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DEVELOPMENT OF RECOMMENDED STANDARDS FOR OCCUPATIONAL EYE AND FACE PROTECTIVE DEVICES

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FINAL REPORT
NIOSH Contract HSM-99-73-17
SwRI Project 02-3703

Prepared for
National Institute for Occupational Safety and Health
Health Services and Mental Health Administration
5600 Fishers Lane
Rockville, Maryland 20852

October 31, 1974

Approved:

H. Norman Abramson
Vice President
Engineering Sciences

BIBLIOGRAPHIC DATA SHEET	1. Report No. NIOSH-HSM-99-73-17	2.	3. Recipient's Accession No. PB 216 [illegible]
4. Title and Subtitle *DEVELOPMENT OF RECOMMENDED STANDARDS FOR OCCUPATIONAL EYE AND FACE PROTECTIVE DEVICES*			5. Report Date *Oct. 31, 1974* 6.
7. Author(s) *Tom D. Dunham, W. J. Astleford, R. L. Bessey, J. J. Kulesz, and M. A. Sissung*			8. Performing Organization Rept. No.
9. Performing Organization Name and Address *Southwest Research Institute* *8500 Culebra Road* *San Antonio, Texas 78284*			10. Project/Task/Work Unit No. *SwRI Project 02-3703* 11. Contract/Grant No. *HSM-99-73-17*
12. Sponsoring Organization Name and Address *National Institute for Occupational Safety and Health* *4676 Columbia Parkway* *Cincinnati, Ohio 45226*			13. Type of Report & Period Covered *Final* 14.

15. Supplementary Notes

16. Abstracts *This is a final report covering work performed to establish recommended standards for occupational eye and face protective devices. The report covers the following areas: the determination of eye and face protection needs; the development of eye and face protection needs versus devices matrix; a study and evaluation of eye injuries involving contact lenses; a search and evaluation of eye threshold limit values; an evaluation of plastic and glass lens performance; an evaluation of current standards and specifications derivations; a study of lens distortion and/or prism effects; the identification and development of applicable eye and face protective attributes; and the development of a recommended standard for occupational and educational eye and face protection.*

17. Key Words and Document Analysis. 17a. Descriptors

Industrial hygiene
Accident prevention
Protectors
Performance evaluation
Safety engineering
Materials testing
Performance standards
Performance tests
Protective mask facepieces

17b. Identifiers/Open-Ended Terms

Personal protective equipment
Safety equipment
Safety glasses

17c. COSATI Field/Group *06/J*

18. Availability Statement	19. Security Class (This Report)	22. Price
Release unlimited	UNCLASSIFIED	PC A 20 / MF A01
	20. Security Class (This Page) UNCLASSIFIED	

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to those individuals who were instrumental in the completion of this project. Mr. Alfonso C. Garcia contributed much of his time and effort to the numerous experiments. Mr. Victor J. Hernandez prepared the many illustrations. Mrs. Kathy L. Cate, Mrs. Catherine Cudd, Mrs. Catherine Dean, Miss Aida A. Guevara, and Mrs. Adeline Raeke typed the manuscript.

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INTRODUCTION

This final report for Department of Health, Education and Welfare (HEW), National Institute of Occupational Safety and Health (NIOSH), Contract HSM-99-73-17, covers the period June 1973 through October 1974. Work during this period has been performed on the following Tasks. Each Task begins a new section in this report.

TASK 1 - DETERMINATION OF EYE AND FACE PROTECTION NEEDS

TASK 2 - DEVELOPMENT OF EYE AND FACE PROTECTION NEEDS VERSUS DEVICES MATRIX

TASK 3 - STUDY AND EVALUATION OF EYE INJURIES INVOLVING CONTACT LENSES

TASK 4 - SEARCH AND EVALUATION OF EYE THRESHOLD LIMIT VALUES

TASK 5 - EVALUATION OF PLASTIC AND GLASS LENS PERFORMANCE

TASK 6 - EVALUATION OF CURRENT STANDARDS AND SPECIFICATIONS DERIVATIONS

TASK 7 - STUDY OF LENS DISTORTION AND/OR PRISM EFFECTS

TASK 8 - IDENTIFICATION AND DEVELOPMENT OF APPLICABLE EYE AND FACE PROTECTIVE ATTRIBUTES

TASK 9 - DEVELOPMENT OF A RECOMMENDED STANDARD FOR OCCUPATIONAL AND EDUCATIONAL EYE AND FACE PROTECTION

Background and Purpose of Contract

The Occupational Safety and Health Act of 1970 gives the Secretary of Labor the authority to promulgate standards relating to occupational safety and health on the basis of information provided him by concerned and qualified organizations or individuals. The National Institute for Occupational Safety and Health (NIOSH) is authorized (Section 22.c of the Act) to develop and establish recommended occupational safety and health standards, and the Director of NIOSH (Section 22.d of the Act) is empowered to conduct research and experimental programs necessary for the development of criteria for the improvement of safety and health standards of the American workers.

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Of all the major body organs prone to occupational injuries, the eye is perhaps the most vulnerable; consequently, protection of the industrial workers and other personnel against eye and face injuries is unquestionably one of the major areas of importance in occupational safety and health. Although the eye does have some natural defenses, it has none to compare with the built-in cleaning mechanism of the lungs, the recuperative power of the ear, or the healing properties of the skin. That is why an eye injury may ultimately be described as the most traumatic loss to the human body.

What is involved in recognizing the critical need for effective eye protection is the unique ability of the human eye to translate radiant energy into nerve impulses which are transferred to the brain through the nerve fibers to form the visual field. That ability is indeed one of the most prized possessions of mankind, and, therefore, every conceivable effort should be made to protect it through the use of proper protective devices wherever injury may occur.

The rapid industrial growth in this country has brought about many new operations requiring a high degree of visual acuity in industry. Along with them have come other hazards from injurious radiation, ionization and flying particles capable of blinding or impairing the worker's eyesight. In view of numerous industrial eye injuries occurring every working day in the United States, many of them resulting in disabling injuries and of which at least some of the injuries inflict a partial or total loss of eyesight, the need for providing proper eye protection is not only warranted, but is highly imperative. Eye protection is important because it is the most necessary sensory channel since it is sight that the individual depends on for gathering most of the information about his environment.

It was the purpose of the research effort under this contract to establish recommended standards for occupational eye and face protective devices. Those recommended standards have been prepared in the form of the following:

- User Standard
- Performance Standard
- Testing Standard.

TASK 1 - DETERMINATION OF EYE AND FACE PROTECTION NEEDS

In accordance with the Scope of Work and the SwRI Technical Proposal, the following items have been performed under this task:

(1) Review of Technical Literature.

(2) The Experience and Data of Manufacturers of Eye and Face Protective Devices (both lenses and frames).

(3) The Experience, Records and Practices of Employers and Employees Working in Environments Hazardous to the Eye and Face.

(4) A Study and Analysis of Eye and Face Accident Statistics.

(5) Human Factor Studies of Eye and Face Protective Devices, Their Proper Fit, Their Degree of Acceptance by Workers, the Pressure Points, Their Proper Weight Distribution, and Degree of Comfort Afforded to the Wearer.

(6) Results of contact with professional and trade associations to help determine the needs for eye and face protection.

These items under Task 1 are discussed sequentially.

(1) Review of Technical Literature

A thorough literature review was conducted through the use of the MEDLINE computer search, the DDC computer search, and a manual reference document search. This literature review has resulted in over 100 pertinent references on hand which are important to the background of this project.

The following access words and phrases were obtained from the Medlar's Thesaurus:

- Eye injuries
- Eye burns
- Explode A9.44 (Eye)
- Infrared rays
- Ultraviolet rays

- Lasers
- Industrial medicine
- Radiation effects
- Radiation injuries
- Radiation injuries, experimental
- Protective devices

Prior to conducting the Medlar's search at the University of Texas Medical School, San Antonio, the following list of key words had been tabulated:

- Welding - Retinal Burns
- Radiation - Injury Threshold
- Welding Arcs - Radiation Spectrum
- Eye Damage - Ultraviolet, Infrared, Visible Radiation (Electromagnetic Radiation)
- Welding Arcs - Spectral Radiance (Pathology)
- Ultraviolet Radiation - Conjunctivitis, Keratitis
- Heat Cataracts
- Rhodopsin - Regeneration

Key Words for Medlar's

Characteristics of Eye Damages as a Result of E. M. Radiation

- Arc Flash Conjunctivitis
- Eye Flash
- Eclipse Blindness
- Photokeratitis (Ultraviolet)
- Welding of Retinal Retachments
- Radiant Energy on Eye - Pathology
- Visual Impairment by High Intensity Light
- Spectral Transmission of Eye
- Effect of Solar Radiation on Eye
- Flashburns - Retinal
- Absorption of EM (Ultraviolet, Infrared, Visible) by Cornea, Lens, Retinal, Aqueous or Vitreous Humor
- Absorption of EM Radiation by Refractive Media
- Transmission of Ocular Media
- Light Hazard to Eye
- Absorption of Thermal Energy by Eye
- Ultraviolet Action Spectrum - Ophthalmic
- Loss of Light Energy in Eye
- Nuclear Detonations E&M Radiation Hazard to Eye
- Eclipse Burns in Eye
- Solar Retinopathy

- Flashblindness
- Ocular Spectral Characteristics
- Contact Lens Transmission Characteristics

Protection of Eye from Mechanical Damage

- Safety Glasses - Efficacy of Material (glass, plastic, etc.)
- Mechanical Damage to Eye with Contact Lenses
- Face Protection from Injury
- Laser Hazards

Characteristics of Eye and Face Protective Devices

- Visual Impairment, Wearing Safety Goggles, Glasses, etc.

Human Engineering - Use of Eye and Face Protective Devices by Personnel

- Psychological Factors in Wearing Eye Protective Devices
- Discomfort in Wearing Eye and Face Protective Devices
- Risk Taking Wearing Eye and Face Protective Devices

The DDC search had been performed using similar key words and phrases.

The bibliography for this project is included in Appendix A

(2) The Experience and Data of Manufacturers of Eye and Face Protective Devices (both lenses and frames)

Eye and face protective device manufacturers have been contacted in person, by telephone or by letter, to obtain their experience and data in relationship to the protection of the eye and face. An inquiry letter was sent to all the companies listed in Table 1-1. As a result of this letter, 28 responses and numerous samples (denoted by an asterisk) were received from the following companies:

- Abrasive Action, Inc.
- Airco Welding Products, a Division of Airco, Inc.
- American Allsafe Company, Inc.*

TABLE 1-1. EYE AND FACE PROTECTIVE DEVICES COMPANIES

Airco Welding Products, Div. of Air Reduction Co., Inc.

American Allsafe Co., Inc.

American Industrial Safety Equipment Co.

American Optical Corp., Safety Products Div.

American Safety Equipment Corp.

American Ultraviolet Co.

Analytic Plastics

Apex Safety Products Div.

Apex Specialties Co.

Applied Instruments, Inc.

Bachmann Bros., Inc.

Bausch & Lomb, Inc.

Beebe Rubber Co.

Black & Decker Co.

Arthur Blank & Co., Inc.

H. L. Bouton Co., Inc

Bracke-Seib X-Ray Co., Inc.

Buck X-Ograph Co.

E. D. Bullard Co., Inc.

Burdett Oxygen Co. of Cleveland, Inc.

George F. Cake Company

Calolympic Glove Co.

Carhoff Co.

Cesco Safety Products, Inc.

Compass Instrument & Optical Co., Inc.

H. S. Cover

W. S. Darley & Co.

Dickson Safety Products

Dockson Corporation

Dunn Products, Inc.

Eastern Equipment Co., Inc.

Eastern Molding Co.

Eastern Safety Equipment Co. Inc.

Edroy Products Co., Inc.

Enco Mfg. Co.

Essay Mfg. Co.

Estwing Mfg. Co.

E-Z Products Co.

Fend-All Co.

Fibre-Metal Products Co.

Flints Products Co.

Flood Safety Products Co.

Foster Grant Co., Inc.

General Hardware Mfg. Co., Inc.

General Scientific Equipment Co.

Gentex Corp.

Gilman Marty, Inc.

Glendale Optical Co., Inc.

Guardian Safety Equip. Co.

TABLE 1-1. EYE AND FACE PROTECTIVE DEVICES COMPANIES (Cont'd)

Halsey-Radelin

Handy Button Machine Co.

Harris Calorific Sales, Inc.

Hazard Controls, Inc.

I L C Industries, Inc.

Industrial Products Co.

Jackson Products Airco Welding Products

Jaxco, Inc.

Jones & Co.

Kedman Company

Kern Chemical Corp.

Kerrco, Inc.

Kimsafe, Inc.

King Optical Co.

Kirk Plastic Co.

Julius Kraft Co., Inc.

Larson Industries, Inc.

Jed Leonard Co.

Lincoln Electric Co.

Lucas Products Corp.

Mack Products

Madson & Howell, Inc.

Mager & Gougelman, Inc.

Magid Glove Mfg. Co.

Mancine Optical Co.

Marine Optical Mfg. Co.

W. I. Martin & Co.

Martindale Electric Co.

E. B. Meyrowitz, Inc.

Miller Ski Co.

Mine Safety Appliance Co.

Mitchell Mfg. Co.

Montgomery & Co., Inc.

Morey Flux & Chemical Co.

Mott Sand Blast Mfg. Co.

National Cylinder Gas, Div. of Chemtron Corp.

New Era Optical Co.

New Jersey Safety Equipment Co.

Ocean Pool Supply Co., Inc.

Ohio First Aid & Pharmacal Co.

Olympic Glove Co.

Omnitech, Inc.

Oxo Welding Equipment Co.

TABLE 1-1. EYE AND FACE PROTECTIVE DEVICES COMPANIES (Cont'd)

Paulson Mfg. Co.

Albert W. Pendergast Safety Equipment Co.

Pennsylvania Optical Co.

Phillips Plastic Mfg. Co.

Pikes Peak Plastics, Inc.

Pioneer Scientific Corp.

Pulmosan Safety Equipment Corp.

Radcon Corp.

Ramco Manufacturing Co., Inc.

Rayex Corp.

Rochester Optical Mfg. Co., Inc.

Rozin Optical Mfg. Corp.

Safety Clothing & Equipment Co., Div. of Safety First Industries, Inc.

Safety First Supply Co., Div. of Safety First Industries, Inc.

Sager Glove Corp.

Schuberth Corp.

Sellstrom Mfg. Co.

Standard Portable Products, Inc.

Standard Safety Equipment Co.

Sterling Products Co.

Surty Mfg. Co.

Telesight Optics, Inc.

Ultra-Violet Products, Inc.

Union Carbide Corp., Linde Div.

United Optical Mfg. Corp.

United States Safety Service Co.

Univis, Inc.

Wallace Optical Co., Inc.

Watchemoket Optical Co., Inc.

Waterbury Companies, Inc., Sub. of Talley Industries, Inc.

Welders Supply of Worcester, Inc.

Welsh Mfg. Co.

Williams & Co., Inc.

Willson Products, Div. ESB, Inc.

Wolf X-Ray Corp.

- American Optical Corp., Safety Products Division*
- American Ultraviolet Company
- Apex Safety Products Division
- Babbitt Industries, Inc., a Subsidiary of American Safety Equipment Corp.*
- Bachmann Brothers, Inc.*
- Bausch and Lomb
- Arthur Blank and Company, Inc.
- E. D. Bullard Company*
- Eastern Safety Equipment Company, Inc.
- Edroy Products Company, Inc.
- Enco Manufacturing Company
- Fibre-Metal Products Company
- Foster Grant Company, Inc.
- Galaxy Optical Manufacturing Company, Inc.
- General Scientific Equipment Company*
- Gentex Corporation*
- Glendale Optical Co.*
- Jackson Products
- Jones and Co.*
- Mine Safety Appliance*
- Pennsylvania Optical Facility, Optical Products Division, ITEK Corp.
- Pulmosan Safety Equipment Corp.
- Sellstrom Manufacturing Company*
- Ultra-Violet Products, Inc.
- Watchemoket Optical Company, Inc., supplied by Standard Safety Equipment Company*

SwRI personnel met with most of the major eye and face protective device manufacturers, the major insurance companies, and the safety directors from numerous industrial organizations. Representatives from the following Exposition exhibitors at the National Safety Congress, October 29-November 1, 1973, were personally contacted, and the individuals are listed in Table 1-2.

- American Allsafe Co., Inc.
- American Optical Corp.
- Apex Safety Products Div.
- Babbitt Industries, Inc.
- Bausch & Lomb Optical
- E. D. Bullard Co.
- Cosco Safety Products
- Eastern Safety Equipment Co., Inc.
- Fend-All Co.

TABLE 1-2. PEOPLE CONTACTED AT THE NATIONAL SAFETY CONGRESS

Baldwin, Willis J.
Safety Director
Defense Supply Agency
Cameron Station
Alexandria, Va. 22314
(202) 274-6027

Binegar, Wave, Salesman
Fend-All Company
11001 Manchester Road
Kirkwood, Missouri
(314) 966-5310

Breckle, Don
Technical Sales Manager
Willson Products Division,
ESB Incorporated
Reading, Pa. 19603
(215) 376-6161

Buete, Les
Regional Sales Manager
Pulmosan Safety Equip. Corp.
30-48 Linden Place
Flushing, N. Y. 11354
( ) 939-3200

Canning, Harry J.
ESB Incorporated
Yardley, Pa.
(Owns Willson Prods. Div.)

Fahr, Carin (Ms.)
Specialist, Adv. & Sales Promotion
G. E.
Pittsfield, Mass. 01201
(413) 494-4782

Hall, Gene P., Asst. to Pres.
Babbitt Industries, Inc.
3535 De La Cruz Blvd.
Santa Clara, Calif. 95050
(408) 244-8191

Hey, Ronald M., Manager
Jones and Company
325 Massasoit Ave.
Rhode Island, 02914
(401) 434-4010

Kranz, Richard E., Vice-Pres.
Fend-All Company
2222 Diversey Parkway
Chicago, Ill. 60647
(312) 384-1100

McKosky, T. S.
Maintenance Coordinator
Bethlehem Steel Corp.
Bethlehem, Pa. 18016
(215) 694-7571

Miller, Wayde B., Jr.
Production Line Manager
Mine Safety Appliances Co.
400 Penn Center Blvd.
Pittsburgh, Pa. 15235
(412) 241-5900

Morse, Douglas
Product Supervisor
Bausch & Lomb
465 Paul Road
Rochester, N. Y. 14624
(716) 247-4000

Mowson, Albert G.
Field Sales Manager
Bausch & Lomb
870 W. Forest Brook Road
Maitland, Fla. 32751
(315) 644-5669

Mulhall, Robert D., President
Babbitt Industries, Inc.
3535 De La Cruz Blvd.
Santa Clara, Calif. 95050
(408) 244-8191

TABLE 1-2. PEOPLE CONTACTED AT THE NATIONAL SAFETY CONGRESS (Cont'd)

Osti, Aldo P.
Manager of Corporate Safety
Pfizer
235 East 42nd Street
New York, N. Y. 10017
(212) 573-3147

Polkosky, Douglas J.
Sales Manager
ITEK
4800 Prudential Tower
Boston, Mass. 02199
(617) 262-7310

Pollina, Vincent
Corporate Director
A. O. Smith
P. O. Box 584
Milwaukee, Wisc. 53201
(414) 873-3000
He suggested the following contacts for user statistical data:
. Ben Cieslek - GMC
. Doug Brown - U. S. Steel
. Fred Barnico - U. S. Steel
. Quincy Tuma - Texaco
. Mike Kreicorean - Brunswick
. Neil McCullum - Crysler

Powell, George, Prods. Mgr.
Titmus
Petersburg, Va. 23803
(703) 732-6121

Raschke, Herb
Asst. Dir. of Marketing
E. D. Bullard Company
2680 Bridgeway
Sausalito, Calif 94965
(415) 332-0410

Rathbun, Ray B., Safety Dir.
General Tele. Co. of the Northwest, Inc.
1800 41st Street
Everett, Wash. 98201
(206) 258-5624

Recht, J. L.
Manager Statistics Dept.
National Safety Council
425 N. Michigan Ave.
Chicago, Ill. 60611
(312) 527-4800

Scott, Gary L.
(Dr. Dick Jackson)Optometrist
Mine Safety Appliances Co.
370 Bond Street
Elk Grove Village, Ill. 60007
(312) 921-7474

Vern Calusen and
Jim Grabowsky
Sellstrom Mfg. Co.
Sellstrom Industrial Park
Palatine, Ill. 60067
(312) 358-2000

Spencer, Eric W.
Director of Safety
Brown University
Providence, R. I. 02912
(401) 863-2530

Sundermann, Bill, Sales
Fibre-Metal Midwest, Inc.
7825 S. Roberts Road
Bridgeview, Ill. 60455
(312) 586-2442

Davis (MD)
Medical Evaluations
Bureau of Regulation Compliance,
Food and Drug Administration

TABLE 1-2. PEOPLE CONTACTED AT THE NATIONAL SAFETY CONGRESS (Cont'd)

Villforth, John (MD)
Director
Environmental Protection Agency
Rockville, Maryland

Proctor, John A.
Office of Standards
Occupational Safety & Health
Washington, D. C.

Militello, J. V.
Vice President
American Allsafe Co.
Buffalo, N. Y. 14213
(716) 883-8300

Caffrey, George D.
Director of Marketing
Gentex Corporation
Carbondale, Pa. 18407
(717) 282-3550

Craig, N. R., Jr.
FDA Safety Officer
Food and Drug Admin.
5600 Fishers Lane
Rockville, Maryland 20852
(301) 443-4200

Friesenborg, N. G., Pres.
Parmelee Industries, Inc.
1535 Walnut Street
Kansas City, Mo. 64108
(816) 842-8500

Jacobson, Alfred H.
Vice President, Sales
Eastern Safety Equip. Co. Inc.
19-79 Steinway Street
Long Island City, N. Y. 11105
(212) 726-2062

McHugh, W. P.
Section Manager, Safety
Combustion Engineering, Inc.
911 W. Main Street
Chattanooga, Tenn. 37402
(615) 265-4631

Miller, Richard
National Sales Manager
Glendale Optical
130 Crossways Park Drive
Woodbury, N. Y. 11797
(512) 921-5800

Tofany, Vince, President
National Safety Council
425 N. Michigan
Chicago, Ill.
( ) 527-4800

O'Neil, Jim
Schools and Industry
Wise Owl Club
(Approx. 60,000 members)

- Fibre Metal Products Co.
- Glendale Optical Co., Inc.
- Guardian Equipment
- Jackson Products Div.
- Jones & Co.
- Mine Safety Appliances
- Pulmosan Safety Equipment Co.
- Schuberth Corp.
- Sellstrom Mfg. Co.
- Standard Safety Equipment Co.
- Titmus Optical Co., Inc.
- Watchmoket Optical Co.
- Welsh Mfg. Co.
- Willson Products Div., ESB, Inc.

