD Data at 10.0 fL, Field Luminance.

[redacted]

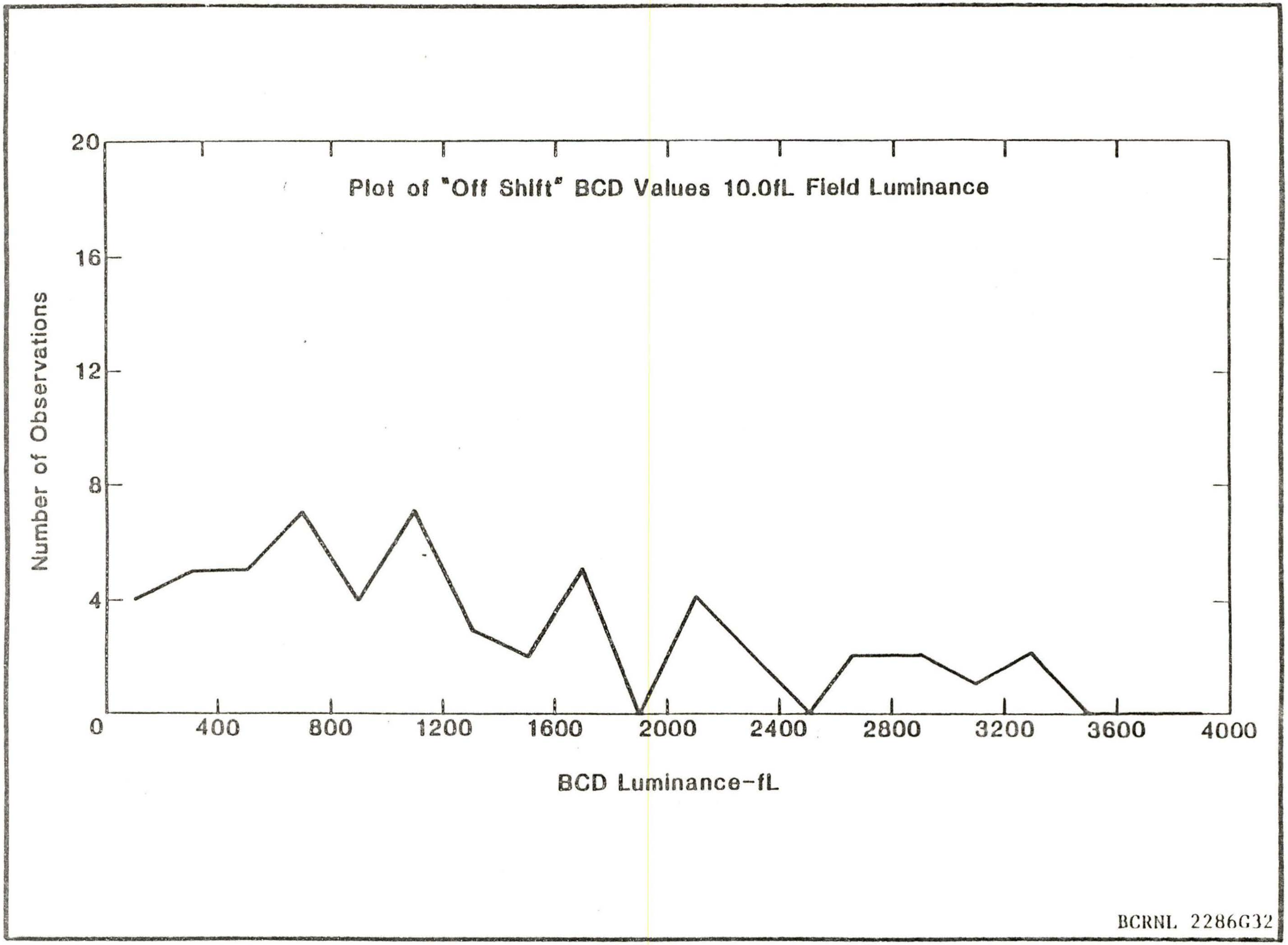


Figure 39. Frequency Plotting for "Off" Shift BCD Data at 10.0 fL, Field Luminance.

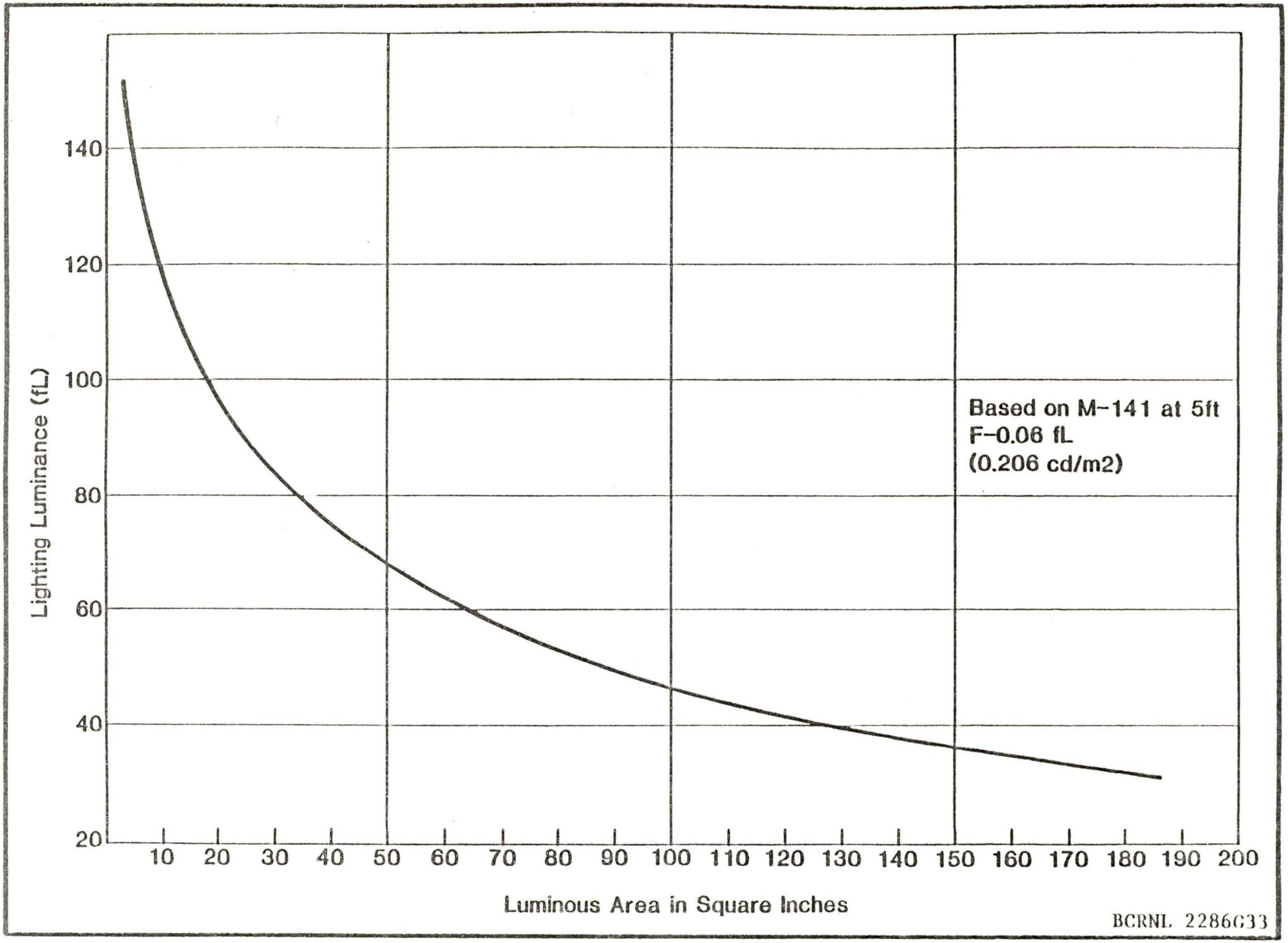


Figure 40. Limiting Luminances for Different Sized Luminaires to be Used in Designing, Which Consider Discomfort.

Revised Luminance formula: $L = 473F^{.32}$

Then use the calculated L, above, to determine the index of sensation M:

$$M = \frac{L\bar{K}\,\omega}{PF^{.32}}$$

Where:

M = Index of Sensation

L = the luminance of the glare source

ω = the solid angle of the glare source in steradians, subtended by the source at the eye of the observer.

$\bar{K}$ = a factor related to the solid angle ω, and found in Appendix F, Table F12.

F = the field or environmental luminance to which the observer is adapted.

P = position factor in relation to the line of sight as shown in the following table:

Angle On the Line of Sight	P
0 degrees	1.0
Angle Above the Line of Sight	
5 degrees	1.2
10 degrees	1.5
15 degrees	1.7
20 degrees	2.1
Angle Below the Line of Sight	
5 degrees	.90
10 degrees	1.13
15 degrees	1.28
20 degrees	1.58
25 degrees	2.03
30 degrees	2.48
35 degrees	3.15
40 degrees	4.05
45 degrees	5.25

From the calculated index of sensation M, determine DGR as shown in the design section for this report and summarized below.

DGR = the Discomfort Glare Rating, is equal to M_t^a which represents the combined indices of sensation of all glare sources contributing to discomfort.

a = a variable exponent equal to $n^{-.914}$ where n is the number of glare sources in the field of view as shown below:

n	a
1	1.000
2	0.939
3	0.904
4	0.880

M_t = the sum of all the indices of sensation.

If the glare sources are widely separated around the mining machine, only one luminaire may be contributing to the glare sensation or at least most of the sensation of the total scene; therefore the disability glare rating, DGR will equal the index of sensation M for the particular unit being observed. One then applies the DGR to Figure 19, using the solid line for determining the percent of the population satisfied using the combined "on" and "off" shift data, and using the dashed line to determine the percentage satisfied using the most sensitive, "off" shift data.

VI. DISCUSSION

Looking at Figure 40, it is seen that for practically sized luminaires, the limiting luminance is comparatively low for which a luminaire would be designed. One possibility could be to go to the next higher level of discomfort "barely uncomfortable" which would allow a multiplier of 1.33 for the limiting luminance and a visual comfort probability of 38%. Another approach would be to use more diffusing luminaires per machine than are currently being used. If prismatic or reflector techniques of light control are used in design, an asymmetric distribution could be produced which would reduce the candlepower in the zone where the worker's eyes would be located. Outside of this viewing zone the candlepower could be greatly increased to throw two beams of light, one beam on the roof, the other washing the floor. This method would hold true only for lighting high coal seams but not for the low coal seam conditions. When all are visualized, we would recommend that indirect lighting be used where all the light is thrown upward to the roof and the upper coal face and ribs, with adequate shielding of the luminaire from the viewer's eyes. The light would then be reflected through the environment, to light the machines and surroundings without glare. With sufficient lumens of light directed upward, all objects should be adequately seen for safety purposes. Should there be a desire to highlight the floor area for greater visibility of ruts and possible obstructions, luminaires could be provided to send out a beam over the floor area to supplement the indirect light. See conclusions of the report to the Bituminous Coal Research, Inc. on reflectivity of coal surfaces by C. L. Crouch[20].

VII. REFERENCES

1. "An Analytic Model For Describing the Influence of Lighting Parameters Upon Visual Performance," CIE Publication No. 19/2, International Commission on Illumination, Paris, France, 1981.

2. M. Luckiesh and L. L. Holladay, Trans. IES, 20, (1925).
   L. L. Holladay, J. Opt. Soc. AM., 12, p. 279, (1926).

3. S. Stiles, Proc. CIE, p. 220, (1928).

4. G. A. Fry, Illum. Eng., 50, p. 31, (1955).

5. H. R. Blackwell, Illum. Eng., 50, p. 286, (1955).
   H. R. Blackwell, JIES, 9, p. 205, (1980).
   H. R. Blackwell, CIE Report No. 19/2, (1981).

6. G. A. Fry, Illum. Eng., 49, p. 98, (1954).

7. A. J. Fisher and A. W. Christie, Vision Res., 5, p. 565, (1965).

8. A. Mariani and G. Longobardi, Atti della Fondazione Giorgia Ronchi, 28, p. 751, (1973).
   L. Ronchi, R. Sulli, G. Longobardi, Atti della Fondazione Giorgia Ronchi, 29, p. 965, (1974).

9. H. R. Blackwell, JIES, 9, p. 205, (1980).
   H. R. Blackwell, JIES, 11, p. 52, (1981).

10. G. A. Fry, CIE Proc., (1955).

11. G. A. Fry, B. S. Pritchard, H. R. Blackwell, Illum. Eng., 58, p. 120, (1963).

12. H. R. Blackwell, Illum. Eng., 54, p. 317, (1959).
    H. R. Blackwell, Illum. Eng., 65, p. 267, (1970).

13. R. J. Lythgoe, "Measurement of Visual Acuity," Special Report No. 173, Medical Research Council, His Majesty's Stationery Office, London, (1932).

14. R. G. Hopkinson, Illum. Eng., 52, p. 305, (June 1957).
    R. G. Hopkinson, and P. Petherbirdge, Trans. Illum. Eng. Soc. (London), 15, p. 39, (1950).

15. G. Sollner, H. W. Bodmann, and E. Senger, Illum. Eng., 61, p. 347, (1966).
G. Sollner, Lichtechnik, 15, p. 142, (April 1963), 17, p. 59A, (May 1965).

16. S. K. Guth, M. Luckiesh, Illum. Eng., 49, p. 650, (1949).

17. J. M. Fugate and G. A. Fry, Illum. Eng., 51, p. 537, (July 1956).

18. C. A. Bennett, Light, Des. and Appl., 7, p. 22, (January 1977).

19. J. F. McNelis, J. Illum. Eng. Soc., 10, p. 55, (1981).

20. C. L. Crouch, "Reflectivity of Underground Coal Mine Surfaces", Report to Bituminous Coal Research, Inc., 1983.

APPENDIX D

TABULATED DISABILITY GLARE FACTOR (DGF) FIELD DATA

APPENDIX D

DGF TABULATED FIELD DATA

and

DISABILITY GLARE INSTRUMENTATION

List of Tables

List of Figures

Instrumentation

TABLE D1. DGF MEASUREMENTS FOR THE CONTINUOUS MINER

Lighting System*	Position 1	Position 2	Position 3	Position 4
A. 15w fluorescent	(T1) **	(T10) 1.000	(T23) 0.043	(T24) 0.791
B. 1500 ma fluorescent	(T2) 0.018	(T14) 0.644	(T28) 0.806	(T29) 0.578
C. 1500 ma fluorescent	(T3) 0.193	(T12) 0.291	(T26a) 0.670	(T25) 0.617
D. 1500 ma fluorescent	(T4) 0.473	(T11) 0.815	(T15) 0.241	(T16) 0.552
E. 1500 ma fluorescent	(T5) 0.557	(T13) 0.477	(T26b) 0.487	(T27) 0.574
F. Incandescent (Unshielded)	(T6) **	(T9) **	xxx	(T17) 0.317
G. Incandescent (Shielded)	xxx	xxx	(19) 0.645	(T18) 0.492
H. Incandescent (Unshielded)	(T7) 0.677	(T8) **	xxx	xxx
I. Incandescent (Partial shield at 45 degrees)	xxx	xxx	(T22) 0.104	xxx
J. Incandescent	xxx	xxx	(T20) 0.977	(T21) 0.311

xxx - Position was not measured
** - DGF could not be calculated
* - In Guth's Analysis in Appendix F, page , he designates the systems as follows:
Continuous Miner: A = 1, B = 2, C = 3, D = 4, F & G = 6, H, I, & J = 7
Bolter: A = 1, B = 2, D = 7, E & F = 6

TABLE D2. DGF MEASUREMENTS FOR THE ACME BOLTER

Lighting System*	Position 1	Position 2	Position 3
A. 15w fluorescent	(T1) 0.116	(T6) 0.229	(T11) 0.100
B. 1500 ma fluorescent	(T2) **	(T7) 0.071	(T12) 0.100
C. 1500 ma fluores-	(T3) 0.411	(T8) 0.360	(T13) 0.306
D. Incandescent	(T4) 0.637	(T9) 0.573	(T14) 0.039
E. Incandescent (Shielded)	(T5a)0.679	(T10b).025	(T15) 0.358
F. Incandescent (Unshielded)	(T5b)0.395	(T10a).400	

** - DGF could not be calculated

TABLE D3. SUMMARY OF MSHA ACADEMY POPULATION CHARACTERISTICS ALONG WITH DISABILITY GLARE FACTOR, DGF, EVALUATIONS AT HIGH LUMINANCE LEVEL

Observer Number	Age	Years as a Miner	Eye Color Light/Dark	Glasses, Contacts, Neither	Visual Acuity	DGF	K
1.	26	1/4	D	G	----	.432	20.2
2.	26	0	D	G	----	.440	19.1
3.	28	0.3	D	G	----	.333	32.3
4.	30	6.0	D	G	R:20/20,L:20/20	.432	20.2
5.	31	5.0	L	N	R:20/20,L:20/20	.493	15.4
6.	34	7.0	D	N	R:20/20,L:20/20	.650	7.8
7.	37	0.1	L	N	----	.714	5.8
8.	38	1.0	D	G	----	.455	18.6
9.	38	2.0	L	N	----	.595	9.0
10.	39	5.0	D	N	----	.431	20.8
11.	38	1.5	D	N	R:20/20,L:20/20	.407	23.1
12.	40	2.5	D	N	----	.418	22.1
13.	41	13.0	L	N	----	.415	22.2
14.	43	0	L	N	----	.421	22.1
15.	45	14.0	L	G	R:20/20,L:20/20	.329	34.7
16.	52	29.0	L	N	----	.608	9.9
17.	55	22.0	D	N	----	.577	11.5
18.	55	22.0	L	N	R:20/30,L:20/30	.316	38.4
20.	59	3/4	D	N	R:20/30,L:20/20	.242	60.5
21.	61	40.0	D	G	R:20/30,L:20/30	.837	2.9
22.	65	35.5	L	N	R:20/60,L:20/60	.824	3.2
23.	74	0	L	N	----	.324	39.9

TABLE D4. SUMMARY OF UNDERGROUND MINING POPULATION CHARACTERISTICS ALONG WITH DISABILITY GLARE FACTOR, DGF, EVALUATIONS AT HIGH LUMINANCE LEVEL

MAPLE MEADOW MINE

Observer Number	Age	Years as a Miner	Work Shift	Eye Color: Light/ Dark	Glasses, Contacts, Neither	Color Vision: Normal/ Deficient	Visual Acuity	DGF	K
1.	30	8	2 on	D	N	N	R:20/20,L:20/20	.481	16.6
2.	37	5	2 on	D	N	N	R:20/20,L:20/26	---	----
3.	25	5	2 on	L	N	N	R:20/20,L:20/20	.742	5.0
4.	41	6	2 on	D	N	N	R:20/20,L:20/20	.608	4.7
5.	28	5	2 on	D	N	D	R:20/20,L:20/20	---	----
6.	30	10	2 on	L	G	N	R:20/20,L:20/20	.610	9.4
7.	33	10	2 on	D	N	N	R:20/20,L:20/20	.914	1.3
8.	34	7	2 on	L	G	N	R:20/45,L:20/32	.600	10.0
9.	39	6	2 on	L	N	N	R:20/32,L:20/32	.538	6.3
10.	30	8	2 on	L	N	N	R:20/32,L:20/32	.600	9.9
11.	24	6	3 on	L	N	N	R:20/20,L:20/20	.538	12.9
12.	33	6	3 on	L	G	N	R:20/45,L:20/45	.210	70.5
13.	32	14	3 on	D	N	N	R:20/20,L:20/20	.311	37.4
14.	39	15	3 on	D	G	N	R:20/20,L:20/20	.622	4.4
15.	40	5	3 on	L	N	N	R:20/20,L:20/20	.283	21.0
16.	28	5	3 on	D	N	N	R:20/20,L:20/20	.839	2.7
17.	42	8	3 on	L	G	N	R:20/32,L:20/32	.318	17.5
18.	50	6	3 on	L	N	N	R:20/20,L:20/20	.518	14.4
19.	25	8	3 on	D	N	N	-----	.300	39.2
20.	28	4	1 on	D	G	N	R:20/20,L:20/20	.518	8.9
21.	31	4	1 on	D	G	N	R:20/20,L:20/20	.514	14.4
22.	37	14	1 on	D	N	N	R:20/20,L:20/20	.720	2.7
23.	23	2	1 on	L	N	N	R:20/20,L:20/20	.523	13.8
24.	33	6	1 on	L	N	N	R:20/20,L:20/20	.529	13.6
25.	40	10	1 on	L	G	N	R:20/20,L:20/20	.382	12.7
26.	23	4	1 on	D	N	N	R:20/20,L:20/20	.589	10.3
27.	23	6	1 on	L	N	N	R:20/20,L:20/20	.556	11.9
28.	21	4	2 off	D	N	N	R:20/20,L:20/20	.345	31.0
29.	31	13	2 off	L	N	N	R:20/20,L:20/20	.500	15.3
30.	30	11	2 off	D	N	N	R:20/20,L:20/20	.522	13.8
31.	26	8	2 off	L	N	N	R:20/20,L:20/20	.674	7.0
32.	26	7	2 off	D	G	N	R:20/20,L:20/20	.345	31.0
33.	28	10	2 off	L	N	N	R:20/20,L:20/20	.629	8.7
34.	44	27	2 off	L	G	N	R:20/20,L:20/20	.713	5.9
35.	41	24	3 off	D	N	N	R:20/20,L:20/20	.400	11.7

TABLE D4. SUMMARY OF UNDERGROUND MINING POPULATION CHARACTERISTICS ALONG WITH DISABILITY GLARE FACTOR, DGF, EVALUATIONS AT HIGH LUMINANCE LEVEL

MAPLE MEADOW MINE
(continued)

Observer Number	Age	Years as a Miner	Work Shift	Eye Color: Light/ Dark	Glasses, Contacts, Neither	Color Vision: Normal/ Deficient	Visual Acuity	DGF	K
36.	38	12	3 off	D	N	N	R:20/20,L:20/20	.500	7.4
37.	30	10	3 off	D	N	N	R:20/32,L:20/45	.615	9.2
38.	22	5	3 off	L	G	N	R:20/32,L:20/32	.377	26.5
39.	34	5	3 off	L	G	N	R:20/20,L:20/20	.714	5.8
40.	44	25	3 off	D	G	N	R:20/38,L:20/45	.441	19.7
41.	37	13	3 off	L	N	N	----	.440	20.3
42	25	5	1 off	L	N	N	R:20/20,L:20/20	.285	42.8
43.	36	3	1 off	D	N	N	R:20/20,L:20/20	.512	14.7
44.	26	3	1 off	D	N	N	R:20/32,L:20/38	.441	19.7
45.	21	12	1 off	L	N	N	R:20/20,L:20/20	.365	28.1
46.	21	3	1 off	L	N	N	R:20/20,L:20/20	.676	7.0
47.	31	12	1 off	L	N	N	R:20/38,L:20/20	.395	24.4
48.	24	6	1 off	L	N	N	R:20/20,L:20/20	.631	8.4
49.	34	7	1 off	L	N	N	R:20/20,L:20/32	---	---
50.	33	7.5	1 off	-	N	N	----	.449	19.2
51.	24	5	1 off	D	N	N	R:20/32,L:20/38	.480	16.6
52.	25	6	1 off	D	N	N	R:20/20,L:20/20	.622	8.9

TABLE D5. SUMMARY OF UNDERGROUND MINING POPULATION CHARACTERISTICS ALONG WITH DISABILITY GLARE FACTOR, DGF, EVALUATIONS AT LOW LUMINANCE LEVEL

MAPLE MEADOW MINE

Observer Number	Age	Years as a Miner	Work Shift	Eye Color: Light/ Dark	Glasses, Contacts, Neither	Color Vision: Normal/ Deficient	Visual Acuity	DGF	K
1.	30	8	2 on	D	N	N	R:20/20,L:20/20	---	--
2.	37	5	2 on	D	N	N	R:20/20,L:20/26	---	--
3.	25	5	2 on	L	N	N	R:20/20,L:20/20	.469	61.7
4.	41	6	2 on	D	N	N	R:20/20,L:20/20	.364	131.0
5.	28	5	2 on	D	N	D	R:20/20,L:20/20	.648	23.7
6.	30	10	2 on	L	G	N	R:20/20,L:20/20	.431	76.4
7.	33	10	2 on	D	N	N	R:20/20,L:20/20	.263	248.0
8.	34	7	2 on	L	G	N	R:20/45,L:20/32	.333	147.3
9.	39	6	2 on	L	N	N	R:20/32,L:20/32	.411	95.5
10.	30	8	2 on	L	N	N	R:20/32,L:20/32	.471	61.0
11.	24	6	3 on	L	N	N	R:20/20,L:20/20	.593	31.8
12.	33	6	3 on	L	G	N	R:20/45,L:20/45	.507	51.2
13.	32	14	3 on	D	N	N	R:20/20,L:20/20	.465	64.5
14.	39	15	3 on	D	G	N	R:20/20,L:20/20	---	--
15.	40	5	3 on	L	N	N	R:20/20,L:20/20	.622	30.0
16.	28	5	3 on	D	N	N	R:20/20,L:20/20	.613	28.6
17.	42	8	3 on	L	G	N	R:20/32,L:20/32	.754	14.2
18.	50	6	3 on	L	N	N	R:20/20,L:20/20	.632	31.1
19.	25	8	3 on	D	N	N	-----	.594	31.7
20.	28	4	1 on	D	G	N	R:20/20,L:20/20	---	--
21.	31	4	1 on	D	G	N	R:20/20,L:20/20	.971	1.0
22.	37	14	1 on	D	N	N	R:20/20,L:20/20	.361	127.0
23.	23	2	1 on	L	N	N	R:20/20,L:20/20	.385	100.5
24.	33	6	1 on	L	N	N	R:20/20,L:20/20	.382	106.0
25.	40	10	1 on	L	G	N	R:20/20,L:20/20	.556	42.8
26.	23	4	1 on	D	N	N	R:20/20,L:20/20	.424	79.5
27.	23	6	1 on	L	N	N	R:20/20,L:20/20	.410	91.0
28.	21	4	2 off	D	N	N	R:20/20,L:20/20	.813	8.6
29.	31	13	2 off	L	N	N	R:20/20,L:20/20	.522	46.7
30.	30	11	2 off	D	N	N	R:20/20,L:20/20	.635	25.4
31.	26	8	2 off	L	N	N	R:20/20,L:20/20	.470	61.5
32.	26	7	2 off	D	G	N	R:20/20,L:20/20	.477	59.0
33.	28	10	2 off	L	N	N	R:20/20,L:20/20	.549	40.2
34.	44	27	2 off	L	G	N	R:20/20,L:20/20	.875	5.6
35.	41	24	3 off	D	N	N	R:20/20,L:20/20	---	--

TABLE D5. SUMMARY OF UNDERGROUND MINING POPULATION CHARACTERISTICS ALONG WITH DISABILITY GLARE FACTOR, DGF, EVALUATIONS AT LOW LUMINANCE LEVEL

MAPLE MEADOW MINE
(continued)

Observer Number	Age	Years as a Miner	Work Shift	Eye Color: Light/ Dark	Glasses, Contacts, Neither	Color Vision: Normal/ Deficient	Visual Acuity	DGF	K
36.	38	12	3 off	D	N	N	R:20/20,L:20/20	.441	79.0
37.	30	10	3 off	D	N	N	R:20/32,L:20/45	.226	333.0
38.	22	5	3 off	L	G	N	R:20/32,L:20/32	.357	120.0
39.	34	5	3 off	L	G	N	R:20/20,L:20/20	.496	55.5
40.	44	25	3 off	D	G	N	R:20/38,L:20/45	.774	12.7
41.	37	13	3 off	L	N	N	----	.245	308.0
42	25	5	1 off	L	N	N	R:20/20,L:20/20	.621	27.4
43.	36	3	1 off	D	N	N	R:20/20,L:20/20	---	---
44.	26	3	1 off	D	N	N	R:20/32,L:20/38	.774	12.7
45.	21	12	1 off	L	N	N	R:20/20,L:20/20	.551	39.7
46.	21	3	1 off	L	N	N	R:20/20,L:20/20	.625	26.8
47.	31	12	1 off	L	N	N	R:20/38,L:20/20	.461	65.3
48.	24	6	1 off	L	N	N	R:20/20,L:20/20	.550	40.0
49.	34	7	1 off	L	N	N	R:20/20,L:20/32	.568	37.7
50.	33	7.5	1 off	-	N	N	----	.615	29.1
51.	24	5	1 off	D	N	N	R:20/32,L:20/38	.753	12.9
52.	25	6	1 off	D	N	N	R:20/20,L:20/20	.720	15.8

TABLE D6. SUMMARY OF UNDERGROUND MINING POPULATION CHARACTERISTICS ALONG WITH DISABILITY GLARE FACTOR, DGF, EVALUATIONS AT LOW LUMINANCE LEVEL

Prescott and Derby Mines

Observer Number	Age	Years as a Miner	Work Shift	Eye Color: Light/ Dark	Glasses, Contacts, Neither	Color Vision: Normal/ Deficient	Visual Acuity	DGF 1st 2nd	K 1st 2nd
Prescott Mine									
53.	24	6	3 on	D	N	N	R:20/20,L:20/20	.915	2.4
			3 off					.446	51.3
54.	30	10	1 on	L	N	N	R:20/20,L:20/20	.358	86.0
			3 off					---	---
55.	30	9	1 on	D	N	N	R:20/20,L:20/20	.281	147.0
			3 off					---	---
56.	26	7	2 on	L	N	N	R:20/20,L:20/20	.358	86.0
			2 off					.462	46.8
57.	29	8	3 on	L	G	N	R:20/20,L:20/20	.860	4.4
			3 off					.434	54.9
58.	28	6	3 on	L	G	N	R:20/20,L:20/20	.838	5.3
			3 off					.791	7.5
59.	29	8	3 on	L	N	N	R:20/20,L:20/20	.594	23.4
			3 off					.182	382.0
60.	27	5	3 on	L	N	N	R:20/20,L:20/20	.844	5.1
								.740	10.4
61.	28	8	1 on	L	N	N	R:20/20,L:20/20	.508	36.6
			1 off					.667	15.9
62.	30	-	1 on	L	N	N	R:20/20,L:20/26	.962	1.0
			1 off					.556	28.4
63.	34	7	3 off	D	G	N	R:20/20,L:20/20	.738	10.9
			3 on					.750	10.1
64.	31	4	3 off	D	G	N	R:20/20,L:20/20	.610	21.5
			3 on					.969	0.8
65.	32	10	2 on	L	N	N	R:20/20,L:20/20	---	---
			2 off					.818	6.3
66.	45	15	2 on	L	N	N	R:20/20,L:20/20	.444	61.0
			2 off					.714	13.8
67.	22	4	3 on	L	N	N	R:20/20,L:20/20	.947	1.4
			3 off					.153	571.0
68.	29	6	3 on	L	N	N	R:20/20,L:20/20	.600	22.6
			3 off					.658	16.6
69.	29	9	3 on	L	G	N	R:20/20,L:20/20	.464	46.4
			3 off					.500	38.2
70.	43	10	3 off	L	N	N	R:20/20,L:20/20	.383	86.0
			3 on					.526	38.0

TABLE D6. SUMMARY OF UNDERGROUND MINING POPULATION CHARACTERISTICS ALONG WITH DISABILITY GLARE FACTOR, DGF, EVALUATIONS AT LOW LUMINANCE LEVEL

Prescott and Derby Mines (continued)