As a result of going to the National Safety Congress and personally contacting these people, the Industrial Safety Equipment Association, Eye and Face Product Group, formed an ad hoc committee to cooperate with SwRI on this project. This ad hoc committee was comprised of the following:

- Mr. Frederick A. Stevens,
  Senior Vice President
  Welsh Manufacturing Company
  9 Magnolia Street
  Providence, R.I. 02909

- Mr. Robert D. Mulhall
  President
  Babbitt Industries, Inc.
  American Safety
  3535 De La Cruz Blvd.
  Santa Clara, California 95050

- Mr. Albert G. Mowson
  Field Sales Manager
  Bausch and Lomb
  870 W. Forest Brook Road
  Maitland, Florida 32751

- Mr. N. G. Friesenborg,
  President
  Parmelee Industries, Inc.
  1535 Walnut Street
  Kansas City, Missouri 64108

Messrs. Stevens, Mulhall, Mowson, and Freisenborg visited Southwest Research Institute on Friday, December 7, 1973, and met with the SwRI project personnel. The visiting ad hoc committee was briefed on the purpose of the project and the tasks being undertaken to accomplish the end objective of the project.

In general, it was a very informal and informative meeting for both the members of the Industrial Safety Equipment Association ad hoc committee and the SwRI project personnel.

The support of the Industrial Safety Equipment Association, the eye and face protective device manufacturers, and the individual companies of Messrs. Stevens, Mulhall, Mowson, and Freisenborg were pledged to the accomplishment of the objectives of this project for the overall good of the eye and face protective device industry.

We submitted a list of eye and face protective devices that we needed to examine to Mr. Fred Stevens so that he could circulate the list among appropriate protective equipment manufacturers. Devices which we received as a result of this inquiry were tested against the current Z87 Standard and were used in the development of new tests for eye and face protective devices.

(3) <u>The Experience, Records, and Practices of Employers and Employees Working in Environments Hazardous to the Eye and Face</u>.

Over a dozen employers and their employees have been contacted about their experiences, records and practices for working in hazardous environments.

We have conducted interviews with personnel of four different companies in San Antonio to obtain information about their records and practices pertaining to eye and face protection and eye and face injuries. Three of those interviewed were owner-managers of local manufacturers and the fourth was a facility Safety Engineer.

The following quoted excerpt is from a report memorandum filed by Mr. J. K. Dean of the SwRI Project Team.

> "All employ from 6 to 800 machinists, machinist helpers, welders, welding helpers, professional and technical personnel, and laborers. Each at one time or another comes into contact with power tools and equipment that could be considered dangerous to the eyes if inadequate or improper protection is worn. All of the four individuals interviewed

supply their people with what appears to be adequate eye protection devices and replace them as needed. Full eye protectors are placed in the immediate vicinity of all areas such as grinders, steel buffers, etc., for everyone to use.

"All four have from 2 to 5% eye accident rates per year and, of these accidents, only one resulted in permanent eye damage which caused complete loss of eyesight. This occurred when a laborer placed one chemical into a glass container which contained another chemical, causing an explosion. According to the interviewee, the individual was not wearing any type of eye protection whatever.

"All four of those interviewed complained that there was very little, if any, incentive on the part of an individual to wear eye protection. Some workers complained that it was uncomfortable, others complained that they couldn't see well enough for close work, others said that it caused headaches and that some devices were too hot. All complaints are valid to some extent. Plastic lens have a tendency to scratch easily, which does interfere with vision, and some of the goggle-type eye protectors do not have, for obvious reasons, very much ventilation.

"Two of the four people interviewed said that they have had some lectures given and films shown by insurance companies and safety groups, with very little success. Their people would wear protection for a day or two at best and then go back to their old habits.

"One very valid complaint by all four interviewed was that of the eye accidents reported; practically all personnel involved would state that they were wearing eye protection—yet when you walk through a plant at any time, very few, if any, would be wearing any eye protection.

"One of those interviewed felt that there has to be some agency outside of the facility (that is, someone who is not employer-related) who can make an employee who will not or does not wear eye protection liable or at least partially liable. Most of their experience indicated that employer-made laws and rules have little or no effect on employees, as it is and has been pretty much of an employee market. The employees will not tolerate any part of a pay suspension. They will quit first, or be fired; it makes little difference, as most of them can find new employment within a few hours,

at worst a few days. Another complaint is that labor unions also will not tolerate such acts against their people. So as employers, they feel they cannot be an effective enforcing agency.

"In one case, the Safety Group feels that the Occupational Safety and Health Act enacted by Congress in 1970 required them to be more specific and regulatory in the mandatory wearing of eye protection. Their employees are expected to comply with the above acts as described in their Safety Manual. Failure to comply with these regulations will be just cause for the following actions:

(1) For a first violation of the safety rules and regulations, an employee will be reminded of the specific regulation and its stipulations under the Occupational Safety and Health Act, either by the immediate supervisor of the employee, by other supervisory personnel within the section, or by the Safety Engineer, if no appropriate supervisory personnel are readily available.

(2) For a second violation of the safety rules and regulations, an employee will be notified in writing by the employee's immediate supervisor or by the Safety Engineer, addressing the communication through the employee's section head, requesting that a second warning be given to this particular employee, stressing the seriousness of his violation of the regulations and the possibility that further violations may result in discharge.

(3) The third failure to comply with safety rules and regulations will result in suspension of duty and the loss of pay for a period of one day.

(4) Repeated violations of the safety rules and regulations will be grounds for permanent dismissal.

"The Safety Engineer also stated that he was not sure how mandatory they could make these regulations, primarily Rule (4), if, in fact, they could or would dismiss an individual who repeatedly violates these rules."

On Friday, November 2, 1973, the Safety Director, Combustion Engineering, Chattanooga, Tennessee, was visited by a project team member. The following quoted excerpt is from the report memorandum:

"Mr. McHugh was very knowledgeable, helpful and dedicated to safety. A walk-through of his facilities confirmed that he had available a full-time M. D. and RN's, as well as an on-site, fully equipped medical emergency receiving room.

"While in his office, I asked him the following questions and have included his responses:

"Q. How do you regard plastic vs. glass lenses?

A. Plastic lenses for safety glasses are not practical because they become scratched too easily and are not cost-practical. Whenever the glass lenses have been impacted, they are replaced.

Q. How do you feel about workers wearing soft contact lenses?

A. We very strongly discourage them to wear contact lenses because they can melt in certain operations and they can shift thereby distracting the wearer's attention from his machine.

Q. How do you tabulate accident data and is it available to us for this project?

A. Upon a letter request from me to him, he will make computer print-out sheets available.

Q. How are people motivated to wear their safety equipment, i. e., how do you contend with the human factors?

A. Each person hired is personally fitted for comfort, appearance, and safety is an on-going thing with movies, talks, enforcement, etc.

Q. Is there a dismissal program for violators?

A. Yes, if warnings are ignored.

Q. Do OSHA inspectors check for protective devices conforming to Z87. 1 Standards in use?

A. Yes.

Q. From practical user aspect, could the Z87. 1 Standard be made more functional and less ambiguous?

A. Yes, it needs a continual upgrading to keep pace with state-of-the-art machinery. Also threshold values for UV are vague.

Q. Concerning user standards, how do you determine the needs, by job/machine, for eye and face protection?

A. By years of experience, we have compiled our own product user guide.

"Additional Information:

All welders wear safety glasses under hood. No snap-on side shields are used; only permanent ones which cannot be removed. Most accident injuries result from misuse or non-use of protective equipment, not device failure. The protective device market is too competitive for inferior product manufacturers to stay in business. If problems with a product arise, the protective device company will either correct and improve the device or design a better product (as for a new machine hazard need introduced into the plant inventory), or they are replaced with a more cooperative supplier."

Mr. Pat McHugh provided us with the following quoted statement concerning contact lenses which Mr. McHugh stated was the opinion concerning contact lenses by Combustion Engineering, and Mr. McHugh thought that Mr. James O'Neil of the National Society for the Prevention of Blindness had published the information on contact lenses.

"Contact Lenses

In the United States approximately three to five million persons wear contact lenses. However, contact lenses should not be worn where exposure to dust, flying particles, chemicals, chemical fumes and other industrial irritants are great.

"One serious problem is to identify workers who wear contact lenses since many are wearing contact lenses and have not reported it to the medical department of their company.

"Another problem encountered with wearers of contact lenses is the sudden displacement or loss of lens from the eye.

"Doctors recommend that under no circumstances should an employee be allowed to work under a mask or hood while wearing contact lenses because the lens which covers the cornea reduces oxygen exchange and to restrict the oxygen supply further would hamper the cooling of the cornea and invite corneal damage.

"Wearers of contact lenses should not work in high temperature environments or be exposed to extremes of infrared rays."

(4) A Study and Analysis of Eye and Face Accident Statistics

In addition to companies contacted, six states have been contacted concerning their eye and face accident statistics:

- Mr. William Treacy, Assistant Executive Director
  Texas Industrial Accident Board
  State of Texas
  111 E. 17th Street
  Austin, Texas 78711

- Mr. Ray Stecker
  Bureau of Occupational Injury and Disease
  Compensation Department of Labor
  State of Pennsylvania

- Mr. Ivan W. Russell
  Department of Labor and Industry
  State of Minnesota

- Mrs. Margaret R. O'Grady, Chief
  Division of Labor Statistics and Research
  State of California
  455 Golden Gate Ave., P.O. Box 603
  San Francisco, California 94101

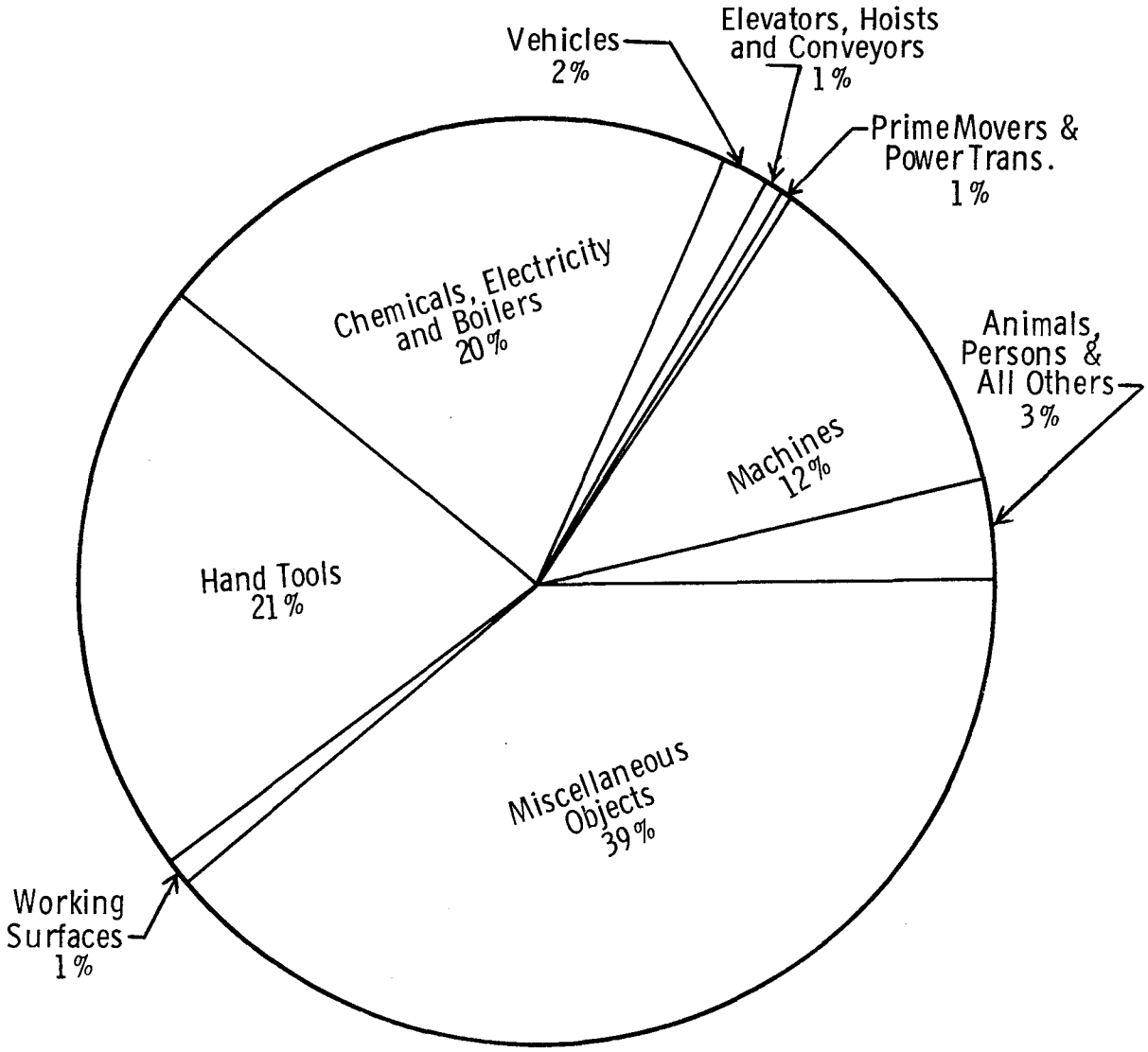
- State of Illinois
  Division of Labor
  (No name)
  Springfield, Illinois

- Mr. Louis Levine, Industrial Commissioner
  Division of Labor
  State of New York
  80 Centre Street
  New York, N.Y. 10013

Examples of the accident statistical tabulation are shown on Tables 1-3, 1-4, and 1-5. They were compiled using the New York data "Characteristics and Costs of Work Injuries from New York State," 1966-1967, Table 2.A, Volumes I through X.

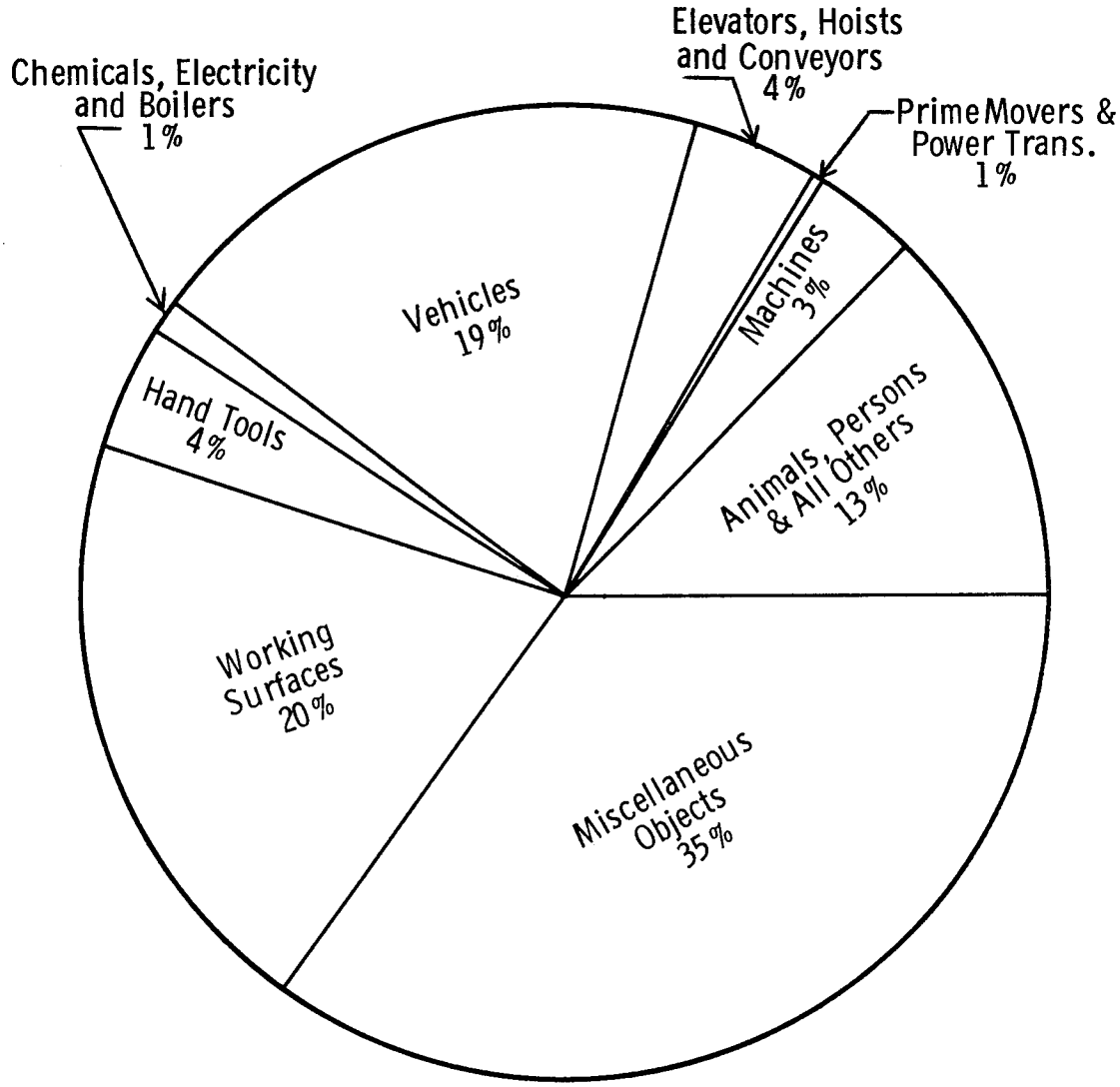
The New York accident data covers the 5-year period from 1966 to 1970, and includes 100 (SIC three-digit) industries that had the largest number of work injuries during that 5-year period.

TABLE 1-3. ACCIDENT STATISTICAL TABULATION
4, 764 EYE INJURIES



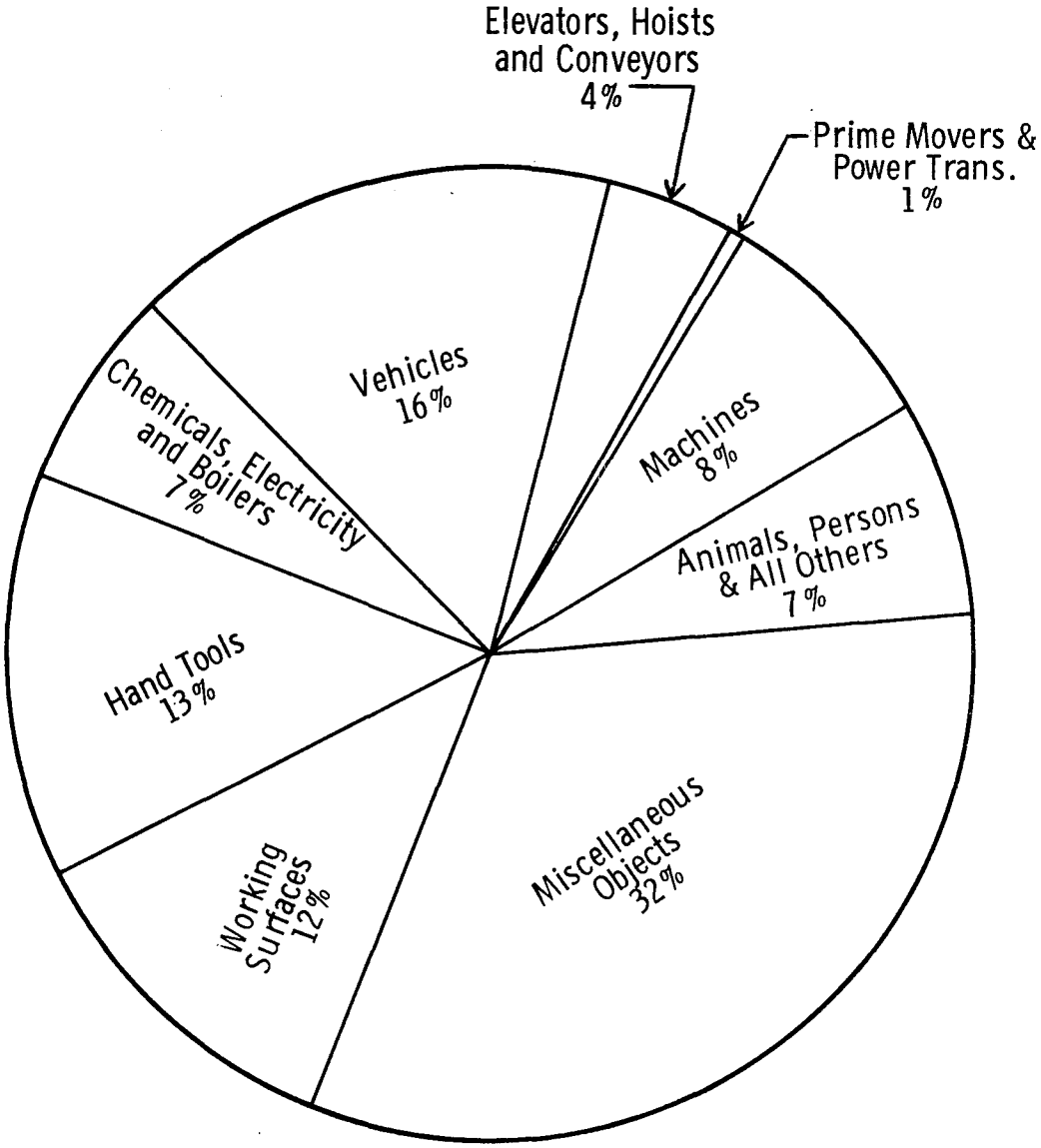
PERCENTAGE OF EYE INJURIES BY MAJOR AGENCY OF ACCIDENT
from
"Characteristics and Costs of Work Injuries in New York State"
1966-1970, Table 2.A, Vols I thru X

TABLE 1-4. ACCIDENT STATISTICAL TABULATION
10, 290 HEAD INJURIES



PERCENTAGE OF HEAD INJURIES BY MAJOR AGENCY OF ACCIDENT
from
"Characteristics and Costs of Work Injuries in New York State"
1966-1970, Table 2.A, Vols. I thru X

TABLE 1-5. ACCIDENT STATISTICAL TABULATION
28, 944 FACE OR NECK INJURIES



PERCENTAGE OF FACE OR NECK INJURIES BY MAJOR AGENCY OF ACCIDENT
from
"Characteristics and Costs of Work Injuries in New York State"
1966-1970, Table 2.A, Vols. I thru X

The pie charts were constructed using the major agency of accident and the part of the body. The pie charts were constructed by calculating each major agency of accident for each industry by part of body, i.e.,

- Eyes
- Head
- Face or neck

The number of accidents were totaled by part of body to obtain these pie charts. The most relevant pie chart is Table 1-3, which contains the following information:

- 4,764 eye injuries
- 39% miscellaneous objects
- 21% hand tools
- 20% chemicals, electrical, and boilers
- 12% machines.

There were 10,290 head injuries (Table 1-4) and 28,944 face or neck injuries (Table 1-5). The same type of information was tabulated for each of these injury categories.

Members of the SwRI project team met with the Loss Prevention Manager, County of Los Angeles, Department of Personnel. He had a computer listing of accidents according to Code 02, Eyes, for the period 2/72 - 8/72. For the eye entries, there were 232 cases listed (see Table 1-6). In these cases, the pertinent employer's first report of injury was reviewed along with the doctor's first report of injury. Out of the 232 cases, there were 22 missing. All of these eye cases were manually pulled and we dictated the cause of accident, Items 21-29, and the nature of injury and part of body affected, Item 30, from the employer's report of industrial injury for the State of California. We also dictated from the doctor's first report of work injury Items 11 and 12, respectively, accident or exposure, and extent of injury or disease (see Tables 1-7, 1-8, and 1-9).

Individual cases are in Appendix B. A careful review of these data leads to the conclusion that this type of data is virtually worthless for this project or any project of this type. Rather than omit the individual case data and explain that it is worthless, it has been included in the report for all readers to arrive at the same conclusion.

Through Mr. Pat McHugh, Safety Director, Combustion Engineering, we obtained eye and face injury data for the years 1971 and 1972. These data were received in computer tabulation form and were used by SwRI to obtain the data shown in Table 1-10.

TABLE 1-6. LOS ANGELES COUNTY SAFETY REPORT

July 1971 through June 1972

Workmen's Compensation and Occupational Health Service

Frequency and Severity Analysis
by Part of Body

Run 7/22/72

Dept. Code	Dept. Name	Number of Claims for Eyes
10	Agricultural Commission	1
20	Air Pollution Control District	2
35	Museum of Art	1
40	Assessor	4
50	Auditor-Controller	1
55	Beaches	4
60	Chief Administrative Office	0
61	Board of Supervisors	0
62	Otis Art Institute	0
65	Music Center Operations	0
66	Farm Advisor	0
68	Human Relations Commission	0
80	Building Services	21
120	Adoptions	0
130	Miraloma	1
140	Public Social Services	0
155	Administration - Medical Center	0
160	LAC/USC Medical Center	11
165	Pediatrics Pavilion	1
170	Psychiatric Hospital	0
175	Womens Hospital	3
160E	LA Clinic	0

TABLE 1-6. LOS ANGELES COUNTY SAFETY REPORT (Cont'd)

Dept. Code	Dept. Name	Number of Claims for Eyes
185	Medical Center Services	4
200	Harbor General Hospital	3
210	John Wesley County Hospital	3
215	L. B. El Cerrito Hospital	3
225	Martin Luther King, Jr. Hospital	4
240	Olive View Hospital	2
250	Crippled Childrens Services	0
260	Rancho Las Amigos Hospital	8
270	Resources and Collections	1
280	Antelope Valley Rehabilitation Center	1
300	Personnel	2
310	County Clerk	3
320	Communications	1
330	Community Services	0
340	Chief Medical Examiner - Coroner	0
350	Mental Health	0
360	County Council	1
365	Data Processing	2
370	District Attorney	1
381	County Engineer	6
383	Sewer Maintenance	2
384	Aviation	3
390	Fire Protection Districts	36
400	Flood Control District	14
410	Forest and Fire Warden	11
430	Health, Eyes	12
440	Museum of Natural History	1
461	Public Library	1
470	County Veterinarian	0

TABLE 1-6. LOS ANGELES COUNTY SAFETY REPORT (Cont'd)

Dept Code	Dept. Name	Number of Claims for Eyes
480	Marshall	2
491	Mechanical	39
503	Beverly Hills Municipal Court	0
504	Burbank Municipal Count	0
505	Citrus Municipal Count	0
506	Compton Municipal Court	0
508	Downey Municipal Court	0
509	East L. A. Municipal Court	0
513	Englewood Municipal Court	0
514	Long Beach Municipal Court	0
516	Los Angeles Municipal Court	2
517	Los Angeles Municipal Reporter	0
518	Los Cerritos Municipal Court	0
519	Newhall Municipal Court	0
522	Pomona Municipal Court	0
525	Santa Monica Municipal Court	0
526	South Bay Municipal Court	0
528	South Gate Municipal Court	0
600	Parks and Recreation	28
620	Animal Control	0
640	Probation	0
645	Probation/Court Wards	1
660	Public Administrator	1
670	Public Defender	0
701	Purchasing and Stores	2
702	Services Division	1
705	Real Estate Management	0
710	Registrar/Recorder	2

TABLE 1-6. LOS ANGELES COUNTY SAFETY REPORT (Cont'd)

Dept. Code	Dept. Name	Number of Claims for Eyes	
720	Regional Planning Commission	0	0
740	Road		24
753	Special Schools		5
760	Weights and Measures		1
767	Military and Veterans Affairs		0
770	Sheriff		47
775	Sheriff/Prisoners		0
790	Treasurer/Tax Collector		4
794	Urban Affairs		0
990	Superior Courts		0

TABLE 1-7. QUESTIONS FROM EMPLOYER'S AND DOCTOR'S FIRST REPORT OF INJURY FORMS*

EMPLOYER'S FIRST REPORT OF INJURY

CAUSE OF ACCIDENT

21. Occupation (Classification Title)
22. How long employed by you at this occupation? Check (✓)
    Less than 6 months ( ); 6 months to 2 years ( ); over 2 years ( )
23. What was employee doing when accident occurred?
    (Describe briefly, such as: loading truck, operating drill press, shoveling dirt, walking down stairs, etc.)
24. How did the accident happen?
    (Describe fully, stating whether the injured person fell, was struck, etc.: give all factors contributing to accident. Use other side of report for additional space)
25. What machine, tool, substance, or object was most closely connected with the accident?
    (Name the specific machine, tool, appliance, gas, liquid, etc., involved)
26. If mechanical apparatus or vehicle, what part of it?
    (State if gears, pulley, motor, etc.)
27. Were mechanical guards, or other safeguards provided?
    (Yes or No)
28. Was injured using them? (Yes or No)
29. What do you recommend for preventing this type of accident?
    (State the specific preventive measures that can be taken by employer and workers)

NATURE OF INJURY AND PART OF BODY AFFECTED

30. (Describe in detail the nature of the injury and the part of the body affected. For example: amputation of right index finger at second joint, fracture of ribs, lead poisoning, dermatitis of left hand, etc.)

DOCTOR'S FIRST REPORT OF WORK INJURY

11. ACCIDENT OR EXPOSURE:
    Did employee notify employer of this injury?
    Employee's statement of cause of injury or illness:
12. NATURE AND EXTENT OF INJURY OR DISEASE
    (Include all objective findings, subjective complaints, and diagnoses. If occupational disease state date of onset, occupational history, and exposures.)

*Individual cases are in Appendix B.

TABLE 1-8. EMPLOYER'S REPORT OF INDUSTRIAL INJURY INSTRUCTIONS

EMPLOYER'S REPORT OF INDUSTRIAL INJURY

INSTRUCTIONS:

SEND REPORT IMMEDIATELY AFTER INJURY
DO NOT WAIT FOR DOCTOR'S REPORT

1) Answer all questions and give complete details.
2) Retain one copy for your files.
3) Mail *ORIGINAL AND ONE COPY* to:
Workmen's Compensation Claims Unit
2235 West Beverly Boulevard
Los Angeles, California 90057

Every question must be answered fully to avoid further correspondence. FAILURE TO FILE IS A MISDEMEANOR SUBJECT TO MAXIMUM FINE OF $100. (Labor Code Sections 6407-6413)

Every work injury to an employee which causes disability lasting longer than the day of the injury, or which requires medical services other than first aid treatment must be reported within five days after the injury. If the injury results in death, a report must be made by telephone or telegraph directly to the Division of Labor Statistics and Research not later than 24 hours after death.

EMPLOYER

1. Name ..... *COUNTY OF LOS ANGELES – LEGALLY UNINSURED* ..... Dept. Code .....
Department & Facility ..... Facility Code .....
2. Department address (No. and Street) ..... City ..... Tel. No. .....

INJURED EMPLOYEE 3. Employee Number ..... Social Security No. .....

3a. Phone Number ..... 3b. Is employee entitled to Sec. 231 benefit? .....

4. Name ..... First Name ..... Middle Initial ..... Last Name .....

5. Address (No. and Street) ..... (City or Town) ..... Zip Code .....

6. Age ..... 7. Sex: Check (√) Male ..... Female ..... 8. Check (√) Married ..... Single .....

9. Worked ..... hours per day for (5, 5½, 6, etc.) ..... days per week. 10. Rate of pay when injured $ ..... per (Hour, Day, Week, Month) .....

11. If board, lodging, or other advantages furnished in addition to wages, give estimated value $ ..... per day, or $ ..... per wk.

11a. Date of Employment or Last Reinstatement Date .....

ACCIDENT

12. Place of accident (No. and Street) ..... (City or Town) ..... (County) .....

13. On employer's premises (Yes or No) ..... 14. Department .....

15. Date of accident ..... 16. Hour of day ..... A.M. P.M. 17. Did injury result in disability beyond day of accident? (Yes or No) ..... 18. If yes, give date last worked ..... 19. Was injured paid in full for this day? (Yes or No) ..... 20. If injured in a mine, check (√) accident location: Surface ... Mill ... Underground ... Shaft ....

CAUSE OF ACCIDENT

21. Occupation (Classification Title) ..... 22. How long employed by you at this occupation? Check (√) Less than 6 months ...; 6 months to 2 years ...; over 2 years ... 23. What was employee doing when accident occurred? (Describe briefly, such as: loading truck, operating drill press, shoveling dirt, walking down stairs, etc.) .....

24. How did the accident happen? (Describe fully, stating whether the injured person fell, was struck, etc.; give all factors contributing to accident. Use other side of report for additional space) .....

25. What machine, tool, substance, or object was most closely connected with the accident? (Name the specific machine, tool, appliance, gas, liquid, etc., involved) .....

26. If mechanical apparatus or vehicle, what part of it? (State if gears, pulley, motor, etc.) .....

27. Were mechanical guards, or other safeguards provided? (Yes or No) ..... 28. Was injured using them (Yes or No) .....

29. What do you recommend for preventing this type of accident? State the specific preventive measures that can be taken by employer and workers. .....

NATURE OF INJURY AND PART OF BODY AFFECTED

30. (Describe in detail the nature of the injury and the part of the body affected. For example: amputation of right index finger at second joint, fracture of ribs, lead poisoning, dermatitis of left hand, etc.) .....

31. Name and address of physician .....

32. Name and address of hospital .....

33. Has employee returned to work? (Yes or No) ..... 34. If yes, give date ..... 35. At what wage? $ ..... per .....

36. Did injury result in death? (Yes or No) ..... 37. If yes, give date .....

38. In case of death, give name and address of nearest relative .....

39. Was accident caused by another person? (Yes or No) .....

40. If yes, give name & details on reverse side. .....

41. Date you were informed of this injury .....

42. SUPERVISOR'S COMMENTS – Attach separate sheet, give names and addresses of witnesses plus any further particulars.

..... Department Head or Authorized Representative ..... Position ..... Date

..... Name and Phone Number of Immediate Supervisor

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FILING OF THIS REPORT IS NOT AN ADMISSION OF LIABILITY

DO NOT WRITE IN THIS COLUMN

Case No.
Employer No.
Industry
Age
Sex and Marital Status
Weekly Wage
County
Accident Date
Occupation
Accident Type
Agency
Agency Part
Mech. Defect
Unsafe Act
Personal Defect
Nature of Injury
Location
Extent of Injury
Insurance Carrier
Report Lag
Coded by

TABLE 1-9. DOCTOR'S FIRST REPORT OF WORK INJURY

DOCTOR'S FIRST REPORT OF WORK INJURY

COUNTY OF LOS ANGELES
WORKMEN'S COMPENSATION CLAIMS UNIT
2235 West Beverly Boulevard
Los Angeles, California 90057

Fill out and forward original & one copy immediately after seeing patient, to

Immediately after first examination mail one copy directly to the Division of Labor Statistics and Research, P. O. Box 965, San Francisco 1, and two copies to the above address. Failure to file a report with the Division is a misdemeanor. (Labor Code, Sections 6407–6413.) Answer all questions fully.

A. INSURANCE CARRIER LEGALLY UNINSURED

DO NOT WRITE IN THIS SPACE

1. **EMPLOYER** _____
2. Address (No. and Street) _____ City _____
3. Business (Manufacturing shoes, building construction, retailing men's clothes, etc.) _____

4. **EMPLOYEE** (First name, middle initial, last name) _____ S.S. No. _____
5. Address (No. and Street) _____ City _____
6. Occupation _____ Age _____ Sex _____ Marital Status _____
7. Date injured _____ Hour _____ M Date last worked _____
8. Injured at (No. Street and City) _____ County _____
9. Date of your first examination _____ Hour _____ M Who engaged your services? _____
10. Name other doctors who treated employee for this injury _____

11. **ACCIDENT OR EXPOSURE:** Did employee notify employer of this injury? _____ Employee's statement of cause of injury or illness:

12. **NATURE AND EXTENT OF INJURY OR DISEASE** (Include all objective findings, subjective complaints, and diagnoses. If occupational disease state date of onset, occupational history, and exposures.)

DID INJURY RESULT AS DESCRIBED ABOVE? YES ☐ NO ☐

13. **X-RAYS:** By whom taken? (State if none)
Findings:

14. **TREATMENT:**

15. Kind of case (office, home, or hospital) _____ If hospitalized, date _____ Estimated stay _____
Name and address of hospital _____
16. Further treatment (estimated frequency and duration) _____
17. Estimated period of disability for: Regular work _____ Modified work _____
18. Describe any permanent disability or disfigurement expected (state if none) _____
19. If death ensued, give date _____

20. **REMARKS** (Note any pre-existing injuries or diseases, need for special examination or laboratory tests, other pertinent information.)

Name _____ (TYPE OR PRINT) { PERSONAL SIGNATURE OF DOCTOR } _____

Date of report _____ Address (No. Street and City) _____ PHONE NO. _____

USE REVERSE SIDE IF MORE SPACE REQUIRED

76D647A–Cdb 10-69

TABLE 1-10. COMBUSTION ENGINEERING EYE AND FACE INJURIES

Occupation	1971 eye inj.	1972 eye inj.	1971 face inj.	1972 face inj.	1971 avg. no. emp. per year	1972 avg. no. emp. per year	1971 % of total eye inj.	1972 % of total eye inj.	1971 % of total face inj.	1972 % of total face inj.	1971 eye inj. /avg. no. emp.	1972 eye inj. / avg. no. emp.	1971 face inj. /avg. no. emp.	1972 face inj. /avg. no. emp.
Assembler	2463	2190	93	88	772	837	26.75	30.34	25.55	27.16	3.1904	2.6165	0.1205	0.1051
Blacksmith	-	1	--	-	----	1		0.01	-----	-----	------	1.0000	------	
Burner	27	22	--	2	19	18	.29	0.30	-----	0.62	1.4211	1.2222	------	0.1111
Carpenter	3	1	--	--	10	10	.03	0.02	-----	-----	0.3000	0.1000	------	------
Checker	14	20	3	2	36	36	.152	0.28	0.82	0.62	0.3889	0.5556	.0833	0.0555
Chipper	69	55	10	3	7	7	.75	0.76	2.75	0.93	9.8571	7.8571	1.4285	0.4285
Cleaner	34	34	3	3	68	60	.37	0.47	0.82	0.93	0.5000	0.5667	0.0441	0.0500
Clerk	3	3	--	--	115	106	.03	0.41	-----	-----	0.0261	0.0283	------	------
Craneman	94	111	4	7	216	233	1.0	1.54	1.10	2.16	0.4352	0.4764	0.0185	0.0300
Draftsman	29	30	1	--	267	254	.32	0.42	0.27	-----	0.1086	0.1181	0.0037	------
Electrician	68	54	4	4	78	77	.74	0.75	1.10	1.23	0.8717	0.7013	0.0512	0.0519
Engineer	52	45	9	3	276	274	.56	0.62	2.47	0.93	0.1884	0.1642	0.0326	0.0109
Expediter	113	76	3	2	65	68	1.23	1.05	0.82	0.61	1.7385	1.1176	0.0461	0.0294
Fitup mechanic	336	255	14	6	112	101	3.65	3.53	3.85	1.85	3.0000	2.5248	0.1250	0.0594
Floor Worker	145	134	24	24	261	261	1.58	1.86	6.59	7.40	0.5556	0.5134	0.0919	0.0919
Foreman	103	79	7	7	194	207	1.12	1.09	1.92	2.16	0.5309	0.3816	0.0360	0.0338
Furnace operator	19	17	1	1	11	11	.21	0.24	0.27	0.31	1.7272	1.5455	0.0909	0.909
Grinder	1087	924	15	12	139	122	11.81	12.80	4.12	3.70	7.8201	7.5738	0.1079	0.0983
Guard	8	12	--	--	24	24	.09	0.17	-----	-----	0.3333	0.5000	------	------
Helper	339	223	31	19	96	67	3.68	3.09	8.52	5.86	3.5312	0.3283	0.3229	0.2835
Inspector	58	57	3	5	113	116	0.63	0.79	0.82	1.54	0.5133	0.490	0.0265	0.0431

TABLE 1-10. COMBUSTION ENGINEERING EYE AND FACE INJURIES (Cont'd)

Occupation	1971 eye inj.	1972 eye inj.	1971 face inj.	1972 face inj.	1971 avg. no. emp. per year	1972 avg. no. emp. per year	1971% of total eye inj.	1972% of total eye inj.	1971% of total face inj.	1972% of total face inj.	1971 eye inj. /avg. no emp.	1972 eye inj. /avg. no. emp.	1971 face inj. /avg. no emp.	1972 face inj. /avg. no emp.
Laborer	27	13	5	3	3	1	0.29	0.18	1.37	0.93	9.0000	13.000	1.6666	3.0000
Layout	20	12	1	1	18	12	0.22	0.17	0.27	0.31	1.1111	1.000	0.0555	0.0833
Loader	9	16	2	1	41	42	.10	0.22	0.55	0.31	0.2195	0.381	0.0487	0.0238
Machinist	140	120	15	21	160	160	1.52	1.66	4.12	6.48	0.8750	0.750	0.0937	0.0937
Maintenance	83	65	6	4	90	102	0.90	0.90	1.65	1.23	0.9222	0.637	0.0666	0.0588
Operator	550	364	28	36	21	21	5.97	5.04	7.69	11.11	26.1905	17.333	1.3333	1.7143
Painter	9	11	3	1	7	7	0.10	0.15	0.82	0.31	1.2857	1.571	0.4285	0.1429
Press operator	18	9	1	1	25	23	0.20	0.12	0.27	0.31	0.7200	0.391	0.0400	0.0434
Rigger	61	73	3	3	13	13	0.66	1.01	0.82	0.93	4.6923	5.615	0.2307	0.2307
Specialist	20	23	1	1	1	1	0.22	0.32	0.27	0.31	20.000	23.000	1.0000	1.0000
Stenographer	2	2	--	--	37	37	0.02	0.03	----	----	0.0541	0.054	------	------
Supervisor	13	11	1	1	139	135	0.14	0.15	0.27	0.31	0.0935	0.0814	0.0071	0.0074
Technician	28	8	--	1	74	70	0.30	0.11	----	0.31	0.3784	0.114	------	0.0143
Truck driver	15	8	--	1	29	22	0.16	0.11	----	0.31	0.5172	0.364	------	0.0455
Truck operator	7	10	--	--	3	3	0.08	0.14	----	----	2.3333	3.3333	------	------
Tool Maker	2	1	--	--	6	6	0.02	0.01	----	----	0.3333	0.1666	------	------
Tube Bender	37	24	3	5	83	76	.40	0.33	0.82	1.54	0.4457	0.31578	0.0361	0.0657
Warehouseman	5	7	--	--	22	18	.05	0.10	---	---	0.2272	0.38888	------	------
Welder	2997	2022	66	54	387	358	32.55	28.01	18.13	16.67	7.7441	5.6480	0.1705	0.0151
Weld operator	53	34	2	1	24	22	.58	0.47	0.55	0.31	2.2083	1.5454	0.0833	0.0454
X-Ray operator	15	9	--	--	26	24	.16	0.12	----	----	0.5769	0.3750	------	------
Unclassified	28	29	2	1	--	--	.30	0.40	0.55	0.31	------	------	------	------

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The following explanations apply for the designated columns:

- Column 1 - Occupation - These are the occupation descriptions used by Combustion Engineering.
- Column 2 - 1971 eye inj. - The number of eye injuries by occupation in 1971.
- Column 3 - 1972 Eye inj. - The number of eye injuries by occupation in 1972.
- Column 4 - 1971 Face inj. - The number of face injuries by occupation in 1971.
- Column 5 - 1972 Face inj. - The number of face injuries by occupation in 1972.
- Column 6 - 1971 avg. no. emp. per year - The average number of employees by occupation in 1971.
- Column 7 - 1972 avg. no. emp. per year - The average number of employees by occupation in 1972.
- Column 8 - 1971 % of total eye inj. - The percentage which in 1971 eye injuries is of the total 1971 eye injuries.
- Column 9 - 1972 % of total eye inj. - The percentage which the eye injuries for this occupation is of the total eye injuries received in 1972.
- Column 10 - 1971 % of total face inj. - The percentage which the face injuries of each occupation is of the total face injuries received in 1971.
- Column 11 - 1972 % of total face inj. - The number of face injuries for each occupation of the total face injuries received in 1972.
- Column 12 - 1971 eye inj./avg. no emp. - The values of Column 2 divided by Column 6 which are the 1971 eye injuries divided by the average number of employees.
- Column 13 - 1972 eye inj./avg. no. emp. - The eye injuries divided by the average number of employees in 1971 which is Column 3 divided by Column 7.
- Column 14 - 1971 face inj./avg. no. emp. - The 1971 face injuries divided by the average number of employees in this occupation in 1971. This is Column 4 divided by Column 6.