Observer Number	Age	Years as a Miner	Work Shift	Eye Color: Light/ Dark	Glasses, Contacts, Neither	Color Vision: Normal/ Deficient	Visual Acuity	DGF 1st 2nd	K 1st 2nd
Prescott Mine (continued)									
71.	26	5	3 off	L	G	N	R:20/26,L:20/20	.656	16.8
			3 on					.610	21.5
72.	35	14	2 on	L	N	N	R:20/20,L:20/20	.391	74.5
			2 off					.700	13.8
73.	40	7	2 off	L	G	N	R:20/32,L:20/26	.714	13.2
			2 on					---	---
74.	29	8	2 off	L	N	N	----	.537	31.5
			2 on					.762	9.1
75.	25	4	1 on	D	N	N	R:20/20,L:20/20	---	---
			1 off						
76.	36	11	2 on	L	N	N	R:20/20,L:20/20	.820	6.1
			2 off					.625	21.0
77.	47	10	3 on	L	N	N	R:20/20,L:20/26	.730	12.8
			3 off					.581	29.9
78.	26	6	3 on	D	N	N	R:20/20,L:20/20	.880	3.6
			3 off					.864	4.2
79.	27	4	3 on	L	N	N	R:20/32,L:20/20	.513	35.7
			3 off					---	---
80.	26	7	2 on	D	N	N	R:20/38,L:20/26	.744	10.2
			2 off					.660	16.4
81.	42	16	2 on	L	N	N	R:20/20,L:20/20	.381	86.0
			2 off					---	---
82.	26	6	1 on	D	N	N	R:20/32,L:20/20	.878	3.7
			1 off					---	---
83.	29	9	2 on	L	N	D	R:20/20,L:20/20	.794	7.4
			1 off					---	---
84.	31	8	3 on	D	N	N	----	---	---
			3 off					---	---
85.	31	8	3 off	L	N	N	----	.565	21.2
			3 on					.580	25.4
Derby Mines									
86.	22	4	3 off	L	N	N	R:20/20,L:20/20	.806	6.8
87.	22	4	3 on	L	N	D	R:20/20,L:20/20	.867	4.1
								.683	14.5

TABLE D6. SUMMARY OF UNDERGROUND MINING POPULATION CHARACTERISTICS ALONG WITH DISABILITY GLARE FACTOR, DGF, EVALUATIONS AT LOW LUMINANCE LEVEL

Prescott and Derby Mines (continued)

Observer Number	Age	Years as a Miner	Work Shift	Eye Color: Light/Dark	Glasses, Contacts, Neither	Color Vision: Normal/Deficient	Visual Acuity	DGF 1st 2nd	K 1st 2nd
Derby Mines (continued)									
88.	47	5	3 on	D	N	N	R:20/26,L:20/20	.808	7.6
89.	25	4	3 on	L	N	N	R:20/32,L:20/20	.652	17.2
								.305	123.0
90.	22	4	2 on	L	N	N	R:20/32,L:20/20	.800	7.1
								.710	12.4
91.	28	4	1 on	L	N	N	R:20/20,L:20/20	1.000	0.1
								.651	17.3
92.	30	6	1 off	L	G	N	----	---	---
93.	24	3	1 on	D	N	N	R:20/26,L:20/26	1.000	0.1
								.746	10.1
94.	31	6	3 off	L	G	N	R:20/20,L:20/20	.444	52.4
								.589	24.2
95.	26	5	1 on	D	N	N	R:20/26,L:20/32	.703	12.9
								.571	26.3
96.	27	8	3 off	D	N	N	R:20/20,L:20/20	.433	55.1
								.453	43.5
97.	25	4		D	G	D	R:20/20,L:20/26	.946	1.4
								.476	43.5
98.	45	7		L	G	N	R:20/20,L:20/20	.750	11.1
								.750	11.1
99.	37	11		L	G	N	R:20/20,L:20/26	.314	126.0
								.340	105.5
100.	46	4		L	N	N	R:20/20,L:20/20	.219	320.0
								.765	10.2
101.	32	8		D	N	D	R:20/20,L:20/20	.523	34.5
								.333	104.0
102.	28	3		D	N	N	R:20/20,L:20/20	.249	192.0
103.	27	8		D	N	N	R:20/20,L:20/20	.519	36.0
								.370	83.5
104.	34	8		D	N	N	R:20/20,L:20/20	.711	13.1
105.	37	4		D	N	N	R:20/20,L:20/20	.972	0.7
106.	38	6		L	N	N	R:20/20,L:20/20	.816	6.3
								.660	16.4
107.	22	5		L	N	N	R:20/20,L:20/20	.740	10.5
108.	31	11		L	N	N	R:20/32,L:20/32	.400	78.2
								.330	123.4

TABLE D6. SUMMARY OF UNDERGROUND MINING POPULATION CHARACTERISTICS ALONG WITH DISABILITY GLARE FACTOR, DGF, EVALUATIONS AT LOW LUMINANCE LEVEL

Prescott and Derby Mines
(continued)

Observer Number	Age	Years as a Miner	Work Shift	Eye Color: Light/ Dark	Glasses, Contacts, Neither	Color Vision: Normal/ Deficient	Visual Acuity	DGF 1st 2nd	K 1st 2nd
Derby Mines (continued)									
109.	44	5		D	G	N	R:40/40,L:20/20	.519 .370	36.0 83.5
110.	32	8		D	N	N	R:20/20,L:20/20	.711	13.1
111.	31	7		D	N	N	R:20/20,L:20/20	.972 ---	0.7 ---
112.	26	7		D	N	N	R:20/20,L:20/20	--- .925	--- 2.1
113.	24	5		L	N	N	R:20/45,L:20/45	.434 .587	51.7 24.2
114.	45	7		L	N	N	R:20/20,L:20/20	.800 .594	7.9 26.9

DISABILITY GLARE INSTRUMENTATION

Visual Task Evaluator (VTE)

Fry[10] in 1955 presented a proposed lens for mounting on the front of a luminance meter that would proportion the response of the photocell through the optical system in accordance with the disability glare effect. This concept was further developed in an actual glare lens in 1963[11]. This has been used extensively in street lighting in this country. In 1959, Blackwell[12] developed a Visual Task Evaluator, (VTE), for measurement of visibility of tasks in commerce and industry. This consisted of a contrast threshold meter that would reduce the unknown task to threshold (the point of bare seeability) and then through a calibration procedure an equivalency was determined between the task being evaluated and the laboratory test object on which extensive visibility data had been collected. The current model of the VTE includes a limited time exposure of 200 milliseconds between the opening and closing of the shutter. This time pause, 200 mSec, represents the eye pause necessary to gather sensory information. The field of view had been limited to two or three degrees to record the foveal response of the eye. Most recently an enlarged field of view was introduced into the optical path of the VTE through the use of the disability glare attachment. The enlarged field can account for age effects as well as the disability glare factor.

The disability glare evaluator (the optical attachment to the VTE) uses a 24 degree field of view to evaluate the visibility with and without glare. Under the skilled operation of an experienced VTE operator, the mine lighting systems' disability glare measurements were made using the disability glare evaluator attached to the VTE. Since precise measurements of visibility were being measured in Phase I, a skilled operator who was calibrated with the VTE, was required. In Phase II where the relative sensitivity of miners' reactions to disability glare was recorded, the same instrumentation was used but did not require the miner to be calibrated, since the actual visibility was not required, just the relative degree of visibility.

Operation of the Visual Task Evaluator

In normal operation the operator of the VTE looks through the instrument at the detail to be measured while simultaneously adjusting an internal veiling luminance which is superimposed over the detail. As the veiling luminance is increased, the contrast of the detail is reduced. The operator continues to adjust the veiling luminance until the detail can just barely be seen. This point of bare seeability is called threshold. At threshold all objects become equal in visibility; therefore they can be compared to determine the factor which would make them equally visible above threshold. This comparison allows details studied in the field to be related to details studied in the laboratory. Tests had been conducted by Blackwell on a population of normally sighted college age students to determine data on a standardized test object, a 4 minute disc (whose visual size is 4' of arc subtended at the eye of the observer). The relationship of threshold contrast versus light level for the 4' disc is an established function as shown in Figure D-1. This threshold function is part of the international system described in CIE 19/2 where visibility is related to visual performance. Each operator of the VTE completes a calibration procedure based on the 4' disc to produce a calibration curve. Through the calibration curve the equivalence in visibility (which includes both size and contrast) for the task being measured and the 4' disc is made. The equivalency is designated <u>equivalent contrast</u> whose symbol is $\tilde{C}$.

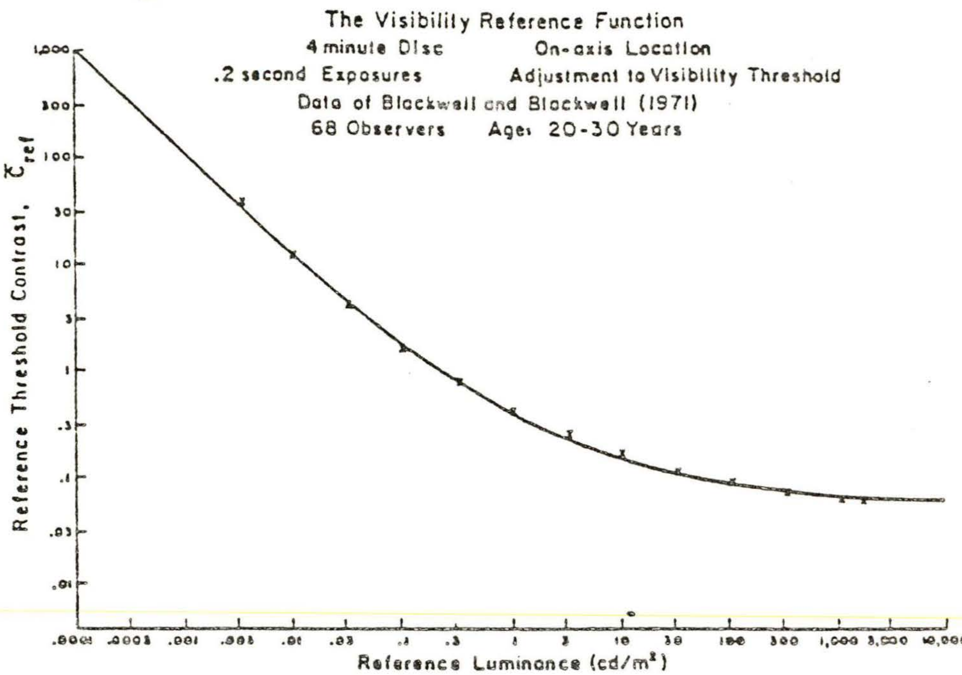


Figure D-1. Curve Showing Relation of Threshold Contrast vs. Luminance for a 4' Disc, Test Object.

APPENDIX E

DEVELOPMENT AND USE OF A QUANTITATIVE MODEL OF DISABILITY GLARE SENSITIVITY AS A FUNCTION OF OBSERVER AGE AND LUMINANCE

APPENDIX E

"DEVELOPMENT AND USE OF A QUANTITATIVE MODEL OF DISABILITY GLARE SENSITIVITY AS A FUNCTION OF OBSERVER AGE AND LUMINANCE"

Dr. H. Richard Blackwell, Director
Institute for Research and Vision
Ohio State University

List of Tables

List of Figures

DEVELOPMENT AND USE OF A QUANTITATIVE MODEL OF DISABILITY GLARE SENSITIVITY AS A FUNCTION OF OBSERVER AGE AND LUMINANCE

Prepared by Dr. H. Richard Blackwell
Director, Institute for Research in Vision, Ohio State University, and
Light and Vision Consultant, Columbus, Ohio

January 20, 1982

A. Introduction

As a portion of their studies of the lighting of coal mines, Crouch and Vincent studied the sensitivity to disability glare of various groups of coal miners, using two especially modified Blackwell Visual Task Evaluators. The technique was new, never having been used previously. It is not surprising, therefore, that experimental "glitches" were encountered which invalidated some of the experimental data obtained. However, two sets of valid data were obtained which have been subjected to analysis. One data set was obtained from a group of 31 miners from Prescott Mine; the second data set was obtained from a group of 28 miners from Derby Mines. In each case, visibility meter measurements were made at a luminance of .206 cd/m^2 (.06 fL).* The data analysis revealed values of glare sensitivity considerably greater than correspond to the classical value of the disability glare constant, K, equal to 10. The result is compatible with the assumption that sensitivity to discomfort glare is a function of the size of the ocular pupil, which is itself related to luminance, a notion first suggested by Mariani and Longobardi and by Ronchi, Sulli and Longobardi as reported in CIE Report No. 19/2 (1981). Accordingly, a quantitative model of disability glare sensitivity as a function of both observer age and luminance has been developed with the idea of comparing predictions from such a model with the data obtained by Crouch and Vincent. Such a comparison was expected to reveal whether or not coal miners exhibit more, less, or the same degree of sensitivity to disability glare as non-mining observers of the same age. Description of the model will proceed in two steps, first involving mean values for observer groups of differing age, and then involving measures of the variability of glare sensitivity among different members of each age group. The model is based upon studies of a total of 2,330 observers.

B. Mean Values for Different Observer Age Groups

The disability glare constant, K, is conceptualized to represent the product of two terms as follows:

$$K = K_{20} \times K_{rel} \qquad (1)$$

*Two other sets of valid data taken at a higher luminance are discussed on page 165.

where K_{20} represents the mean value of K for a population of normal observers aged 20 years, and K_{rel} equals values of K for observer groups of other ages expressed relative to the value for a 20 year age group under otherwise identical conditions. Values of K_{20} vary with luminance, whereas values of K_{rel} are independent of luminance.

The variation of K_{20} with luminance depends upon the variation in ocular pupil diameter for different luminance levels. We start by relating pupil diameter to luminance, using the standard data of deGroot and Gebhard expressed as follows:

$$p = \text{antilog}\ [.8558 - .000401\ (\log L + 8.60)^3] \qquad (2)$$

where L equals luminance in units of cd/m^2. Figure E-1 presents data of Blackwell and Blackwell obtained as part of a study of 235 observers of differing ages at two luminance levels, 100 and 1.7 cd/m^2. Experimentally determined values of K_{20} are plotted as a function of pupillary diameter calculated from Equation (1) for each of the two luminance levels. The solid line fitted through the two data points represents the empirical relationship:

$$K_{20} = 8.0 + 3.523(p - 1.82) \qquad (3)$$

where p equals pupillary diameter in mm.

Experimental values of K_{rel} as a function of age are presented in Figure E-2 representing the data of Blackwell and Blackwell for the 100 and the 1.7 cd/m^2 luminances and the very extensive data of Adrian obtained on 2095 observers of varying age at a luminance level of 0.1 cd/m^2. It is considered that Figure E-2 confirms the assumption that K_{rel} is independent of luminance within the precision of the experimental data. The two solid lines in Figure E-2 define the following relationships between K_{rel} and age:

For age $\leq$ 42.76 years $K_{rel} = 1$ (4a)

For age > 42.76 years $K_{rel} = \text{antilog}\ [1.778(\log A - 1.631)]$ (4b)

where A equals age in years.

Based upon these arguments, the quantitative model predicts the full gamut of interrelations between K, observer age and luminance. Simply compute pupillary diameter, p, for any level of luminance of interest from Equation (2), compute K_{20} from the value of p obtained using Equation (3), compute K_{rel} from observer age using Equation (4a) or (4b), and then compute K from the values of K_{20} and K_{rel} obtained in the earlier steps of computation using Equation (1). (It should be noted that the model is undoubtedly oversimplified since it is known that age affects the relation between pupillary diameter and luminance. No account has been taken of this complication since the experimental data shown in Figures E-1 and E-2 appear to

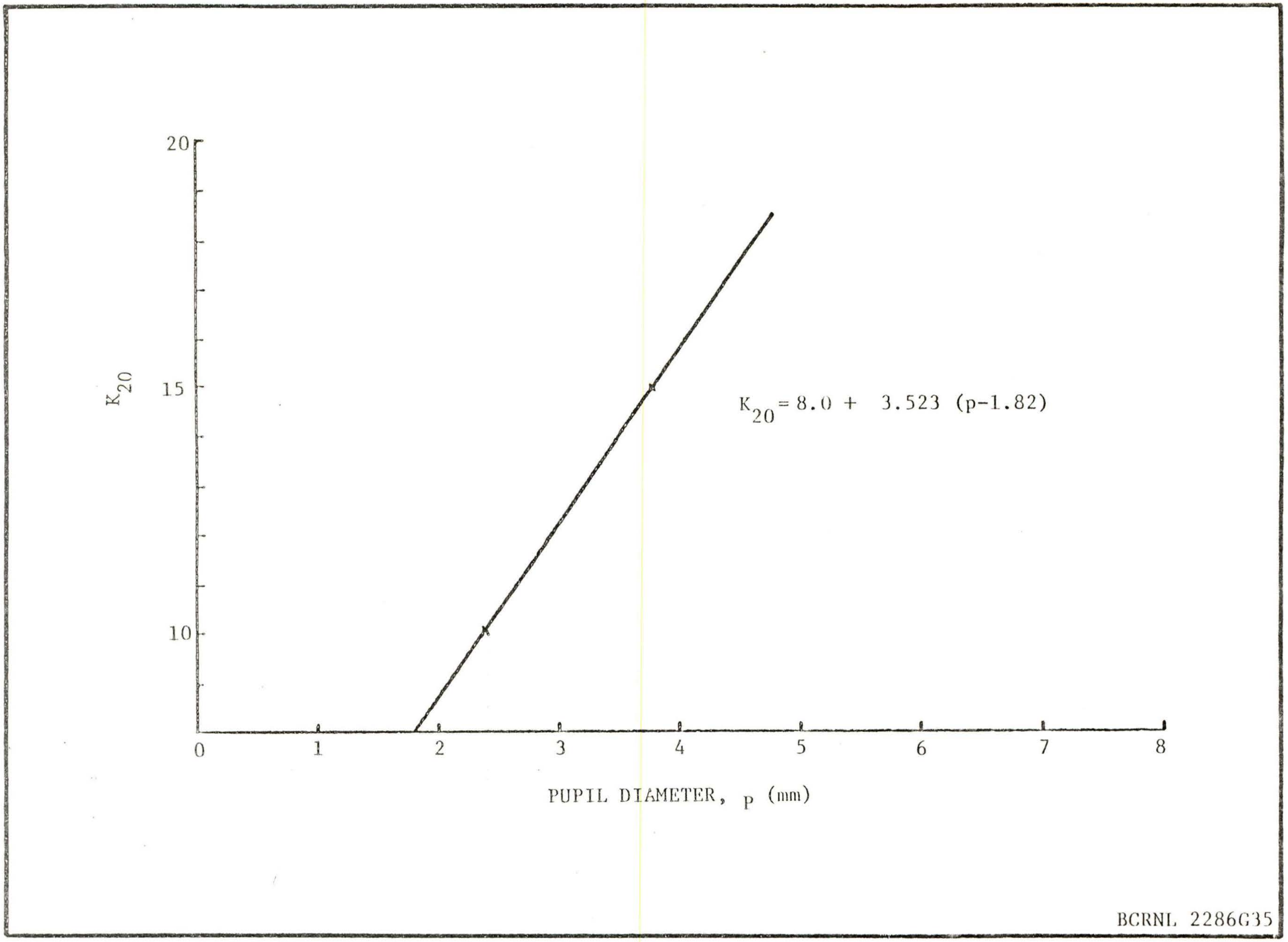


Figure E-1. Disability Glare Constant Values as a Function of Observer Pupil Diameter.

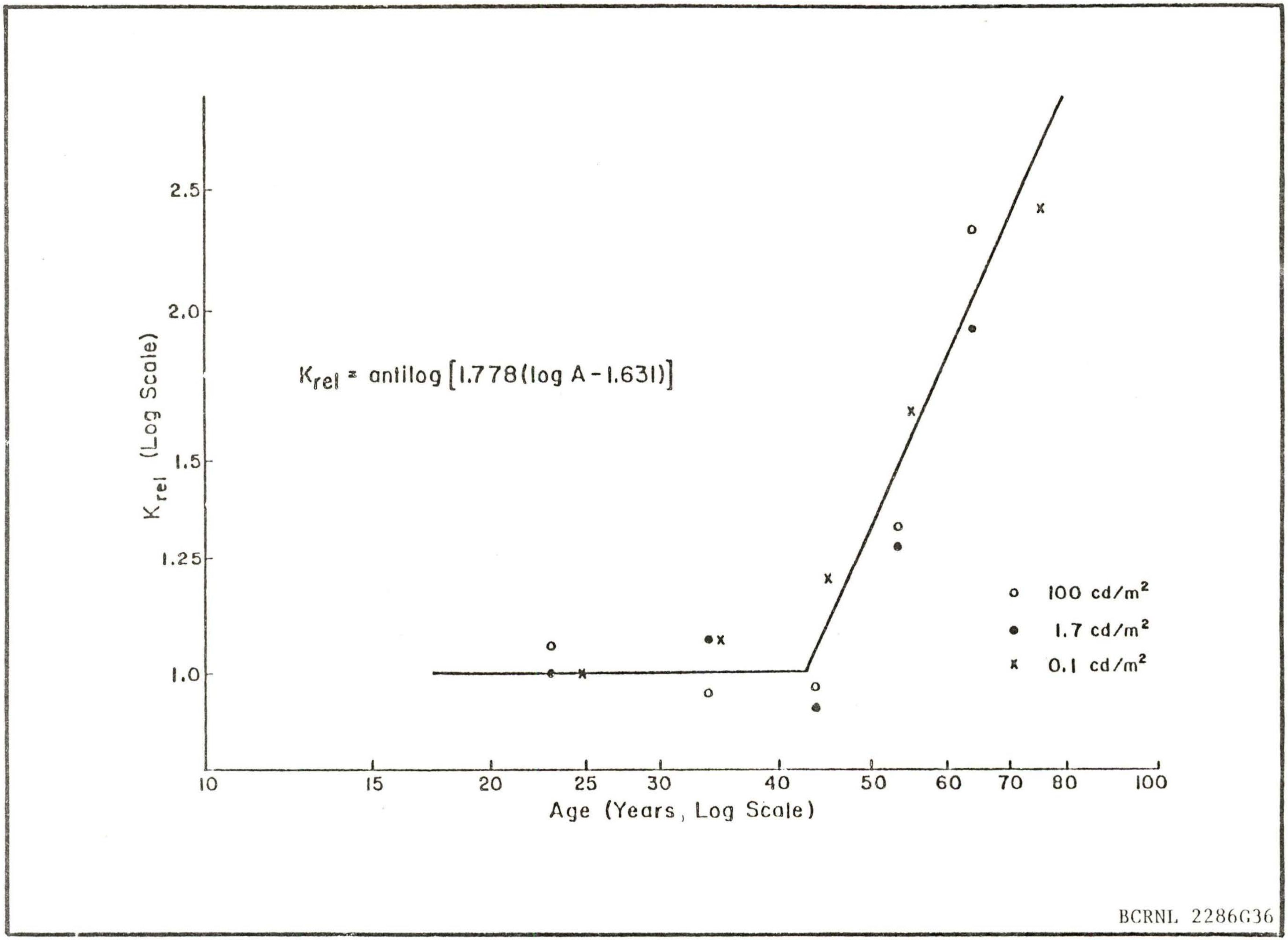


Figure E-2. Disability Glare Constant Values Related to Observer Age.

justify the simplified model within the precision limits of the data.)

The simplified model expressed by Equations (1) through (4) above was used to predict the values of appropriate constants corresponding to the luminance level of .206 cd/m^2 used by Crouch and Vincent in their primary measurements. The value of p equaled 4.54 mm. The value of K_{20} equaled 17.58. Values of K_{rel} and K were calculated for each miner based upon appropriate values of age, A, from which individual values of the DGF ratio to be expected for each miner were calculated. Standard statistical methods were used to calculate the mean DGF ratio to be expected for the group of 59 miners, which equaled .679. The mean DGF ratio actually obtained by the group of 59 miners equaled .646 + .085, the latter representing the standard error of the mean. There is obviously no significant difference between obtained and predicted mean DGF ratio values, the observed difference being less than .4 standard error units.

It is interesting to report the results of a similar evaluation carried out on a total of 73 different observers operating at a much higher luminance level, one more similar to those usually used in the measurement of sensitivity to disability glare, namely 20.6 cd/m^2. The 22 MSHA Academy people* were studied in Beckley, and an additional 51 miners were studied at the Maple Meadow Mining Company. Individual values of the DGF ratio to be expected for each miner based upon age were calculated as before. The mean DGF ratio actually obtained by the group of 73 miners was .536 + .070. Again, there is no significant difference between obtained and predicted results. Note that the direction of the difference between obtained and predicted results is opposite in the two cases. These results are taken to indicate that mean values of glare sensitivity for mining and nonmining observers do not differ significantly. (It is considered, indeed, that the Crouch-Vincent mean data provide excellent confirmation of the mean values predicted by the model and vice versa. It would seem reasonable to conclude that the model is supported by data from a grand total of 2,462 observers, representing studies at a total of four luminance levels, counting both mining and nonmining observers from the four studies.)

C. Individual Differences in Glare Sensitivity Within Age Groups

Data of Blackwell and Blackwell for the 235 observers of differing age were analyzed in terms of individual differences within age groups. The initial analyses were made in terms of the variability of DGF ratios, that is, the variability of the ratios of sensitivity obtained under conditions involving a bright glare annulus divided by sensitivity obtained by the same observer under conditions of uniform luminance. (These ratios are described as DGF ratios since there is some disability glare effect in the field of uniform luminance, there being a much greater disability glare effect of course in the case of the bright glare annulus.) It was found that values

*Mine Health and safety Administration, Academy, furnished 22 observers; however, they were not active underground miners.

of (σ/mean) of the DGF ratios were essentially equal for the reference observers in the 20-30 year age group and the "off the street" observers of differing age including the 20-30 year age group. It was also found that values of (σ/mean) of the DGF ratios were essentially equal for data obtained at the 100 and the 1.7 cd/m^2 luminances. Interestingly, the values of (σ/mean) of the DGF ratios obtained in all these experiments were considerably less than the values of (σ/mean) of individual visibility thresholds obtained by the same observers. This was taken to signify that the use of ratios of sensitivities (i.e. inverse thresholds) on the same observer under the uniform and the glare annulus conditions tended to reduce individual differences among different individuals in each age group. It was found that the raw values of (s/mean) of DGF ratios had to be reduced only by .962 in order to eliminate the spurious variability among individuals due to experimental uncertainties. (This is to be compared with the reduction of values of (σ/M) of the age multiplier m_1 by .610 required for the same purpose.) Values of DGF ratio are used to derive values of the disability glare constant K as described in CIE Report No. 19/2. Variability in K increases by about 2.5 times with respect to variability in DGF ratio simply because of the mathematical operations required to make the transformation. Values of (σ/M) of K were reduced by multiplying by .962 and then converted into values of logarithmic sigma with a resulting value of .211 as the measure of individual variability in K among members of any age group. (Use of the logarithmic sigma is indicated since the values of (σ/M of K are found to be essentially independent of the magnitude of the mean values of K.)

Figure E-3 exhibits the predictions of the model with respect to both mean values of K for different age groups, and individual variability among different members of each age group with respect to the value of K, luminance level being set at .206 cd/m^2. The tick marks falling at the center of each bell-shaped distribution represent the mean values of K predicted by the model for the different age groups. The bell-shaped distributions represent the frequency distributions of individual values of K for the members of each age group. (These distributions are normal because logarithmic value of K are used on the horizontal scale.) Note the considerable overlap of the log normal frequency distributions of K for individual members of different age groups. This signifies that individual differences in K are large in comparison with systematic differences in mean K from one to another age group.

The measure of individual variability among members of each age group obtained by Crouch and Vincent was 2.98 times as large as the measure used in constructing Figure E-3. We consider that this reflects a large amount of spurious individual variability due to experimental uncertainties in the rather crude psychophysical method used in the visibility meter study of the miner's sensitivity to disability glare. This degree of difference in individual variability among different observers due to differences in psychophysical methodology agrees well with earlier results reported by the present author. It is suggested that measures of individual variability among members of given age groups obtained by the visibility meter methodology not be used as measures of individual variability. Thus, whereas we concluded

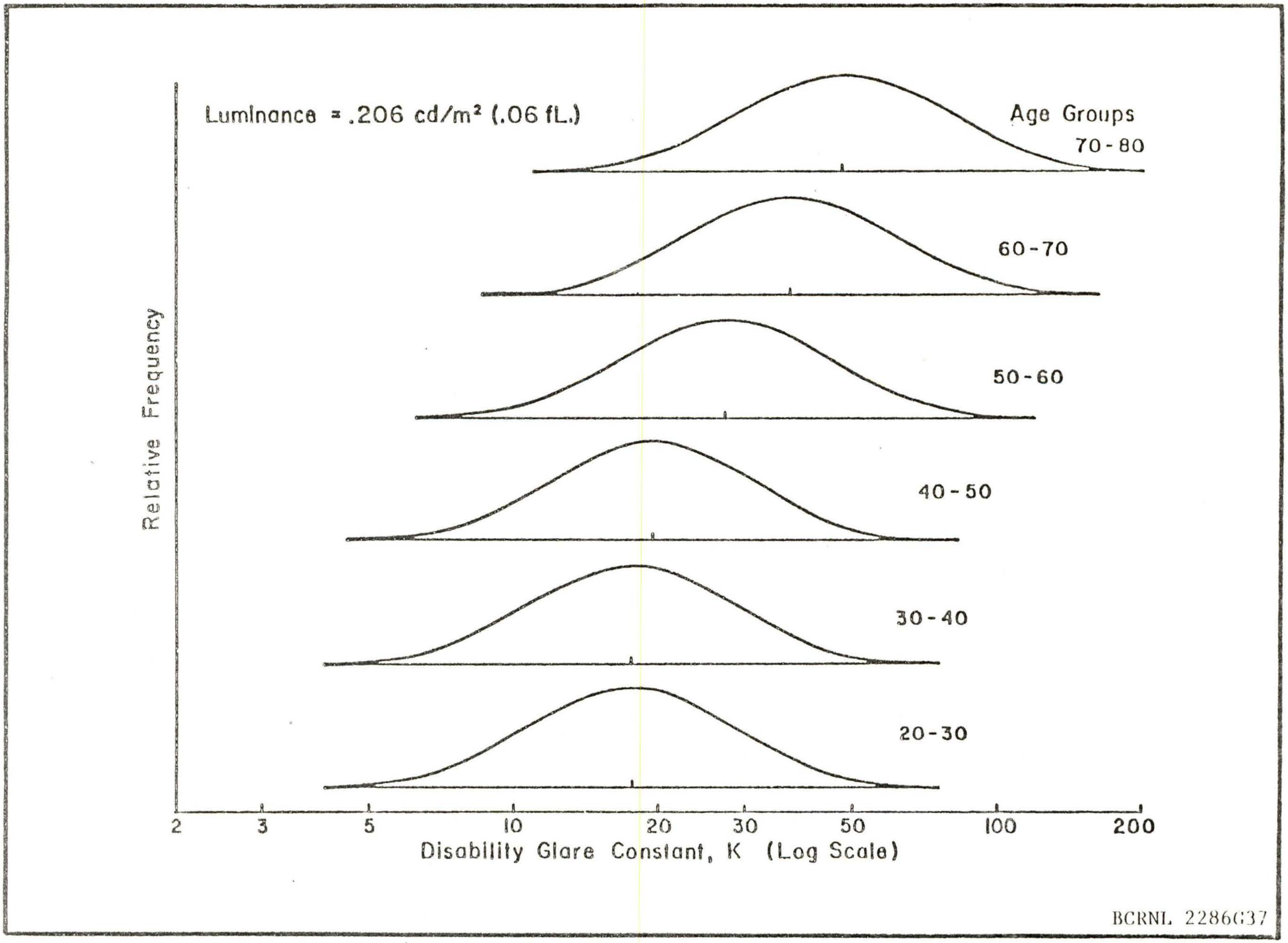


Figure E-3. Predicted Values of the Disability Glare Constant for Different Age Groups.

earlier that mean values obtained by Crouch and Vincent agree very well with values predicted by the model, we here conclude that individual variability measures predicted by the model represent the true state of affairs much better than the measures obtained by Crouch and Vincent.