Column 15 - 1972 face inj./avg. no. emp. - This is 1972 face injuries divided by the average number of employees for this occupation in 1972. It is Column No. 5 divided by Column No. 7.

The following are the total eye and face injuries per year for the data presented in Table 1-10.

- 1971 eye injuries - 9206
- 1972 eye injuries - 7218
- 1971 face injuries - 364
- 1972 face injuries - 324

Table 1-11 contains the ranking of the occupations by injury per average number of employees of that occupation at Combustion Engineering. Although these data are for only one company and cannot be considered as indicative of all industry in the United States, they do illustrate the type of data that is useful to this type of project.

Most industrial organizations do not have this type of data, and many of those that do have this type of data will not release it for public use. Thus, one is faced with the dilemma which is the lack of sufficient statistical data to arrive at general indices based upon rate of exposure (i.e., injury type/average number of employees).

Conclusions

The seven occupations at Combustion Engineering with the highest incidence of Eye Injuries are:

- Operator
- Specialist
- Chipper
- Laborer
- Grinder
- Welder
- Rigger

Although their ranking varies some between the years 1971 and 1972, they all rank in the highest seven.

TABLE 1-11. RANKING OF OCCUPATIONS ACCORDING TO HIGHEST NUMBER OF INJURIES PER AVERAGE NUMBER OF EMPLOYEES IN THE OCCUPATION

1971 EYE INJURIES			1972 EYE INJURIES			1971 FACE INJURIES			1972 FACE INJURIES		
Rank	Occupation	1971 Eye Inj./Avg. No. Emp.	Rank	Occupation	1972 Eye Inj./Avg. No. Emp.	Rank	Occupation	1971 Face Inj./Avg. No. Emp.	Rank	Occupation	1972 Face Ing./Avg. No. Emp.
1	Operator	26.1905	1	Specialist	23.000	1	Laborer	1.6666	1	Laborer	3.0000
2	Specialist	20.000	2	Operator	17.333	2	Chipper	1.4285	2	Operator	1.7143
3	Chipper	9.8571	3	Laborer	13.000	3	Operator	1.3333	3	Specialist	1.0000
4	Laborer	9.0000	4	Chipper	7.8571	4	Specialist	1.0000	4	Furnace Operator	0.909
5	Grinder	7.8201	5	Grinder	7.5738	5	Painter	0.4285	5	Chipper	0.4285
6	Welder	7.7441	6	Welder	5.6480	6	Helper	0.3229	6	Helper	0.2835
7	Rigger	4.6923	7	Rigger	5.615	7	Rigger	0.2307	7	Rigger	0.2307
8	Helper	3.5312	8	Truck Operator	3.3333	8	Welder	0.1705	8	Painter	0.1429
9	Assembler	3.1904	9	Assembler	2.6165	9	Fitup Mechanic	0.1250	9	Burner	0.1111
10	Fitup Mechanic	3.0000	10	Fitup Mechanic	2.5248	10	Assembler	0.1205	10	Assembler	0.1051
11	Truck Operator	2.3333	11	Painter	1.571	11	Grinder	0.1079	11	Grinder	0.0983
12	Weld Operator	2.2083	12	Weld Operator	1.5454	12	Machinist	0.0937	12	Machinist	0.0937
13	Expediter	1.7385	13	Furnace Operator	1.5445	13	Floor Worker	0.0919	13	Floor Worker	0.0919
14	Furnace Operator	1.7272	14	Burner	1.2222	14	Furnace Operator	0.0909	14	Layout	0.0833
15	Burner	1.4211	15	Expediter	1.1176	15	Checker	0.0833	15	Tube Bender	0.0657
16	Painter	1.2857	16	Blacksmith	1.000	16	Weld Operator	0.0833	16	Fitup Mechanic	0.0594
17	Layout	1.1111	17	Layout	1.000	17	Mainte-nance	0.0666	17	Mainte-nance	0.0588
18	Mainte-nance	0.9222	18	Machinist	0.750	18	Layout	0.0555	18	Checker	0.0555
19	Machinist	0.8750	19	Electrician	0.7013	19	Electrician	0.0512	19	Electrician	0.0519
20	Electrician	0.8717	20	Mainte-nance	0.637	20	Loader	0.0487	20	Cleaner	0.0500
21	Press Operator	0.7200	21	Cleaner	0.6667	21	Expediter	0.0461	21	Truck Driver	0.0455
22	X-Ray Operator	0.5769	22	Floor Worker	0.5134	22	Cleaner	0.0441	22	Weld Operator	0.0454
23	Floor Worker	0.5556	23	Guard	0.5000	23	Press Operator	0.0400	23	Press Operator	0.0434
24	Foreman	0.5309	24	Inspector	0.490	24	Tube Bender	0.0361	24	Inspector	0.0431
25	Truck Driver	0.5172	25	Craneman	0.4764	25	Foreman	0.0360	25	Foreman	0.0338
26	Inspector	0.5133	26	Press Operator	0.391	26	Engineer	0.0326	26	Craneman	0.0300
27	Cleaner	0.5000	27	Ware houseman	0.38888	27	Inspector	0.0265	27	Expediter	0.0294
28	Tube Bender	0.4457	28	Foreman	0.3816	28	Craneman	0.0185	28	Loader	0.0238
29	Craneman	0.4352	29	Loader	0.381	29	Super-visor	0.0071	29	Welder	0.0151
30	Checker	0.3889	30	X-Ray Operator	0.3750	30	Draftsman	0.0037	30	Technician	0.0143
31	Technician	0.3784	31	Truck Driver	0.364		Burner	----	31	Engineer	0.0109
32	Tool Maker	0.3333	32	Helper	0.3283		Carpenter	----	32	Super-visor	0.0074
33	Guard	0.3333	33	Tube Bender	0.31578		Clerk	----		Carpenter	----
34	Carpenter	0.3000	34	Tool Maker	0.1666		Guard	----		Clerk	----
35	Ware-houseman	0.2272	35	Engineer	0.1642		Stenographer	----		Draftsman	----
36	Loader	0.2195	36	Draftsman	0.1181		Technician	----		Guard	----
37	Engineer	0.1884	37	Technician	0.114		Tool Maker	----		Stenographer	----
38	Draftsman	0.1086	38	Carpenter	0.1000		Truck Driver	----		Tool Maker	----
39	Super-visor	0.0935	39	Super-visor	0.0814		Truck Operator	----		Truck Operator	----
40	Steno-grapher	0.0541	40	Steno-grapher	0.054		Warehouseman	----		Warehouseman	----
41	Clerk	0.0261	41	Clerk	0.0283		X-Ray Operator	----		X-Ray Operator	----

The seven occupations at Combustion Engineering with the highest number of Face Injuries are:

- Laborer
- Chipper
- Operator
- Specialist
- Painter (in 1971 but not in 1972)
- Helper
- Rigger
- Furnace Operator (in 1972 but not in 1971)

Like the eye injuries, their ranking varies between the years 1971 and 1972. They all rank in the highest seven. Also, the occupations of painter and furnace operator appear only in one year.

It is to be concluded that it should be the responsibility of each company's Safety Director to tabulate the incidence of injury (i.e., Injury per Average Number of Employees in an occupation) to isolate problem areas and to work toward reduction of injuries. Because working environments vary widely from year to year and from company to company, it is not possible to set specific occupation eye and face protection requirements for occupations by only title. Thus, Safety Directors for each individual company will have to work within the general guidelines set forth in the user section of the Standard to determine specific eye and face devices for specific occupations.

(5) Human Factor Studies of Eye and Face Protective Devices, Their Proper Fit, Their Degree of Acceptance by Workers, The Pressure Points, Their Proper Weight Distribution, and Degree of Comfort Afforded to the Wearer.

Human factors are very subjective and have certain limitations because they cannot be quantified. However, the human factors aspect of this work is important in relationship to eye and face protective device standards. Therefore, it was our continuing concern to objectively evaluate and categorize the information we received so that input to the program contributed to the full extent possible.

Selection of Body Dimensions[1.1]*

The human body can be measured in an infinite number of ways. The initial task in preparing to conduct an anthropometric survey is not to determine what body measurements can be measured, but what measurements should be measured. Each user of anthropometric data has a list of body dimensions that he considers essential for the solution to his particular problems. The list of any one user rarely coincides with the list favored by another.

In the report, "Anthropometry of U.S. Army Aviators-1970," there were some 15 dimensions of the head and face which were chosen for measurement as being the most useful ones which could be obtained in the time for which each subject would be available.

The percentiles are a group of statistics belonging to a class of measures designated as "Measures of Order or Position." These measures can be thought of as being obtained by arranging the data in order from the smallest value to the largest one and then observing the value of the datum which lies at a specified position in the array.

The percentiles differ from other statistics in that there usually is not a value and especially not a unique value satisfying the exact definition of the percentiles. Any method of computation of the percentiles will of necessity require some compromise with the definition, and the method of computation becomes the de facto definition.

Human Variability[1.2]

There are wide differences in body dimensions between different national or ethnic groups and even within them. Caucasian, Negroes and Orientals differ from one another in height, weight, body proportion and in body physique. For example, stature varies from about 4.5 ft among Congo pygmies to more than 6.5 ft among certain African tribes among whom individuals of 7 ft are not unknown. Various groups of Northwest European derivations also are among the world's tallest people. The population of the United States in national group of mixed racial origins is among the larger-size members of the human species. Even within the same national population there is a wide range of size and proportions. For example, steel workers, truck drivers and athletes are usually larger and more muscular than bookkeepers, college professors and artists. Usually there are size differences between successive generations and within a given generation individuals tend to change size as they are from young adulthood.

*Superscript numbers in parentheses refer to List of References at the end of each Task Section discussion.

Because of human variability, anthropometric data for design use must be perceived as a range of values rather than an average. The use of the average alone is an error. Hence, each machine and/or each piece of personal protective equipment should include the adjustability needed to accommodate the range of sizes of operators and users. Adjustability of equipment is a keynote of design.

The Fallacy of the "Average Man"[1.3]

The designing to fit the "average man" is a serious error. By definition, 50% of any group might suffer from a design sized to the 50th percentile, and this would have serious consequences. For example, the smaller 50% would be able to reach a control just fitted to the average or 50th percentile operator.

A further fallacy of the "average man" concept is that it ignores the fact that no one is average in all respects, and few people in several. To demonstrate this for any sample, if one takes the middle third of any dimension, then takes the middle third of that third with respect to an unrelated dimension and then repeats the process for a third independent dimension, one obtains $1/3 \times 1/3 \times 1/3 = 1/27$, or less than 4% of the sample who will "average" in three traits. This has been found to be true for stature, weight and chest circumference in spite of the fact that these dimensions are correlated.

Even fewer persons, about 1%, will be average in four traits and the fraction becomes vanishingly small as the number of traits included increases further.

The "average man" concept is equally unfit for muscle strength and other biomechanical data. For example, in the design of an ejection seat, if trigger force requirements were set to the strength capacities of the average or 50th percentile pilot, then weaker 50% of pilots would be unable to escape.

(6) Result of Contact with Professional and Trade Associations to Help Determine the Needs for Eye and Face Protection

The following associations were contacted:

- National Safety Council
- American Chemical Society
- National Society for the Prevention of Blindness
- American Society of Safety Engineers

- American Academy of Ophthalmology
- American Welding Society

The responses received from these organizations were of no help in helping to determine eye and face protection needs.

James O'Neil, National Society for the Prevention of Blindness, has openly stated that it is his opinion that current eye and face protective devices are adequate and that the only problem is to get workers to use the protective devices.

LIST OF REFERENCES

1.1. Churchill, Edmund, et al., "Anthropometry of U.S. Army Aviators-1970," Anthropology Research Project, Yellow Springs, Ohio, Dec. 1971, AD 743-528.

1.2. Van Cott, Harold P., and Kinkade, Robert G., Human Engineering Guide to Equipment Design, American Institutes for Research, Washington, D.C., 1972.

1.3. Daniels, G.S., "The 'Average Man'?," Report No. WCRD-TN-53-7, 1972, Wright Air Development Center, Wright-Patterson AFB, Ohio.

TASK 2 - DEVELOPMENT OF EYE AND FACE PROTECTION NEEDS VERSUS DEVICES MATRIX

In accordance with the Scope of Work and the SwRI Technical Proposal for this project, the following items have been performed under this task:

(1) Development of a matrix system depicting the needs for occupational eye and face protection versus the possible eye and face protective devices that are available or could be produced to meet the needs.

(2) Identification of those needs that cannot be met by the manufacturers of the protective devices within the state-of-the-art.

(3) Indication in the matrix of which eye and face protective devices are covered by any existing standards and those for which there are not standards.

(1) Development of a Matrix of Hazards Versus Appropriate Eye and Face Protective Devices

The matrix presented in this task is not intended to be the panacea for eye and face protection. The matrix does, however, include the main hazardous environments and likely choices of eye and face protectors which will afford adequate protection for these situations. This matrix is only a recommendation for choosing particular types of protectors for particular types of tasks. It is the duty of the plant safety officers to examine the guidelines presented in the matrix and expand them to their particular needs. This is no small chore and should not be handled lightly, but rather with the utmost care.

The categories of protective devices has been made as general as possible so that the matrix will apply as the state-of-the-art of protectors increases with time. Since most working environments involve impacts of some type or another, all eye protectors shall be impact resistant.

The basic categories of eye and face protectors are as follows:

A. Spectacles

1. Clear lenses, without sideshields (Figure 2-1)
2. Clear lenses, with sideshields (Figure 2-2 and Figure 2-3)
3. Filter lenses, without sideshields
4. Filter lenses, with sideshields

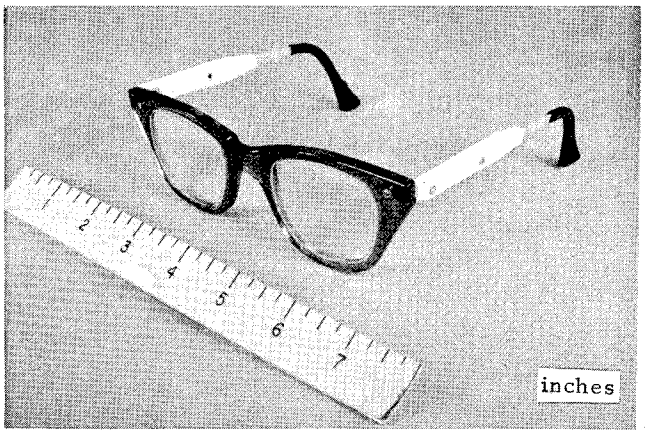

FIGURE 2-1. PLASTIC FRAME SAFETY SPECTACLES WITH CLEAR LENSES AND WITHOUT SIDESHIELDS

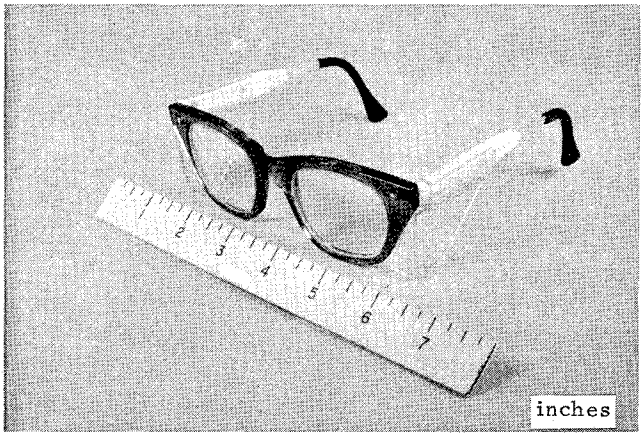

FIGURE 2-2. PLASTIC FRAME SAFETY SPECTACLES WITH CLEAR LENSES AND WITH FLAT-FOLD SIDESHIELDS

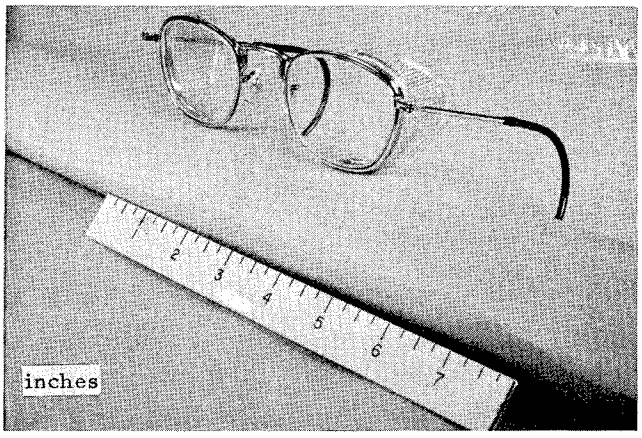

FIGURE 2-3. METAL FRAME SAFETY SPECTACLES WITH CLEAR LENSES AND WITH CUP-TYPE SIDESHIELDS

B. Cup and Cover Cup Goggles (Covers only eyes and immediate surrounding area)

1. Dust
2. Chemical splash
3. Impact (Figure 2-4 and 2-5)
4. Welding and cutting (Figures 2-6 and 2-7)
5. Molten metal
6. Combination of above

C. Facial Goggles (Including flexible fitting and cushioned fitting goggles)

1. Dust
2. Chemical splash
3. Impact (Figure 2-8)
4. Welding and cutting (Figure 2-9)
5. Molten metal
6. Combination of above

D. Face Shields

1. Chemical splash (Figure 2-10)
2. Impact (Figure 2-10)
3. Welding and cutting
4. Molten metal
5. Combination of above

E. Welding Helmets (Figure 2-11)

F. Visitors Spectacles (Figure 2-12)

- Dust protectors are characterized by indirect fine screen ventilation and close seal to face.

- Chemical splash protectors are characterized by indirect ventilation, close seal to face and chemical inertness.

- All protectors in the new standard should be impact resistant since it is difficult to find a working environment where eye protectors are needed and impact hazards are not present. Impact protectors are characterized by their resistance to impacting particles.

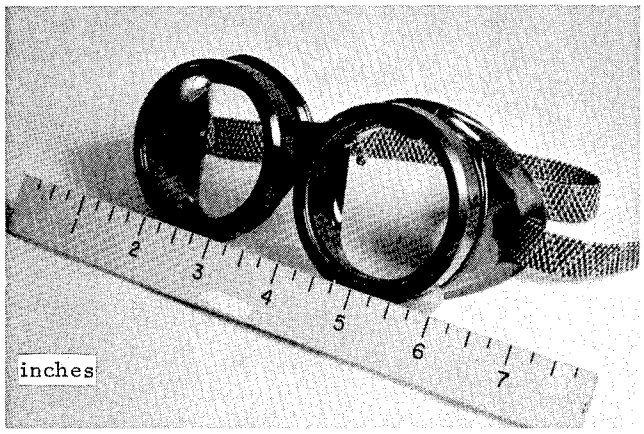

FIGURE 2-4. CUP GOGGLE FOR IMPACT PROTECTION

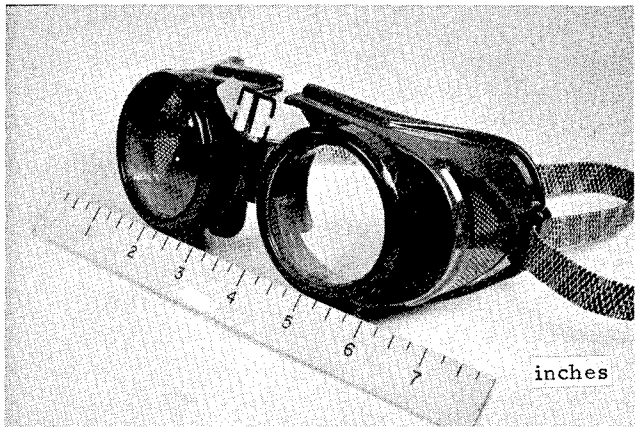

FIGURE 2-5. COVER CUP GOGGLE FOR IMPACT PROTECTION

FIGURE 2-6. CUP GOGGLE FOR WELDING AND CUTTING PROTECTION

FIGURE 2-7. COVER CUP GOGGLE FOR WELDING AND CUTTING PROTECTION

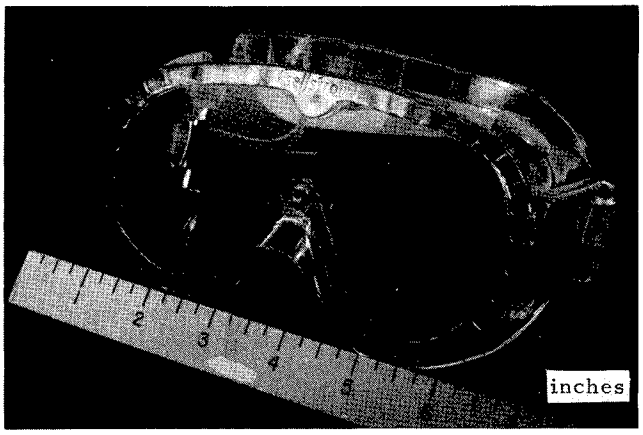

FIGURE 2-8. FACIAL GOGGLE FOR IMPACT PROTECTION

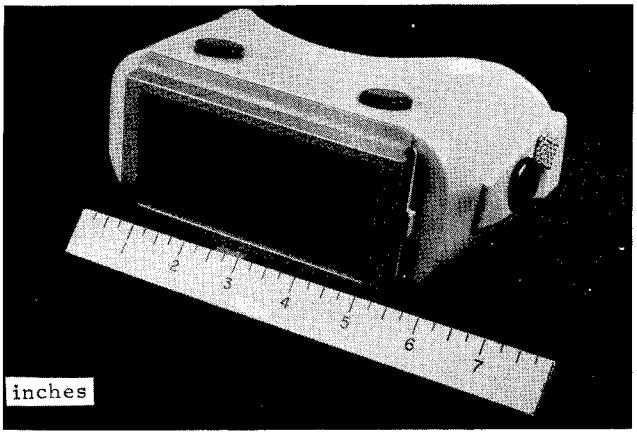

FIGURE 2-9. FACIAL GOGGLE FOR WELDING AND CUTTING PROTECTION

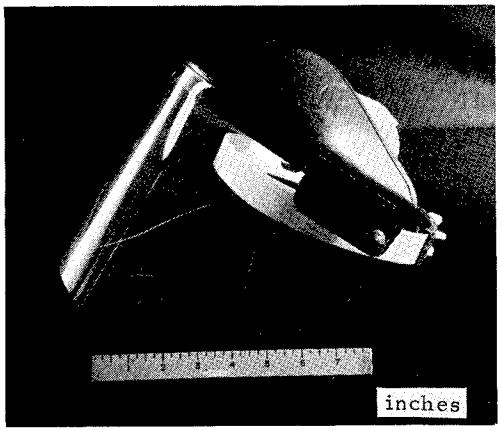

FIGURE 2-10. FACESHIELD FOR CHEMICAL SPLASH AND IMPACT PROTECTION

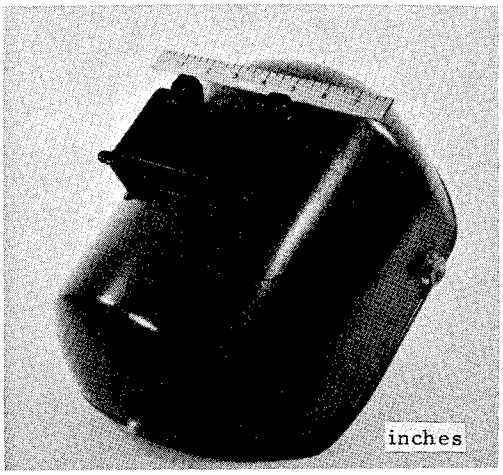

FIGURE 2-11. WELDING HELMET

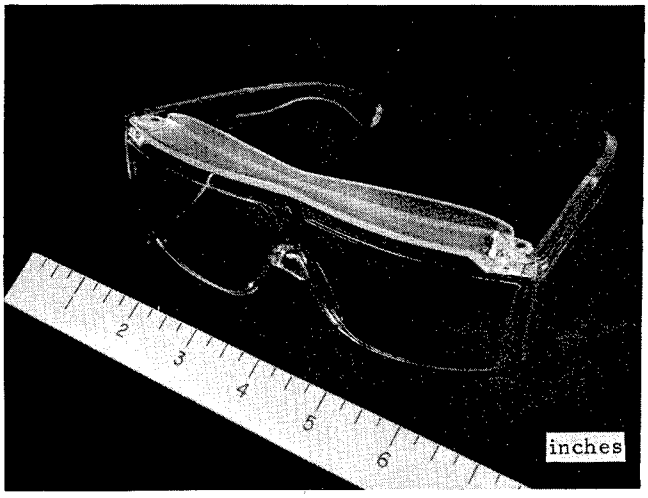

FIGURE 2-12. VISITOR'S SPECTACLES

- Welding and cutting protectors are characterized by their specific spectral transmittance properties and resistance to heat.

- Molten metal protectors are characterized by their resistance to hot objects and, in some instances, by their specific spectral transmittance properties.

There are a number of hazardous environments in which the worker needs eye and face protection. The general categories of hazards are given in the matrix. These categories, and proper eye and face protective devices for each category, were partially arrived at by consolidating the information given in the ANSI Z87.1 - 1968 "USA Standard Practice for Occupational and Educational Eye and Face Protection," appropriate portions of OSHAct Regulations Subpart I, "Personal Protective Equipment," Section 1910.133, Eye and Face Protection, and an "Occupational Health Bulletin," Vol. 26, 1971, Nos. 9-10 published by the Occupational Health Division of the Department of National Health and Welfare, Ottawa, Canada. With the aid of these three documents, accident statistics data showing sources of eye injuries, and the assistance of the chief safety engineer, Southwest Research Institute, the matrix of "Methods of Eye and Face Protection for Various Hazards," was constructed (Table 2-1).

(2) Protective Needs for Which Protective Devices are Lacking

The statistics do not show by themselves whether eye protective devices are sufficient to combat all hazards since many statistical accumulations of data in this area do not specify if protective equipment was worn during the accident. Conversations with eye and face protective equipment manufacturers, (listed in Task 1) revealed that they felt that the existing protectors were suitable, within reason, for all purposes. The safety directors mentioned in Task 1 had the same opinion, as did the National Safety Council. The SwRI safety director believes that, in most instances, eye protective devices are adequate. However, when conducting maintenance work beneath large motor vehicles, he believes that there are no "comfortable" eye protectors that can withstand the impacts of heavy articles such as "U" joints and drive shafts. He cited a case when a truck "U" joint fell on a worker's safety spectacles, shattering one lens. The pieces of the lens remained in the frame thus saving the eye, but had the projectile been slightly larger, the eye could have been extensively damaged.

In conclusion, there appears to be adequate eye and face protection for practically all hazards. With good protective equipment available, it is evident that a primary goal of every safety engineer should be to insure that the proper safety equipment is available to each worker and that every worker exposed to the hazardous conditions wear the safety equipment. The

TABLE 2-1. RECOMMENDED METHODS OF EYE AND FACE PROTECTION FOR VARIOUS HAZARDS

NOTE: There are six basic categories of protective devices in this matrix, (1) spectacles, (2) cup and cover cup goggles, (3) facial goggles, (4) face shields, (5) welding helmets, and (6) visitor's spectacles.

Each category has some or all of the following basic attributes:

Dust - indirect fine screen ventilation and close seal to face.
Chemical splash - indirect ventilation, close seal to face and chemical inertness.
Impact - resistant to impacting particles.
Welding & Cutting - specific transmittance properties and resistance to heat.
Molten Metal - resistance to hot objects and, in some instances, specific transmittance properties.

"XX" denotes that the attribute for which the protector is designed should be adequate for a particular hazard (e. g., impact).

"X" denotes that the protector must be designed for more than one attribute for a particular hazard (e. g., impact and dust) or, two protectors, one for each attribute, should be used.

	SUITABLE EYE AND FACE PROTECTIVE DEVICES																			
	Spectacles				Cup and Cover Cup Goggles					Facial Goggles					Face Shields					
Hazards	Clear lenses w/o sideshields	Clear lenses with sideshields	Filter lenses w/o sideshields	Filter lenses with sideshields	Dust	Chemical splash	Impact	Welding & cutting	Molten metal	Dust	Chemical splash	Impact	Welding & cutting	Molten metal	Chemical splash	Impact	Welding & cutting	Molten metal	Welding Helmets	Visitor's Spectacles* 1
Acids & Caustics (burns, splashes, fumes)											XX				XX					
Babbitting		XX					X		X			X		X		X		X		
Chemicals (splash, glass breakage)		XX				XX					XX				XX					
Chipping (flying particles)		XX					XX					XX				XX				
Compressed Air (30 PSI or less)					X		X			X		X								
Dusts					XX					XX										
Furnace Operations (glare, heat, molten metal)			XX	XX					XX					XX						
Glare - harmless			XX	XX																XX
Glare - harmful (infrared and ultraviolet)				XX				XX					XX			XX			XX	
Grinding - light (buffing, machining, flying particles)					X		X			X		X								
Grinding - heavy (flying particles, sparks)					X		X			X		X								
Hand and Power Tools	XX	XX					XX					XX				XX				
Machine Shop Operations (flying particles)		XX					XX					XX				XX				
Molten Metals (heat, glare, sparks, splash)				XX			X		X			X		X		X		X		
Riveting		XX					XX					XX								
Sand Blasting										X		X								
Steam Boiler Operations		XX					XX					XX				XX				
Welding, Cutting, Burning - Acetylene (sparks, harmful rays, molten metal, flying part)			XX	XX				XX					XX				XX			
Welding - Electric Arc (sparks, molten metal, harmful rays)								XX					XX						XX	
Welding - Spot and Butt (sparks, flying particles)		XX		XX			X		X			X		X		X		X		
Welding - helpers and adjacent to				XX				XX					XX				XX		XX	
Woodworking (dust)					X		X			X		X								
Woodworking (flying particles)		XX					XX					XX				XX				

*1 Protection for plant visitors should depend upon their exposure to particular hazards.

user of protective devices must be educated to recognize potential hazards and to minimize his (and others') possibility of becoming injured. This not only requires wearing proper protective equipment, but also practicing safe working habits.

(3) Indication of Which Protective Devices in the Matrix of Eye and Face Protective Devices Versus Hazards are Included in Existing Standards and Which Are Not.

All of the protective devices mentioned in the matrix are included in ANSI Z87.1 - 1968 "USA Standard Practice for Occupational and Educational Eye and Face Protection" except for the following. Visitors' spectacles are not mentioned in any existing standards. Shades for spectacle lenses and face shields are given only in terms of light, medium, and dark with specific luminous transmittance properties and no mention of transmittance properties in the infrared and ultraviolet regions of the spectrum. Cup and cover cup goggles to be used in operations involving molten metal, other than when welding or cutting, are not indicated. Requirements for facial goggles (flexible or cushioned fitting goggles in Z87.1) are not sufficiently developed in Z87.1, especially as regards to processes involving molten metal. Face shields designed for welding and cutting and molten metal protection are not mentioned in the existing standards. Some of the above items may not be available but could, if designed properly, offer good protection from various hazards. It is assumed that one of the protective equipment manufactuers' major goals is to offer the best possible protection at a competitive reasonable price. Protective devices should be able to withstand, with minimal damage, the working conditions for which they are designed. They should be comfortable to wear and should be appealing so that the workers will want to wear them.

TASK 3 - STUDY AND EVALUATION OF EYE INJURIES INVOLVING CONTACT LENSES

In accordance with the Scope of Work and the SwRI Technical Proposal for this project, the following items have been performed under this task:

(1) Study and evaluation of the cause and effect relationship existing in eye injury cases where contact lenses were used by the injured person.

(2) Conclusions concerning usage of contact lenses in working environments which are potentially hazardous to the eye and face.

(1) Study and Evaluation of the Cause and Effect Relationship Existing in Eye Injury Cases Where Contact Lenses Were Used by the Injured Person.

More than seven million Americans have contact lenses and approximately 750,000 sets of contact lenses are prescribed each year[3-1]*. There are two basic types of contact lenses, the conventional rigid contact lenses generally made from polymethyl methacrylate (PMMA), and new flexible "soft" contact lenses generally made from a hydrophilic (fluid-absorbing) compound such as hydroxyethyl methacrylate (HEMA). Although there has been increasing concern about the safety aspects of wearing contact lenses in a working environment, no significant statistical evaluation has been performed. The conclusions formed in this task are an accumulation of the opinions of the "experts" and a small amount of statistical evaluation. Since "soft" contact lenses are fairly new and are not as common as the conventional rigid contact lenses (approximately 300,000 pairs of "soft" contact lenses worldwide[3-2], further discussion on contact lenses is primarily directed toward the rigid lenses. Of the two basic types of rigid lenses, scleral (cover the whole front of eye including a portion of the sclera (white) and corneal (covers only the cornea), " sclera contact lenses are rarely encountered in industry"[3-3]. In fact, "at least 90 percent of contact lenses being fitted today in this country (United States) are corneal."[3-1]

Contact lenses have several distinct advantages over conventional corrective spectacles. Conventional rigid contact lenses have approximately 96 percent light transmission compared with 92 percent for spectacle lenses. More accurate size of the retinal image is attainable with contact lenses. The retinal image quality is better with contact lenses since the wearer views

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* Superscript numbers in parenthesis refer to list of References at the end of each Task Section discussion.

through the optical center of the lens at nearly all times. Peripheral vision is restored with contact lenses, and a better approximation of normal vision, especially for wearers with myopia (nearsightedness), is attainable with contact lenses than with spectacle lenses. With proper adaptation, contact lenses are more comfortable than eyeglasses, many of which are heavy and cumbersome and produce noticeable pressure on the wearer's nose and ears. Contact lenses are adaptable to more situations than eyeglasses and do not have to be removed as often. Since contact lenses provide much of the same natural protection to the eye as eyeglasses and do not extend beyond the face, they are not as susceptible to breakage under normal conditions. In fact, "10 years' wearing of the same set is common"[3-1]. When worn, contact lenses stay at body temperature and do not fog when the wearer goes from cold to hot or humid environments. Another major advantage of contact lenses is psychological. Because of the "cosmetic" attractiveness of contact lenses, wearers believe that they look better. In fact, in a "study of 1,622 youngsters, all of whom had previously worn glasses, more than 60 percent reported higher grades, 97 (percent) thought they looked better, (66 percent) reported more dates, more club activity, more sports activity, and more organized church and after-school participation"[3-1]. If it is proper to extend these statistical results to the working environment, one might expect an increase in job productivity from individuals who begin wearing contact lenses.

The advantages of contact lenses are slightly tainted by their disadvantages. Being a foreign object, contact lenses require an adaptation time. Typical adaptation problems include lacrimation with resulting lens movement, hazy vision, burning, corneal edema, lens slippage off of the cornea and occasionally lenses falling out. These adaptation problems desist after a few weeks for those contact lens wearers who have sufficient motivation and proper physiological attributes. Since contact lenses are fragile, they can be easily chipped, scratched, or even broken when subjected to improper handling. It is essential that contact lenses be cleaned and stored properly when not in use. Solid particles and chemicals which drift into the eyes can be trapped between the lens and eye and cause irritation and abrasion. Prolonged wearing of contact lenses and improper blinking and tearing can cause some of the difficulties experienced during the adaptation period.

So far, no specific cases of eye accidents involving contact lenses have been mentioned in this report. Although, to our knowledge, there is no extensive statistical evaluation available, some accident statistics are available. In fact, the statistics on eye accidents involving contact lenses was so well presented in a paper entitled "Eye Protection from Contact Lenses"[3-4] that it is included in Appendix C in this report. In this study, a questionnaire was presented to 300 optometrists and ophthalmologists, 65 percent of which responded. They asked for "descriptions of individual instances in which contact lens wearers experienced eye protection" or damage following exposure to chemicals, fumes and foreign bodies. The

128 incidents are presented in five categories: sports, automobile, workshop, chemical and miscellaneous. Comments on individual accidents are also presented. The summary of this paper states that "the protection from contact lenses is obvious in cases of physical trauma, in comparison to a survey of spectacle lens injuries, as well as the large amount of literature on the subject of ocular injuries in general. In addition, animal experiments and the patients reported here show contact lenses provided protection in chemical accidents. From this evidence it is difficult to accept generalizations that contact lenses are unsafe in chemical environments. Specific examples include: several automobile accidents in which the windshields shattered causing the contact lens to be scratched but no damage done to the eye; several working situations where projectiles were prevented from causing serious damage to the eye because of the presence of the contact lenses; a case where a person, welding with no eye protection, was struck with some welding slag which burned a hole in his contact lens but only caused slight corneal damage to his eye; and several cases of chemical splashes where damage was done to the eye around the periphery of the lens but none where the lens covered the eye. Some negative effects, possibly partially due to contact lenses, can be found in this small statistical sampling. These especially hazardous areas for contact lens wearers occurred where there was exposure to chemical fumes and dust. Rengstorff and Black emphatically state that they do not intend in this paper that contact lenses be used as eye protection in place of existing industrial and educational eye protection.

The "Contact Lens White Paper"[3-1] presented by the American Optometric Association (January 1972) also makes statements which support the work done by Rengstorff and Black. "Breakage of a contact lens being worn has rarely been reported, and no permanent eye damage has been found as a result. Solid particles and chemicals which draft into the eye are blocked in some cases by contact lenses, particularly scleral lenses, but can be trapped under the lens." In fact, the "White Paper" states that "profesionally prescribed contact lenses, properly cared for and worn according to schedule, are as safe as eyeglasses in wearing and safer in certain respects." This paper also quotes a statement made by Commercial Aviation which states that the probability of properly fitted contact lenses falling out are astronomical, and that this is not the case with eyeglasses which, by their nature, are in one unit.

(2) Conclusions Concerning Usage of Contact Lenses in Working Environments Which Are Potentially Hazardous to the Eye and Face

The conclusions presented below are for conventional rigid contact lenses and not for "soft" contact lenses. The accident data available for the latter is even scarcer than for rigid contact lenses. Our conclusions are made from the limited number of documents available to us, discussions with various safety engineers and eye and face protective equipment manufacturers. As more knowledge on the subject becomes available, there may be need for a reevaluation and update of these conclusions:

- At no time should contact lenses be considered as substitutes for eye protection.

- The contact lens wearer should be known to all who may be called upon to tend to his needs in case of an accident.

- Means for removal of contact lenses should always be readily available.

- At least one person in the immediate working vicinity of the contact lens wearer, trained to remove contact lenses from another, should be available in case of injury.

- Wearing contact lenses in hazardous environments during the adaptation period should not be allowed unless approved by the physician fitting the lenses.

- A person wearing contact lenses should not be allowed to work in areas where there is extensive exposure to fumes, smoke, dust or fine particles, and, in some cases, chemical and molten metal unless approved by the physician fitting the lenses.

- The contact lens wearer should have a suitable means of cleaning and storing his contact lenses and a reliable pair of opthalmic eyeglasses immediately available.

LIST OF REFERENCES

3-1. "Contact Lens White Paper," American Optometric Assocation, January 1972.

3-2. "Outlook for Soft Contact Lenses," Service to Investors, Arthur D. Little, Inc., September 17, 1973, pp. 1-15.

3-3. Novak, Joseph F., M. D., and Saul, Robert W., M.D., "Contact Lenses in Industry," Journal of Occupational Medicine.

3-4. Rengstorff, Roy H., O.D., Ph.D., and Black, Chester J., M.D., "Eye Protection from Contact Lenses," Journal of the American Optometric Association.

TASK 4 - SEARCH AND EVALUATION OF EYE THRESHOLD LIMIT VALUES

The following items have been performed under this task:

(1) Ultraviolet Radiation Threshold Limit Value

(2) Visible Radiation Threshold Limit Value

(3) Infrared Radiation Threshold Limit Value

(4) Welding Arc Spectral Data

(5) Evaluation of Recommended Filter Shades

Metal joining and metal removal are two industrial operations in which the employee's eyes are subjected not only to the hazards from flying metal debris but also to the hazards from exposure to the optical radiation that is emitted by the welding arc or cutting flame. Both the ANSI Standard Z49.1[4-1] and the Accident Prevention Manual for Industrial Operations[4-2] recommend the filter shade number that should be worn in conjunction with a given type of welding operation. From the manufacturing standpoint, the current Z87.1 Standard defines the allowable radiation transmission characteristics of these filter plates. The broad objective of Tasks 4 and 6 is to determine if the recommended filters for preselected processes are effective in attenuating the optical radiation spectrum of the arc to subocular damage levels. The optical radiation spectrum includes the ultraviolet (UV), visible and infrared (IR) wavelengths, and various segments of this spectrum are capable of producing distinctly different modes of damage to the unprotected or inadequately protected eye.

The research effort on these two tasks excludes protection criteria for radiation sources such as lasers since these devices are covered in ANSI Standard Z136.1.[4-3]

Optical radiation protection involves three major areas of inquiry:

- What is the origin of or rationale behind the welding filter transmittance specifications that are contained in Z87.1, and are these specifications based on ocular damage thresholds? (Task 6)

- What are the Threshold Limit Values (TLV) or ocular damage thresholds for the UV, visible and IR segments of the optical radiation spectrum?