D. Significance of Individual Differences in Sensitivity to Disability Glare

The significance of the large individual differences in sensitivity to disability glare shown in Figure E-3 depends, of course, upon the degree to which actual lighted coal mines produce disability glare. Fortunately, we have additional data from the Crouch and Vincent study of coal mine lighting which permit us to estimate how much disability glare is to be expected. Crouch and Vincent made psychophysical determinations of the degree of disability glare to be expected in coal mines lighted in accordance with common practice. Data on 45 different lighting situations were available from studies of a simulated coal mine. These data were used to establish mean parameters of lighted coal mines with respect to their production of disability glare, using the standard concepts upon which the Surround Device of the Blackwell Visual Task Evaluator was based. The basic idea is that a visibility meter operator measures his sensitivity in detecting a given visual task under each of three conditions: (a) a situation in which the surround luminance matches the task background luminance; (b) a situation in which the surround luminance constitutes a uniform glare annulus of known luminance considerably greater than the task background luminance; and (c) the situation in which the real surround of the lighted coal mine surrounds the task in a realistic manner. Values of the visibility meter operator's sensitivity obtained under conditions (a) and (b) are used to establish the meter operator's value of K. Then, values of the sensitivity obtained in conditions (c) and (a) are used to derive a value of the luminance of a uniform glare annulus producing the same disability glare effect as produced by the actual nonuniform task surround. This equivalent glare annulus luminance may then be used to calculate the loss in visibility under real-life conditions of full-field viewing for an observer with any given value of the disability glare constant, K.

In the case at hand, the mean value of the equivalent glare annulus luminance for the 45 mine lighting simulations was 43.81 times the task background luminance, the mean task background luminance being .680 cd/m2. Assuming that geometries of lighting were maintained but that task background luminance was reduced to the target value of .206 cd/m2 assumed relevant to actual coal mining installations, we may use the model to compute the following values of DGF as a function of the disability glare constant, K.

K	DGF
3	.806
5	.728
10	.605
15	.529
20	.476
30	.405
50	.324
100	.236
200	.171

The percentage loss in visibility resulting from the degree of disability glare represented by a given value of DGF equals 100 (1 - DGF). Thus, the values given in the table above represent visibility loss ranging from 19.4% for K = 3 to 82.9% for K = 200. Note from Figure E-3 that individual members of a total worker population may be expected to have sensitivity levels to disability glare covering nearly this entire range of values of K. Hence, individual members of a total worker population may be expected to have visibility losses covering nearly the entire range from 19.4 to 82.9%. However, since most miners included in the two groups studied by Crouch and Vincent were less than 60 years of age, the practical upper limit of K is about 90, signifying that the upper limit of visibility loss is about 75%, still a tremendously large loss to contemplate.

E. Populational Evaluation of Sensitivity to Disability Glare

The data presented in Figure E-3 suggest that, although the sensitivity to disability glare is to some extent age related, the most important conclusion is that individuals vary greatly in their sensitivity to disability glare (only in part because of differences in age). It would seem most appropriate, therefore, to carry out a populational evaluation of sensitivity to disability glare. What is obviously required in addition to the data presented to this point is an age distribution of the miner population to serve as a weighting function of the various bell-shaped curves in Figure E-3.

Figure E-4 presents the age distribution of the 59 miners for whom measurements of sensitivity to disability glare were made by Crouch and Vincent, presented in the form of the histogram represented by the rectangular blocks. Each histogram block has a height corresponding to the proportion, p_M, of the population of miners falling within an age range defined by the histogram width. The solid curve is the continuous function best fitting the histogram rectangles, and represents p_M as a function of miner age. Values of p_M may be read from the continuous function for each one year age span.

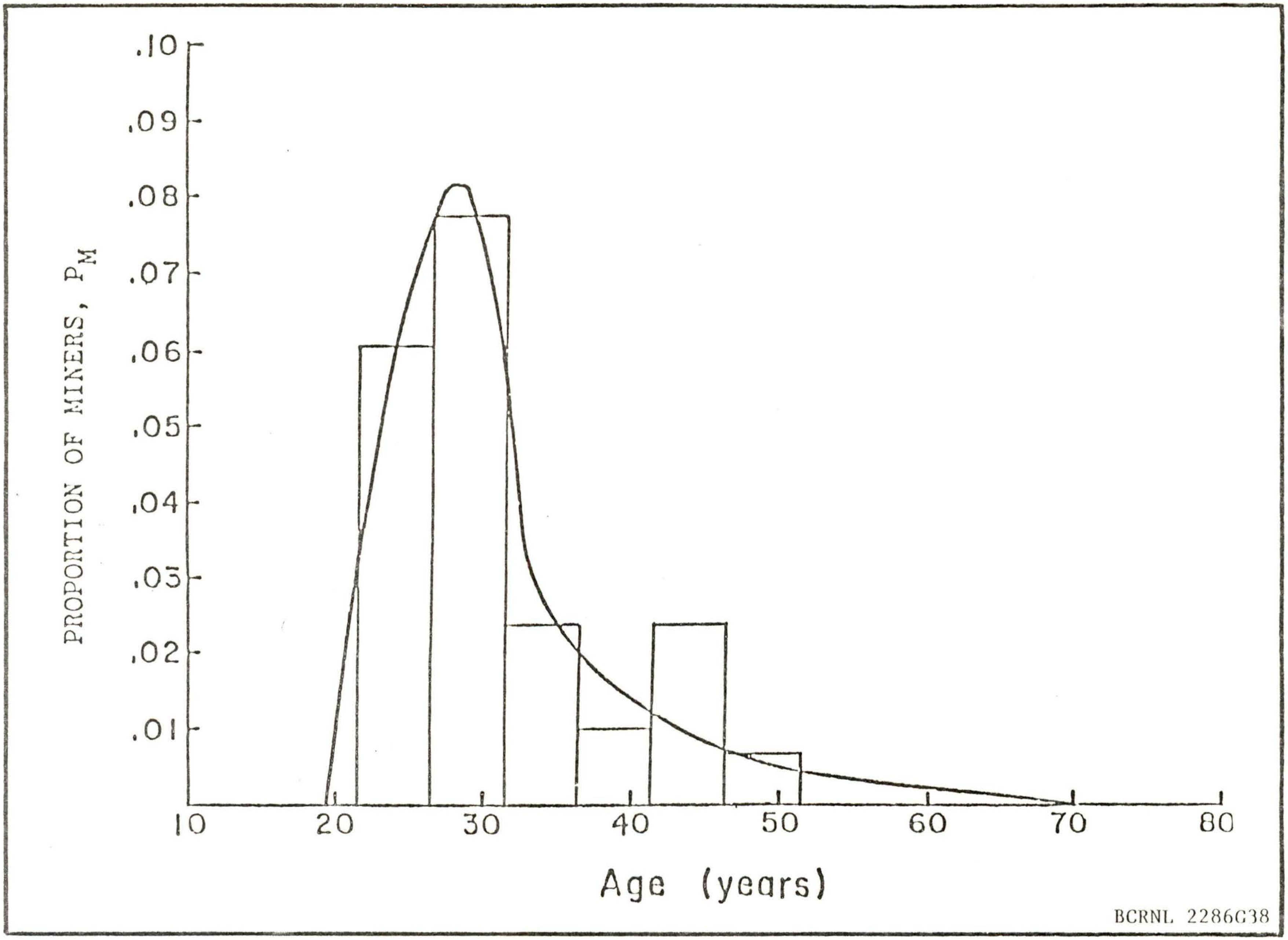


Figure E-4. Age Distribution of 59 Participating Miners from Prescott and Derby Mines.

TABLE E1. PERCENTAGE VISIBILITY LOSSES FOR DIFFERENT MEMBERS OF THE 59 MINER POPULATION

PM	K	DGF	Percentage Visibility Loss
.0013	4.105	.760	23.98
.0062	5.264	.720	28.00
.0228	6.750	.677	32.30
.0668	8.656	.632	36.80
.1587	11.10	.586	41.42
.3085	14.23	.539	46.09
.5000	18.25	.493	50.71
.6915	23.40	.448	55.21
.8413	30.01	.405	59.52
.9332	38.49	.364	63.59
.9772	49.35	.326	67.37
.9938	63.28	.291	70.85
.9986	81.15	.260	74.01

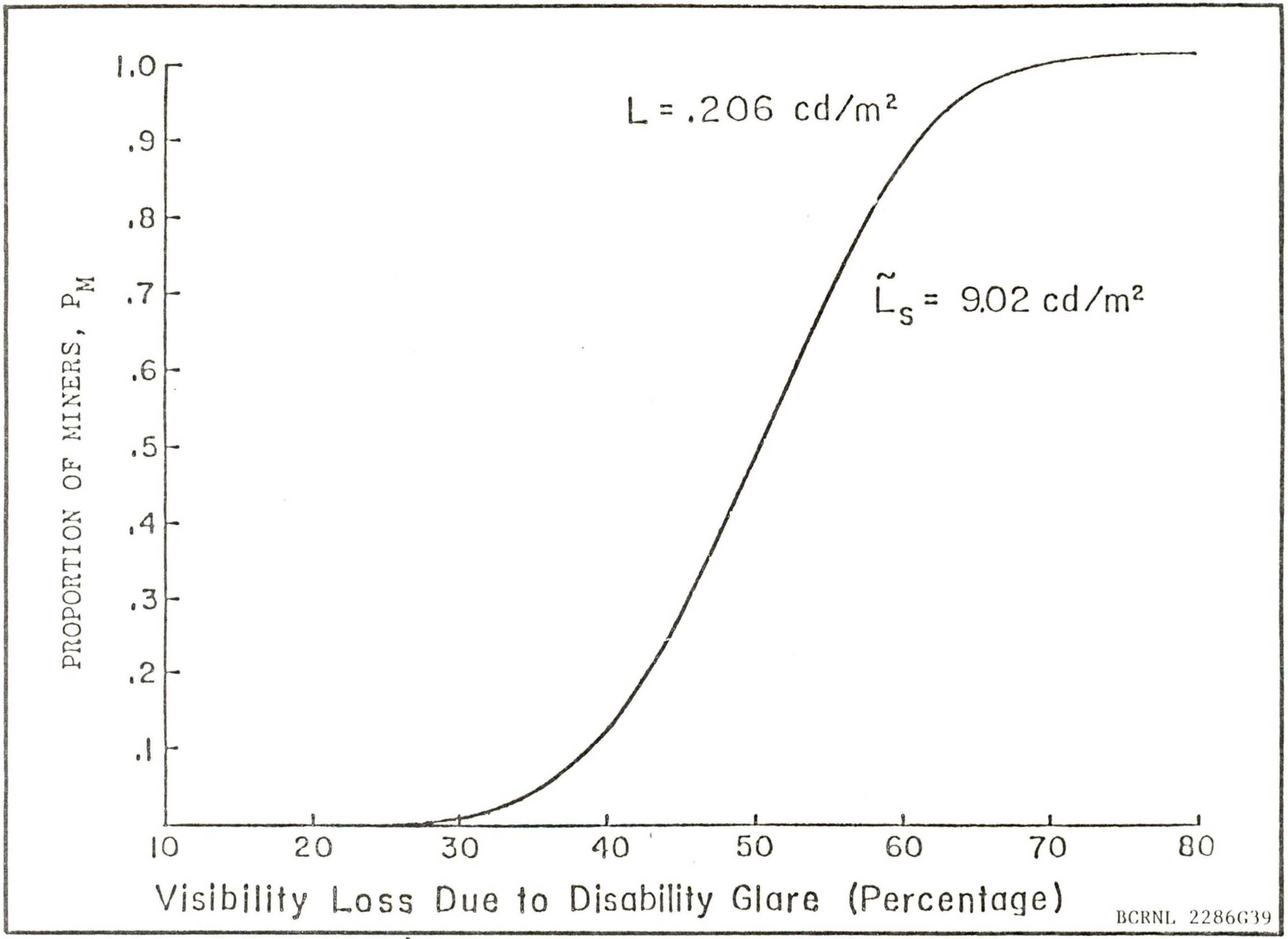


Figure E-5. Miner's Visibility Loss Due to Disability Glare.

might not be representative of miner populations in general, an analysis was made of the distributions of sensitivity to disability glare to be expected from the entire working population of the U.S. The appropriate age distribution function is presented in Figure E-6. The histogram represented by the rectangular blocks was based upon the reported results of the U.S. 1979 Census. The solid curve was constructed as the best-fitting function to fit the histogram rectangles. This solid curve may be used to define values of the proportion of the entire U.S. population, p_p, whose ages fall within each one year age range. The solid curve may also be used to derive values of p_{WP}, the proportion of members of the "working population" of the U.S., defined as those members of the U.S. population with ages between 20 and 70 years. (All that is involved is a truncation and renormalization of the age distribution function of the entire population.) These values have been used to reevaluate the distribution of sensitivities to disability glare under the conditions of coal mines, calculation being entirely analogous to those carried out for the miner population distribution function shown in Figure E-4.

In this case, the statistical parameters were as follows: the mean value of K equaled 22.28 (log K = 1.348); logarithmic sigma equaled .243. The increases in both mean K (from 18.25 to 22.28) and logarithmic sigma (from .215 to .243) are to be expected, of course, because of the relatively greater incidence of older individuals in the U.S. working population than was found in the miner populations by Crouch and Vincent. These revised statistical parameters were used to derive the populational values reported in Table E-2.

The interpretation of the various quantities is as before. Now, 99.86% of the assumed population of miners have visibility loss of 78.30% or less, only .13% have visibility loss of 24.19% or less, and 50% have visibility loss of 54.33% or less. (Similarly, 50% will have visibility loss equal to or greater than 54.33%.) All these values exceed those found with the assumed younger miner population, although perhaps the most significant result of the two analyses is that visibility losses are of approximately the same very large magnitude within the rather wide age limits of the two assumed worker age distributions. Thus, it is probably safe to assume that realistic miner populations will have visibility loss of approximately the values shown in Tables E-1 and E-2.

Finally, Figure E-7 presents the data of Table E-2. Here also the function is not that of a simple ogive. Therefore, as before, if values of visibility loss are desired for different values of p_{WP} than those contained in Table E-2 interpolation from the solid curve in Figure G may be used.

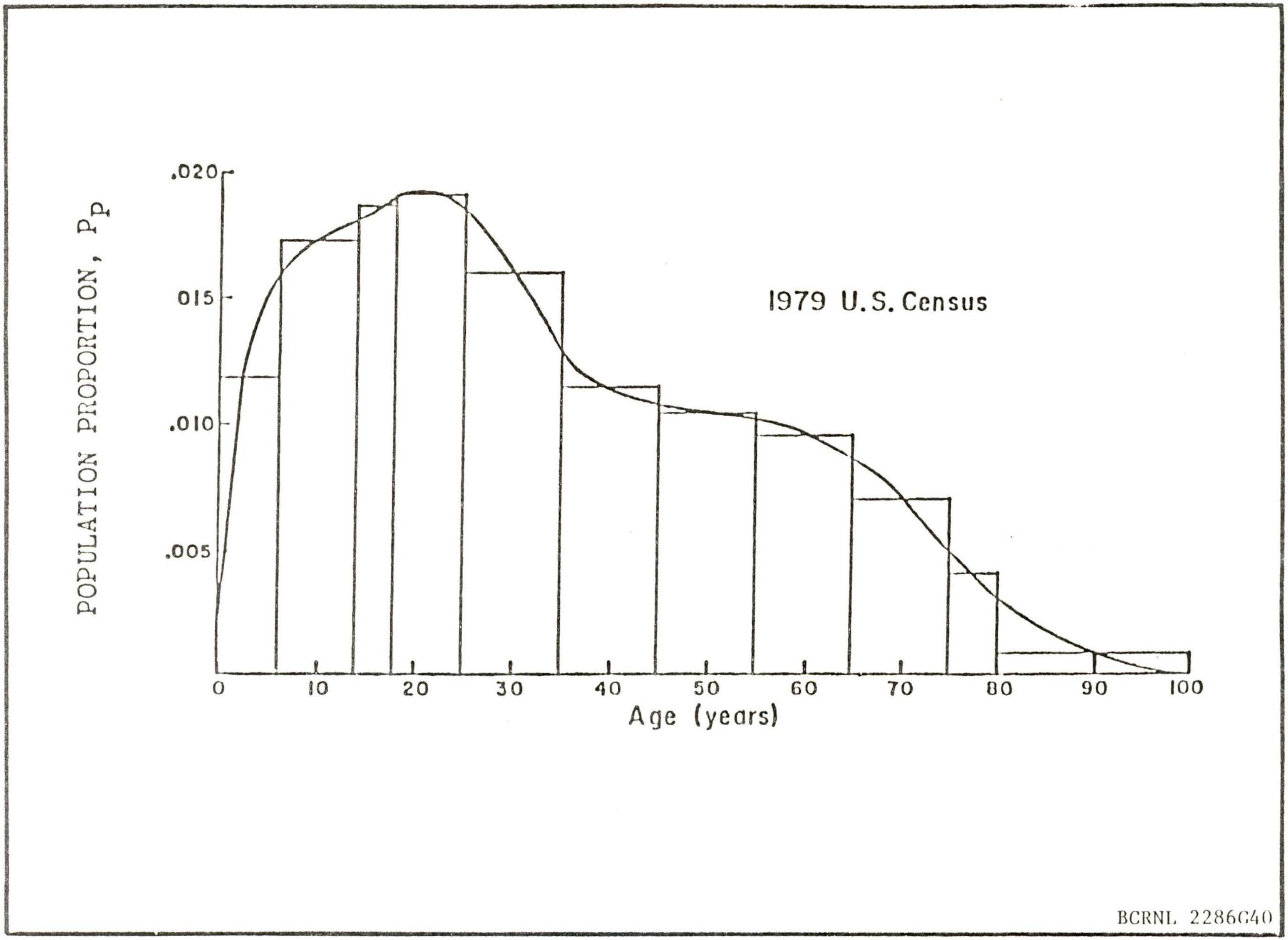


Figure E-6. The Solid Curve Can be Used to Define Values of the Proportion of the Entire U.S.

TABLE E-2. PERCENTAGE VISIBILITY LOSSES FOR DIFFERENT MEMBERS OF THE U.S. WORKER POPULATION

PM	K	DGF	Percentage Visibility Loss
.0013	4.159	.758	24.19
.0062	5.502	.713	28.75
.0228	7.278	.664	33.64
.0668	9.627	.612	38.77
.1587	12.74	.560	44.00
.3085	16.85	.508	49.23
.5000	22.28	.457	54.33
.6915	29.48	.408	59.21
.8413	38.99	.362	63.79
.9332	51.58	.320	68.01
.9772	68.23	.282	71.84
.9938	90.26	.247	75.27
.9986	119.40	.217	78.30

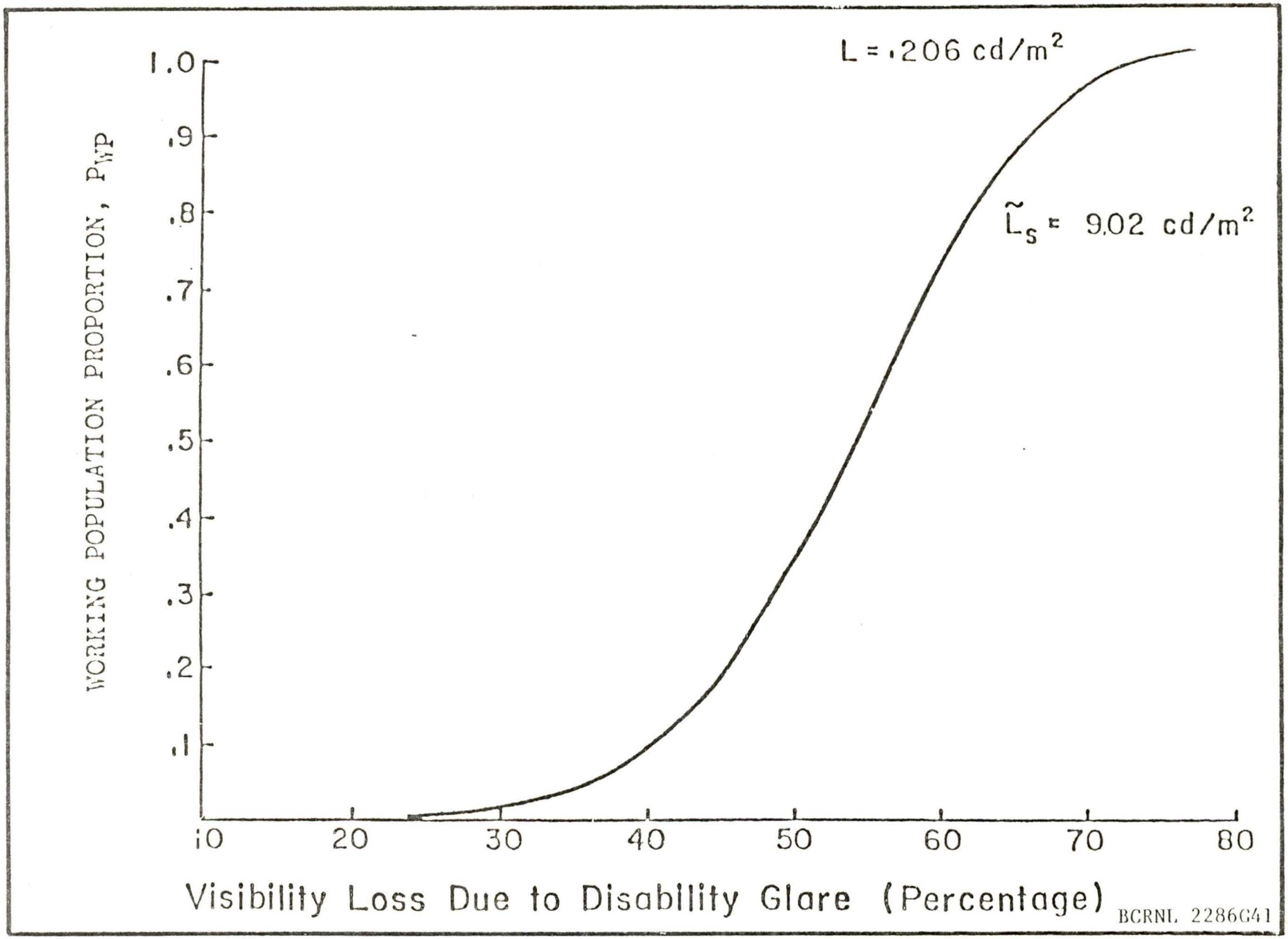


Figure E-7. Working Population Visability Loss Due to Disability Glare.

APPENDIX F

DISCOMFORT IN MINE LIGHTING

APPENDIX F

"DISCOMFORT GLARE IN MINE LIGHTING"

Dr. Sylvester K. Guth
Lighting Consultant
Cleveland, OH 1932

List of Tables

List of Figures

DISCOMFORT GLARE IN MINE LIGHTING
by

Sylvester K. Guth

I. INTRODUCTION

Extensive investigations of discomfort glare have been conducted over a period of many years. While most of them have been concerned with the evaluations of conditions pertaining to interior lighting in offices, schools and industry, some were related to roadway lighting. It is recognized that conditions encountered in underground mines are considerably different from typical above-ground lighted environments. Nevertheless, certain fundamental relationships can be expected to pertain to any situation even though it may be necessary to make minor adjustments in how they are applied.

Glare is defined as the sensation produced by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort or loss in visual performance or visibility.[1] The magnitude of the sensation of glare depends upon a number of physical factors: the size, luminance and location of the source; the number of sources; and the field or adaptation luminance. In addition, it also is necessary to take into account the sensitivity of the individuals who are exposed to the glare.

It is evident that glare may be considered to be a negative characteristic of the visual environment. In many real-life situations it may not be possible to completely eliminate glare. However, by understanding how the various factors contribute to glare and their relative importance, one can design lighting systems which will minimize the degree of sensation and thereby increase the acceptability of the lighting system. In the long run, such an approach can be expected to improve productivity, safety and morale.

The earlier investigations[2] resulted in the development of a discomfort glare evaluation procedure for interior lighting[3]. Those investigations, conducted over a period of about twenty years, involved more than 200 observers who made subjective evaluations of a wide variety of lighting conditions. A significant result of employing the large number of observers was the development of a Visual Comfort Probability (VCP) basis for rating lighting systems. This permitted expressing discomfort glare evaluations in terms of the percent of observers who would be expected to judge a lighted environment as being acceptable. The VCP scale was derived from subjective judgements and thus represents the relative sensitivity to discomfort glare of that population sample. Applications of the VCP procedure to interior lighting systems indicated that it was consistent with experience.

Underground mines present a unique type of visual environment. It therefore is appropriate to investigate certain aspects of discomfort glare with special reference to the lighting conditions encountered in the mines. Accordingly, the present investigation has two primary objectives:

1. To evaluate lighting systems mounted on continuous mining machines and bolters.

2. To determine if those who spend considerable time in underground coal mines are more or less sensitive to glare than an above-ground population.

From such information it is hoped that improved design criteria can be established for mine lighting.

II. EVALUATING DISCOMFORT GLARE

A. Criterion. The basis of the researches[2] which led to the development of the discomfort glare evaluation system[3] was a criterion which could be defined by the experimenter and also could be interpreted by the observer as a relatively definite sensation. It also was found to be a basis for devising a discomfort glare rating scale which takes into account subjective differences.

This criterion was the sensation at the borderline between comfort and discomfort and is termed the BCD sensation[4]. It also has the advantage of being meaningful from a luminance condition which, if a little brighter would not be acceptable, and, if a little less bright, would not be particularly objectionable. This criterion has been used for more than thirty years with considerable success. Very few individuals were unable to make consistent judgments with this criterion.

B. Instrumentation. The BCD sensation serves as basis for determining the acceptability of lighting systems in terms of discomfort glare and also for rating the glare sensitivity of individual observers. It is a key element in the use of the Discomfort Glare Evaluator[5] employed in the present investigation. The instrument is shown in Figure F-1 as used for evaluating interior lighting systems. The components include a head-rest with a movable shield, a light source, and control units for the experimenter and the observer.

When the movable shield is in the "down" position, all of the test luminaires are excluded from the field of view of the observer. When the shield is rotated upward, the luminaires are included in the field of view.

The circular test source consists of a transilluminated diffusing glass. It is viewed in a small mirror (Figure F-1) located on the line of sight which can be in any direction, depending upon the experimental conditions. A gray mask, the reflectance of which is selected so its luminance approximates that of the area viewed by the observer, surrounds the test-source.

C. General Procedure. A timing mechanism in the operator's control unit governs the exposure sequence of the test-source and the lighting system. When BCD evaluations are made, the movable shield on the head-rest remains in the "down" position at all times. The test-source is presented for one-second exposures separated by one-second intervals during which the observer is exposed only to the field luminance. A ten-second cycle is used during which the test-source is presented for subjective evaluations three times, and the remaining short period is allowed for the observer to alter its luminance.

When making comparative evaluations of a lighting system, the source on line of sight--now termed the comparison-source--and the luminaires

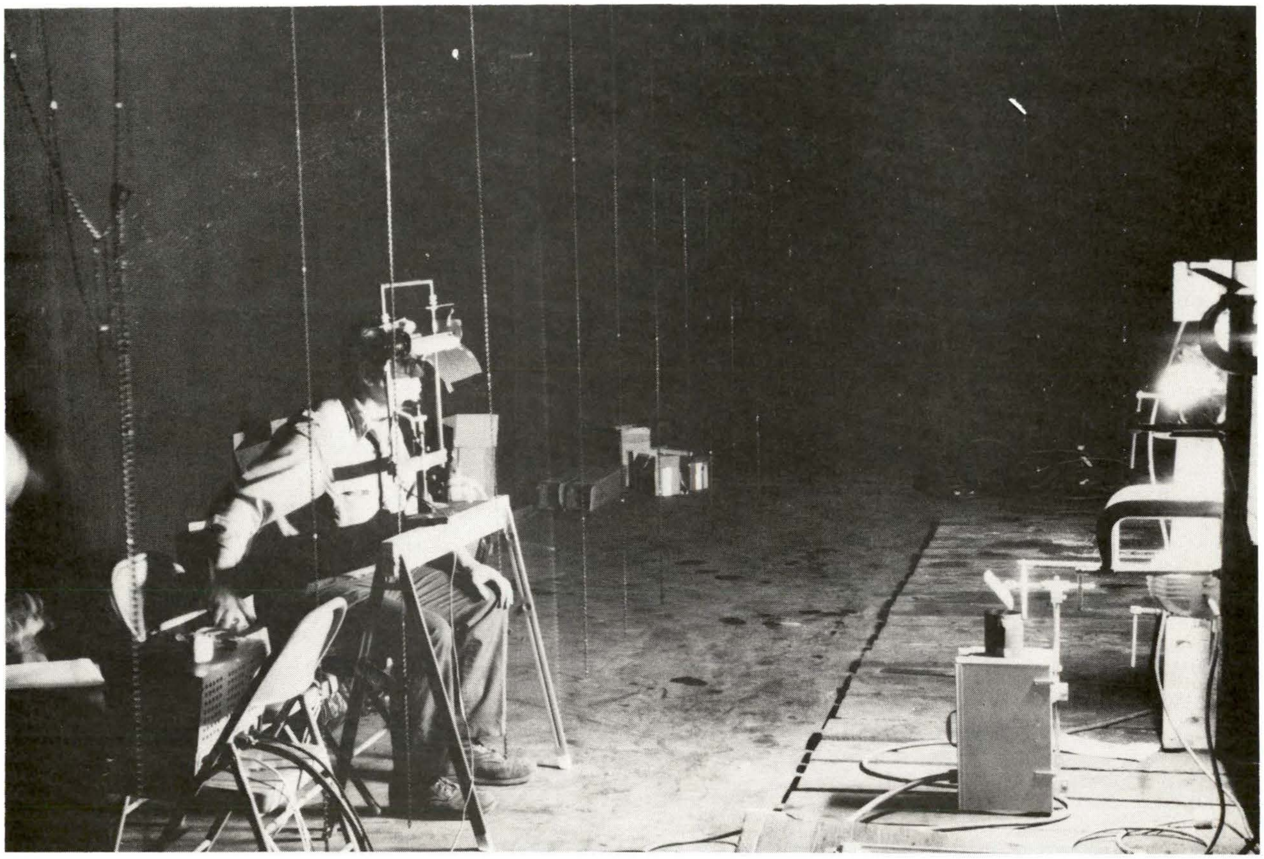


Figure F-1. Discomfort Glare Evaluator Located at the Side of the Continuous Miner.

are alternately exposed to view. When the moveable shield rotates upward to expose the luminaires, the comparison-source is turned off. When the shield returns to the "down" position, the comparison source is again turned on. The exposures are of one-second duration, separated by one-second intervals. Each group of three exposures is followed by a five-second period for evaluating the sensation and altering the luminance of the comparison-source. The observers are required to adjust the luminance of the comparison-source until it produces the same sensation as the luminaires. At all times the observer keeps his eyes fixated upon the position of the comparison-source. He is permitted as many cycles as necessary for making an appraisal.

The preceding is a general description of the procedure employed in BCD investigation. More specific information is given in the sections dealing with the actual experimental conditions used in the present study.

III. EVALUATING MINING MACHINE LIGHTING

It was evident that it would be impossible to evaluate the glare produced by lighting systems on mining machines in an underground mine. Therefore, arrangements were made to use the laboratory of the Westmoreland Coal Company, Big Stone Gap, Virginia, for these studies. However, before embarking on this part of the investigation, the research team visited a mine in order to better understand the visual and physical conditions encountered by miners when working around continuous miners and bolters. The information gained during that visit was used for establishing the experimental conditions in the laboratory and to assure that they were reasonable simulations of those in the mine.

A. Continuous Miner

1. Experimental Arrangement: The laboratory provided a dark environment which corresponded to that of an underground mine. Each of seven different lighting systems was mounted on the continuous miner at the standard locations. The systems included the following:

1. 430 ma, 15 watt F lamps
2. 1500 ma, 64 watt F lamps
3. Self-contained F lamps
4. Four unit single control F lamps
5. Self-contained F lamps
6. Incandescent Triangular
7. Incandescent, square

Two observer positions were employed. One was located opposite the matching operator's position on the on-side, looking downward toward the rear as a machine helper would when keeping cables clear of the machine. The second position was on the off-side, opposite the cab, with the observer looking downward toward the front of the machine. These positions are indicated on a sketch of the continuous miner in Figure F-2. In both cases, the lighting units on the observer's side of the machine were in view when the movable shield of the Discomfort Glare Evaluator was rotated upward, and hidden from view when in the down position. A typical arrangement, as seen from near the operator's position (on-side) is shown in Figure F-1.