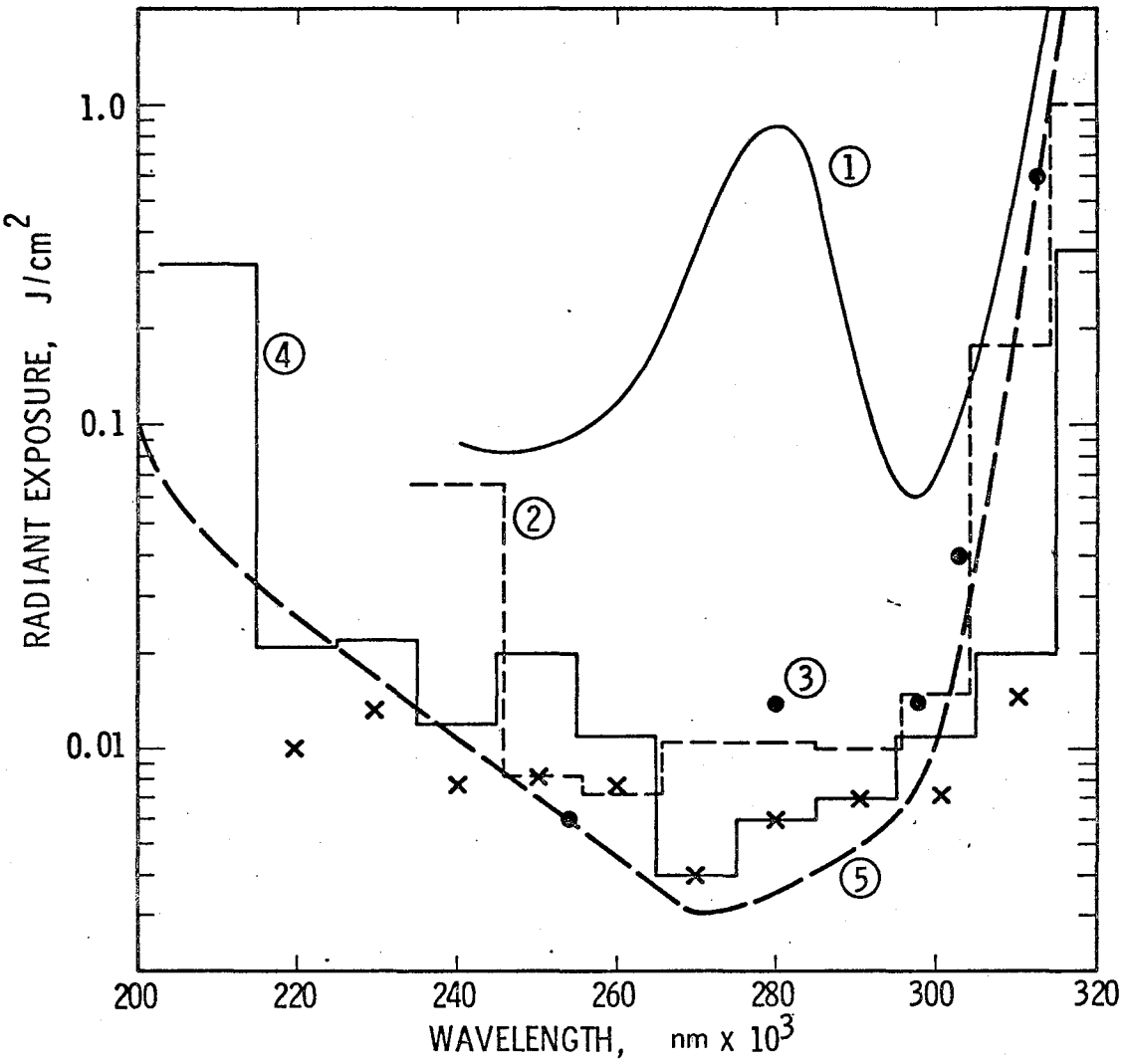
- What are the radiation spectra that are emitted by the most commonly used welding processes, and does the use of the recommended filter shade or shades reduce the incident radiation on the eye to sub-TLV levels? That is, is the filter transmittance specification compatible with the filter usage recommendation so as to provide adequate eye protection?

(1) Ultraviolet Radiation Threshold Limit Value

A comprehensive presentation of the photochemical effects of ultraviolet radiation (200 to 400 nm) on the eye is contained in several recent publications by D. H. Sliney[4-4, 5]. For purposes of discussing ultraviolet Threshold Limit Values (TLV) for the eye, the ultraviolet region can conveniently be divided into the actinic region (200 to 315 nm) and the near UV (315 to 400 nm). Direct biological effects from UV wavelengths shorter than 200 nm do not occur because these wavelengths are completely absorbed by the atmosphere. The primary biological effects of actinic ultraviolet (excluding lasers) are skin erythema and keratitis and conjunctivitis of the eye. The wavelengths that are involved in the production of these effects define the so-called action spectrum or region of effectiveness. At the present time, TLV's for actinic ultraviolet emitted by broad band sources have been proposed by the American Conference of Governmental Industrial Hygienists (ACGIH)[4-4], and have been incorporated into the ANSI Laser Standard Z136.1. The basis for the proposed keratoconjunctivitis/erythemal threshold is shown in Figure 4-1, which was modified from Reference 4-5. This figure represents a composite of the thresholds that have been experimentally determined by various investigators as well as the proposed exposure envelope. Specific literature citations for these data are contained in References 4-4 and 4-5.

Two erythemal thresholds are shown--moderate and minimal. Peak sensitivity of the skin for moderate erythema occurs at 254 nm and at 300 nm. The peak in the action spectrum for minimal erythema also occurs near 250 nm. The effective dose for erythema production as determined by Berger is indicated by the solid dots.

The action spectrum for keratoconjunctivitis of the primate eye is indicated by the solid line histogram. Peak sensitivity occurs at 270 nm, and decreases rapidly as the wavelength approaches 320 nm. The exact rate of change of ocular sensitivity in this region is open for discussion, since the experimental procedure utilized a constant bandwidth exposure which produces a reduced resolution when the threshold is increasing rapidly. Consequently, from 300 to 320 nm, the proposed ACGIH exposure envelope approximates the erythemal threshold. From 230 to 300 nm, the proposed threshold lies below the keratitic threshold that was determined by Pitts. Below 230 nm, the exposure threshold is faired into a corneal dose of 0.1 J/cm^2 at 200 nm. Note the apparent margin of safety between the ACGIH curve and the sensitivity peak in the keratitic threshold at 270 nm.



① MODERATE ERYTHEMA (COBLENTZ)
② MINIMAL ERYTHEMA (FREEMAN, EVERETT)
③ ERYTHEMA (BERGER)
④ KERATITIS, PITTS, PRIMATE
⑤ ACGIH PROPOSED THRESHOLD ENVELOPE
× KERATITIS, PITTS, HUMAN

$$t_{exp}^{T}(\text{sec}) = \frac{1}{\Sigma H(\lambda) / Q^{T}(\lambda)}$$

FIGURE 4-1. ACTINIC ULTRAVIOLET ACTION SPECTRA AND PROPOSED THRESHOLD LIMIT VALUES

In Figure 4-1, the primate data according to Pitts[4-7, 8, 9] were obtained using the Macaca Mulatta primate. Pitts also determined the keratitic action spectrum for the rabbit. The action spectra for these two species peak at the same wavelength band (260 to 270 nm). In this region, the primate threshold is 80 percent of the rabbit threshold (5 mJ/cm^2). At all other wavelengths, the primate threshold is considerably below the rabbit threshold. The criteria that were used in establishing these thresholds were the appearance of corneal granules and epithelial haze. The early work of Pitts on the human tolerance to actinic ultraviolet indicated a threshold dose of 5 mJ/cm^2 at 280 nm. Since that time Pitts has published a keratitic action spectrum for humans[4-10] in the wavelength band from 220 to 310 nm. Seven criteria were used to determine the human UV threshold--epithelial debris, epithelial haze, epithelial granules, photophobia, symptomatology, visual acuity, and corneal light scatter. Three to four positive responses to these criteria defined the threshold. Between 270 and 290 nm, the human threshold coincides with the primate threshold. Beyond 290 nm, the human tolerance is approximately 70 percent of the primate threshold. Below 250 nm, the human threshold is well below the primate curve. Based on these data, Pitts suggests that the human UV action spectrum covers the range from 220 to 310 nm as opposed to the primate and rabbit spectra which includes wavelengths from 210 to 320 nm. In this recent publication, Pitts proposed a banded UV exposure threshold. The lower boundary of this band corresponds to an exposure spectrum which results in minimal decrease in visual acuity, minimal discomfort and impairment of visual performance. The upper boundary (20 percent above the lower boundary) defines the level required for discomfort and incapacitation (photophobia, decreased acuity).

The fact that the action spectrum for the human lies below the ACGIH exposure envelope would suggest that the envelope should be modified downward. However, at this time, there is insufficient evidence to justify such a proposal. This statement is based on the previously mentioned uncertainties in the slope of the threshold curve at the extremities of the action spectrum. Based on the ACGIH curve, D. H. Sliney has calculated that the keratitic threshold should be exceeded during short duration exposure to diffuse sunlight. In reality, such a condition does not occur, which indicates that the slope of the exposure envelope may be too shallow at the extremities of the action spectrum. Consequently, we believe that the ACGIH envelope should be applied with caution until more definitive data is obtained following the development of narrower bandwidth UV sources.

With respect to keratitis, the effects of repeated exposure to actinic ultraviolet are cumulative, and the keratitic eye regenerates in approximately 24 hours. Since the effects are cumulative, the time required to exceed the threshold can be estimated as shown in Figure 4-1, where $H(\lambda)$ is the spectral irradiance of the radiation source and $Q^T(\lambda)$ is the spectral dose threshold. The critical exposure time is then obtained by

weighting the ultraviolet irradiance spectrum of the source with the UV action spectrum.

For ocular protection in the near UV (315 to 400 nm), the ACGIH recommends a maximum corneal dose of 1.0 J/cm^2 for exposure times less than 1000 sec and a total irradiance of 1.0 mW/cm^2 for times greater than 1000 sec. Cataracts have been produced by a 1000-sec exposure to a 325 nm laser at a corneal irradiance of approximately 1.0 J/cm^2-sec[4.4] (total corneal dose of 1000 J/cm^2). The recommended standard appears to be based on the application of a safety factor of 1000 to the corneal dose that produced a cataract under the assumption that reciprocity of irradiance and exposure time holds for exposure times less than 1000 sec. For exposure times greater than 1000 sec, the threshold corneal irradiance is held constant at a level that is three orders of magnitude below the irradiance needed to produce a cataract at a 1000 sec exposure. Interestingly, the 1.0 J/cm^2 threshold for times less than 1000 sec coincides exactly with the ACGIH keratitic threshold at 315 nm. Finally, this near ultraviolet threshold is wavelength independent--a behavior that has been assumed because of a lack of data to the contrary.

(2) Visible Radiation Threshold Limit Value

Optical radiation in the 400 to 750 nm wavelength range is transmitted to the retina with minimal attenuation or absoprtion by the anterior ocular media[4-11]. Primary absorption takes place at the retina and choroid. The energy that is absorbed can either enter into a photochemical reaction or be converted into heat. Matelsky[4-12] states that the energy emitted by visible radiation sources is insufficient to produce a photochemical reaction that would result in irreversible damage to the eye. However, the proper combination of source intensity, source geometry and exposure time can produce irreversible thermal damage to the ocular tissues, i.e., a burn.

The ability of the eye to tolerate these thermal effects can be expressed in terms of a Threshold Limit Value (TLV) or damage threshold which is based on an appropriate damage criterion. At the present time, visible radiation TLV's do not exist for all components of the ocular media. Since the majority of the incident visible radiation is transmitted to the retina, a substantial amount of research has been conducted to establish tolerance limits for chorioretinal burns resulting from exposure to lasers[4-3, 6] and broad band light sources[4-13]. Reference 4-6 contains corneal safe exposure limits for the monochromatic sources. Jacobson, et al.[4-14] researched the tolerance limits for the cornea and iris with a selectively filtered broad band light source.

The chorioretinal burn thresholds for visible light that will be presented are based on the broad band exposure data of Miller and White[4-13].

The laser damage data in the visible region was specifically excluded because:

- It is difficult to confidently state a retinal image diameter for calculating radiation dose,
- The industrial sources of interest are not monochromatic,
- In the visible spectrum, extrapolation of a monochromatic threshold to a broad band threshold is questionable, i.e., macroscopic versus microscopic effects.

The retinal burn threshold for the Macaca Mulatta primate (rhesus monkey) is shown in Figure 4-2. The optical structure of the monkey's eye is such that the image quality approximates the human eye even though the focal length is 20% less than in the human eye. Retinal dose, $Q_r{}^T$, is shown as a function of image diameter and exposure duration. The damage criterion is the appearance of a visible lesion within five hours after exposure. If a lesion does not appear within that time, there is a high probability that one will not appear at a later time. Miller and White also determined an extramacular threshold in addition to the foveal threshold that is shown in this figure. Their results indicate that the foveal threshold is approximately 25% lower than the extramacular threshold for all image diameters and exposure times. Therefore, the most critical exposure conditions are represented in Figure 4-2.

The primary histologic characteristic of the burns is the total absence of the outer nuclei layer. In addition, beneath the lesion is a hyperpigmented region (increase in number of pigment granules) in the epithelium surrounded by a hypopigmented area. Ophthalmoscopically, the lesions appear as concentric light and dark rings.

In the Miller and White experiments, the integrated average, retinal irradiance, $\overline{H}_r$, was generated by applying an average transmission factor for the ocular media of 0.59 to the average corneal irradiance. This average transmission factor reflects the wavelength dependent absorption properties of the ocular media as applied to the source input spectrum.

The energy source that was used in generating the chorioretinal lesions was a Meyer-Schwickerath photocoagulator that was modified to accept a high-pressure Xenon lamp. The relative spectral irradiance of this source[4-15] is shown in Figure 4-3. A KG-3 infrared absorbing filter was added to reduce the IR content of the source. Also shown in this figure is normalized spectral distribution of a 5800°K black body which approximates the solar spectrum (6250°K) above the atmosphere.[4-15]

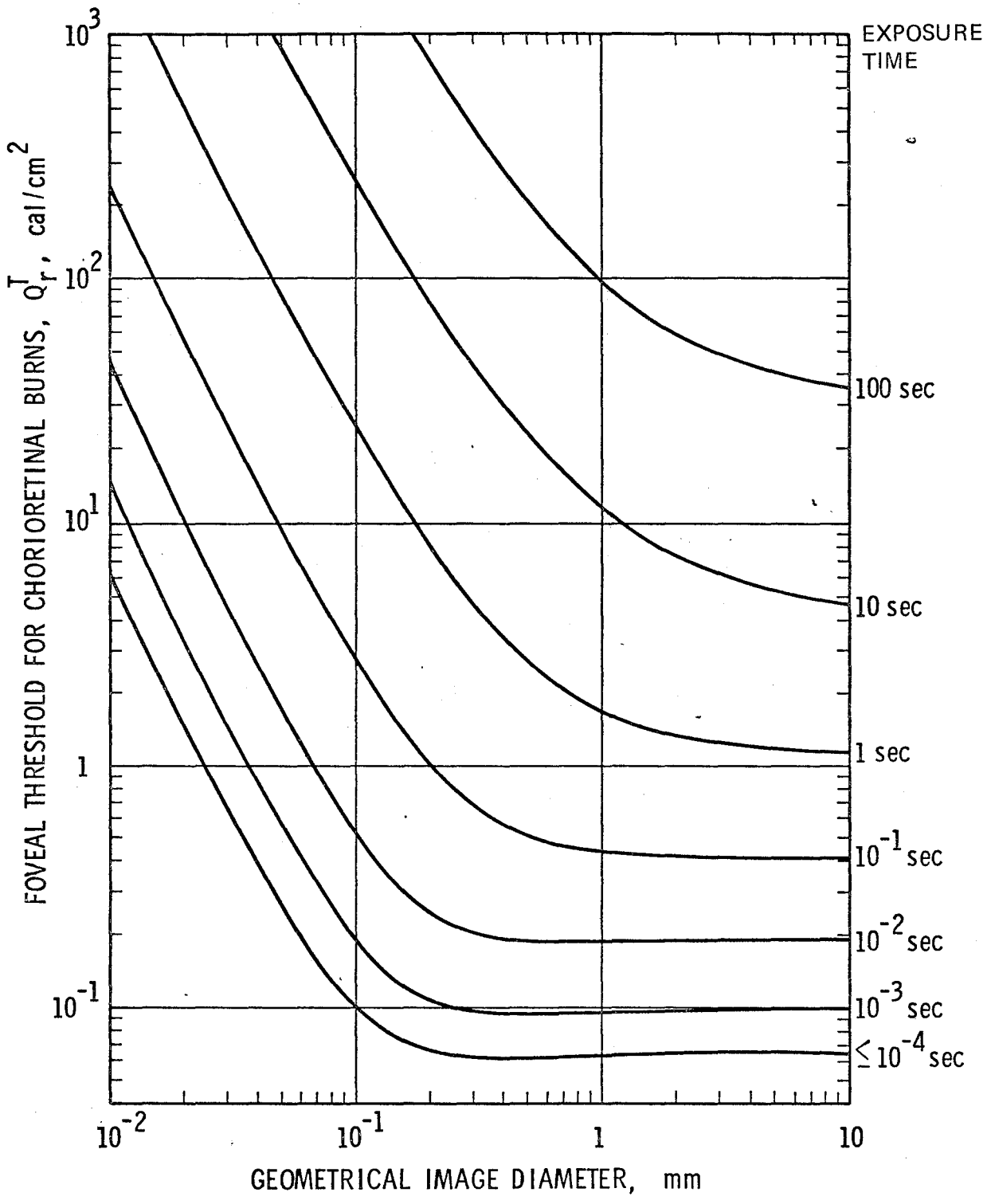


FIGURE 4-2. CHORIORETINAL BURN THRESHOLD FOR PRIMATES

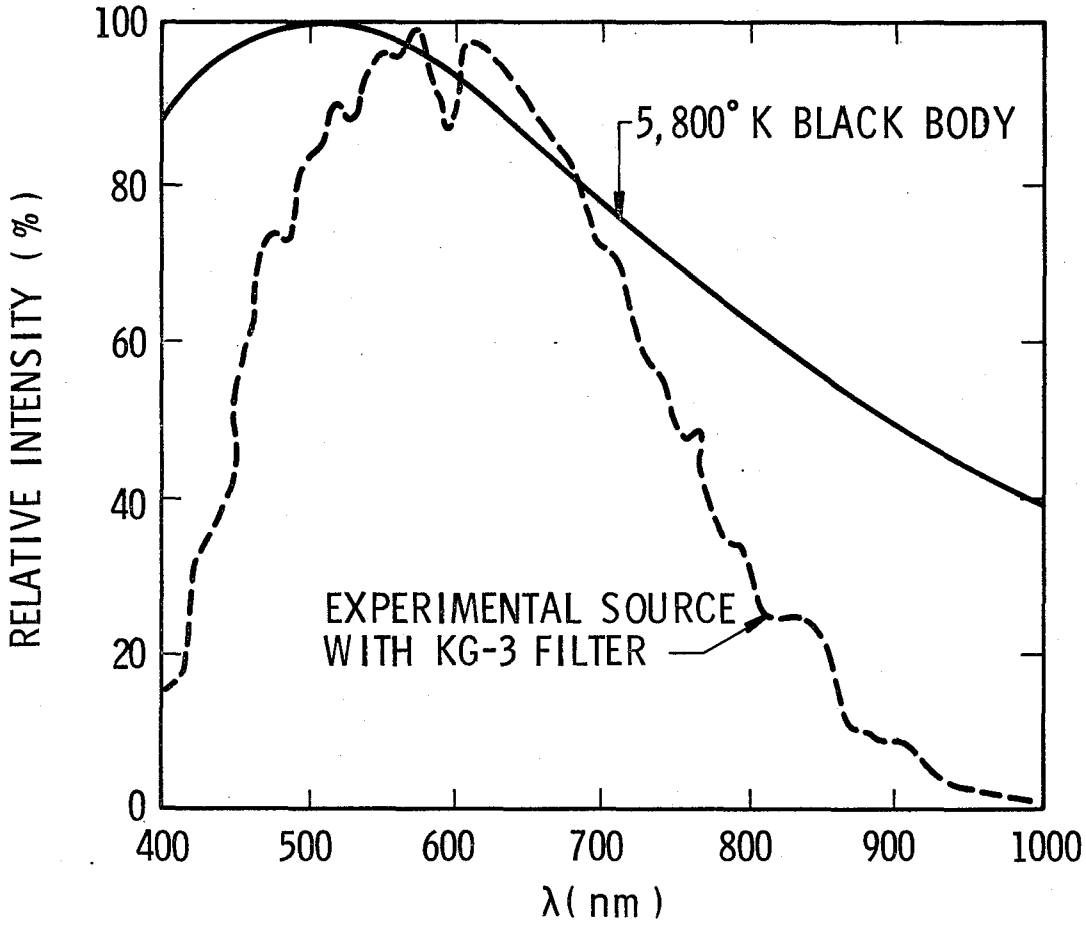


FIGURE 4-3. KG-3 FILTERED XENON SPECTRUM FROM THE MODIFIED COAGULATOR-NORMALIZED TO THE SPECTRUM OF A 5800°K BLACK BODY (Ref. 4-15)

The temperature of a welding arc plus molten metal pool is roughly 6000°K[4-16] and has a spectrum similar to that of the sun but shifted slightly toward the red wavelengths[4-11]. By deduction, the spectral distribution of the filtered Xenon source, from which the retinal burn thresholds were derived, is a usable approximation of arc spectrum in the visible region.

The application of this chorioretinal burn threshold in the visible region is summarized in Figure 4-4. The retinal dose, exposure time and retinal image diameter must be known. The image diameter, d_i, is a function of the focal length of the eye, a characteristic dimension of the radiation source, D_S, and the separation distance, D, from the source to the corneal plane. The average corneal irradiance is obtained by averaging the product of the arc irradiance spectrum and the filter transmission spectrum. Retinal irradiance is related to corneal irradiance through the magnification properties of the eye's optical imaging system. This magnification factor involves the square of the ratio of the pupil diameter, D_P, to the image diameter, d_i. The attenuation of visible energy by the ocular media is reflected in the average transmission factor, $\bar{k}$. Retinal dose is defined as the product of retinal irradiance and exposure time. In this manner, the adequacy of a recommended filter shade can be evaluated. For purposes of retinal heating during arc welding, an exposure time of one to two minutes is consistent with arc times in job shops. To be on the conservative side, we recommend the use of a 7-mm pupil diameter for calculation purposes. This pupil diameter represents the most critical condition that can exist behind a filter plate in that this diameter yields the maximum retinal irradiance.

As was stated earlier, Jacobson, et al. established burn thresholds for the iris and cornea exposed to a selectively filtered visible light source. Since the thresholds were established for rabbits, it is questionable if the data can be extrapolated to predict the response of the human eye. Nevertheless, the iris and cornea dose thresholds were essentially constant for wavelengths between 370 and 830 nm. Average values in this range were 0.88 cal/cm^2 for the cornea and 0.84 cal/cm^2 at the cornea for iris damage.