It is obvious that all possible worker positions around the machine could not be appraised. The two that were selected are reasonably representative and provide good bases for evaluating the lighting systems.

2. Observers: A total of eleven observers participated in this part of the investigation. Because of the time required for changing lighting systems and the limited number of days available, all observers did not evaluate every lighting system. This, of course, limits some analytical comparisons, but nevertheless the results are considered extremely useful for general conclusions.

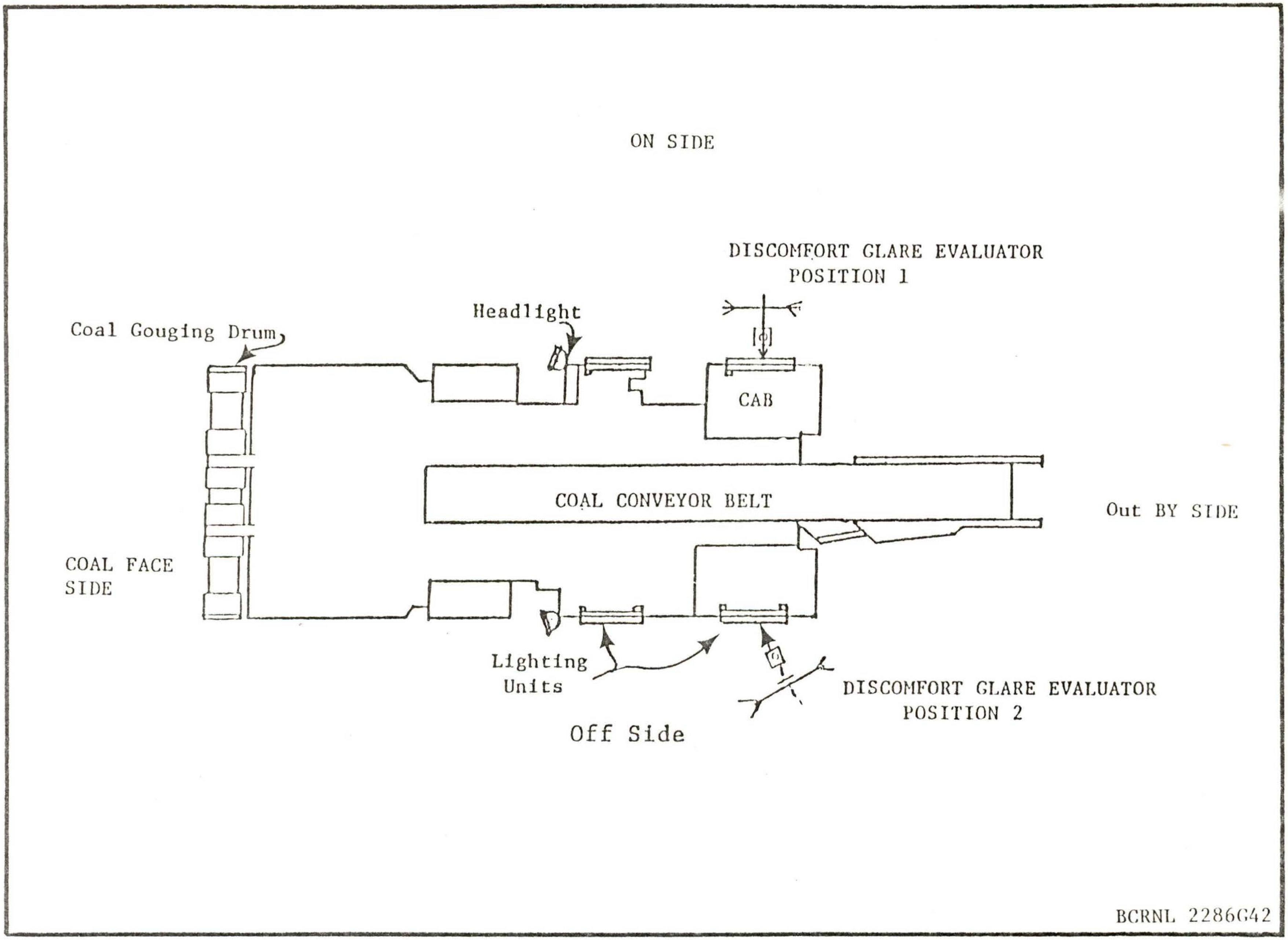


Figure F-2. Sketch of Continuous Miner Showing the Two Positions Used for Evaluating Machine-Mounted Lighting Systems.

The observers made two sets of observations with a lighting system: (1) comparison evaluations of the lighting system, and (2) BCD evaluations with the shield in the down position. The observer was permitted as many 10-second cycles as necessary for making a complete appraisal of each lighting system and BCD judgments.

3. Discomfort Glare Evaluations: The results obtained are summarized in Table F-1 for the on-side observer position and in Table F-2 for the off-side position. COMP (L_c) represents the luminance of the circular comparison source of the Discomfort Glare Evaluator judged by the observer to produce the same sensation as the lighting system being evaluated. BCD (L_{bo}) is the luminance of the test-source judged to be at the borderline between comfort and discomfort with the movable shield in the "down" position. The ratio L_c/L_{bo} provides a relative numerical rating of a lighting system expresed in terms of the BCD sensation. The higher this rating, the less comfortable the system is judged to be.

The relatively large differences among the observers for both L_c and L_{bo} are not unexpected because it is well known that individuals vary greatly in their judgments of discomfort glare. Averaging the results obtained for each lighting system would be meaningless because the same observers did not evaluate every system. Therefore, the most pertinent analysis is in terms of the individual relative ratings, L_c/L_{bo}.

Considering first the data presented in Table F-1, it is seen that with one exception every rating is greater than 1.0. This indicates that the observers judged all the lighting systems to be quite uncomfortable. The only exception was Observer No. 1 who judged System 5 to be at BCD. All other ratings are greater than about 1.7. Thus the main conclusion one can draw is that all the lighting systems are very glaring.

Since the significance of numerical ratings usually is difficult to visualize, it is appropriate to express them in terms of descriptive adjectives. Luckiesh and Holladay[3] devised 13 levels of sensation which later were related to discomfort glare ratings by Guth[2]. Using the numerical ratings obtained by those investigators which correspond to the several levels of sensation, the scale illustrated in Table F-3 may be used for indicating the degree of discomfort produced by the ratings given in Table F-1.

From Table F-3 it is seen that four of the lighting system ratings were judged to be perceptibly uncomfortable. Many of the observers judged the lighting systems to be uncomfortable and even intolerable.

Similar results were obtained when the observers were located on off-side of the continuous miner. It is interesting to note that one observer (No. 10) judged System 5 to be "distracting but not uncomfortable" according to the adjective ratings of Table F-3. Several of the observers rated

TABLE F-1. DISCOMFORT GLARE EVALUATIONS OF SEVEN LIGHTING SYSTEMS ON A CONTINUOUS MINER: ON-SIDE OBSERVER POSITION

Observer	COMP L_c (fL)	BCD L_{bo} (fL)	Rating L_c/L_{bo}	VCP %
System 1				
1	5100	2890	1.76	28
2	3080	1210	2.55	15
System 2				
1	5160	3000	1.72	28
2	3550	690	5.14	4
3	2210	635	3.48	7
4	2640	940	3.87	7
5	8290	1650	5.02	4
6	8520	190	44.84	0
7	2110	235	8.98	1
System 3				
1	4430	2640	1.68	30
2	1970	610	3.23	10
System 4				
1	6350	1920	3.31	9
2	3720	575	6.47	2
5	4280	2210	1.94	24
8	12550	1330	9.44	1
9	3680	190	19.37	0
System 5				
1	6890	2770	2.49	16
2	6050	630	9.60	1
System 6				
1	2210	2210	1.00	50
2	3400	400	8.50	1
System 7				
2	1830	470	3.89	7

TABLE F-2. DISCOMFORT GLARE EVALUATIONS OF SEVEN LIGHTING SYSTEMS ON A CONTINUOUS MINER: OFF-SIDE OBSERVER POSITION

Observer	COMP L_c (fL)	BCD L_{bo} (fL)	Rating L_c/L_{bo}	VCP %
System 1				
5	1890	850	2.22	19
8	2990	260	11.50	0
10	1915	1825	1.05	48
System 2				
1	2880	2630	1.09	46
5	2530	1065	2.38	16
System 3				
10	1645	1065	1.54	32
11	3800	71	53.52	0
System 4				
10	2310	1090	1.94	24
System 5				
1	2310	2310	1.00	50
5	3120	780	4.00	6
System 6				
5	1195	310	3.83	7
10	510	680	0.75	65
System 7				
5	1410	635	2.22	19
10	1000	940	1.06	49

TABLE F-3. ADJECTIVE RATING SCALE FOR INDICATING THE DEGREE OF DISCOMFORT OF RELATIVE NUMERICAL RATINGS

Adjective rating of glare		Relative Numerical Rating	VCP %
no glare	less than	0.29	92
unnoticeable		0.29	92
acceptable but not imperceptible		0.42	85
acceptable		0.54	77
distracting but not uncomfortable		0.75	64
BCD		1.00	50
barely uncomfortable		1.33	38
perceptibly uncomfortable		1.83	26
uncomfortable		2.50	16
just intolerable		3.33	9
intolerable	greater than	3.33	9

Systems 1, 2, and 5 to be at about BCD. Excluding Observer No. 11, it appears that on the off-side the lighting systems are not quite as uncomfortable as they are on the on-side. The probable reason for this is that one of the two units in the field of view is displaced more from the line of sight and thus contributes less to the sensation of glare. Nevertheless, the majority of the observers indicate that the lighting systems are in the uncomfortable range.

The three observers (Nos. 6, 9, and 11) listed in Tables F-1 and F-2 who gave very high ratings of L_c/L_{bo} appear to be extremely sensitive to glare. This is indicated by the relatively low values of L_{bo} which they judged to be at BCD.

The advantage of analyzing the results in terms of the ratio L_c/L_{bo} is that each observer acts as his own control by providing his own reference for rating purposes. This minimizes the dependence upon absolute values of the comparison-source luminance L_c and takes into account the individual sensitivity to glare. The effects can be illustrated by Observers 2 and 5 when evaluating System 2 (Table F-1). Observer 2 reported an L_c of 3550 fL and Observer 5 reported 3290 fL. Taking these by themselves, one would assume that Observer 5 judged the system to be much more uncomfortable. However, when one takes into account the BCD evaluations--690fL for Observer 2 and 1550 fL for Observer 5--which represent their respective sensitivities to glare, it is seen that the ratings in terms of L_c/L_{bo} are very nearly the same. In other words, a high comparison-source luminance, L_c does not necessraily mean that an observer judges a lighting system to be more uncomfortable. Indeed, in Table F-1 it is seen, for example, that observer No. 1 usually gave higher COMP values than many other observers. Nevertheless, because of correspondingly big BCD values his ratings are among the lowest.

It must be emphasized that the ratings are relative indices of sensation and should not be considered as absolute ratings. Thus, for example, a relative rating of 3.0 is not intended to imply that a lighting system is twice as uncomfortable as one having a relative rating of 1.5. It is, of course, more uncomfortable and the degree of discomfort can be expressed in terms of the adjective rating in Table F-3.

Another way of presenting ratings is in terms of a Visual Comfort Probability (VCP) which expresses the relative BCD luminance in terms of the percent of observers who would be expected to find a given lighting system acceptable. This is a procedure which was developed for interior lighting systems[1,2] and has been found to be readily understood and appreciated. Thus, using the relationship shown by the solid line in Figure F-3, VCP values for the relative numerical ratings in Tables F-1, F-2, and F-3 have been determined and are tabulated in the columns headed VCP. (The development of Table F-12 is discussed in Part IV of this report.)

The relatively large differences in VCP ratings for some observers again reflect the variations in individual judgments of what constitutes discomfort glare. They also emphasize the need for employing a large group of

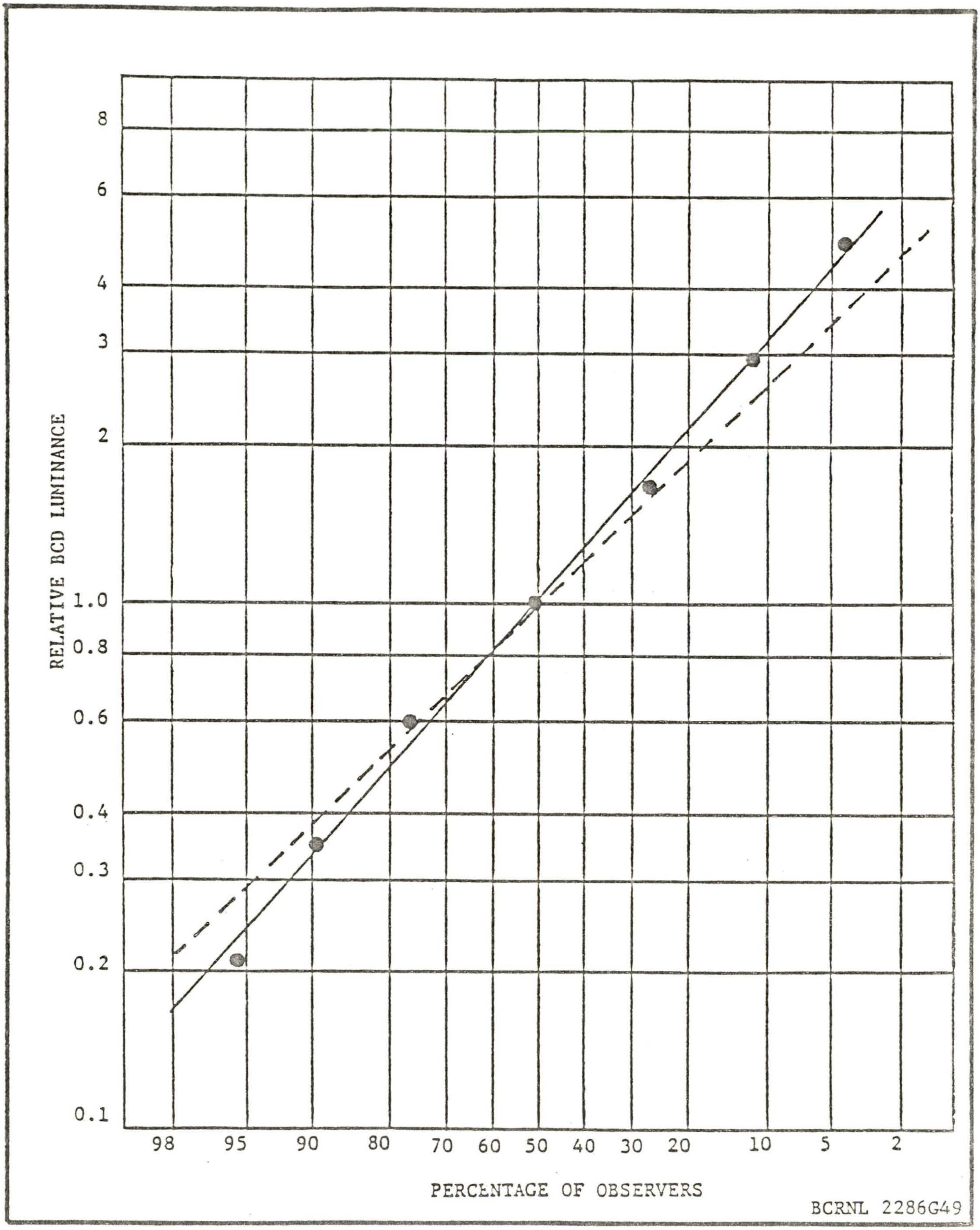


Figure F-3. Probability Plots of Relative BCD Luminance for Underground Miners, Excluding Low Values (Solid Line), and for the Guth Formula (Dotted Line).

observers or, at least, a smaller group of representative observers in order to obtain what may be considered suitable average ratings. Nevertheless, the VCP ratings illustrate very dramatically the high degree of discomfort glare produced by the various lighting systems mounted on the continuous miner. The majority of the VCP values are very low and indicate a poor probability of acceptance.

A comparison of the VCP ratings for the on-side position (Table F-1) with those for the off-side position (Table F-2) confirm that the latter is less uncomfortable. However, the relatively low VCP values for both observer positions emphasize that considerable glare is produced by all lighting systems. For interior lighting it has been concluded that if the VCP is at least 70, discomfort glare should not be a problem. For mining nachine lighting it may be necessary to adopt a somewhat lower criterion such as 50.

An additional analysis will be of interest. Observer No. 2 judged all of the lighting systems at the on-side position of the continuous miner. He had participated in many discomfort glare investigations and thus could be considered an experienced observer. In addition to making BCD judgments with the movable shield in the "down" position, he also made them with it in the "up" position. In the latter case the luminaires on the machine were in the field of view. The reason for doing this is that in the investigations of interior lighting systems it was found that the luminaires contributed to the field luminance which somewhat mitigated the glare effect. (It should be pointed out that the reason for using the "down" position of the shield in the present investigation for the other observers is that it was easier for the inexperienced observers to make the BCD evaluation. Furthermore, the results were for what might be called "worst" condition.)

The judgments made by Observer No. 2 are summarized in Table F-4. It can be seen that the values of L_{bg} (with the luminaires in view) are higher than those of L_{bo} (without the luminaires in view.) The latter also are given in Table F-1. Each set of three data--L_c, L_{bo}, and L_{bg}--were taken at the same sitting. The computed values of L_c/L_{bg} are less than those of L_c/L_{bo}--on the average,, about half. Nevertheless, they all indicate a relatively high degree of discomfort which means that even though the luminaires have increased the effective field luminance, their presence has not made the various lighting systems comfortable. The VCP values for the two methods used for obtaining the relative numerical ratings lead to the same conclusion.

Since the values given in Table F-4 are for the same observer, one can use them for determining the relative merits, in terms of discomfort glare, of the various lighting systems. It is interesting to note that the method for obtaining the BCD judgments has no appreciable effect upon the rank order of the systems. System 1 is the least uncomfortable in both cases, and System 5 is the most uncomfortable.

TABLE F-4. DISCOMFORT GLARE AND BCD EVALUATIONS BY OBSERVER NO. 2 FOR SEVEN LIGHTING SYSTEMS ON A CONTINUOUS MINER; ON-SIDE OBSERVER POSITION

System	Comp L_c (fL)	BCD with glare L_{bg} (fL)	BCD without glare L_{bo} (fL)	Ratings $\frac{L_c}{L_{bg}}$	VCP %	$\frac{L_c}{L_{bo}}$	VCP %
1	3080	2490	1210	1.24	43	2.55	15
2	3550	1460	690	2.43	17	5.14	3
3	1970	920	610	2.14	21	3.23	10
4	3720	1740	575	2.14	21	6.47	2
5	6050	1490	630	4.06	6	9.60	1
6	3400	1200	400	2.83	13	8.50	1
7	1830	1070	470	1.70	29	3.89	6

B. Bolter

1. Experimental arrangement: Five of the lighting systems were mounted on the bolter at the standard locations. (Systems 3 and 5 were not used.) Three observer positions were employed:

Position 1: on the off-side of the bolter.
Position 2: at the rear for observing the cables.
Position 3: on the operator's side at the bolt-making area behind the left wheel.

These are marked on the sketch of the bolter shown in Figure F-4. In all cases the positioning of the Discomfort Glare Evaluator was similar to that when evaluating the lighting systems on the continuous miner.

2. Observers: Four observers participated in this part of the investigation. Two of them had made judgments in the first part and two were new. The same procedure of making comparison evaluations and BCD judgments was employed. Because of time limitations it was not possible to obtain evaluations for all lighting systems at each of the three positions by all of the observers.

3. Discomfort Glare Evaluations: The observed data are summarized in Table F-5. They are grouped according to the lighting system, and within groups by the position around the bolter. As in the case of the continuous miner, the significant values are the relative ratings of L_c/L_{bo} and the VCP values.

In general, the relative discomfort glare ratings indicate about the same degree of discomfort as was when the lighting systems were mounted on the continuous miner. Two of the observers judged System 6 to be in the "distracting but not uncomfortable" region of sensation, and one found System 7 to be approximately BCD. However, the majority of the judgments were more than "perceptibly uncomfortable." The VCP ratings also illustrate the relatively poor visual comfort of the various lighting systems.

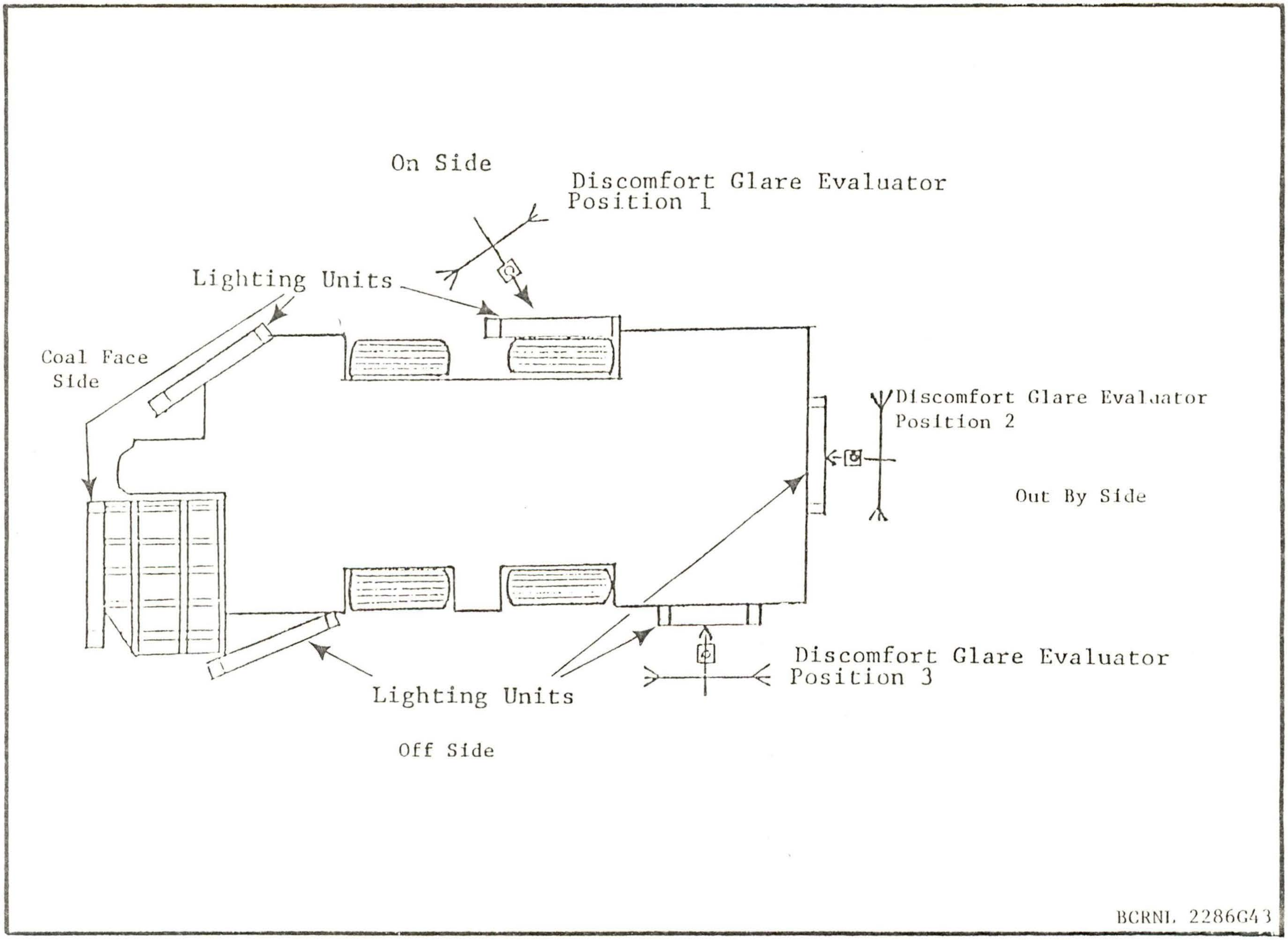


Figure F-4. Sketch of the Bolter Showing the Positions from Which the Lighting Systems were Evaluated.

TABLE F-5. DISCOMFORT GLARE EVALUATIONS OF FIVE LIGHTING SYSTEMS AT THREE POSITIONS AROUND A BOILER

Observer	Position	COMP L_c (fL)	BCD L_{bo} (fL)	Rating L_c/L_{bo}	VCP %
System 1					
1	1	6050	4270	1.42	36
12	1	1195	510	2.34	18
13	1	1485	550	2.72	14
1	2	9300	3675	2.53	15
1	3	5840	4125	1.42	36
System 2					
1	1	9540	3120	3.06	11
1	2	7120	5500	1.29	40
1	3	8500	3675	2.31	12
System 4					
1	1	9050	3530	2.56	15
12	1	3390	2010	1.69	29
13	1	1000	400	2.50	16
System 6					
1	1	2880	4770	0.60	74
3	1	685	390	2.01	22
3	2	1000	1265	0.79	62
1	3	2315	1915	1.21	44
System 7					
1	1	4610	3970	1.16	45
1	2	6260	2880	2.17	20
1	3	3530	3390	1.04	49

IV. GLARE SENSITIVITY OF UNDERGROUND MINERS

The objective of this part of the study was to determine if those who spend considerable time in underground mines are more or less sensitive to glare than an above ground population. The first step involved measurements made at the National Mine Health and Safety Academy (MSHA) with observers who currently were not or had never been underground miners. This was followed up by measurements made at three mines in the Big Stone Gap area with observers who currently were underground miners.

A. Experimental Arrangement: The basic discomfort glare investigations were conducted in a two-meter diameter sphere[3]. This provided a standard and controlled environment which was employed in many subsequent studies. More recently, McNelis[7] developed a cubicle which was a practical and portable approximation of the sphere.

The cubicle, consisted of a box, 100 cm deep, 80 cm high and 60 cm wide. A head- and chin-rest were positioned at the front opening so as to locate the eyes of the observer even with the front panel. The test-source was viewed through a circular aperture on the horizontal line of sight in the rear panel of the cubicle. The aperture subtended a solid angle of 0.0011 steradian, the same as that used in the original discomfort glare investigations.

The source luminance was provided by the luminous element of the Discomfort Glare Evaluator. This was reflected toward the observer's eyes by a diagonal mirror located outside the rear of the cubicle. The luminance of the source, which was under the control of the observer, was continually variable from 0 to about 12,000 fL.

The interior of the cubicle could be illuminated to provide uniform field luminances of 0.01, 0.1, 1.0, and 10 fL. The arrangement for obtaining the source luminance, being external, did not measurably affect the internal luminance of the cubicle.

B. Procedure: The procedure was identical to that employed in the original discomfort glare evaluations[4] and in the previous parts of the present investigation (see Part I, Introduction). The observer adjusted the luminance of the test-source, which was momentarily exposed for 1-second periods, until it was judged to produce a sensation at the borderline between comfort and discomfort (BCD). The 1-second exposure procedure was found to be long enough for the observer to receive the full impact of glare but sufficiently short so that it did not significantly affect adaptation. The latter point is particularly important when the field luminance is low, as in the present investigation.

Each observer made a series of at least five BCD judgments for each field luminance at one sitting or test period. Ideally, at least two such series of measurements should be made by each observer on different days.

Unfortunately, because of the lack of continued availability of the observers and the time limitations, only a few of them were able to provide the repeat measurements. Nevertheless, the results obtained are considered to be valid and useful.

C. Measurements at MSHA:

1. Observers: Those who participated in this part of the investigation were attendees at the Academy course plus a number of staff and research team members. At first it had been hoped that currently active underground miners would be available. However, it turned out that few of the observers had been full-time miners; those who had been miners had not worked in that capacity for a number of years. Therefore, the results obtained should be considered as being for an "above-ground" population and thus could provide a reference basis for the later test of underground miners. In all, 22 observers participated in this part of the study.

2. BCD Results: The BCD judgments of the MSHA (Academy) observers are summarized in Table F-6 and the geometric mean values are represented by the solid line in Figure F-5. Also included in the table are BCD values derived from the glare formula[2] which represent the population used for developing the discomfort glare rating procedure for interior lighting[3]. These are plotted in Figure F-5 by the dotted line.

Several things are evident from these data. One is that the relationship between BCD luminance, L, and field luminance, F, for the Academy observers is not as steep as that represented by the BCD formula. The equations for the two lines are:

Academy observers: $L = 503\ F^{0.33}$ (1)

BCD formula: $L = 355\ F^{0.44}$ (2)

While the difference in the exponents seems large, and over a wide range of field luminances may have a significant effect, the net effect for a limited range of F will be quite small. For example, for field luminances of 0.08 and 0.12 (0.1 + 20%) the ratios of BCD luminance for the Academy observers to that obtained by the glare formula are 1.83 and 1.798, respectively. This difference is not considered too significant. Of course, when large changes in F are involved, the effects of the exponents can be very significant.

A second point is that, on the average, the Academy observers appear to be less sensitive to glare than those whose judgments were used for developing the BCD formula. The lower sensitivity to glare is indicated by the higher BCD luminances selected by the Academy observers. It is interesting to note that for a field luminance of 10 fL, both groups gave very nearly the same BCD judgments.

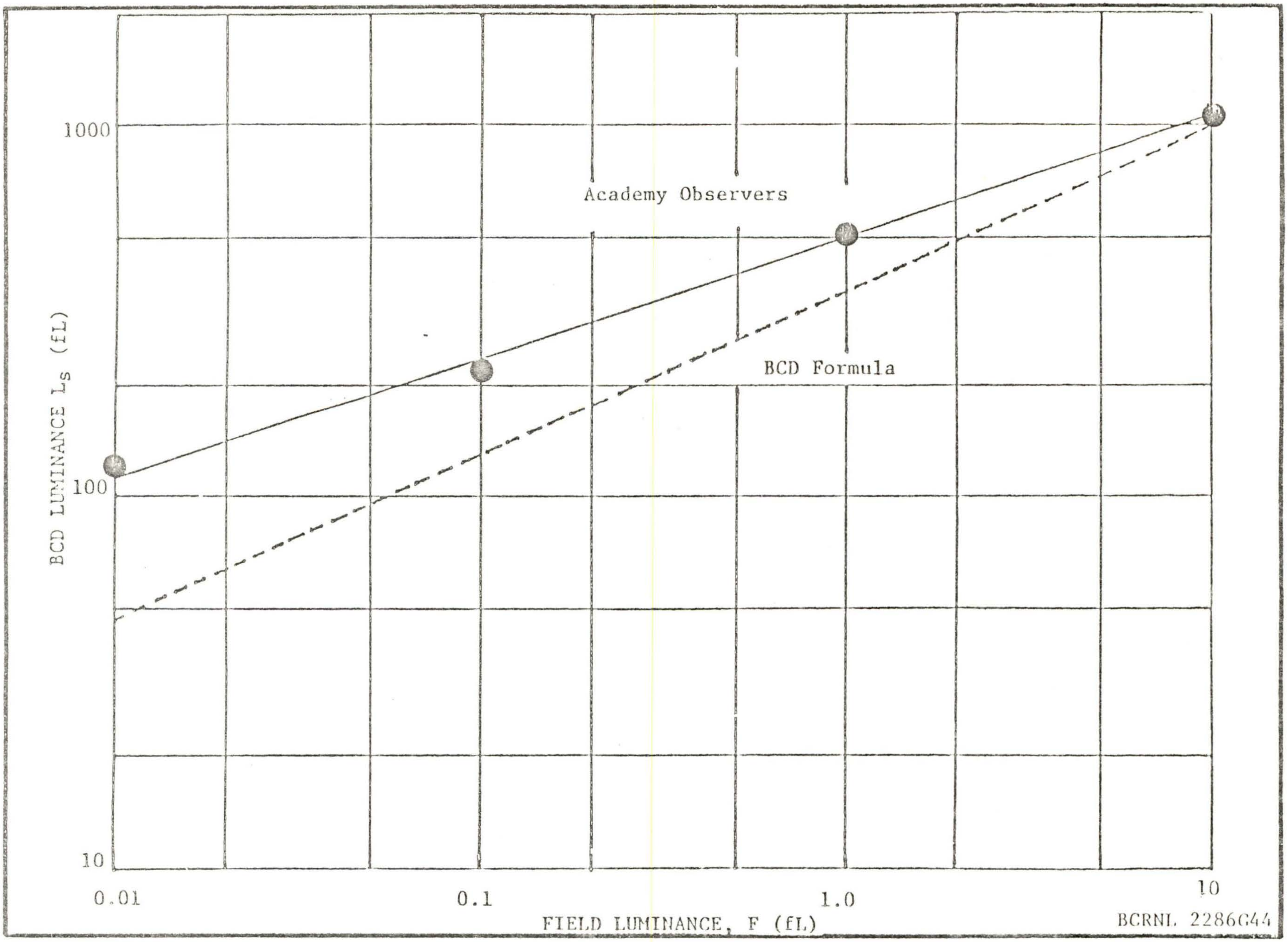


Figure F-5. The Relationships Between BCD Luminance and Field Luminance for Academy Observers (Solid Line) and Guth Formula (Dotted Line).

TABLE F-6. BCD JUDGMENTS BY ABOVE-GROUND PERSONNEL AT FOUR FIELD LUMINANCES (ACADEMY OBSERVERS)

Observer	Field luminance (fL) 0.01	0.1	1.0	10
1	12	28	157	495
2	68	265	1200	3450
3	100	140	280	700
4	10	36	150	140
5	160	355	495	1280
6	1205	2770	4920	7040
7	46	54	91	147
8	14	19	64	168
9	240	300	445	660
10	385	605	1105	1920
11	470	700	1320	1700
12	40	100	140	182
13	1260	1810	2830	5350
14	44	67	133	221
15	9	17	150	280
16	580	750	1000	1270
17	1465	3580	5620	7660
18	115	240	830	2240
19	1570	4650	6200	9400
20	750	880	2240	6850
21	150	182	380	580
22	77	187	465	3100
23	7	9	28	240
Geometric mean	131	221	510	1048
BCD Formula	47	129	356	981

A third point is the relatively large range of the BCD judgments at each field luminance as shown by the individual data in Table F-6. It was much greater than that encountered in the original BCD investigation[4]. For example, for a field luminance of 10 fL the range was 9400 to 140, or a ratio of 67:1. In the original BCD investigation, for the same field luminance, it was 1600 to 315, and a ratio of 5:1. In a more recent study by McNelis[7], for comparable conditions, the range was 6009 to 750, with a ratio of 8:1. The ranges at the three lower field luminances in the present investigation were much greater, the ratios being 224, 517, and 221 for field luminance of 0.01, 0.1, and 1.0 fL, respectively. These large spreads in the data are caused both by relatively high and low BCD luminances.

No specific reasons can be given for these large subjective differences. They may be due in part to the observers not having previously participated in this type of investigation and in part to different interpretations of what constitutes BCD. However, it should be mentioned that the observers in the original BCD studies and those used by McNelis also had no prior experience with this type of subjective judgment.

In spite of these variations, the average results are considered good. Each observer, by himself, was quite consistent. That is, those giving high or low BCD judgments at one field luminance were correspondingly high or low at the other field luminances. The data shown in Table F-6 should provide a good reference basis for the results obtained by the underground miners because all were obtained under identical conditions.

D. Measurements at Mine Sites:

In order to obtain observers who currently were active underground miners, arrangements were made to carry on the investigation at three opeations in the Big Stone Gap area of Virginia. These included the Maple Meadow Mine, Prescott Mines Nos. 1 and 2, and Derby Mines Nos. 4 and 5.

1. Observers: A total of 114 underground miners particpated in the investigation. However, incomplete or very erratic data were obtained from eight observers and so their results have been excluded. The miners came in for testing either just before going on a work-shift or as they came off a shift. For convenience, the shifts were desginated as follows:

Shift 1: midnight to 8 AM
Shift 2: 8 AM to 4 PM
Shift 3: 4 PM to midnight

While workers from all shifts were represented, it was not possible to obtain complete equality of numbers of observers for each shift. In a few cases, data were obtained by the same observer before and after the same shift, but on different days.

2. Experimental Conditions: The cubicle used at the Academy was set up at a convenient location near each mine. An objective was to minimize the time required for an observer leaving the mine, arriving at the test locations and making the BCD judgments. This was particularly important for those coming off shifts 1 and 2, which involved daylight hours. The procedure employed was identical to that used for the Academy tests.

Because of time limitations, it was decided to obtain BCD judgments at three field luminances--0.1, 1.0, and 10 fL. These are adequate to determine if there are any significant differences between miners and nonminers. In addition to making BCD judgments of a source on the line of sight, a number of observers also made evaluations when the source was located 20 degrees above and below the line of sight.

E. BCD Results:

Considerable personal information was obtained from each observer, including shift worked, age, number of years as a miner, and color of eyes. Thus, in addition to the standard types of analyses, the BCD judgments could be evaluated to determine if any of these factors had a significant effect upon the results. These various analyses are presented and discussed briefly in the following paragraphs.

1. Grouped by Mines: The average BCD judgments of each of the observers is given in Table F-7. They are grouped according to the mine in which each observer worked. Also included are the shift, age, number of years as an underground miner, and eye color (L for light and D for dark). The letters A and B following an observer's number indicated those individuals who made BCD judgments before going on a shift and when coming off a shift. Thus, the 104 observers yielded a total of 124 average judgments for each of the field luminances. Each individual datum is the average of at least five BCD judgments.

The geometric mean for each of the groups is given in Part A of Table F-8 and plotted in Figure F-6. These data indicate that, by selecting lower average BCD luminances, the Maple Meadow miners are more sensitive to glare. On the other hand, the Prescott miners are least sensitive, selecting higher average luminances. The Derby miners are approximately midway between the other two groups.

To determine if these differences are significant, standard errors of the means have been calculated. These are shown by the short vertical bars on each of the plotted curves which represent plus and minus one sigma. The percent standard errors are 13% for Maple Meadow, 17% for Prescott, and 31% for Derby. The standard errors reflect two primary points regarding the data for each group; the number of observers and the variation among them. The number of observers are given in Part A of Table F-8. The variation among the observers (see Tabel F-7) can be illustrated by the range of BCD judgments for the 1 fL field luminance:

TABLE F-7. BCD JUDGMENTS OF UNDERGROUND MINERS

Observer no.	Shift	Age	Years as Miner	Eye Color	Field luminance, fL 0.1	1.0	10
Maple Meadow							
1	2 on	30	8	D	545	1225	2110
2	2 on	37	5	D	335	600	1065
3	2 on	25	5	L	38	75	345
4	2 on	41	6	D	165	290	495
5	2 on	28	5	D	405	805	1200
6	2 on	30	10	L	1650	6580	11800
7	2 on	33	10	D	140	705	1500
8	2 on	34	7	L	330	470	895
9	2 on	39	6	L	700	1210	4860
10	2 on	30	8	L	155	520	1065
11	3 on	24	6	L	155	305	2080
12	3 on	33	6	L	690	1725	5110
13	3 on	32	14	D	26	48	79
14	3 on	39	15	D	140	265	445
15	3 on	40	5	L	1000	2770	4350
16	3 on	28	5	D	180	780	1880
17	3 on	42	8	L	220	425	945
18	3 on	50	6	L	620	1275	2540
19	3 on	25	8	D	1560	1740	2050
20	1 on	28	4	D	32	117	250
21	1 on	31	4	D	400	750	1240
23	1 on	23	2	L	1115	2440	6460
24	1 on	33	6	L	1670	2040	2610
25	1 on	40	10	L	10	25	70
26	1 on	23	4	D	300	540	1005
27	1 on	23	6	L	245	890	1500
28	2 off	21	4	D	12	43	166
29	2 off	31	13	L	505	1030	1670
30	2 off	30	11	D	370	585	1170
31	2 off	26	8	L	83	315	5100
32	2 off	26	7	D	225	590	1395
33	2 off	28	10	L	395	1160	2750
34	2 off	44	27	L	155	210	575
35	3 off	41	24	D	165	385	510
36	3 off	38	12	D	460	835	2070
37	3 off	30	10	D	430	1590	3110
38	3 off	22	5	L	55	87	130
39	3 off	34	5	L	365	530	780
40	3 off	44	25	D	465	630	890
41	3 off	37	13	L	130	395	730
42	3 off	25	5	L	630	780	1005
45	1 off	21	3	L	32	87	275
46	1 off	21	3	L	395	755	1420
47	1 off	31	12	L	330	395	630
48	1 off	24	6	L	39	185	465

TABLE F-7. BCD JUDGMENTS OF UNDERGROUND MINERS
(continued)

Observer no.	Shift	Age	Years as Miner	Eye Color	Field luminance, fL 0.1	1.0	10
Maple Meadow (continued)							
51	1 off	24	5	L	87	250	275
52	1 off	25	6	D	780	890	1205
Prescott							
53	3 off	24	6	D	1090	3055	3205
54	1 on	30	10	L	160	200	330
55	1 on	30	9	D	220	505	1465
56A	2 on	26	7	L	505	640	1030
56B	2 off	26	7	L	850	1310	1725
57A	3 on	29	8	L	905	1425	2440
57B	3 off	29	8	L	465	1235	1635
58	3 off	28	6	L	1465	1820	2020
59A	3 on	29	8	L	300	905	1160
59B	3 off	29	8	L	14	71	140
60A	3 on	27	5	L	1160	2115	4415
60B	3 off	27	5	L	465	792	1635
61A	1 on	28	8	L	640	1090	1465
61B	1 off	28	8	L	330	685	1030
62	1 off	30	-	-	590	792	965
63A	3 on	34	7	L	505	2685	6775
63B	3 on	34	7	L	1385	3475	7980
64A	3 on	31	4	D	965	1385	2115
64B	3 off	31	4	D	180	395	850
65A	2 on	32	10	L	11	29	60
65B	2 off	32	10	L	60	140	395
67A	3 on	22	4	L	465	1090	1920
67B	3 off	22	4	L	300	685	1635
68A	3 on	29	6	L	1160	1910	3785
68B	3 off	29	6	L	395	1090	2210
69	3 off	29	9	L	180	300	465
70A	3 on	43	10	L	2330	6385	9595
70B	3 off	43	10	L	3205	4785	10500
71	3 on	26	5	L	160	330	685
72	2 off	35	14	L	160	590	1160
73A	2 on	40	7	L	430	1090	2020
73B	2 off	40	7	L	1310	1465	2020
74A	2 on	29	8	L	1030	1465	2440
74B	2 off	29	8	L	300	505	1030
75A	1 on	25	4	D	550	1465	2930
75B	1 off	25	4	D	850	1385	2930
76	2 off	36	11	L	300	850	1545
77A	3 on	47	10	L	360	850	1385
77B	3 off	47	10	L	245	685	1310

TABLE F-7. BCD JUDGMENTS OF UNDERGROUND MINERS
(continued)

Observer no.	Shift	Age	Years as Miner	Eye Color	Field luminance, fL 0.1	1.0	10
Prescott (continued)							
77A	3 on	47	10	L	360	850	1385
77B	3 off	47	10	L	245	685	1310
78	3 on	26	6	D	1310	1635	2020
79A	3 on	27	4	L	110	430	1090
79B	3 off	27	4	L	180	330	505
80A	2 on	26	7	D	180	505	965
80B	2 off	26	7	D	200	395	905
83	1 on	29	9	L	792	2115	3475
84	3 on	31	8	D	60	71	180
85	3 off	31	8	L	35	125	330
Derby							
86	3 off	22	4	L	71	110	220
87	3 on	22	4	L	7	14	71
88	3 on	47	5	D	2380	4415	9595
89	3 on	25	4	L	550	1160	3205
90	2 on	22	4	L	330	550	6385
91	1 on	28	4	L	300	395	850
92	1 off	30	6	L	300	505	640
93	1 on	24	3	D	590	1440	7015
94	3 off	31	6	L	550	792	1030
95	1 on	26	5	D	360	1030	2440
96	3 off	27	8	D	200	220	270
97	3 off	25	4	D	1030	1235	2115
98	3 on	45	7	L	220	792	1465
99	3 off	37	11	L	505	2020	2685
100	2 on	46	4	L	1235	1910	5535
101	3 on	32	8	D	395	685	4265
102	3 off	28	3	D	29	125	330
103	2 off	27	8	D	430	550	1090
104	1 off	34	8	D	300	550	735
105	3 off	37	4	D	1385	2220	3205
106	2 on	28	6	L	505	850	1235
107	1 on	22	5	L	2560	4955	14550
108A	2 on	31	11	L	3	35	160
108B	2 off	31	11	L	3	14	35
109	3 off	44	5	D	430	550	685
110	2 on	32	8	D	905	1235	2440
111	1 on	31	3	D	395	1030	1160
112	2 off	27	7	D	590	2330	2931
113	3 on	24	5	L	792	1725	2440
114	3 off	45	7	L	220	465	685

TABLE F-8. MEAN BCD LUMINANCES OF UNDERGROUND MINERS GROUPED BY MINES AND SHIFTS

	No. of Observers	Field luminance, fL 0.1	1.0	10
A. MINES				
Maple Meadow	47	228	500	1049
Prescott	47	370	764	1382
Derby	30	279	600	1269
B. ALL DATA	124	288	614	1219
Shift 1	29	245	509	902
Shift 2	35	264	592	1409
Shift 3	60	332	691	1296
D. ON-AND OFF-SHIFT				
I. Shift 1				
On	17	340	777	1499
Off	12	153	279	439
II. Shift 2				
On	19	370	786	1895
Off	16	177	422	990
III. Shift 3				
On	28	371	798	1685
Off	32	301	610	1030
IV. All data				
On	64	362	786	1692
Off	60	228	473	850
V. Same observers on- and off-shift				
On	18	339	839	1658
Off	18	265	580	1127

213.

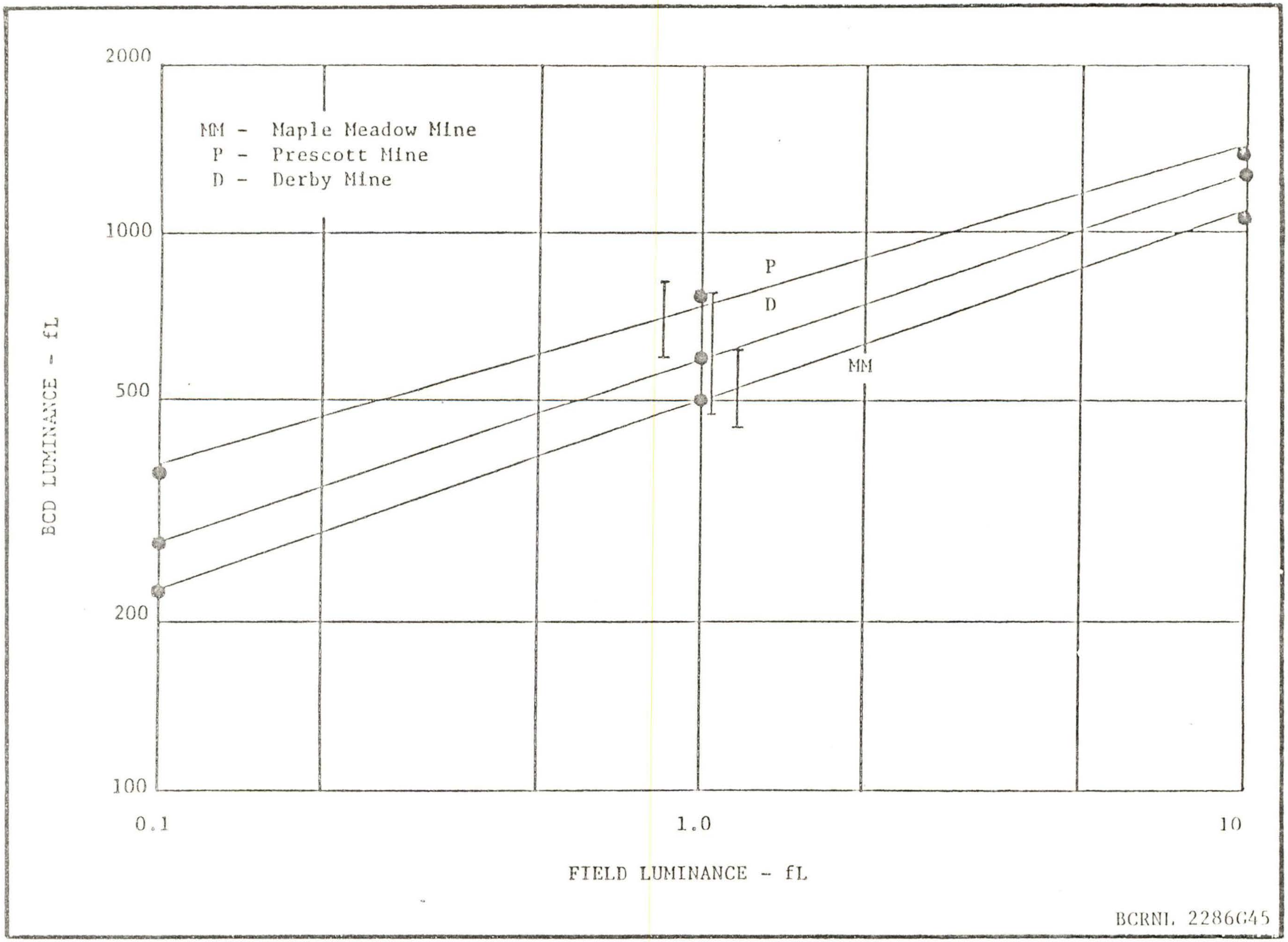


Figure F-6. The Relationships Between BCD Luminance and Field Luminance for Observers from 3 Mines.

Maple Meadow	25 to 6580
Prescott	29 to 6385
Derby	14 to 4955

The ratios (high/low) are quite large, being 263 for Maple Meadow, 220 for Prescott and 354 for Derby. These contrast with ratios of from 10 to 20 encountered in the various earlier BCD investigations[3,7]. The large ratio for Derby coupled with a fewer number of observers' results in a higher standard error of the mean for that group. Taking into account the standard errors, it can be concluded that the differences among the three groups of miners are not particularly significant.

2. All Data: The geometric mean of all the data in Table F-7 are given in Part B of Table F-8, and plotted as the solid line in Figure F-7. The dotted line represents the corresponding results obtained by the non-mining observers at the Academy (Table F-6 and Figure F-5). This comparison is more appropriate than one with the original BCD data because both were obtained with identical experimental conditions.

The curves in Figure F-7 indicate that the miners, on the average, are slightly less sensitive to glare than the non-mines. The former selected BCD luminances that were approximately 20 percent higher than the Academy observers.

The two short vertical lines represent the average standard error of the means for the two groups, which are 12 percent for the miners and 36 percent for the Academy observers. The length of the lines correspond to one sigma. Thus, while there is a trend toward less glare sensitivity among the miners, the difference cannot be considered highly significant.

The equation for the underground miner relationship is

$$BCD = 600F^{0.32} \qquad (3)$$

in which the exponent of F is almost the same as in the equation for the Academy observers (Eq. 1). This indicates that the effect of field luminance upon the BCD judgments is the same for the two groups.

An analysis of the distribution of the BCD judgments of the miners is illustrated in Figure F-8. For this purpose the data for each of the three field luminances were converted into relative BCD luminances. This permitted combining all of the data into a single relationship. These then were divided into twelve groups, each encompassing a range of relative luminances of about 0.23 log unit. The resultant groups, the number of observers in each group, and the mean relative BCD luminances are given in Table F-9. The curve shown in Figure F-8 illustrates the skewed distribution caused by the observers selecting rather low BCD luminances. This point also is illustrated in Figure F-9, which is a probability plot of the percent of observers selecting a given BCD luminance or less. A normal distribution would be indicated by a single

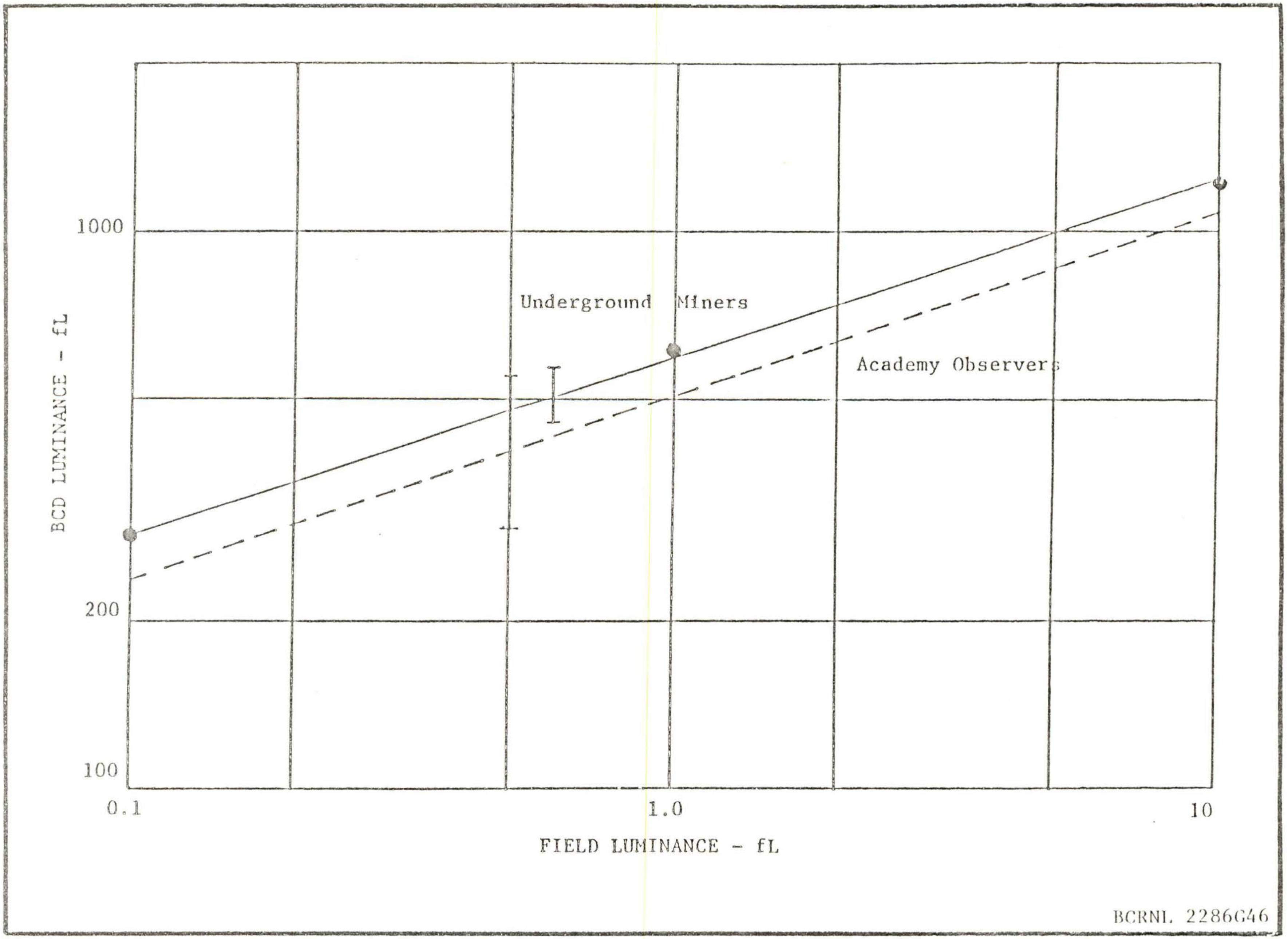


Figure F-7. Relationships Between BCD Luminance and Field Luminance.

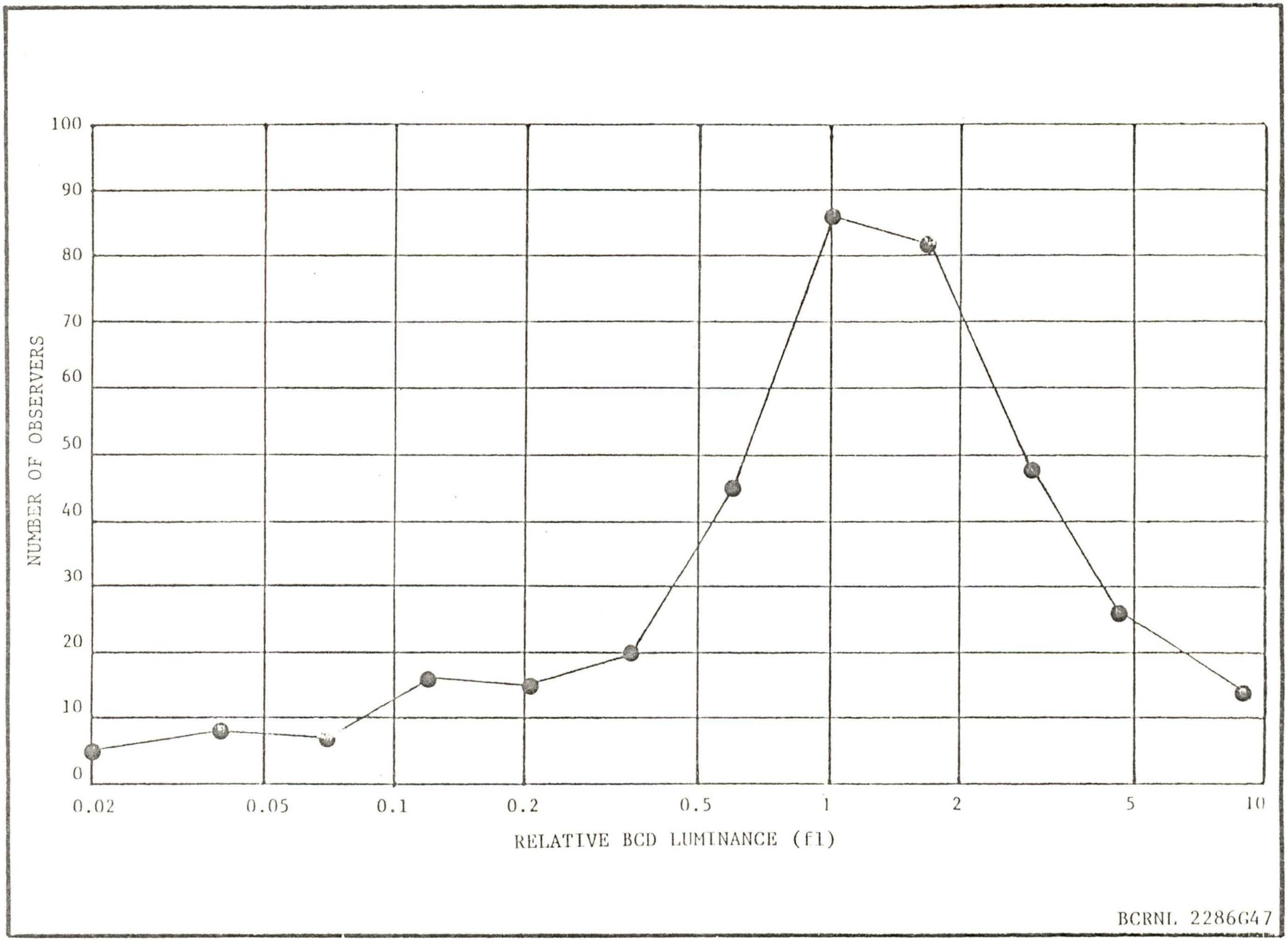


Figure F-8. Frequency Plot of Number of Miners Selecting BCD Luminances in Various Ranges.

TABLE F-9. NUMBER OF OBSERVERS SELECTING VARIOUS RANGES OF RELATIVE BCD LUMINANCES

Range of relative BCD luminance	Number of observers	Mean relative BCD luminance
0.01 - 0.02	5	0.02
0.02 - 0.05	8	0.04
0.06 - 0.09	7	0.07
0.10 - 0.15	16	0.12
0.16 - 0.25	15	0.21
0.16 - 0.44	20	0.35
0.45 - 0.75	45	0.60
0.76 - 1.30	86	1.01
1.31 - 2.25	48	2.94
3.91 - 6.60	26	4.84
6.61 -12.00	14	9.02

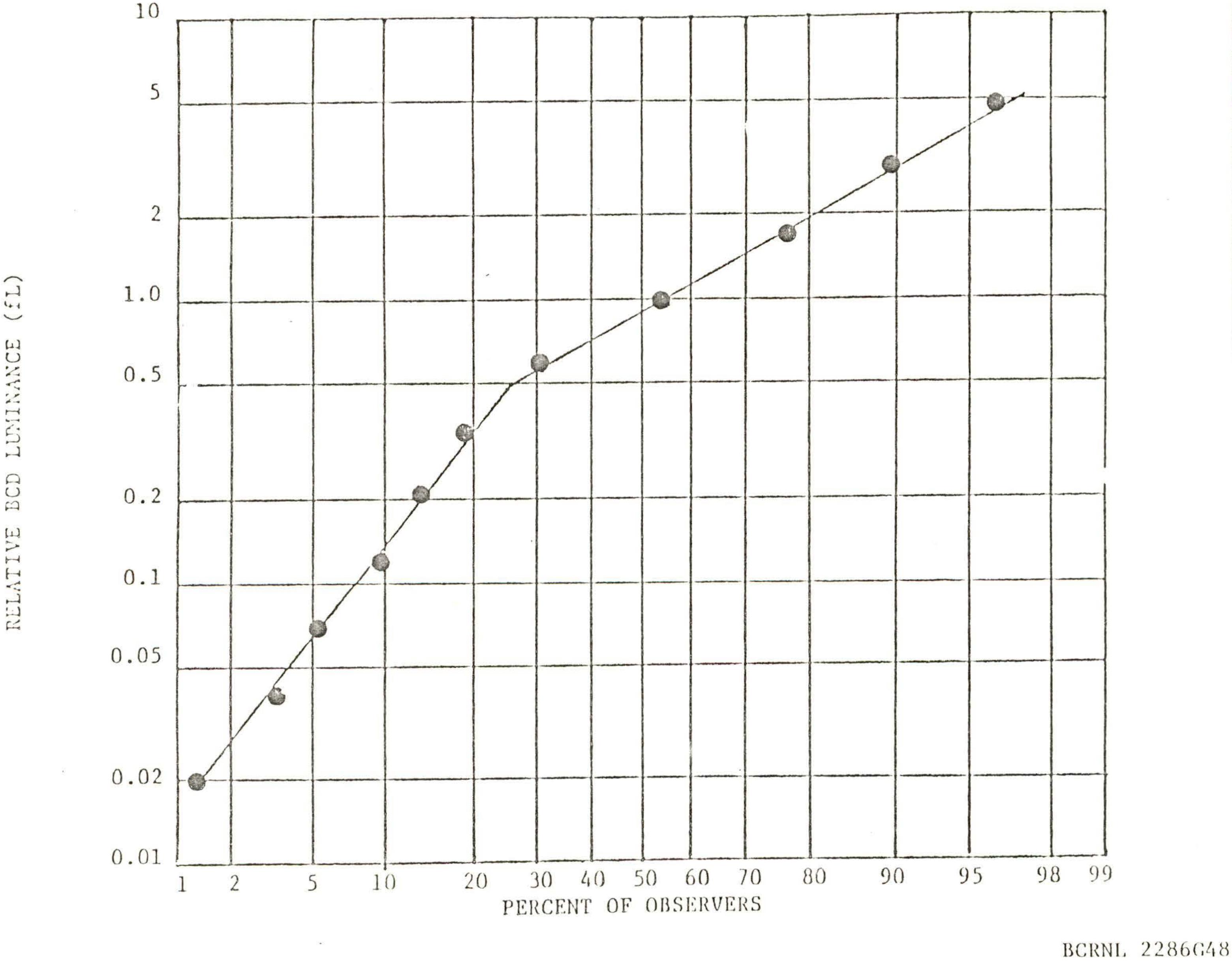


Figure F-9. Probability Plot of Relative BCD Luminances for All Miners.

straight line. In this case, the lower and higher relative BCD luminance values follow different relationships.