(3) Infrared Radiation Threshold Limit Value

Approximately 30 percent of the total radiation emitted by a welding arc is contained in the infrared region beyond 750 nm[4-16]. As will be noted later in this section, the experimentally determined arc spectra for numerous processes do not support this distribution. As the wavelength increased from 750 to 1400 nm, infrared radiation is transmitted in decreasing amounts through the ocular media to the retina; that is, the spectral absorption by the ocular media increases as a function of wavelength. These wavelengths are not preceived as

$$d_i = \frac{F D_s}{D}$$

$$\bar{H}_r = \bar{H}_c(D)\,\frac{D_P^2 D^2}{F^2 D_s^2}\,\bar{k}\;;\quad \bar{H}_c(D) = \overline{H_{arc}(\lambda, D)\,t(\lambda)}$$

$$\bar{Q}_r = \bar{H}_r\, t_{exp}$$

F = focal length of the eye

D_P = pupil diameter

D_s = characteristic dimension of source

D = distance from source to cornea

$\bar{k}$ = transmission factor for ocular media

$\bar{H}_c(D)$ = average corneal irradiance

$\bar{H}_r$ = average retinal irradiance

$\bar{Q}_r$ = average retinal dose

$t(\lambda)$ = filter transmission spectrum

FIGURE 4-4. APPLICATION OF RETINAL BURN THRESHOLD TO A SOURCE RADIATING IN THE VISIBLE SPECTRUM

visible light but are absorbed by the retina which results in retinal heating. Between 1400 and 1900 nm, virtually all of the IR is absorbed by the cornea and aqueous humor[4-5, 12]. Beyond 1900 nm, all of the incident IR energy is absorbed by the cornea[4-5, 12]. Consequently, beyond 1400 nm, the primary effect of IR is corneal heating.

Because of the lack of IR threshold limit value data for broadband or extended sources, it is necessary to rely on laser or monochromatic TLV's. The use of a laser TLV in this region is considered to be conservative when applied to a broadband IR source.

The threshold limit value for corneal lesion from IR wavelengths greater than 1400 nm is essentially the same as the TLV for the skin in the same wavelength range[4-5]. The accepted TLV for irreversible corneal lesions is 100 mW/cm^2 (corneal irradiance) at exposure times greater than 10 sec[4-3, 5]. This threshold corneal irradiance is recognized by the ACGIH and the ANSI Z136.1 Committee and is based on corneal lesion and heat sensation thresholds for the CO_2 laser (10600 nm)[4-18]. This laser exposure criteria is conservative for acute exposure to all IR wavelengths greater than 1400 nm. In addition, 100 mW/cm^2 is used by the U.S. Army as the threshold irradiance for continuous operation of extended sources that emit beyond 1400 nm.

The TLV data for visible radiation are applicable strictly to wavelengths less than approximately 750 nm. To bridge the gap between 750 and 1400 nm, the maximum permissible exposure, or MPE, for direct ocular intra-beam viewing of a laser as presented in ANSI Z136.1[4-3] has been adapted to the current problem. Strictly speaking, this MPE, which is shown in Figure 4-5, applies to retinal burns at a wavelength of 750 nm and is expressed as corneal threshold irradiance, a function of exposure time. In the Z136.1 Standard, this MPE increases as a function of wavelength between 400 and 1400 nm. Since wavelengths up to 750 nm have been accounted for in the visible TLV, it is recommended that the laser TLV for λ = 750 nm be used as the TLV for all wavelengths between 750 and 1400 nm. It is readily seen that this decision will impart a desirable factor of safety for radiation in this wavelength band.

(4) Welding Arc Spectral Data

Optical radiation spectra in the form of corneal irradiance versus wavelength have been obtained for all of the processes that are contained in Tables 4-1 and 4-2. In only two cases was it deemed necessary to deviate the original test matrix.

- The electrode diameter for E70S-4 solid wire was increased to 1/16-inch from 0.045-inch in order to expand the arc amperage range.

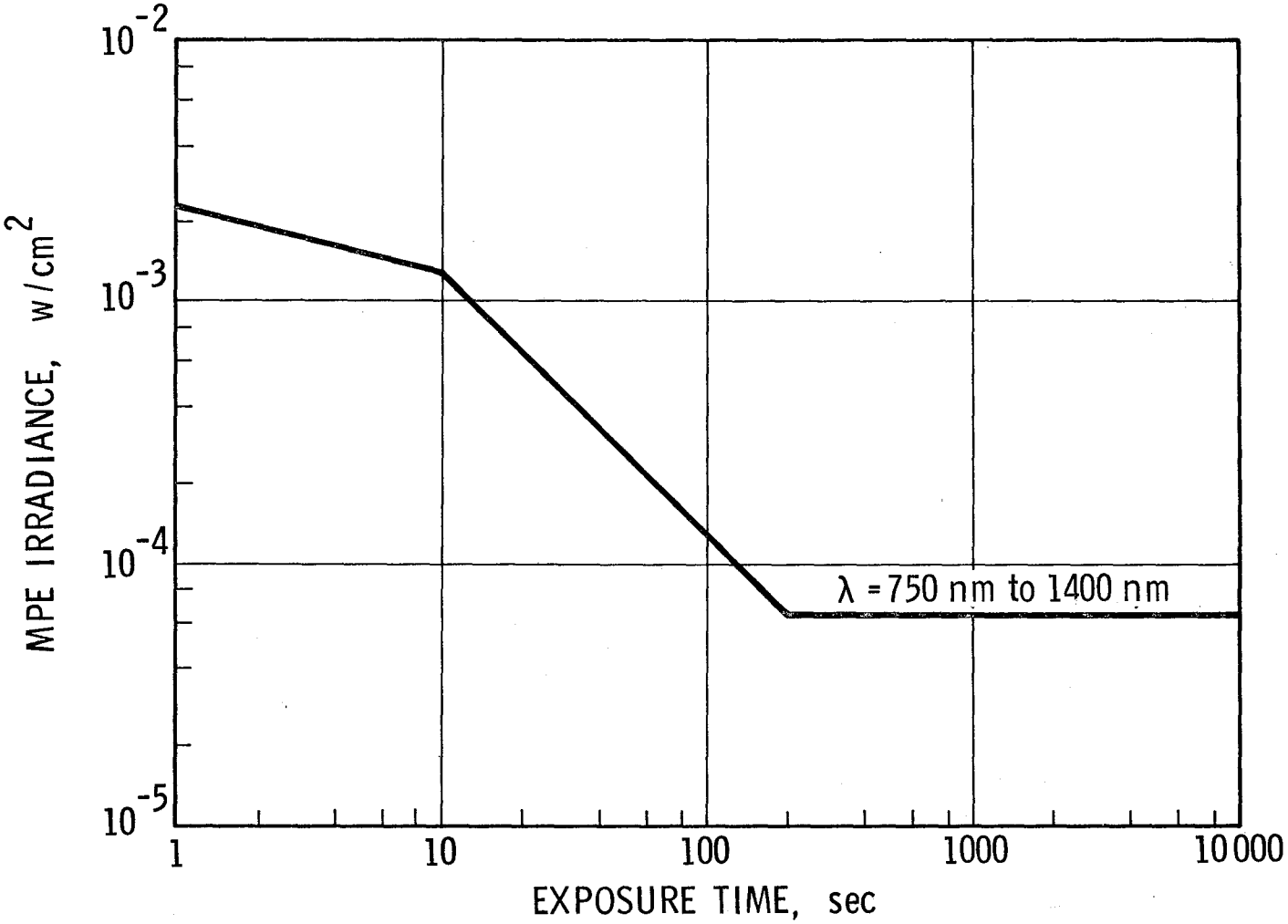


FIGURE 4-5. MPE CORNEAL IRRADIANCE FOR RETINAL BURNS
(FROM ANSI Z136.1)

TABLE 4-1. PROCESS VARIABLES FOR WELDING AND CUTTING OF CARBON STEEL

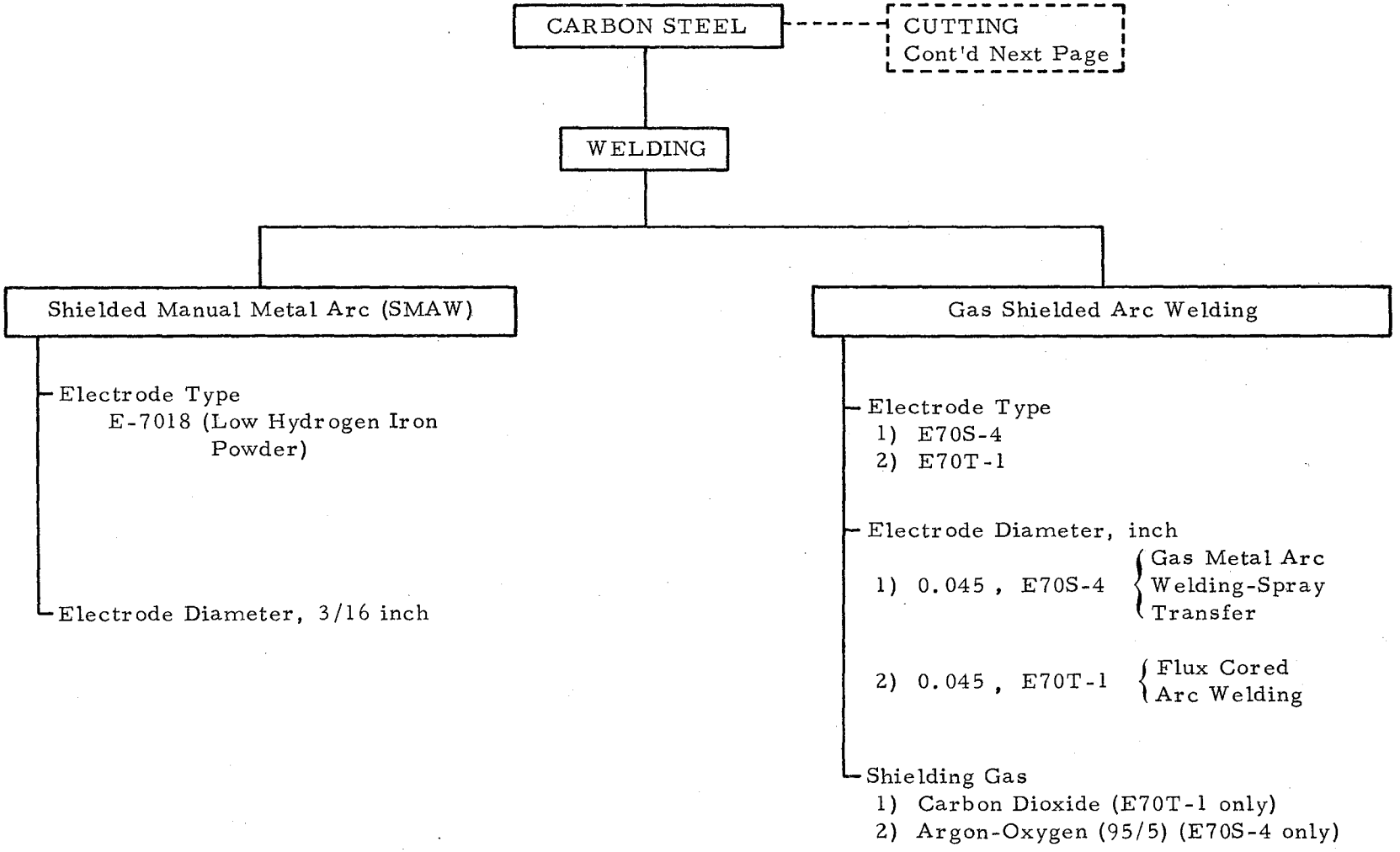
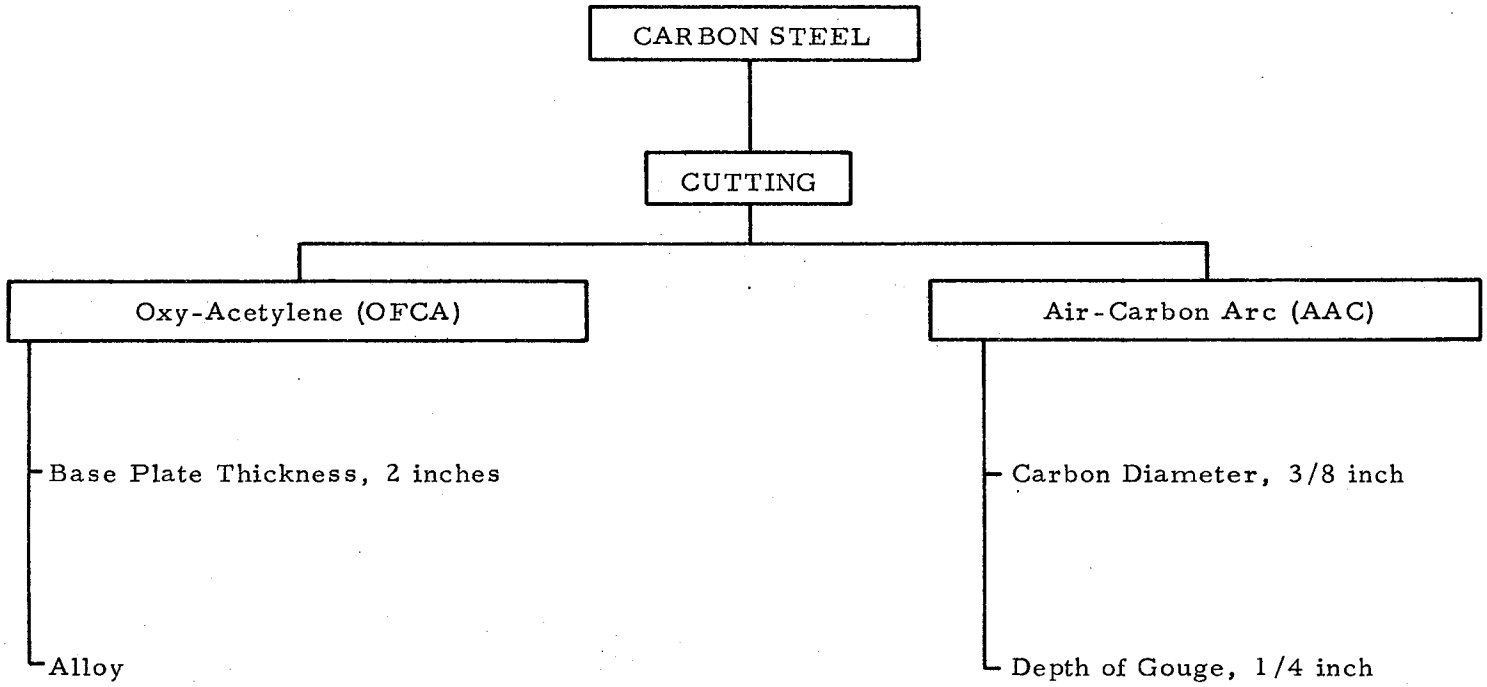
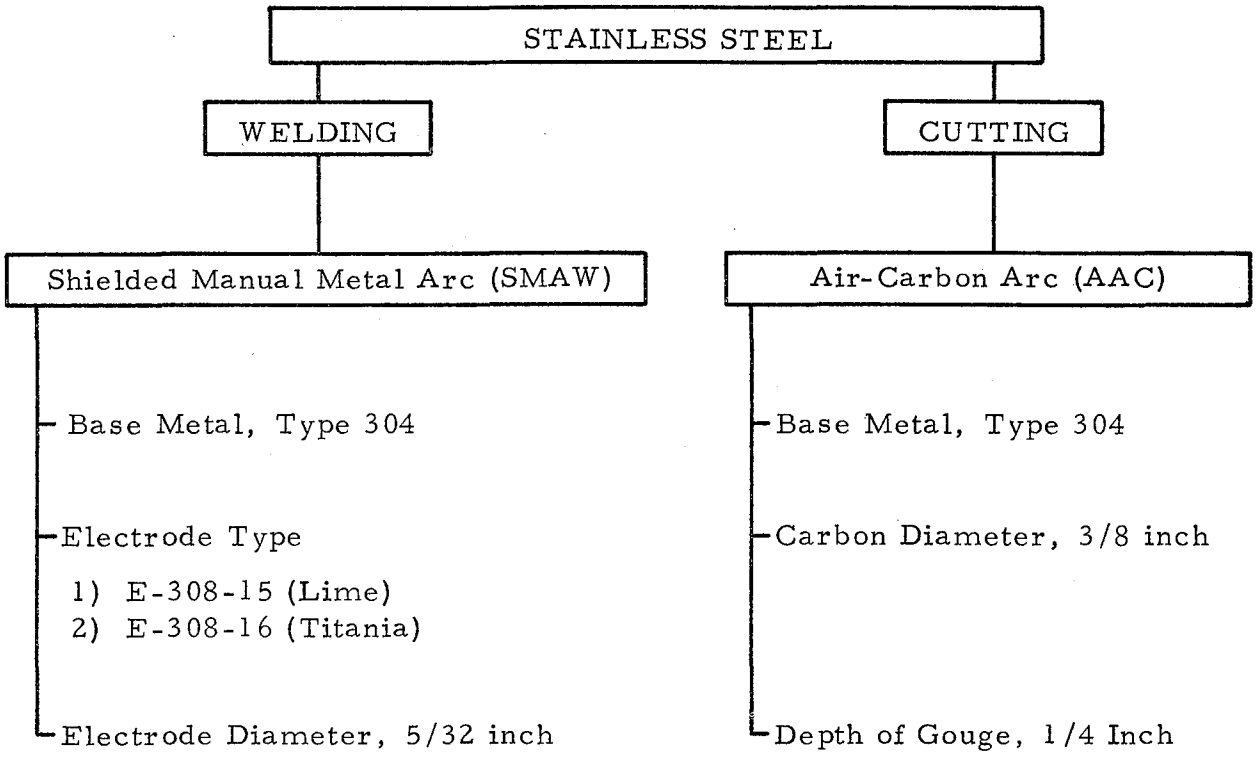


TABLE 4-1. PROCESS VARIABLES FOR WELDING AND CUTTING OF CARBON STEEL (Cont'd)



1) Carbon Steel
2) Low Alloy - High Strength Steel (A588-Grade G)

TABLE 4-2. PROCESS VARIABLES FOR WELDING AND CUTTING STAINLESS STEEL



- Oxyacetylene cutting was performed on 1/2-inch thick carbon steel plates instead of 2-inch plates because the 2-inch plate would have excessively loaded the drive gears on the rotating table, which is described later, and because the thick plate is manually unmanageable. The entire radiation spectrum for OFCA on carbon steel was considerably lower than any of the other process conditions. Consequently, OFCA on low alloy-high strength steel was deleted.

The amperage-voltage set-points for the tests are summarized below:

Electrode Type	Diameter (in.)	Current (amps)	Voltage (volts)
E-7018	3/16	195-205	21-23
E-70S-4	1/16	325-335	26-28
E-70T-1	0.045	180-220	28-20
Arc Gouging	3/8	370-375 (Carbon)	38-48
		370-375 (Stainless)	42-45
E-308-15	1/8	115-120	22-26
E-308-16	1/8	115-120	22-25

These settings are consistent with the electrode manufacturer's recommendations.

Figure 4-6 shows the facility that was assembled for the spectral measurements. A circular base plate rotates in the horizontal plane beneath a stationary welding gun or electrode holder. The plate is attached to a table whose rpm is continuously variable and is calibrated against weld bead radius for compatibility with electrode burn-off rate. In this manner constant-quality weld beads can be laid down in concentric circles. The fumes that are generated during the arc time are removed from the work area by the lateral crossdraft table and are exhausted to the atmosphere. In addition to the health and safety aspects that are involved, fume removal permits an unobstructed view of the naked arc.

Spectral measurements of the arc are made with a monochromator or thermopile that is located behind a standard curved-chin welding helmet. The separation distance, L, from the arc site to the anterior plane of the cover plate as well as the elevation of viewing angle, θ, combine to simulate the helmet orientation that is adopted by job-shop personnel for standard down-hand operations. The viewing angles and separation distances that were used are average values obtained from numerous measurements on active welding personnel at Kelly Air Force Base and SwRI. The elevation angles and separation distance are summarized below.

Process	θ (°)	L (in.)
SMAW - Shielded Manual Metal Arc Welding	61	16
GMAW - Gas Metal Arc Welding	59	12
OFCA - Oxy/Fuel Cutting-Acetylene	55	15
AAC - Air Carbon Arc Gouging	60	16

The positioning sting that is shown in the foreground of the facility photograph was inserted into the filter plate holder to obtain the correct separation distance, L. The elevation and position of the instrument platform are then adjusted to achieve the desired helmet attitude. Elevation angle was measured by a spirit level protractor on the tilt table and a protractor-plumb line combination on the helmet filter holder.

The entrance slit of the monochromator is centered behind the opening in the filter plate holder at a distance of 3.2 inches. This distance coincides with the separation distance from the anterior surface

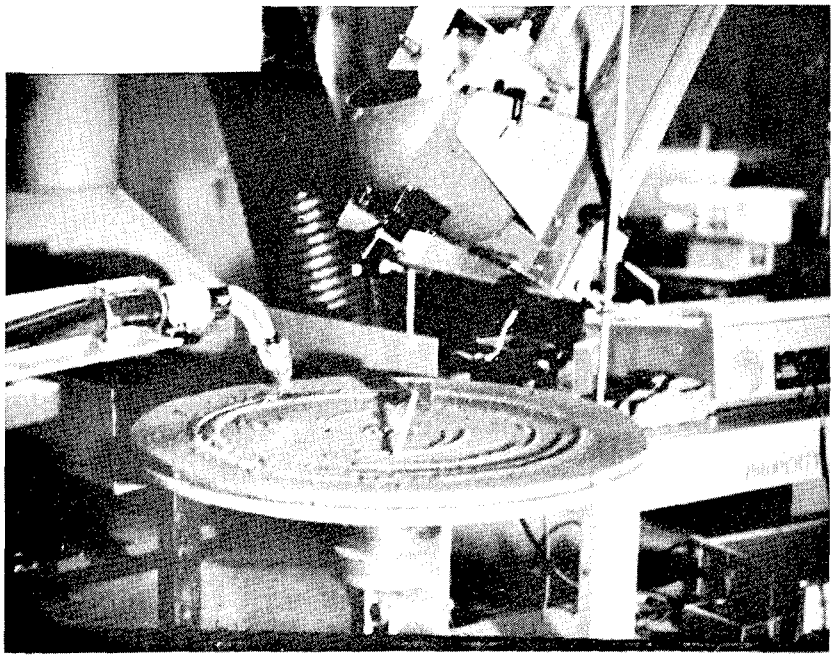


FIGURE 4-6. SPECTRAL MEASUREMENT APPARATUS

of the filter plate to the corneal plane of the eye as measured with this helmet on a 50-th percentile anthropomorphic dummy head.