When the very low relative BCD luminances are excluded (i.e. those less than about 0.1), the resulting relationship is shown in Figure 12. The straight line through the plotted points indicates a normal distribution. In this case the scale on the abscissa has been reversed so that a point on the line now represents the percent of observers selecting relative BCD lumiances equal to or greater than that indicated by the point. For example, 90 percent of the observers selected relative BCD luminances greater than about 0.38. Similarly, 20 percent selected relative BCD luminances greater than 2.2.

The dotted line in Figure F-10 represents the corresponding relationship obtained in the original basic BCD investigation[2]. As is evident, while the two lines have different slopes, the disparity is not very great.

The solid line in Figure F-10 can be used as a basis for a Visual Comfort Probability (VCP) rating system for underground miners. As such, it would correspond to the one that was used for developing a VCP procedure for interior lighting[2,3].

3. Effect of Shift: To determine whether the shift being worked on had an effect upon BCD judgments, the data in Table F-7 were divided into three groups. The resulting geometric means are given in Part C of Table F-8. For field luminances of 0.1 and 1.0 fL there was a progressive increase in BCD luminance for the three shifts. Observers from the 4 PM to midnight shift gave the highest BCD luminances, whereas those on the midnight to 8 AM shift gave the least. At a field luminance of 10 fL, the results for Shift 2 were highest.

4. On- Vs. Off-Shift: A natural question pertains to whether after working underground for an eight-hour shift results in a greater sensitivity to glare. To check this point, the BCD judgments were divided into six groups (on and off for each shift) as shown in Part D I to D III of Table F-8. In addition, all data were averaged (Part D IV of Table F-8). The results in all cases indicate that there appears to be a greater sensitivity to glare when coming off a shift.

One problem in evaluating these data is that the population of all groups is not identical. That is, observers of equal glare sensitivity are not represented in each of the groups. Thus, the apparent differences between on- and off-shift observers may be caused by differential sensitivities to glare to the observers in each group. Fortunately, eighteen observers were tested twice, once before going on a shift and again when coming off a shift. These are the observers listed in Table F-7 with A and B following their numbers. While the A and B data were taken on different days, they did involve the same shift. These results, which are summarized in Part D V of Table F-3, indicate that when tested after a shift the observers are more sensitive to glare.

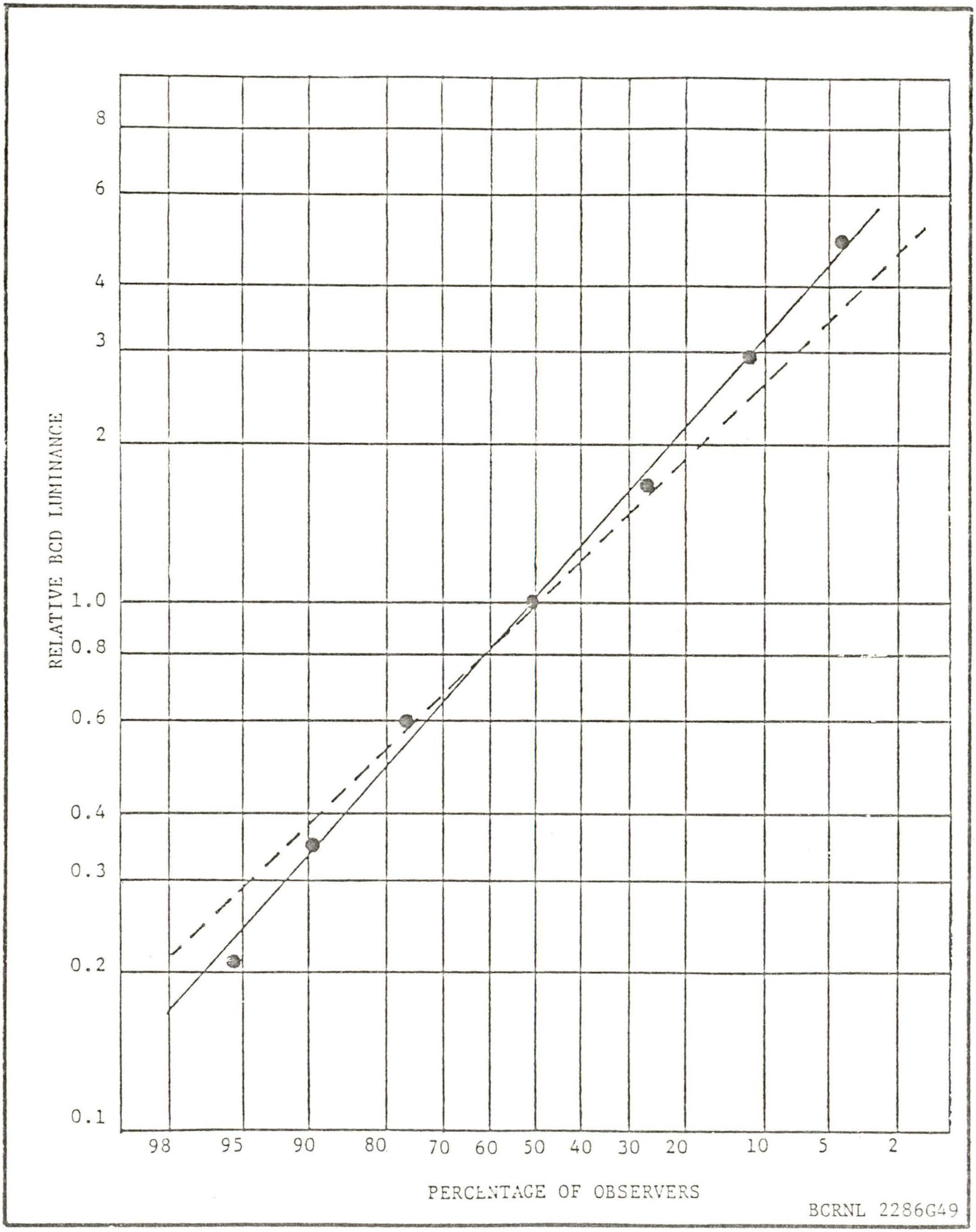


Figure F-10. Probability Plots of Relative BCD Luminance for Underground Miners, Excluding Low Values (Solid Line), and for the Guth Formula (Dotted Line).

While the differences are not highly significant in terms of standard errors of the means, they do show that there is a definite trend toward greater sensitivity to glare after working underground for a period of eight hours.

5. Effects of Age: In Table F-10 are summarized the data for various five-year age groups. The mean values for each age group are plotted in Figure F-11. The results indicate no definite trend in glare sensitivity because of age. The apparently considerably higher BCD luminance selected by the 46-50 age group is not considered significant because of the small number of observers involved.

6. Years as a Miner: From on- and off-shift data, which indicated that spending time working underground increased glare sensitivity, one might consider that the same effect would be produced by many years as a miner. The results of this analysis are summarized in Table F-11 and the mean BCD luminances are plotted in Figure F-12. These data indicate that there is a trend toward increased sensitivity to glare with the number of years as a miner, even though the plotted points are represented by a jagged line, with a considerable reversal for the 21-25 group. In general, one would expect that the average age of observers in the groups would increase with the number of years as miners. While there is a trend in the increase of average age for each group, all are less than 45. Thus, considering the age data of Figure F-11 which shows no significant differences in glare sensitivity for observers under age 45, it was surprising that the data given in Figure F-12 do exhibit a trend.

7. Eye Color: There has been speculation that individuals with light colored eyes might be more sensitive to glare than those with dark colored eyes. Since the eye color of the observers had been recorded, it was possible to test this. For simplicity, the observers were divided into two groups: blue, green, hazel, and gray were considered light colored eyes; those having brown eyes were put in the dark group. The geometric mean BCD judgments were:

Dark eyes (n = 45)	582 fL
Light eyes (n = 73)	630 fL

On the average those with brown eyes selected a lower BCD luminance, and thus could be considered as being slightly more sensitive to glare. This is the opposite to what one might expect. However, the difference between the two groups is not considered significant, being only about 8 percent. This is about half of the standard error of the mean.

8. Displacement of Glare Source: One of the fundamental components in the discomfort glare formula is the Position Index, P. This is a quantity which indicates how much brighter a glare source can be if it is displaced from the line of sight. Luckiesh and Guth[4] reported the results of an extensive exploration of glare source locations above the line of sight. This was

TABLE F-10. EFFECTS OF AGE ON BCD JUDGMENTS

Age Group	Number of Observers	Field luminance, fL 0.1	1.0	10	Mean BCD Luminance
21 - 25	27	254	534	1228	550
26 - 30	45	322	699	1300	664
31 - 35	25	178	408	837	393
36 - 40	12	339	422	1402	505
41 - 45	10	383	723	1204	693
46 - 50	5	691	1443	3004	1441

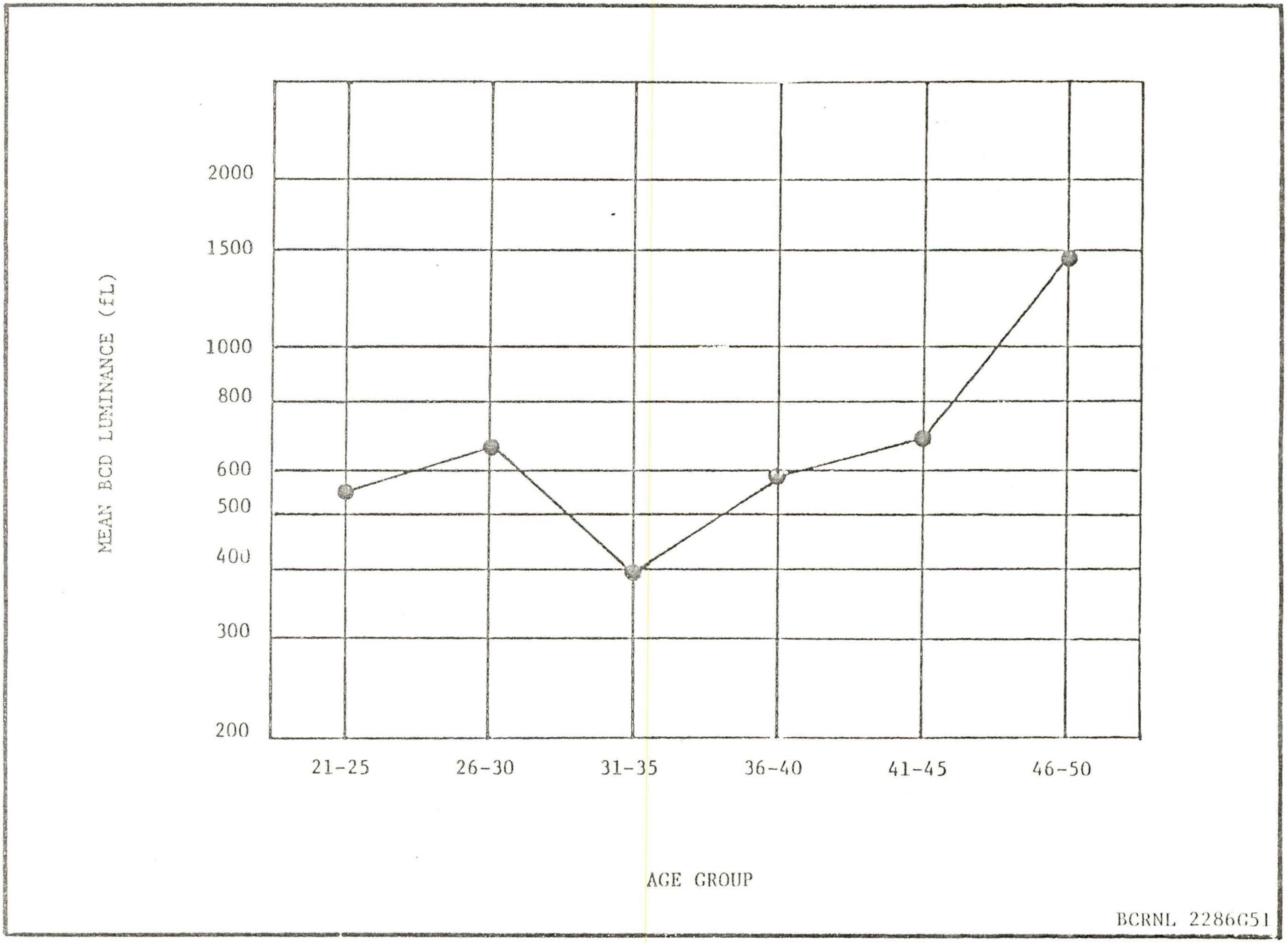


Figure F-11. BCD Luminances Selected by Various Age Groups of Miners

TABLE F-11. BCD LUMINANCE VS. NUMBER OF YEARS AS AN UNDERGROUND MINER

Years as miner	Average age	Number of observers	Field luminance, fL 0.1	1.0	10	Mean BCD Luminance
1 - 5	28	43	284	595	1266	590
6 - 10	32	65	341	730	1405	705
11 - 15	34	12	110	298	590	268
16 - 20	-	0	-	-	-	-
21 - 25	42	2	277	492	674	451
26 - 30	44	1	155	210	575	266

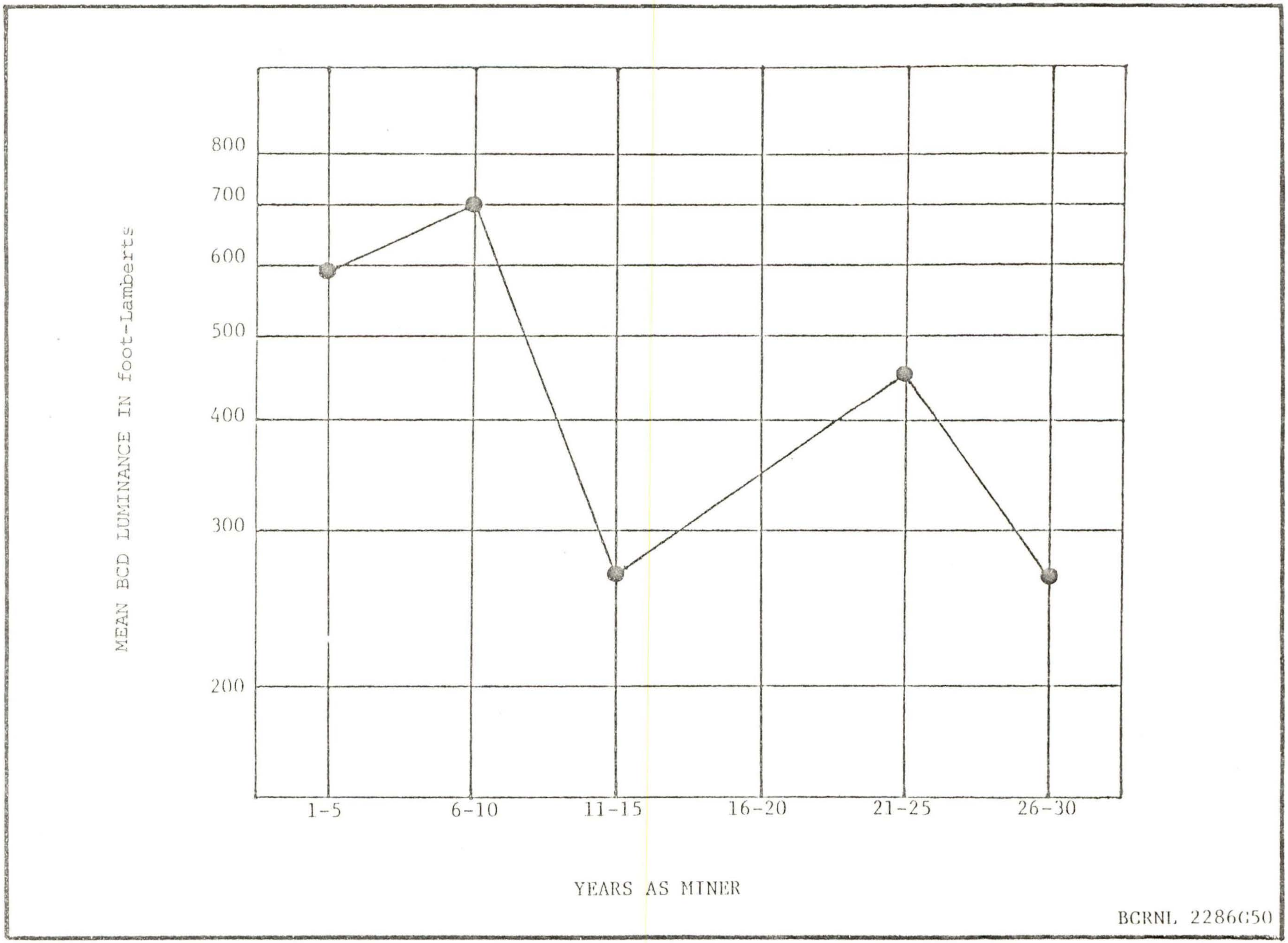


Figure F-12. BCD Luminances for the Number of Years as an Underground Miner.

adequate for interior lighting glare evaluations because in typical lighting systems the sources always are located in the upper part of the field of view. However, in mine lighting, especially with equipment mounted on machines, the luminaires may be located below the line of sight.

A report by Netusil[8] included evaluations of sources located in the lower part of the visual vield. His results for sources above the line of sight were in good agreement with those reported by Guth[2].

In the present investigation, BCD judgments were made by a small group of observers when the test-source was located 20 degrees above and below the line of sight as well as on the line of sight. The results, together with the corresponding values obtained by Guth and by Netusil are presented in the following table:

	20^{o} below	0^{o}	20^{o} above
Miners	1.58	1.00	1.96
Guth	-	1.00	2.10
Netusil	1.42	1.00	1.66

The values are relative BCD luminances which correspond to the Position Indices.

The agreement is considered quite good, considering the differences among observers and the experimental conditions. It is interesting to note that the Position Index for the sources at 20^{o} below the line of sight for the miners is less than that obtained for 20^{o} above the line of sight. Netusil reported a similar difference. The ratios 20^{o} below/20^{o} above for the miners and Netusil's observers are 0.81 and 0.85, respectively, which are not significantly different.

From this it is evident that the position index data reported by Netusil and by Guth can be combined into a single relationship for the entire field of view.

V. DISCUSSION AND CONCLUSIONS

The results of the evaluations of lighting systems on a continuous miner and a bolter lead overwhelmingly to the conclusion that, in terms of discomfort glare, they are very uncomfortable.

It is well established that discomfort glare is influenced adversely by increasing source luminance and area, and is mitigated by higher field luminances and greater displacement of the sources from the line of sight. Obviously, the mobility of workers around a machine and the dark visual environment present certain constraints on what can be done to minimize the glare effects. Thus, it appears that source luminance and area are the primary factors to be controlled in order to make the visual situation more bearable. Furthermore, changing the placement of the luminaires may offer some additional improvements in glare.

The primary function of the luminaires on the continuous miner is to provide illumination on mine surfaces so that the operator and the helper can see objects and surfaces around the machine. On the other hand, lighting on the bolter must serve two purposes: illuminate the area around the machine and the roof area where bolts are to be installed; and to illuminate certain areas on the machine where a worker selects and assembles the bolts. The two lighting requirements on the bolter are not easily provided for by a single luminaire type and location.

It is self-evident that reducing the luminance of the luminaires will reduce glare. However, this also will reduce the illumination on the mine surfaces. What appears to be needed is better shielding and relocation of the lighting units so that the luminances seen by the miner are reduced. At the same time, the light distribution from the luminaires should be controlled so as to maintain the desired illumination where the worker must see things.

An objective of this investigation was to obtain data and other information which could be used for evaluating and predicting the discomfort glare produced by lighting systems on mining machines. It would be desirable to be able to make such predictions from the physical and photometric characteristic of proposed luminaires while they still are in the "drawing board" stage or from mock-up samples.

The extensive data obtained with the large group of underground miners provide some clues as to how the glare formula and procedure developed for interior lighting can be modified for use in mine lighting. The basic formula developed for interior lighting is:

$$M = \frac{LQ}{PF^{c}} \qquad (4)$$

where the index of sensation M is expressed as a function of the luminance L, solid angle factor Q and position index P of a source, and the field luminance F. In the formula for interior lighting the exponent 'c' is equal to 0.44. However, as shown in Figure F-9, the BCD judgments of the underground miners indicate that the exponent of F for the mine environment is 0.32. Thus, Eq. (4), when evaluating mining machine lighting becomes

$$M = \frac{LQ}{PF^{0.32}} \qquad (5)$$

In a restatement[9] of the glare formula, the quantity Q is replaced by $K\omega$, and Eq. (5) becomes

$$M = \frac{LK\omega}{PF^{0.32}} \qquad (6)$$

K is a function of solid angle ω. The solid angle is approximated by

$$\omega = \frac{A_p}{D^2} \qquad (7)$$

where A_p is the projected area of the luminaire from the observer's viewing position and D is the distance from the eye to the center of the luminaire. Values of K have been tabulated[3] and are included in Table F-12.

Eq. (6) is used for calculating the index of sensation M for each luminaire in the field of view. The resulting discomfort glare rating (DGR) is obtained from

$$DGR = M_t^a \qquad (8)$$

where M_t is the sum of the individual indices of sensation and 'a' is a variable exponent.

$$a = n^{-0.914} \qquad (9)$$

In Eq. (9), n is the number of values of M included in M_t. In general, there will be only two or three luminaires in the field of view of a worker around a mining machine. Thus, the value of 'a' of concern are:

n	a
1	1.000
2	0.939
3	0.904
4	0.880

TABLE F-12. FUNCTION K OF SOLID ANGLE ω

ω	0	1	2	3	4	5	6	7	8	9
					RANGE: 0.0000010 to 0.0000099					
0.000001	20930	20700	20410	20080	19720	19360	18990	18630	18280	17940
.000002	17600	17280	16970	16670	16380	16100	15830	15570	15320	15080
.000003	14840	14620	14400	14190	13990	13800	13610	13420	13250	13070
.000004	12910	12750	12590	12440	12290	12150	12010	11870	11740	11610
.000005	11490	11360	11240	11130	11020	10910	10800	10690	10590	10490
.000006	10390	10300	10200	10110	10020	9940	9850	9770	9680	9600
.000007	9530	9450	9370	9300	9230	9150	9080	9020	8950	8880
.000008	8820	8750	8690	8630	8570	8510	8450	8390	8330	8280
.000009	8220	8170	8120	8060	8010	7960	7910	7850	7820	7770
					RANGE: 0.000010 to 0.000099					
0.00001	7720	7290	6910	6570	6280	6010	5770	5550	5350	5170
.00002	5000	4850	4700	4570	4440	4320	4210	4110	4010	3920
.00003	3830	3750	3670	3600	3520	3460	3390	3330	3270	3210
.00004	3160	3110	3060	3010	2962	2917	2874	2832	2792	2753
.00005	2714	2678	2643	2609	2575	2543	2512	2482	2452	2423
.00006	2395	2368	2342	2316	2291	2267	2243	2220	2197	2175
.00007	2154	2132	2119	2092	2072	2053	2034	2016	1998	1980
.00008	1963	1946	1929	1913	1897	1882	1865	1851	1837	1822
.00009	1808	1794	1780	1767	1754	1741	1728	1716	1703	1691
					RANGE: 0.00010 to 0.00099					
0.0001	1679	1571	1477	1395	1325	1262	1206	1155	1109	1067
.0002	1029	994	962	932	904	878	854	831	810	790
.0003	771	753	736	720	705	690	677	664	651	639
.0004	628	617	606	596	586	577	568	559	551	543
.0005	535	528	520	513	507	500	494	487	481	476
.0006	470	464	459	454	449	444	439	434	430	425
.0007	421	417	413	409	405	401	397	394	390	387
.0008	383	380	376	373	370	367	364	361	358	355
.0009	352	350	347	344	342	339	337	334	332	330
					RANGE: 0.0010 to 0.0100					
0.001	327.0	306.0	287.9	272.2	258.5	246.4	235.7	226.0	217.3	209.4
.002	202.2	195.6	189.5	183.9	178.7	173.8	169.3	165.1	161.2	157.4
.003	153.9	150.6	147.5	144.6	141.8	139.1	136.6	134.2	131.9	130.0
.004	127.6	125.6	123.7	121.8	120.1	118.4	116.7	115.1	113.6	112.2
.005	110.8	109.4	108.1	106.8	105.6	104.4	103.2	102.1	101.0	100.0
.006	99.0	98.0	97.0	96.1	95.2	94.3	93.4	92.6	91.8	91.0
.007	90.2	89.4	88.7	88.0	87.3	86.6	85.9	85.2	84.6	84.0
.008	83.4	82.8	82.2	81.7	81.0	80.5	80.0	79.4	78.9	78.4
.009	77.9	77.4	76.9	76.5	76.0	75.6	75.1	74.7	74.2	73.8
.010	73.4									
					RANGE: 0.010 to 0.130					
0.01	73.4	69.7	66.4	63.7	61.3	59.1	57.3	55.6	54.0	52.7
.02	51.4	50.3	49.2	48.2	47.3	46.5	45.7	45.0	44.3	43.6
.03	43.0	42.5	41.9	41.4	40.9	40.5	40.0	39.6	39.2	38.8
.04	38.5	38.1	37.8	37.5	37.2	36.9	36.6	36.3	36.1	35.8
.05	35.6	35.4	35.1	34.9	34.7	34.5	34.3	34.1	33.9	33.8
.06	33.6	33.4	33.2	33.1	32.9	32.8	32.6	32.5	32.4	32.2
.07	32.1	32.0	31.8	31.7	31.6	31.5	31.4	31.2	31.1	31.0
.08	30.9	30.8	30.7	30.6	30.5	30.4	30.3	30.3	30.2	30.1
.09	30.0	29.9	29.8	29.8	29.7	29.6	29.5	29.5	29.4	29.3
.10	29.2	29.2	29.1	29.0	29.0	28.9	28.8	28.8	28.7	28.7
.11	28.6	28.5	28.5	28.4	28.4	28.3	28.3	28.2	28.2	28.1
.12	28.1	28.0	28.0	27.9	27.9	27.8	27.8	27.7	27.7	27.6
.13	27.6									

The application of the variable exponent to M_t is an important part of the glare rating procedure. It takes into account, for example, that two identical glare sources in the field of view are not twice as uncomfortable as one of them alone. The effect of the exponent can be illustrated by assuming that two sources, each of which has an index of sensation equal to 100. Thus, M_t equals 200, and applying the exponent a = 0.939, the DGR is equal to 144. This is considerably less than the sum (200) and indicates that the rating for the two sources is only 44 percent greater than one of them.

As was pointed out in the discussion of Table F-4, a more representative value of the field luminance includes the luminaires. A useful approximation is the illumination at the eye which can be calculated from the photometric data for the luminaire or measured.

The position index P can be obtained from a chart such as the one in Figure 5 of reference 2. Ultimately, a chart will be available for source locations below the line of sight.

Having obtained a DGR for a lighting system, the next step is to translate this into a meaningful number such as a Visual Comfort Probability (VCP) rating. This can be done by employing a relationship such as is shown by the solid line of Figure F-10.

According to the data for the miners (Figure F-7), the DGR for the average BCD sensation is 200. This is the DGR for the 50 percent point on the probability plot of relative luminance shown by the solid line of Figure F-10. Taking this into account, the DGR probability plot shown in Figure F-13 has been prepared. If, for example, a lighting system has a DGR of 400, the Visual Comfort Probability (VCP) will be 20 percent. On the other hand, a DGR of 100 will give an 80 percent VCP.

The advantages of a chart such as shown in Figure F-13 are that it converts discomfort glare ratings into meaningful visual comfort probabilities. Moreover, it takes into account all of the visual comfort judgments obtained from the large group of underground miners.

In effect, glare is a situation in which sources are more conspicuous than the things that need to be seen. The data obtained in this investigation provide a basis for evaluating the degree of discomfort glare from mining machine lighting in underground mines. The objective should be to design the lighting equipment so that it will have a visual comfort rating of at least 50 percent, and preferably much higher.

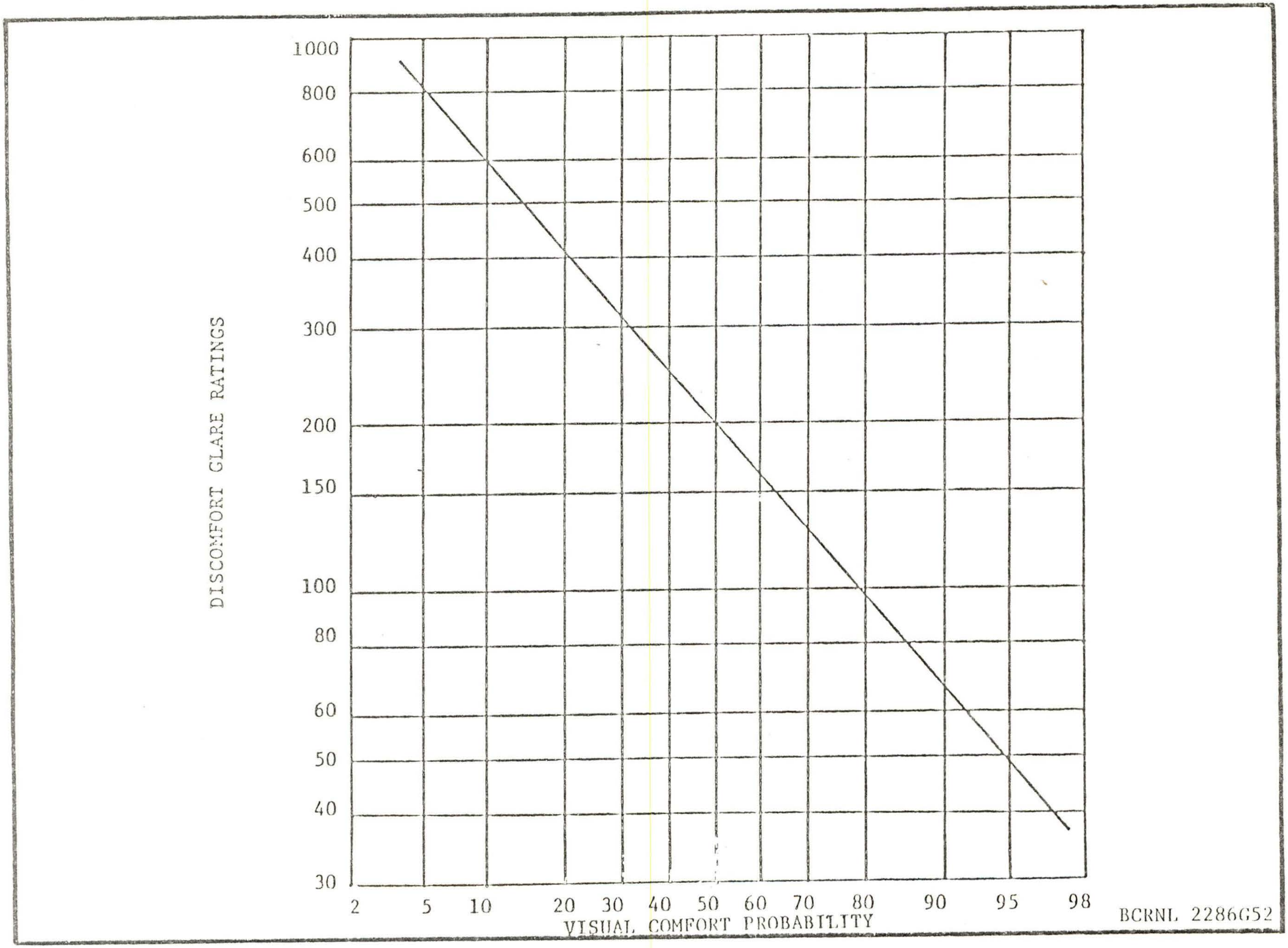


Figure F-13. A Chart for Converting Discomfort Glare Ratings to Visual Comfort Probabilities, the Percent of Observers Who Would be Expected to Judge a Lighting System to be at or More Comfortable Than the Borderline Between Comfort and Discomfort, BCD.

VI. REFERENCES

1. "Nomenclature and Definitions of Illuminating Engineering," American National Standard ANSI/IES RP-16-1980, Illuminating Engineering Society of North America.

2. Guth, S.K.: "A Method for the Evaluation of Discomfort Glare", Illuminating Engineering, 58, 1963, 351.

3. Committee on Recommendations of Quality and Quantity of Illumination: "Outline of a Standard Procedure for Computing Visual Comfort Ratings for Interior Lighting", RQQ Report No. 2 (1972), Journal of the Illuminating Engineering Society, 3, 1973, 328.

4. Luckiesh, M., and Guth, S.K.: "Brightness in Visual Field at Borderline Between Comfort and Discomfort (BCD)", Illuminating Engineering, 44, 1949, 650.

5. Guth, S.K., and McNelis, J.F.: "A Discomfort Glare Evaluator", Illuminating Engineering, 54, 1959, 398.

6. Luckiesh, M., and Holladay, L. L.: "Glare and Visibility", Transactions of the Illuminating Engineering Society, 20, 1925, 221.

7. McNelis, J.F.: "A Discomfort Glare Calibrating Device; Subjective Evaluations in a Standard Environment", Journal of the Illuminating Engineering Society, 10, 1981, 55.

8. Netusil, Ya: "Quantitative Estimation of Glare", Svetoteknika, 5, No. 7, 1959, 13.

9. McGowan, T.K., and Guth, S.K.: "Extending and Applying the IES Visual Comfort Rating Procedure", Illuminating Engineering, 64, 1969, 253.

PART III - REFLECTIVITY OF UNDERGROUND COAL MINE SURFACES

C. L. Crouch

Summary

Measurements of reflectivity of underground coal mine surfaces were made in eight mines in five states. This variety of mines in different states represented different coal seams with different reflective patterns. The measurements for face and ribs varied from 2.3% reflectance to 6.6%. Averages range from 4 to 4.5%. However by mines and therefore seams, there were low reflectances in some and high in others. A significant feature was the comparatively high reflectance of the roofs in all of the mines. This could be especially helpful in designing a lighting system to minimize glare and transient adaptation losses and produce a greatly improved visual environment.

REFLECTIVITY OF UNDERGROUND COAL MINE SURFACES

Introduction

For many generations of coal miners, the lighting has consisted of small spotlights, called caplamps, stabbing the darkness with feeble beams. Only recently has the mining world begun to realize the importance of environmental lighting. The change has not only been significant but dramatic as the surroundings became illuminated instead of tiny spots of light roving over black surfaces. Now it has changed from the era of the firefly to the larger area surroundings. These lighted surroundings give a feeling of security and therefore safety. One can now see the contours of the coal surfaces, the obstructions on the floor surfaces, and best of all, the possible loose rock in the roofs which might clue the possibility of a rock fall. One can see the other workers and the contours of the machines working in the mining area.

This provision of environmental lighting has proven greatly helpful to the miners themselves and while there are still some difficulties with overly bright lighting fixtures, the survey of miners indicated that the new lighting systems providing general lighting were a great improvement over the former caplamp system of lighting. Of course the caplamps still are used as localized lighting for seeing particular detail, but the illuminated surroundings ameliorate the harshness of spots in surrounding darkness. Psychophysical studies from the early 1900's to the present time have resulted in our understanding that the lighted surroundings have a tremendous influence on the ability of the visual system to see the details in the object of regard. König[1], working on the ability of the visual system to resolve detail, called visual acuity, found that it increased as the illumination on the target area increased. But then, when it reached a given level it began to decrease because of the strong difference between the illumination of the detail and the darkness of the surroundings. In 1932, Lythgoe[2], both a medical doctor and an engineer, conducted a classical study on visual acuity and found that the luminance of the surroundings must be maintained in a given balance with the luminance of the detail in order to get maximum ability to see the detail. Further he found that if the surroundings exceeded that of the luminance of the background of the immediate detail, then there began to be a fall off of ability to see detail (visual acuity). Since that time a number of authors have confirmed the same finding. Earlier in 1926, Holladay[3] had been able to determine the fact that bright light sources in the surroundings in the field of view contributed to both disability and discomfort glare. He developed formulation for both types of glare. His finding that bright light sources in the surroundings caused a decrease of visibility tied in with that of Lythgoe who found that brighter surroundings than that of the task resulted in decreased visual acuity. More recently it has been found by Boynton[4] that if one looks away from a lighted area to a darker area there is a change in adaptation of the visual system so that there is a temporary loss of ability to see detail. This is called transient adaptation.

In application of these psychophysical results, the Bureau of Mines has seen fit to sponsor a study in disability and discomfort glare from general lighting systems now being currently used and to measure the changes in sensitivity of miners to disability and discomfort glare. While there was significant improvement by furnishing general lighting systems, it has been found that these systems in and of themselves constitute glare sources which greatly reduce visibility of the detail to be seen. Not only is there a decrease in visibility but there is a great increase in the feeling of discomfort from the bright light sources themselves. Thus the U.S. Bureau of Mines is now beginning to realize that while much progress has been made, there still can be great improvements in the lighting of the surroundings so as to preserve optimum visibility of the details to be seen and provide a goodly degree of comfort from the lighting systems which might be used. In order to get at the solution of better surroundings it was necessary to go back to fundamentals and find out the reflectivity of the underground coal mining surfaces in order to design lighting that would give the lighted effect of visually efficient and comfortable surroundings. Once having determined the reflectivity of these surfaces, the designers can then utilize these values to design the lighting that will give the proper effects.

Reflectivity Studies

Method of measurement:

Interior surfaces, as far as illumination is concerned, are fairly easy to measure. They are flat surfaces, and in general diffuse the light rays in reflection from the light incident on the surface. However, in the coal mine situation the reflectivity involves a much more complex pattern. The incident light rays are reflected from small mirror type surfaces that are disposed in relation to the incident light in every conceivable plane. Of course, the coal is gouged out by bits being located on a drum. Since coal in general is in a laminate structure, the laminations are broken and crumbled up so that the glossy reflective surfaces are small and pointed in every direction. There are projections, there are cavities, all of which present to the eye of the observer a series of sparkling highlights interspersed with dull reflections and actual shadows. These rough, uneven surfaces present a problem of measurement since some of the projections will project into the reflectometer and some of the cavities will be outside of the reflectometer. Thus it was felt that in making such measurements one should take an integration of the return of reflections from a fairly large area of the coal face. The writer of this report conceived of the use of sending a rather large patch of light onto the coal surface and then picking up the reflections in a diffuse reflecting hemisphere and measuring the amount of light collected by the hemisphere. This was communicated with Dr. H. R. Blackwell of the Institute for Research in Vision at Ohio State Universtiy, and out of these discussions came the reflectometer that was used to measure the reflectivity of coal mine surfaces. The design that was finally evolved was a hemisphere of 24 inches in diameter and a rather wide beam of light that was directed at the coal surfaces of approximately seven inches by ten inches elliptical pattern which was screened from the hemisphere by suitable baffles and then the return into the hemisphere was measured by four photodiodes equally spaced around the perimeter of the hemisphere and electronically averaged into a figure of reflectance. At first there appeared to be errors in the measurements and it was discovered that the beam of light being sent to the coal surface was actually being somewhat spilled into the hemisphere before arriving at the coal surface. Increased baffling resulted in providing for the beam being completely independent of the hemispherical surface. Further it was found that Eastman Kodak gray paper, having been carefully calibrated at 18% reflectance, could be used as a calibration medium. When all of the refinements were made, it was found that the performance of the reflectometer was very accurate in its reproduction of the 18% reflectance. The reflectometer is shown in Figure 41.

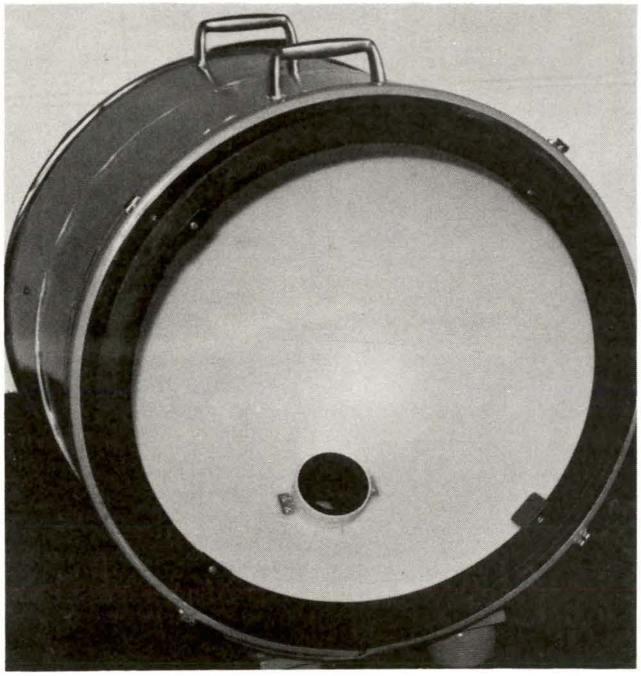
Since the light fixtures of current lighting systems on continuous miners and bolters are mounted low on the machines, the light in general is thrown upward across the face and ribs of the coal. Therefore in designing the reflectometer it was felt that the light should be thrown onto the coal surface at roughly a 45 degree upward angle from the horizontal. Therefore in the hemisphere the design was arranged so that a beam of light of approximately seven inches across and ten inches high was thrown upward at an angle of 45 degrees to the vertical surface. Of course, only the center of the patch of light would be at the 45 degrees and the rest of the patch would be at varying angles from above the horizontal to sixty degrees with the horizontal. Prof. Trotter, Canada, had also made a study of reflectivity in which he directed the light upward toward the coal surface at approximately 45 degrees with the horizontal.

However, in thinking of the use of the reflectometer in making measurements of coal surfaces it was thought wise to not only take a measurement with the beam directed upward, but also to make measurements with the beam turned horizontally to the right, to the left, and downward. Thus one could conclude that the averages of these four measurements would show an average of the total reflectance from the coal surface regardless of the angle of incidence. This was not done in the first two mines visited because this thought of the various angles of incidence was not fully conceived.

One must remember that in looking at the measurements made which are recorded later in this report, the large aperture of the collecting hemisphere would encompass not only the highlights or glossy reflections but would record the dull, non-glossy reflections and the actual reflectance of shadows. Truly the encompassing of a large aperture would be representative of what would occur in actual practice as the miners worked about their task of mining. If one had used only a small aperture, that aperture would have encompassed only the particular highlights and reflections that would have occurred at a spot on the mine surface. This was not what was wanted, but the overall reflectance encompassing all types of reflections was desired to properly assess the luminous environment of the workers.

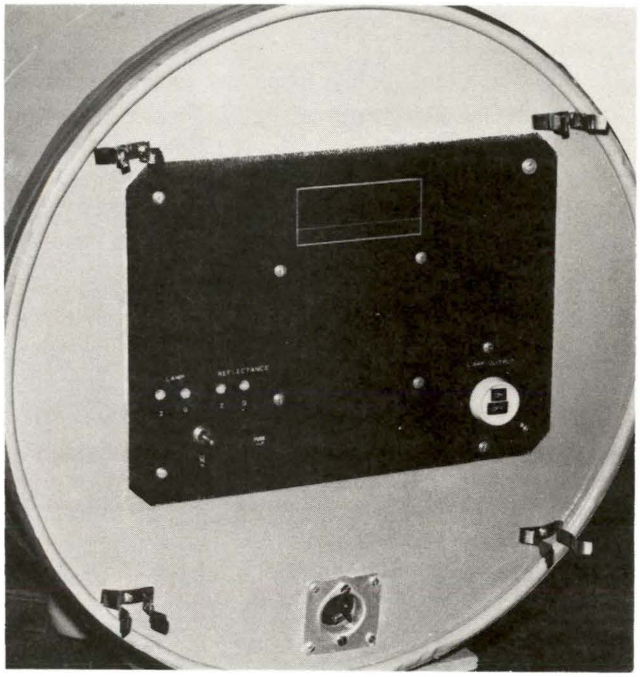
Range of measurements:

At the beginning of the experiments it was felt that probably different seams of coal would have different degrees of reflectivity, both from the viewpoint of the glossy reflections as well as the non glossy reflections. It was felt that some coal would be far more sparkling and



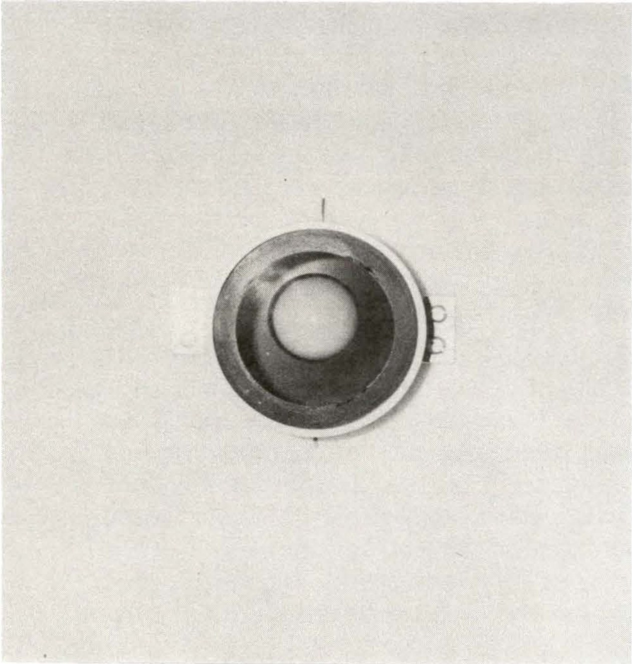
2286P16

A. Light Collecting Hemisphere



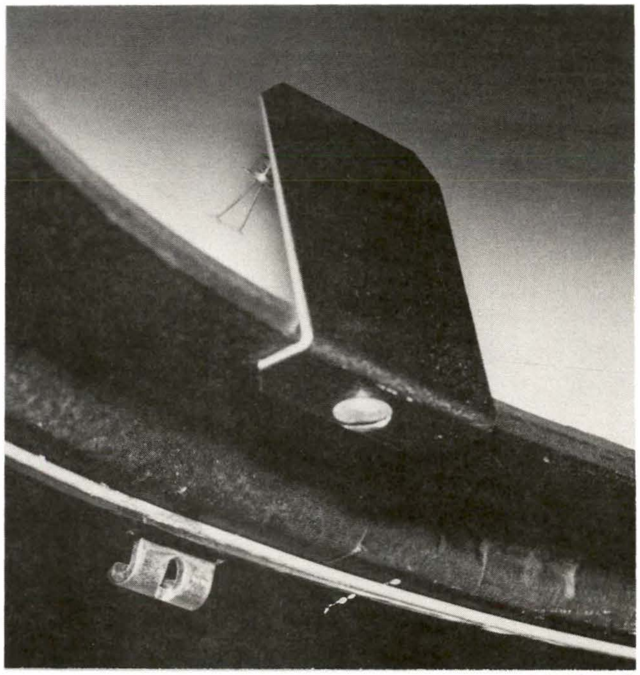
2286P14

B. Control Panel



2286P17

C. Light Source



2286P18

D. Light Measuring Photodiodes

Figure 41. Hemispherical Reflectometer

some would be much more dull in reflection. Therefore it was decided that a whole series of mines representing different types of seams of coal should be measured. Thus locations were selected which would sample the various seams. A total of eight mines were measured beginning in Alabama with three mines, then in Kentucky with one mine, and two in Illinois. Later measurements were made at two other locations, one in West Virginia and one in Virginia.

Results:

All of the measurements made in all of the mines are shown in Table 11, 12, and 13. Table 11 is for the measurements at the coal face for all of the mines. Table 12 includes the measurements of the ribs at all of the mines, and Table 13 includes measurements made on the roofs and the floors of all the mines. More measurements were made at some of the mines than at others. More measurements were made at the face in some mines than for the ribs, the roofs, or the floors. The measurements had to be made under the prevailing conditions. Sometimes those conditions represented only a small available area for making the measurements. At other times there was a limitation of time for making the measurements. By having more measurements for a particular mine than for other mines, this would tend to influence the average more than those mines in which only few measurements were able to be made. Thus if one wants to have values that are representative of the different seams, then one should take averages for the different mines and look at those in comparison with other mines having different seams. This plan was followed in Tables 14, 15, and 16. Thus, Table 14 represents the average values for the face found in each of the eight mines. Table 15 represents the average value obtained for the ribs in each mine. Table 16 represents the average values for the roofs and the floors in each one of the mines. Since averages are made of the total amount of measurements regardless of the mine location in Tables 11, 12, and 13, one notices that the averages of these values are not too greatly different from the averages of Tables 14, 15, and 16. Nevertheless, to be representative of the various seams as represented by the mines, then one should be using the values in Tables 14, 15, and 16.

As noted previously, each bell-shaped curve in Figure E-3 is the same logarithmic normal frequency distribution with a standard deviation, logarithmic sigma, equal ot .211. Standard statistical methods are available for calculating the distribution of a population of distributions such as the bell-shaped cures of Figure E-3. The basic idea is that there is a logarithmic normal frequency distribution with logarithmic sigma equal to .211 corresponding to each year of chronological age. The "combined" logarithmic sigma of a population of miners of differing ages is derivable from the proportions of miners in each age group and the mean values of the distributions, examples of which are indicated by the tick marks in Figure E-3. The mean of the combined distribution is also derivable from the mean values and the age proportions of the miner populations. In the present case, the mean value of the populational distribution of values of the disability glare constant, K, was found to equal 18.25 (log K = 1.261), and the logarithmic sigma was found to equal .216. These statistical parameters of the populational distribution of miner sensitivities to disability glare were used together with standard tables of the normal frequency distribution to derive the data presented in Table E-1. In this table, values of p_M represent proportions of the miner population. Values of K were obtained directly from the statistical parameters. These pairs of values of p_M and K have the following meaning. As many mines as p_M may be expected to have sensitivity to disability glare equal to or less than K. Using the Crouch and Vincent assessments of the level of disability glare to be expected in coal mines, we calculate the values of DGF corresponding to each value of K, following which we calculate the values of visibility loss defined previously. Here the meaning is that as many miners as p_M may be expected to have visibility losses equal to or less than the values paired with them.

Table E-1 may be used to quantify the general conclusions reached at the end of the last section of this report. For example, it may be stated that 99.86% of the miner population may be expected to have visibility loss equal to or less than 74.01%. (This quantifies the statement that "the upper limit of visibility loss is about 75%".) We may also state that only .13% of the miner population will have visibility loss equal to or less than 23.9%, and that half of the miner population, i.e. p_M = 50%, may be expected to have visibility loss equal to or less than 50.71%. Similarly, 50% will have visibility loss equal to or greater than 50.71%. (All these numbers quantify the statement that visibility losses will "cover nearly the entire range from 19.4 to 82.9%".)

Figure E-5 presents a graph of the values of p_M as a function of visibility loss contained in Table 1. Note that the S-shaped cumulative distribution curve is not a simple ogive (normal frequency function). However, the interested reader may use Figure E-5 to interpolate values of visibility loss corresponding to values of p_M not contained in Table E-1.

It was pointed out earlier, and is apparent from Figure E-4, that the sample of 59 miners studied by Crouch and Vincent included very few individuals whose age exceeded 50 years. Since the Crouch-Vincent sample

TABLE 11

FACE

	Upward	Right	Left	Down	Average
North River	5.2	5.1	--	--	5.2
Energy Corporation	5.5	5.5	--	5.5	5.5
Alabama					
All By Product	4.5	3.9	--	--	4.2
Gorgas No. 7	3.0	2.8	--	4.2	3.3
Alabama					
Jim Walters	4.7	3.0	--	4.3	4.0
Blue Creek	3.2	3.0	--	3.9	3.4
Alabama	3.0	3.3	--	3.2	3.2
Island Creek	4.0*	4.9*	4.5*	4.1*	4.4*
Hamilton #2	3.5*	3.5*	4.9*	3.8*	3.9*
Morganfield, KY					
AMAX	4.2	2.3	3.6	4.5	3.7
Wabash	3.6	2.3	3.4	4.4	3.4
Keansburg, IL	3.4	2.4	3.3	4.0	3.3
Near Mt. Carmel, IL	3.8	2.5	3.7	5.2	3.8
	3.5	2.7	3.5	5.2	3.7
	3.6	2.7	3.5	4.0	3.5
	3.4	2.3	3.4	4.5	3.4
	3.4	--	3.7	4.2	3.8
	3.5	--	--	4.2	3.9
	--	--	--	4.1	4.1
Old Ben	5.0*	4.0*	5.8*	4.3*	4.8*
Benton, IL	5.0*	4.1*	6.1*	4.9*	5.0*
	5.3*	4.3*	5.7*	4.7*	5.0*
	5.0*	3.7*	5.3*	4.6*	4.7*
	5.0*	5.1*	--	--	5.1*
	4.7*	4.8*	5.0*	4.5*	4.8*
	4.8*	4.8*	5.2*	4.7*	4.9*
	6.0*	5.2*	5.7*	4.7*	5.4*
	5.1*	5.0*	4.5*	4.4*	4.8*
Westmoreland	5.3	5.1	5.7	5.6	5.4
Hanson No. 3	6.0	5.8	5.8	6.6	6.1
Westmoreland, WVA					
Bishop Coal	4.7	4.7	6.2	4.5	5.0
Bleeders	4.3	4.2	5.4	3.6	4.4
Pocahontas, VA	4.2	4.2	4.5	3.9	4.2
AVERAGE	4.4	3.9	4.7	4.5	4.3

Average of 4 positions 4.4
Average of averages 4.3

*Value has been corrected by 1.068 from measured value because of escape of reflect[ed] light due to concavity of coal surface.

TABLE 12

RIBS

	Upward	Right	Left	Down	Average
North River	5.0	5.0	--	--	5.0
Energy Corporation	6.5	6.5	--	--	6.5
Alabama					
All By Product	4.5	3.9	--	--	4.2
Gorgas No. 7	3.0	2.8	--	4.2	3.3
Alabama					
Jim Walters	3.1	3.4	--	3.8	3.4
Blue Creek	3.0	2.9	--	3.8	3.2
Alabama	3.2	3.0	--	3.9	3.4
Island Creek	4.4	4.8	4.7	4.3	4.6
Hamilton #2	4.4	4.8	4.7	4.4	4.6
Morganfield, KY					
AMAX	2.6	2.6	3.0	2.8	2.8
Wabash	2.3	2.6	3.0	3.0	2.7
Keansburg, IL	2.6	2.5	2.7	2.7	2.6
Near Mt. Carmel, IL	3.6	2.5	4.5	2.9	3.4
	3.6	2.5	4.4	2.9	3.4
Old Ben	5.5	4.1	4.8	5.0	4.9
Benton, IL	5.2	4.2	4.2	3.8	4.4
	5.2	4.6	4.8	3.7	4.7
	4.7	4.8	4.4	3.7	4.7
Westmoreland	5.7	5.7	5.4	5.2	5.5
Hanson No. 3	5.0	4.8	4.5	4.2	4.6
Westmoreland, WVA					
Bishop Coal	5.1	4.9	3.7	4.1	4.5
Bleeders	4.3	4.2	4.4	4.0	4.2
Pocahontas, VA					
	4.2	4.0	4.2	3.8	4.1

Average of 4 positions 4.1
Average of Averages 4.1

TABLE 13

ROOFS

North River Energy Corp., AL	--	
All By Products, Gorgas No. 7 Mine, AL	11.0	
Jim Walters, Blue Creek Mine, AL	5.2	
	7.7	
Island Creek, Hamilton #2, KY	8.4	
	8.5	
	8.2	
	8.5	
AMAX, Wabash Mine, IL	8.4	
	8.5	
	8.2	
	8.5	
Old Ben Mine, IL	6.1	
	6.2	
	6.4	
	6.4	
Westmoreland, Hanson No. 3, WVA	6.9	
	6.7	
Bishop Coal, Bleeders, VA	10.1	
	10.9	
	7.9	AVERAGE

FLOORS

North River Energy Corp., AL	--	
All By Products, Gorgas No. 7 Mine, AL	--	
Jim Walters, Blue Creek Mine, AL	3.7	
Island Creek, Hamilton #2, KY	4.6	
	4.6	
AMAX, Wabash Mine, IL	4.6	
	4.6	
Old Ben Mine, IL	4.3	
	4.3	
Westmoreland, Hanson No. 3, WVA	4.2	
Bishop Coal, Bleeders, VA	2.8	
	4.2	AVERAGE

TABLE 14

FACE (by mines)

Upward	Right	Left	Downward	Average	
5.4	5.3	--	5.5	5.4	
3.8	3.4	--	4.2	3.8	
3.6	3.1	--	3.8	3.5	
3.7*	4.2*	4.7*	4.0*	4.2*	
3.6	2.5	3.5	4.4	3.5	
5.1*	4.6*	5.4*	4.6*	4.9*	
5.7	5.5	5.8	6.1	5.8	
4.4	4.4	5.4	4.0	4.6	
4.4	4.1	5.0	4.6	4.5	AVERAGES

TABLE 15

RIBS (by mines)

Upward	Right	Left	Downward	Average	
5.8	5.8	--	--	5.8	
3.8	3.4	--	4.2	3.8	
3.1	3.1	--	3.8	3.3	
4.4	4.8	4.7	4.4	4.6	
2.9	2.5	3.5	2.9	3.0	
5.2	4.4	4.6	4.1	4.6	
5.4	5.3	5.0	4.7	5.1	
4.7	4.6	4.1	4.1	4.4	
4.4	4.2	4.4	4.0	4.3	AVERAGE

*Value has been corrected by 1.068 from measured value because of escape of reflected light due to concavity of coal surface.

TABLE 16

ROOFS (by mines)

North River Energy Corp., AL	--
All By Products, Gorgas No 7 Mine. AL	11.0
Jim Walters, Blue Creek Mine, AL	6.5
Island Creek, Hamilton #2, KY	8.4
AMAX, Wabash Mine, IL (Mt. Carmel)	8.4
OLD Ben Mine, IL	6.3
Westmoreland, Hanson No. 3, WVA	6.8
Bishop Coal, Bleeders, VA	10.5
AVERAGE	8.3

FLOORS (by mines)

North River Energy Corp., AL	--
All By Products, Gorgas No. 7 Mine, AL	--
Jim Walters, Blue Creek Mine, AL	3.7
Island Creek, Hamilton #2, KY	4.6
AMAX, Wabash Mine, IL (Mt. Carmel)	4.6
Old Ben Mine, IL	4.3
Westmoreland, Hanson No. 3, WVA	4.2
Bishop Coal, Bleeders, VA	2.8
AVERAGE	4.0

In Tables 11 and 14, one sees the footnote that some of the values have been corrected due to the concavity of the surface of the face of the particular mine being measured. Apparently the diameter of the drum on which the bits were located on the continuous miner was small enough so as to leave a concave surface when the miner was withdrawn from the seam. The degree of concavity was measured as one inch depth at the middle of the diameter of the reflectometer. It was noted that light was escaping from these openings under the edge of the reflectometer and some measurements in the field indicated that there was a degree of error because some of the light flux was not being collected by the hemisphere for registering the reflectance. Since small differences in the measurements of the percentage reflectance would make significant difference in the return of light to the eye of the miner, it was decided to carefully measure the possible loss due to this concavity. A metal model of the concave surface was formed and measurements made by careful photometry as to the degree of this loss. Since a greater degree of accuracy can be obtained in measuring light surfaces instead of dark, measurements were made of the loss of reflectance using a white surface, a gray surface, and a black surface. A photograph of the curvature plate is shown in Figure 42. The average reflectance loss was 6.4%, or in other words, the hemisphere was collecting 93.6% of the flux that it would normally collect from a flat surface. Correction would therefore be 1.068 times the value obtained by the hemisphere at that point. The record of these measurements of the degree of error is shown in a communication from Mr. Paul R. Smester, Director of Metrology, Edison Price, New York. It is shown as Appendix G.

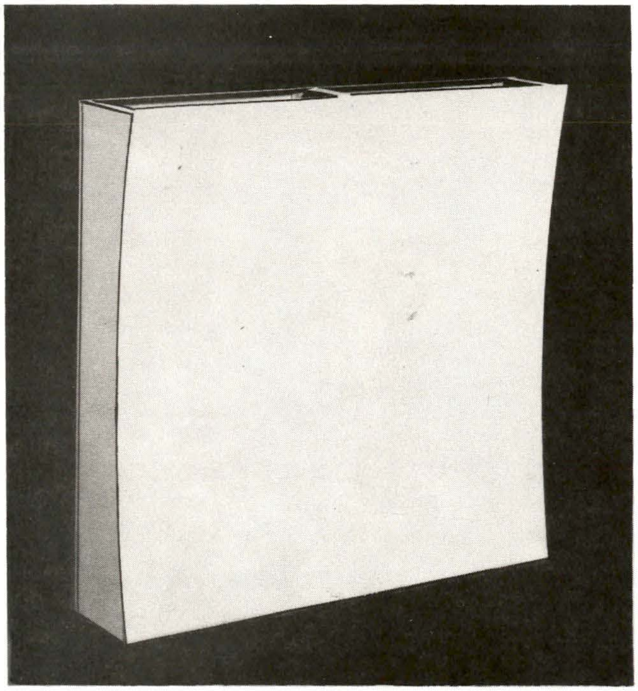


Figure 42. Model for Measuring Concavity Reflectance Loss

Discussion of Results

The averages as shown in Tables 11 and 12 are comparative to the averages shown in Tables 14 and 15. They hover around 4% reflectance varying from 4.0 to 4.5% reflectance. These averages appear to be in confirmation of the value currently assumed for reflectance of coal mine surfaces as shown in the MSHA regulations. However, the individual mines with their particular seams vary from 3.5 to 5.8, a 66% change. In fact, the ribs change from 3.3 to 5.8, a change of 75%.

If one would take only the upward beam reflectance as representative of lighting conditions in the currently lighted mines, the range would be from 3.0% reflectance to 6%. For the ribs it would be a range of 2.3% to 6.5%, a variation of 100% to 183%. Thus if one takes a low reflectance face and ribs, then one would get roughly only one-half or one-third as much light as a high reflectance face and ribs. The lighted environment of one mine would be so much lower than that of another mine having higher reflectance. From the illuminating engineering viewpoint the design for the low reflectance coal mine should be compensated in relation to the high reflectance mine.

One very significant feature showed up through the measurements of the various coal mine surfaces. That had to do with the roof reflectance. Table 16 shows an average of 8.3% which is roughly double that of the face averages and the rib averages. This unique fact may well lead to a method of lighting which would be superior to that of current lighting systems.

Additional Related Information

As the measurements proceeded, there was an inspiration to pick up samples of coal from the AMAX Wabash Mine near Mt. Carmel, Illinois and also from Old Ben Mine in Benton, Illinois. The writer thought it might be interesting to compare the measurements on pieces of coal with that of the overall surface as measured by the hemisphere. Of course the hemisphere would have both highlights and dull reflections and reflections from shadows. The reflections from pieces of coal would be highlights and diffuse components that were not represented in the highlights. Accordingly it was agreed that photometric measurements should be made on these pieces of coal as a comparison. The pieces were taken to the Electrical Testing Laboratories of Cortland, New York which had facilities such as the Baumgartner sphere reflectometer and the small sphere reflectometer. The results are shown in the Electrical Testing Laboratories' report, Appendix G. A piece of slate that was picked up along the way as representative of the roof of a mine was also measured. In these measurements it was discovered that coal apparently is composed of laminated layers. If one looks at the surface of the laminate, then one sees highly glossy reflections. If one looks at a cross section of the laminates composing a piece of coal, one sees that the reflections are much less and are more of the diffuse reflection character. This is illustrated in coal samples 3 and 4, in Fig. 43, from the Old Ben Mine.

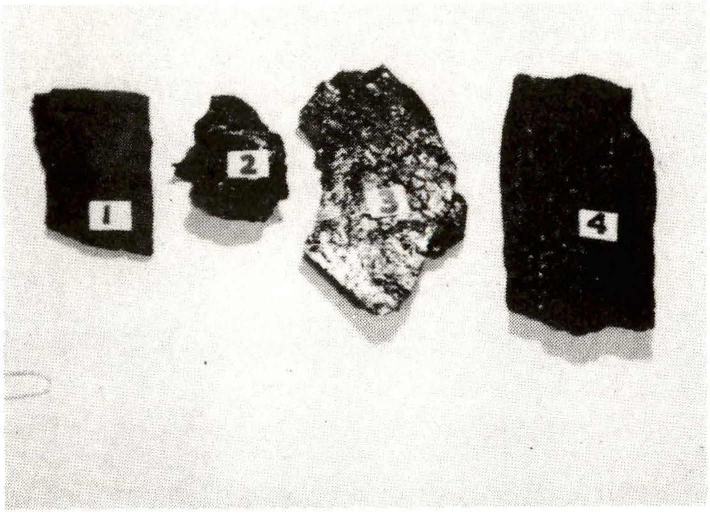


Figure 43. Mine Samples Used to Measure Surface Reflectivity in the Laboratory

1. Slate sample
2. Mount Carmel Coal Sample (AMAX Wabash)
3. Old Ben Coal Sample Measured Perpendicular to Laminate
4. Old Ben Coal Sample Measured Parallel to Laminate

Sample 3 shows the glossy reflections from the surface of the laminate and sample 4 indicates the reflection from a cross section of a series of laminates composing the piece of coal. One should note that the Baumgartner sphere reflectometer had a one inch diameter aperture and the small sphere reflectometer had a one-eighth inch diameter aperture. The one inch aperture allowed the inclusion of highlights and diffuse reflections while with the small sphere aperture one could measure just the highlights or the more diffuse components. One notices a very significant difference when the glossy reflections are measured by taking the measurements perpendicular to the laminate while the lower reflections are from the cross sections of the laminates measured parallel to the laminations. One also can note that the values of the highlights are higher when measured with the small sphere aperture as represented by 6.7 and 6.2.

The Mt. Carmel (AMAX Wabash) sample was much less glossy than the Old Ben samples and really represented the more diffuse type of reflections all the way around the sample of the coal.

Because of the considerable variation in glossiness vs. diffuse type of reflectance, it was postulated that the coal seams with high glossiness of the laminations would have the overall greater reflectance in the large hemisphere than those with less glossiness. Thus, the glossy reflections were superimposed upon the diffuse type of reflectance and gave higher values in those mines having highly specular laminations.

Further, the thought occurred to the writer while the tests were being made at the Electrical Testing Laboratories that the extreme of the non specular reflectance would be so-called "lamp black." The term "lamp black" came from the blackening of the chimneys of kerosene lamps in the early 1900's. The majority of homes were then lighted by kerosene lamps. If the wick was turned too high, the wick smoked and the smoke accumulated on the interior of the chimney near the top where the glass was the coolest. "Lamp black" has been used over the years as a form of paint, with the particles of the "lamp black" being placed in a vehicle for coating surfaces. Furthermore, it is still being used for mixing with cement to get varying degrees of gray or black cement. This material was found at a hardware and sent to Electrical Testing Laboratories for a few additional measurements. We have now received a report from ETL that the reflectance of "lamp black," or carbon black as it is sometimes called, was measured at a value of 2.3%.

Thus, it would appear that the basic reflectance of coal is 2.3% and that the additional higher reflectances are caused by glossiness of the coal surface which superimposes a mirror-type reflection on the basic reflection factor of 2.3%. Perhaps a simplistic supposition would be that due to pressure of the overburden, a glaze of glossiness has been formed on the laminations or joints which causes a higher reflectivity than the basic material. Therefore, one would expect that in some mines the pressure has not been so great, and, therefore, there is less glossiness and a greater degree of the basic reflectance being exposed. This would appear to be justified by the measurements of the coal samples taken from Old Ben Mine as compared with those taken from Mt. Carmel (AMEX Wabash) Mine. Without an analysis of the basic properties of the coal itself, (the chemistry of the material in the coal might make a contribution to the glossiness as well), it would appear that pressure and possibly chemistry would account for the degree of glossiness superimposed upon the basic carbon content of the coal. On the assumption of this reasoning, we would conclude that anthracite would be much more glossy because of being more purely carbon and having been formed by greater pressure on the organic material.

Conclusion and Recommendations

From all the measurements made of both face and rib in the eight different mines with the four orinentations of the reflectometer, the reflectance measurements of coal surfaces varied from 2.3% to 6.6%. If one considers only the upward beam positions of the reflectometer, the measurements of both face and rib of the eight mines varied from 2.3% to 6.5%. If one looks at the measurements for all positions of the reflectometer, the averages of all of the measurements at the eight mines varied from 2.6% to 6.5%. These values are shown in the average column for both face and rib in Tables 11 and 12.

If one looks at the averages of the measurements by mines of the various positions of the reflectometer for both face and rib, one sees the variations from 2.5% to 5.8%. If one takes only the upward position of the beam, then the variation is from 2.9% to 5.8%. If the averages are considered in Tables 14 and 15 (by mines), then the variation for all positions is from 3% to 5.8%.

In Tables 14 and 15, if one takes only the upward components one can draw a frequency curve for the averages of the individual mines in accordance with Figure 44. While this curve is representative of the values involved, one should not lose sight of the fact that there are not many figures involved. Eight mines may not be representative of all of the seams across North America or even representative of a given seam in various locations. As we discussed above, there might be many more samples of coal that are representative of the lower reflectance because of the less glossiness and greater proportion of the pure carbon being exposed to view.

Another interesting graph is that of Figure 45 in which a frequency curve is drawn for all of the measurements by mines taken in all of the four positions of the reflectometer. Here again, the same comment applies regarding the meagerness of samples of low or high reflectance, which may not be representative of all of the reflectances of mines in the country.

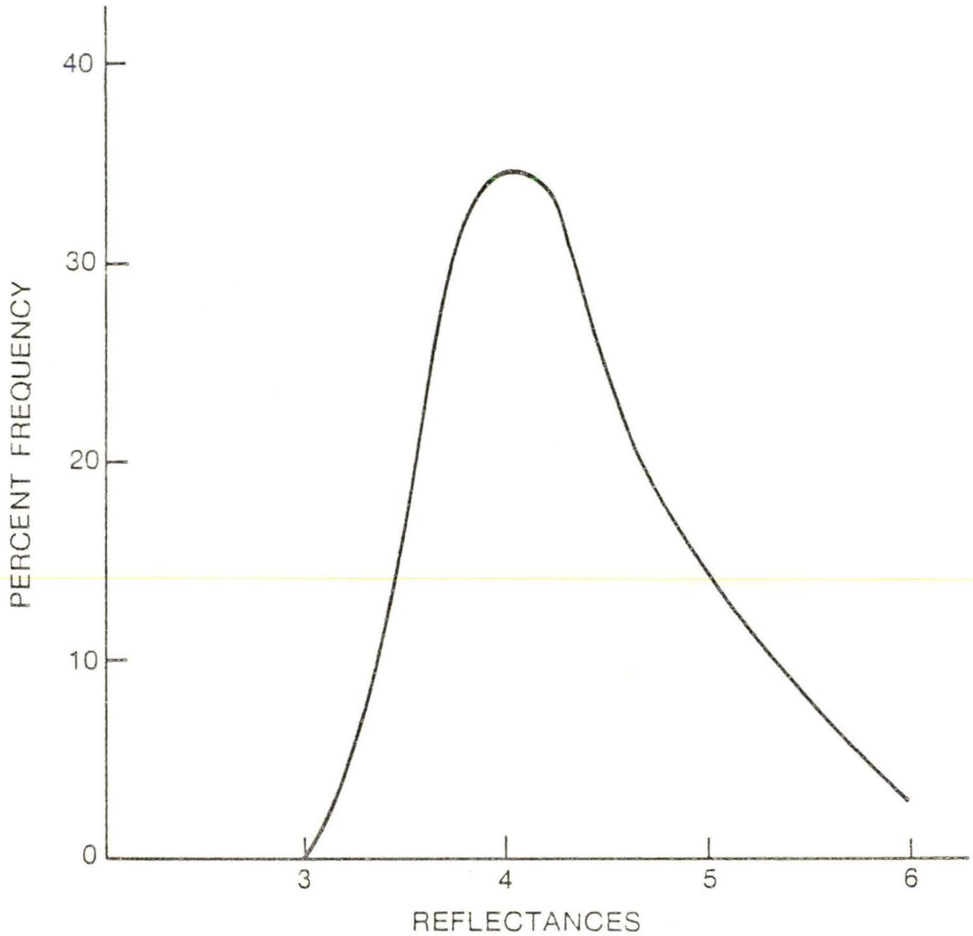


Figure 44. Frequency of Upward Reflectances (By Mines) for Face and Rib

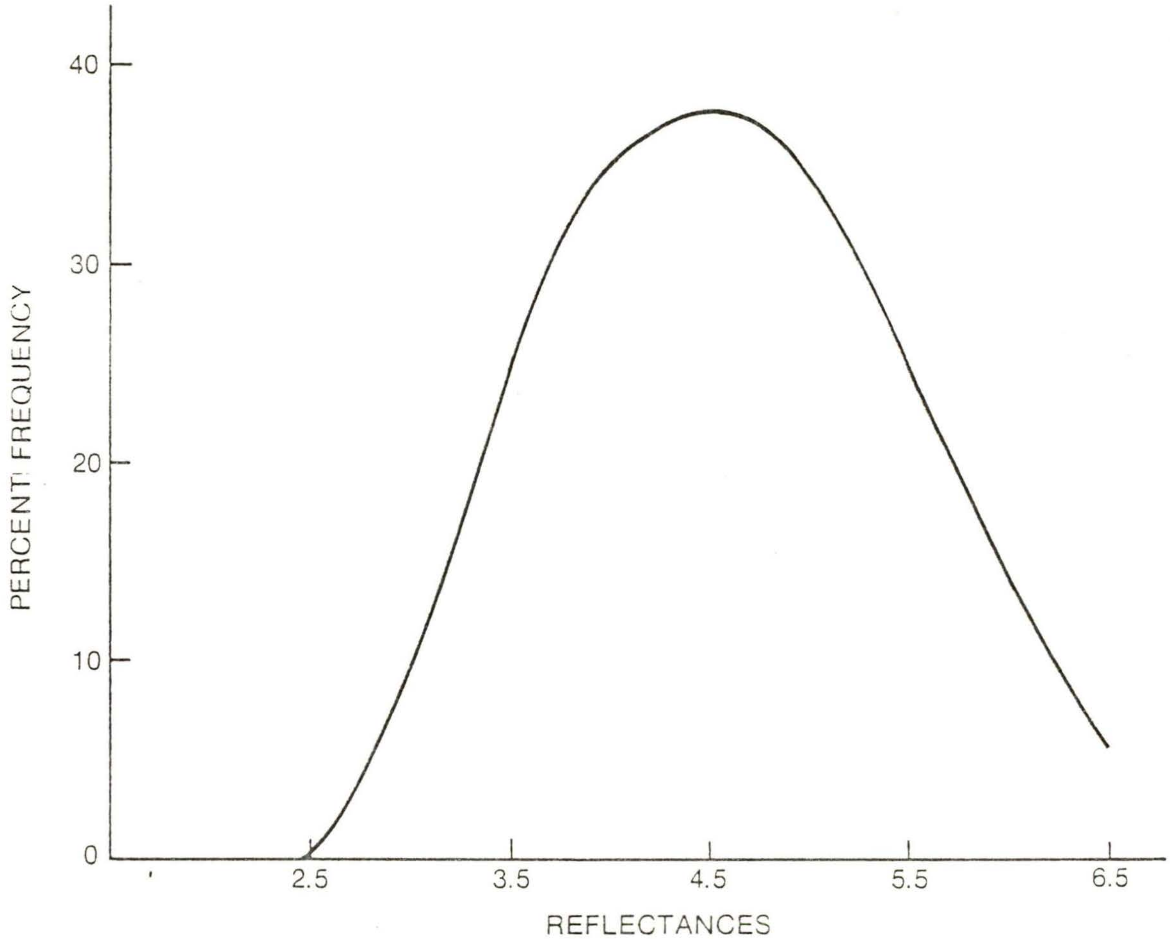


Figure 45. Frequency of All Positional Reflectances (By Mines) for Face and Rib

The Significance of Reflectances for the Light Environment

In the introduction it was pointed out the very vital significance of the illumination of the surroundings for optimum visibility and maximum comfort. There needs to be a balance between the luminance of the surroundings and the luminance of the task or the details to be seen. There needs to be an elimination of both disability glare and discomfort glare. In order to eliminate transitional adaptation losses of sensitivity, the luminance of the surroundings needs to be in appropriate proportion to the luminance of the task or the details to be seen. These conditions have been met for interior lighting for many years. It may not be possible to attain this goal for mine lighting, but one should strive within the realm of good economics to approach the conditions as nearly as possible.

A very significant feature has appeared in the measurements that now may point the way to a better visual environment. This has to do with the reflectance of the roofs of the mines. We note that in the seven mines the average was 8.3%. This is double the average for the measurements of the faces and ribs of all of the mines. It is interesting to note that the proportional reflectance for the mine environment is approximately the same as that recommended for the lighting of interiors. In interiors the recommended reflectances[5] of the ceiling are 70 to 90% with an average of 80%; the walls are 40-60% with an average of 50%; and the floors are from 30-50% with an average of 40%. Now if we look at the proportional coal reflectances the ceiling has approximately 8%; the walls have an average of 4.4%; and the floors have an average of 4%.

As early as the 1920's, illuminating engineers had learned by experience that in order to overcome the glare of overly bright light sources the very best possible quality of lighting was obtained from indirect lighting where the light was directed from the lamp to the ceiling and diffused downward throughout the room.

The light was spread over the whole ceiling and therefore there was no glaring high brightness to shock the worker in the office as he looked up from his work and looked around the room. With the proper interior reflectances of ceiling walls and floor there were relatively small differences of change of brightness so that losses of sensitivity due to transient adaptation were not significant. There was a minimum of shadow due to the large ceiling light source (reflected light). Therefore detail was well seen in every part of the room. Further the ceiling, which had become the light source being the brightest part of the room, was above the normal zone of seeing and therefore not a source of visual disturbance due to glare or transient adaptation. Of course if carried to extreme, indirect lighting of poor distribution across the ceiling causing "hot spots" would become a glare source itself. If too much light is sent to the ceiling it becomes an overly bright part of the room and thus a potential glare source and a source of distraction. In summary therefore the answer is appropriate design of the lighting system.

Experience with indirect lighting indicated two drawbacks -- maintenance and apparent inefficient use of light. In the era of indirect lighting in the 1930's and early 1940's the luminaires were open bowls reflecting light to the ceiling. These bowls collected dirt and there was heavy depreciation. The advent of air conditioning greatly ameliorated this loss of light. Then when fluorescent came in the luminaires became area sources like parts of the ceiling and gave the diffusion and limited brightness toward the eyes formerly obtained from indirect lighting.

Indirect lighting has lower efficiency in utilization of light. Sending light to the ceiling and back involves greater losses.

How does all this apply to underground mines? If current practice of interior lighting with fluorescent luminaires spread over the "roof" could be carried out this would be the preferable system. This, with proper glare control (shielding), would give the appropriate diffusion and light up the whole environment with the most efficient use of light. From considerations to date this course appears impractical. The need for explosion- proof luminaires would limit the flexibility of design for glare control at a reasonable cost. Furthermore a general explosion-proof mining system together with the luminaires would present costs that would appear prohibitive in comparison with the current lighting systems mounted on the machines. It appears therefore that in the foreseeable future lighting on and from the machines will continue.

Lights on the machines are located in the very zone of maximum visual activity. Any source in this zone emitting light toward the eyes of the miners is a hazard both from the viewpoint of glare and transient adaptation. Every time a miner's glance hits a light, even though it be limited in brightness, he has a serious loss of sensitivity (visibility) as he looks away to the low luminance of the surrounding environment. This is due to transient adaptation.

There is a zone of emission from a machine-mounted luminaire which would miss the visual zone of activity and light the roof with its higher reflection factor for indirect lighting.

Indirect lighting in the 30's and 40's was done with incandescent lamps with 20 lumens of light per watt. Now there are high intensity discharge lamps of 80 to 120 lumens per watt to provide lots of lumens to overcome the low reflectances of the mine surfaces. Calculations have been made on the basis of 4% reflectance surface and it appears that one 400 watt high pressure sodium indirect luminaire would produce enough light including depreciation to assure the current regulation of .06 foot-lamberts on the coal surfaces. Of course for better distribution of light in the environment, this might be directed into two 250 watt luminaires. From the viewpoint of maintenance, an explosion-proof luminaire can be designed with dust and dust shedding features. In order to give a feeling of how such a low reflectance area might appear, a rough set-up was made in a photometric test area of 4% reflectance surfaces. The result is shown in Figure 46.

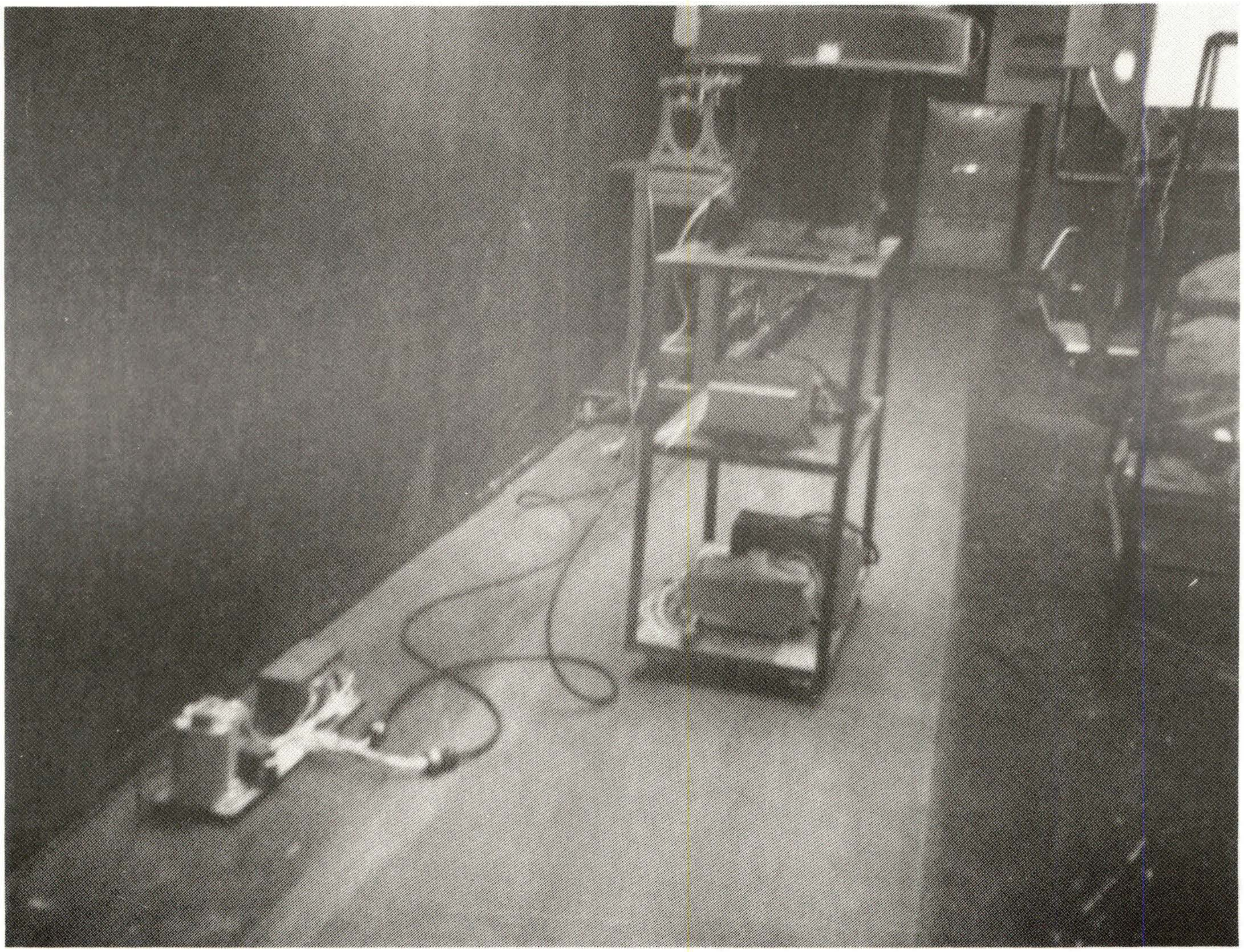


Figure 46. Light Distribution in a Low Reflectance (4%) Room Using Indirect Lighting

BIBLIOGRAPHY

1. A. König, Die Abhängigkeit der Sehschärfe von der Beleuchtungs-intensität, Gesammelte Abhand. zur Physiol. Optik, 1903.

2. R. J. Lythoe, "Measurement of Visual Acuity", Special Report No. 173, Med. Research Council, H.M. Stationery Office, London 1932.

3. L. L. Holladay, "The Fundamentals of Glare and Visibility", Four. Optical Society, April 1926.

4. R. M. Boynton and Norma D. Miller, "Visual Performance under Conditions of Transient Adaptation", Illuminating Engineering LVIII, August 1963.

   R. M. Boynton, Edward J. Rinalducci and Charles Sternheim, "Visibility Losses Produced by Transient Adaptational Changes in the Range of 0.4 to 4000 Footlamberts", IE LXIV, April 1969.

   R. M. Boynton, T. R. Corwin and Charles Sternheim, "Visibility Losses Produced by Flash Adaptation," IE LXV, April 1970.

5. IES Lighting Handbook, 1981 Application Volume, Figs. 5-5 and 6-3.

APPENDIX G

COAL REFLECTANCE DATA DETERMINED BY LABORATORY MEASUREMENTS ON COAL SAMPLES

409 EAST 60TH STREET, NEW YORK, N. Y. 10022 • TEMPLETON 8 - 5212

EDISON PRICE LIGHTING
INCORPORATED

9 September 1982

Mr. Cash Crouch
95-15 238th Street
Bellrose, NY 11426

Dear Mr. Crouch:

We completed the measurements to determine the reflectance loss when a standard reflecting surface is placed in a concave surface having a radius of curvature of 61 inches resulting in a separation of 1 inch between the contact rim of the mine reflectance photometer and the trough of the curvature plate.

The reflectance loss was determined by measuring the reflectances of white, high reflectivity, gray, medium reflectivity and black, low reflectivity surfaces both on a flat surface as well as on the curved plate.

The average reflectance loss measured due to the curvature of the plate is 6.4%. A photograph of the curved plate form to be used for these measurements is enclosed.

Very truly yours,

EDISON PRICE INCORPORATED

P. R. Smester

Paul R. Smester, Director of Metrology

Encl.

REPORT

ETL TESTING LABORATORIES, INC.

INDUSTRIAL PARK CORTLAND, NEW YORK 13045

Order No. 23673-L Date November 30, 1982

REPORT NO. 458070

TOTAL AND SPECULAR REFLECTANCE
MEASUREMENTS OF COAL AND SLATE SAMPLES

RENDERED TO

C. L. CROUCH

DATA REQUESTED

Total reflectance measurements and specular reflectance measurements of one slate sample and several coal samples were requested by the client.

AUTHORIZATION

This report was authorized by your personal application.

MATERIAL SUBMITTED

One slate sample and three coal samples were submitted for test purposes. One coal sample was designated Mount Carmel. One coal sample was designated Old Ben Coal with the readings taken parallel to laminate. One coal sample was designated Old Ben Coal with the readings taken perpendicular to laminate.

TESTS AND TEST METHODS

Total reflectance measurements on the samples were obtained with a Baumgartner sphere reflectometer and a small sphere reflectometer. The Baumgartner sphere reflectometer has a one inch diameter aperture. The small sphere reflectometer has a 1/8 inch diameter aperture. The sphere reflectometers were calibrated against a Kodak gray paper with an 18 percent reflectance. A series of measurements on each sample were conducted and the range recorded.

ETL
SINCE 1896

TESTS AND TEST METHODS (cont'd)

Specular reflectance measurements on the samples were obtained with a Photovolt Glossmeter. The measurements were first obtained when a 45 degree attachment was connected to the Glossmeter. Another series of measurements were obtained when a 60 degree attachment was connected to the Glossmeter. The calibration of the Glossmeter was traceable to a NBS Gloss Standard. The range of readings on each sample was recorded.

RESULTS OF TESTS

Percent Total Reflectance

Sample Designation	Measurements Made on Baumgartner Sphere Reflectometer	Measurements Made on Small Sphere Reflectometer
Slate Sample	5.5 to 7.0	5.2 to 5.6
Mount Carmel Coal Sample*	4.3 to 4.4	4.6
Old Ben Coal Sample Measured Perpendicular to Laminate	5.8 to 6.2	5.2 to 6.7
Old Ben Coal Sample Measured Parallel to Laminate	4.9 to 5.4	4.8 to 6.2

The Mount Carmel Coal had a single point of high reflectivity of 5.3 percent. The small reflectometer was used to measure the point.

GLOSSMETER MEASUREMENTS

The Glossmeter measurement of the slate sample was 2 percent when the 45 degree attachment was used. The Glossmeter measurements of the coal samples were in the range of 6 to 14 percent. There were points of high gloss (20 percent) on the coal samples.

Measurements taken with the 60 degrees attachments were slightly lower than the measurements taken with the 45 degree attachment.

Report Approved by:

Gordon Bonvallet

Gordon Bonvallet, Manager
Photometric Division

Report Prepared by:

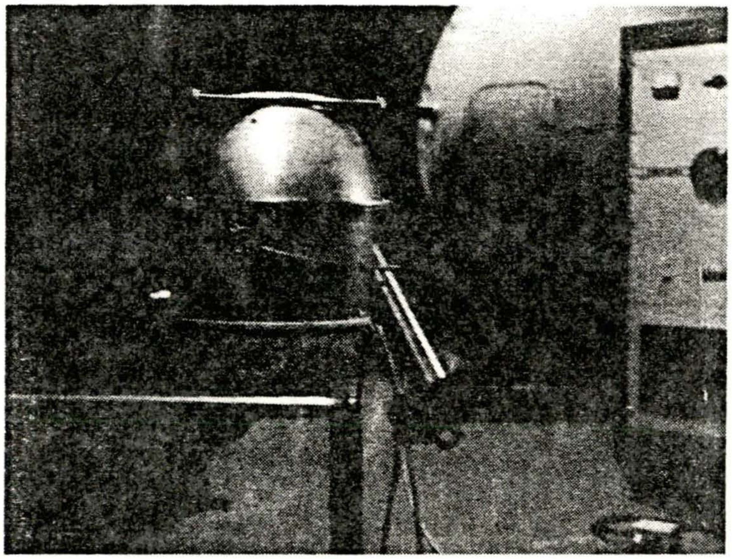
David Ellis

David Ellis

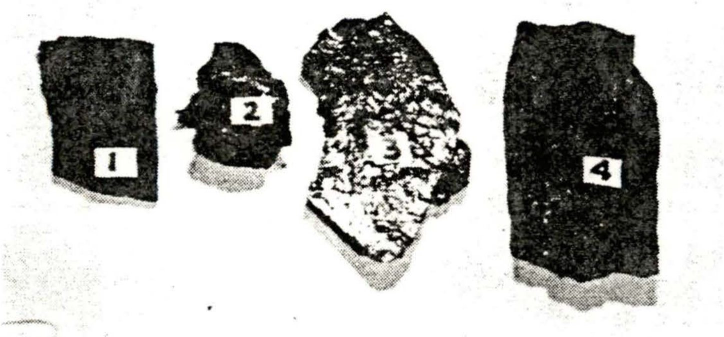
Copied by: DE/mm
Checked by: ed

* AMAX Wabash

TESTED FOR C. L. CROUCH



Baumgartner Sphere Reflectometer



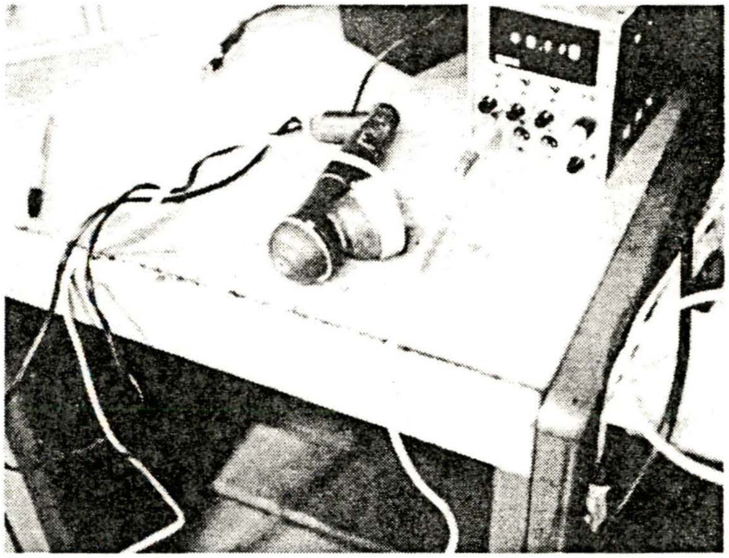
1. Slate Sample
2. Mount Carmel Coal Sample (AMAX Wabash)
3. Old Ben Coal Sample Measured Perpendicular to Laminate
4. Old Ben Coal Sample Measured Parallel to Laminate

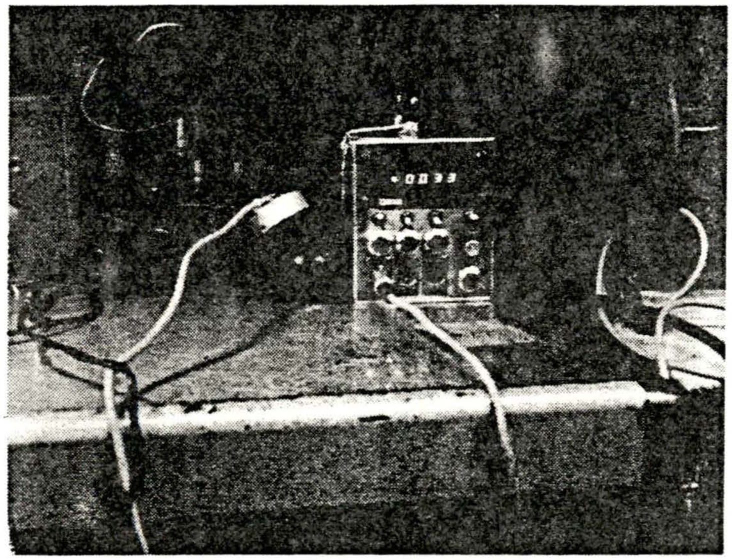
ETL Testing Laboratories, Inc.

Report No. 458070
Order No. 23673-L
Plate No. 88676

TESTED FOR C. L. CROUCH

Small Sphere Reflectometers





ETL Testing Laboratories, Inc.

Report No. 458070
Order No. 23673-L
Plate No. 88677

ETL Testing Laboratories, Inc.

Industrial Park Cortland, New York 13045 Telephone 607-753-6711 TWX 510 252 0792

Testing Inspection Certification

Acoustical • Air Conditioning & Refrigeration • Chemical • Electrical • Mechanical • Photometric

Letter Report No. 458378

January 14, 1983

Order No. 23673-L

Mr. C. L. Crouch, P.E.
95-15 238th Street
Floral Park, NY 11001

Dear Mr. Crouch:

Reflectance measurements were made on the sample of lamp black submitted by you. The material was placed on a flat black piece of cardboard and the lamp black piled to an 1/8" depth. A small integrating sphere reflectometer was used for the measurements.

The average reflectance of the lamp black was 2.3%. The reflectometer was standardized with a Kodak Grey material with a reflectance of 18 ± 2%.

On examination of the lamp black material with a microscope, it was apparent there are many very small particles of white substance in the lamp black. This would raise the reflectance value slightly.

Very truly yours,

Gordon Bonvallet, Manager
Photometric Division

GB/mm