For the conditions that are described above, UV, visible and IR spectral data were taken using the optical instrumentation that will be described subsequently. A monochromator with interchangeable gratings was used for all wavelength below 1400 nm. The IR radiation above 1400 nm was obtained with an Eppley thermopile in the following manner. The thermopile in series with an IR pass filter recorded the integrated IR radiation above the filter cut-off wavelength of 800 nm. The integrated IR irradiance above 1400 nm is obtained by integrating the spectral irradiance from the IR monochromator from 800 to 1400 nm and subtracting this value from the thermopile reading. This approach to IR evaluation is justified based on the IR TLV for the eye. Above 1400 nm, all radiation is absorbed at the cornea, and total heating or integrated heating rate is the important parameter.

Optical Test Setup for Visible Spectral Measurements (350 to 800 nm

Figure 4-7 gives the details for the setup of instrumentation used for spectral measurements in the visible region on welding arcs. The arc occupied a position 40 to 50 cm in front of the entrance slit to a grating monochromator (Bausch & Lomb 33-86-25). The grating was ruled at 1350 grooves per mm, blazed at 500 nm (Bausch & Lomb 33-86-02) and had a reciprocal linear dispersion factor of 6.4 nm per mm. The entrance slit was maintained at a width of 1mm; the exit to

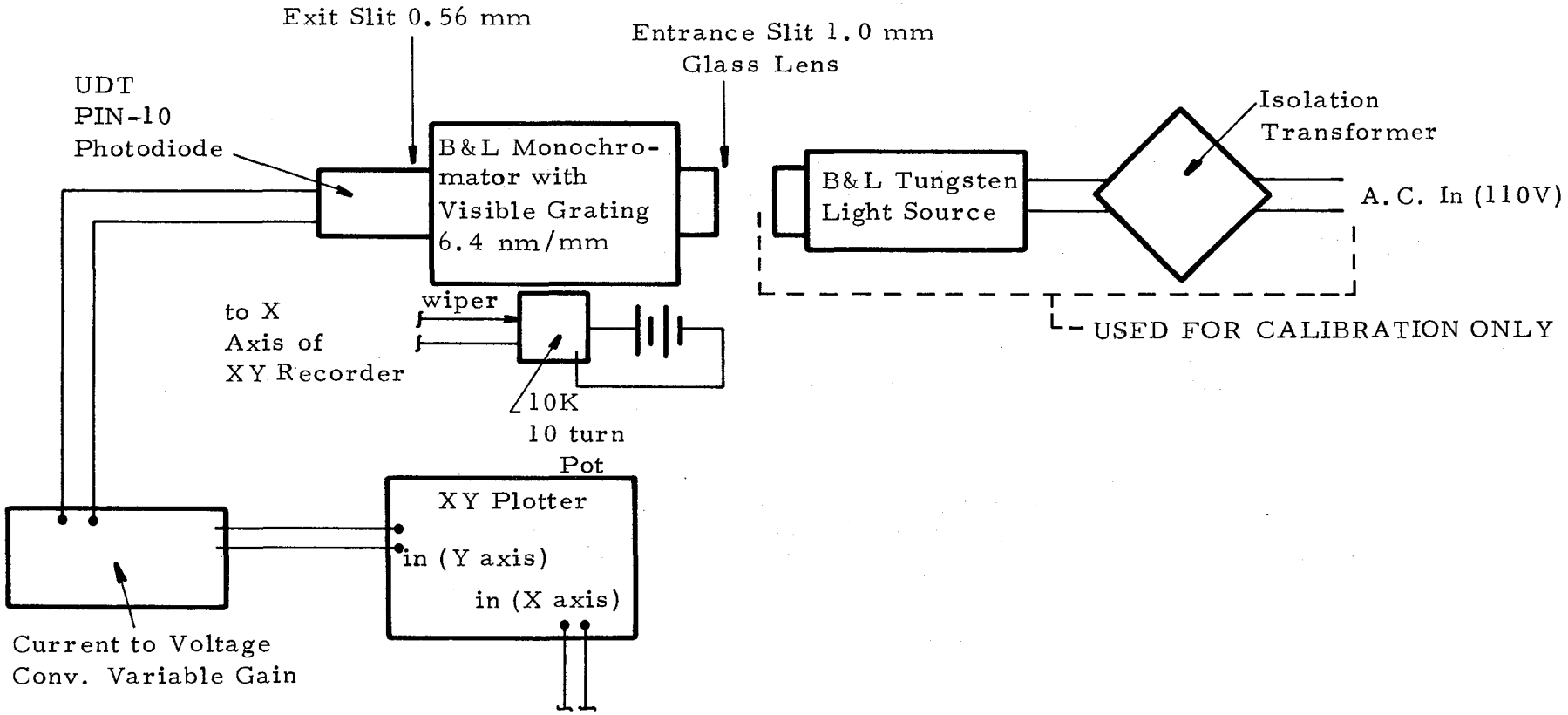


FIGURE 4-7. VISIBLE SPECTRAL MEASUREMENTS: TEST SETUP

entrance slit ratio was 1.78, for a resolution of 6.4 nm. The input condenser lens was glass to minimize second order effects from the UV. A ten-turn potentiometer voltage divider circuit was mechanically linked to the monochromator wavelength dial to produce a DC voltage proportional to wavelength. The wavelength dial was calibrated with the Hg lines in the visible using a high pressure Hg arc lamp.

A PIN silicon photodiode with active area of 1.25 cm^2 (UDT-PIN-10) and a spectral response from 300 to 1100 nm was mounted at the exit slit of the monochromator. This photodiode was operated in the photovoltaic configuration with a variable gain, current-to-voltage converter (see Figure 4-7 for diagram). Output from this photosensing device was recorded on the Y axis of an X-Y plotter (Moseley Autograph Model 2D); the voltage proportional to wavelength from the 10-turn pot was recorded on the X axis of the plotter.

With this test setup, a plot of spectral irradiance versus wavelength (in the range $350 \leq \lambda \leq 800$ nm) was made for a given stand-off distance and angle of view of the monochromator entrance slit for each arc configuration. The test setup had to be calibrated in terms of some absolute irradiance standard to allow for the relative transmission properties of the monochromator and the relative sensitivity of the photodetecting device with wavelength. This was accomplished by measuring the output of the system over wavelength from 350 to 800 nm with the entrance slit illuminated by a calibrated tungsten light source, and ratioing the irradiance per unit wavelength to the output voltage over the wavelength band. The resolution of the system was unchanged between calibration and data acquisition on the arcs.

Optical Test Setup for Infrared Spectral (IR) Measurements (800 to 1400 nm)

Figure 4-8 gives the details for the setup of instrumentation used for spectral measurements in the near infrared region. The arc occupied a position, as described for the visible measurements, before the entrance slit of the monochromator. The grating used was ruled at 675 grooves per mm and blazed at 1000 nm (Bausch & Lomb 33-86-77). This grating has reciprocal linear dispersion of 12.8 nm per mm. The entrance slit was maintained at 2 mm width, and the exit slit was as described for the visible measurements; thus, the resolution was 25.6 nm for the IR spectral measurements. A glass input condenser lens and an IR pass filter were used at the entrance slit. The IR pass filter (Rolyn Optics 65.1395) passed more than 90% of the IR flat above 750 nm and less than 0.5% below 700 nm and was used to limit second-order effects from the visible and ultraviolet. A fifteen-turn potentiometer voltage divider circuit was mechanically linked to the monochromator wavelength dial to produce a DC voltage proportional to wavelength input to the X axis of the X-Y recorder.

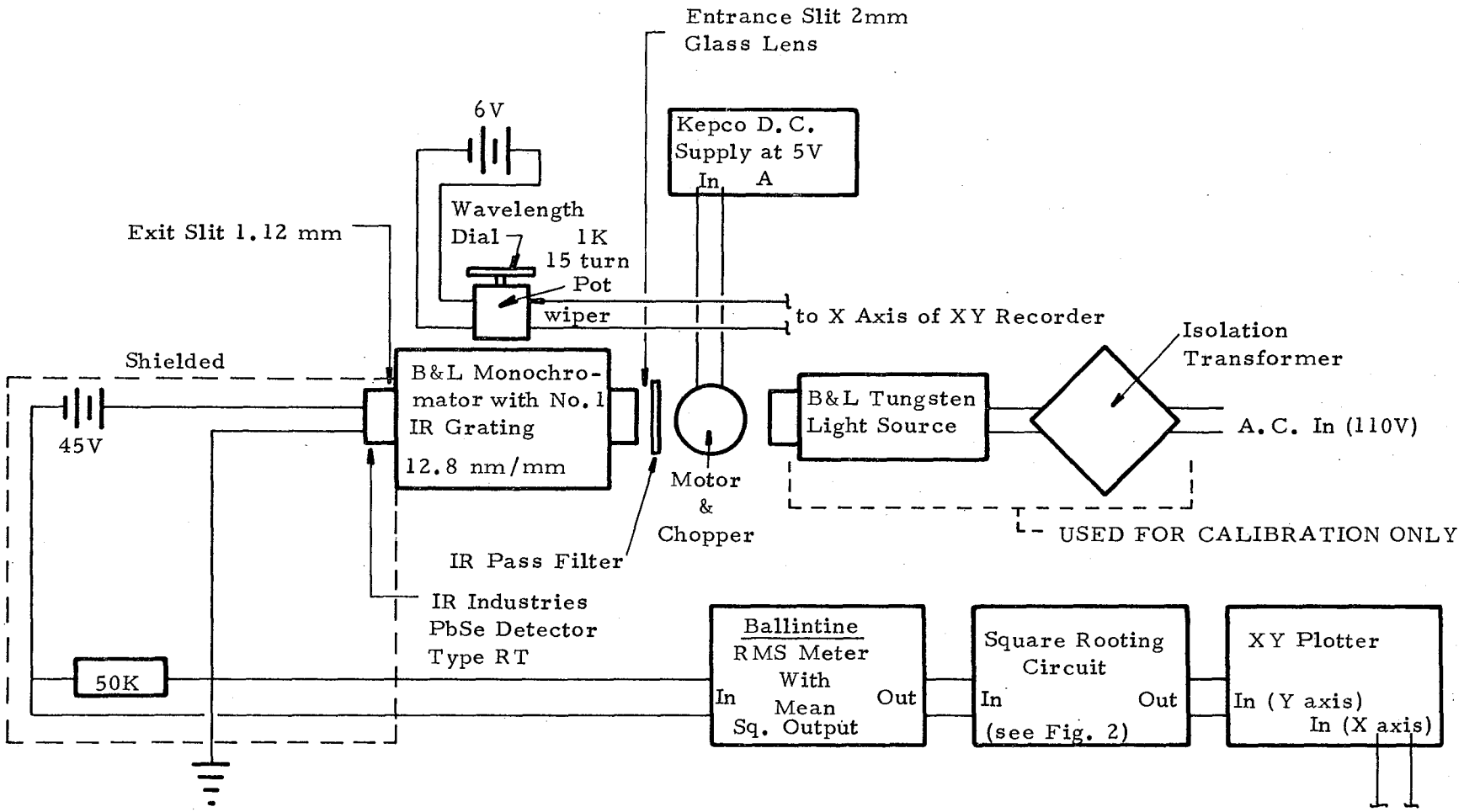


FIGURE 4-8. INFRARED SPECTRAL MEASUREMENTS: TEST SETUP

A lead selenide detector (IR Industries, Type RT) was mounted at the exit slit of the monochromator. This detector has a spectral response from 800 to 5000 nm at ambient temperatures and requires a chopped light input for irradiance measurement. Chopping was provided by a DC motor and chopper blade at the monochromator input slit operated at 1 kHz from a continuously adjustable DC current supply. The output of the IR detector, operated in a photoconductive mode, was input to a true RMS meter (Ballentine) which produced an output signal proportional to the mean square of the input signal. This signal was input to an operational amplifier square-rooting circuit (SwRI design, see Figure 4-9) whose output was proportional to the mean of the IR detector signal. This signal was displayed on the Y axis of the X-Y plotter.

With this instrumentation setup, a plot of spectral irradiance versus wavelength (in the range $800 \leq \lambda \leq 1400$ nm) was made for a given stand-off distance and angle of view for each arc studied. The irradiance per unit wavelength per output voltage as a function of wavelength (i.e., system calibration) was accomplished with the use of the calibrated tungsten lamp. This calibration method accounts for the relative transmission of the IR pass filter and monochromator, as well as the relative sensitivity of the detector as a function of wavelength.

In addition to the IR spectral measurements, the irradiance in the IR integrated over the black body wavelength region was measured with the use of a 14-junction Eppley thermopile. The entrance slit to the thermopile was covered with the IR pass filter described above to eliminate the detection of UV and visible radiations.

Optical Test Setup for Ultraviolet Spectral Measurements (200 to 400 nm)

Figure 4-10 gives the details for the setup of instrumentation used for spectral measurements in the ultraviolet (UV). A grating with a ruling of 2700 grooves per mm, a 250 nm blaze, and a reciprocal linear dispersion factor of 3.2 nm per mm (Bausch & Lomb 33-86-01) was used in the monochromator. A fused quartz condenser lens was used at the entrance slit (slit width 0.1 mm) to pass the UV. The monochromator resolution for this configuration was 0.32 nm. A potentiometer circuit was linked to the wavelength dial to produce a voltage proportional to wavelength as in the setup for visible measurements. The wavelength dial was calibrated with Hg lines in the UV using a high pressure Hg arc lamp.

A photomultiplier tube (RCA 4501-V4) having a fused silica window and a bialkali photocathode sensitive to wavelength down to 180 nm was used to detect the UV output of the monochromator at the

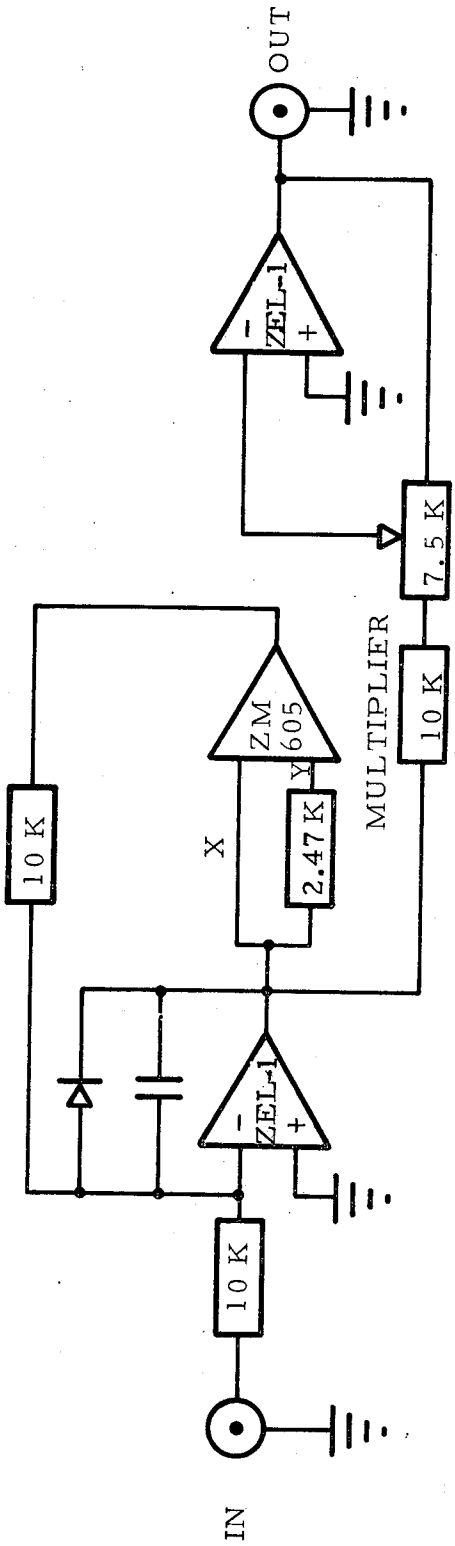


FIGURE 4-9. SQUARE ROOTING CIRCUIT

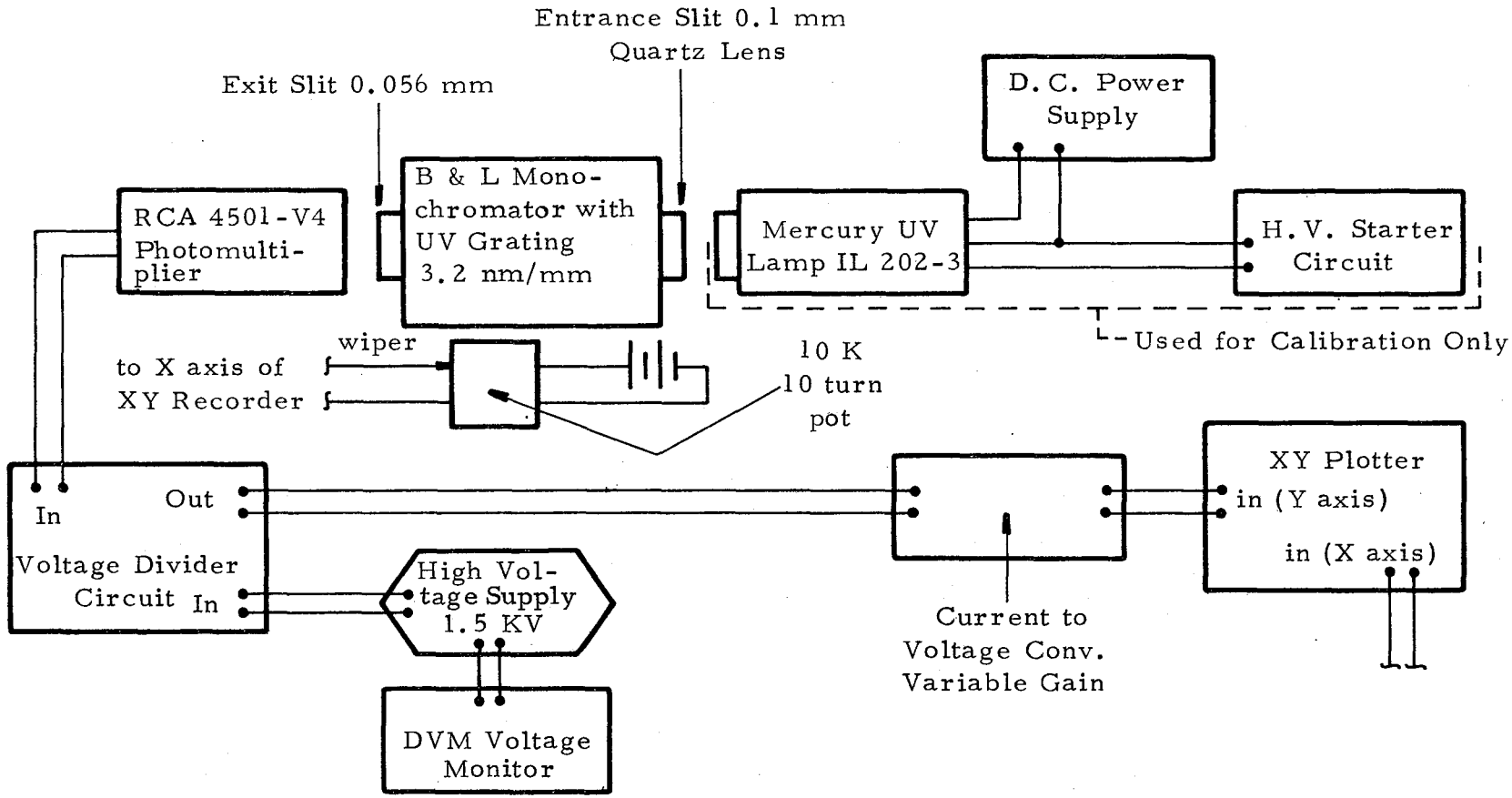


FIGURE 4-10. ULTRAVIOLET SPECTRAL MEASUREMENTS: TEST SETUP

exit slit. This photomultiplier was operated at approximately 1.5 kv using the voltage divider network and current-to-voltage converter seen in Figure 4-11. The high voltage supplied was maintained with 1% of the desired value (NJE Model H 10--100 high voltage supply) and was continuously monitored with a DVM (HP Model 3443A) during the course of calibration and data acquisition.

With this setup, a plot of spectral irradiance versus wavelength could be obtained for each arc condition studied in the wavelength range (180 to 400 nm). The irradiance calibration was accomplished as described in the following section.

Calibration of Spectral Measurement Apparatus

Calibration of the spectral measurement apparatus for the visible wavelengths was performed by illuminating the monochromator entrance slit with a known irradiance in the visible from a calibrated lamp, and plotting the system output (in volts) versus wavelength. A calibration curve of irradiance per unit wavelength per volt versus wavelength was then plotted (see Figure 4-12) which in turn was used to convert raw data obtained from arc measurements into plots of absolute irradiance per unit wavelength versus wavelength (for each arc condition measured). The calibrated lamp used was a tungsten filament lamp operated at a color temperature of 2700°K. The irradiance of the lamp at a fixed distance in a restricted wavelength range was measured using a 14-junction, copper-bismuth Eppley thermopile (calibration traceable to NBS and made within one year of measurements) and an IR reject filter (Rolyn 65.1150). Using the relative radiance of the light source and the integrated measurement of the thermopile, a plot of absolute irradiance per unit wavelength versus wavelength for the lamp could be made for the fixed distance chosen. To calibrate the spectral measurement system, the entrance slit of the monochromator had to be positioned at this same fixed distance from the calibrated light source. Calibration of the spectral measurement apparatus for the IR wavelengths was performed by illuminating the monochromator entrance slit with the tungsten source as with the visible measurements case. For the IR, however, the calibration at 800 nm was used to make an absolute calibration curve of the relative "sensitivity" curve of the combination of IR detector monochromator, and IR filter. The relative curve was obtained by multiplying together the relative curves for each individual component at each wavelength. The calibration at 800 nm was obtained by dividing the IR system output in volts into the output of the tungsten lamp at 800 nm in irradiance per unit wavelength units. A check on the relative curve was obtained by "correcting" it for the relative radiance of the tungsten lamp and comparing this curve to the output curve of the IR system in volts versus wavelength. The IR calibration curve is seen in Figure 4-13.

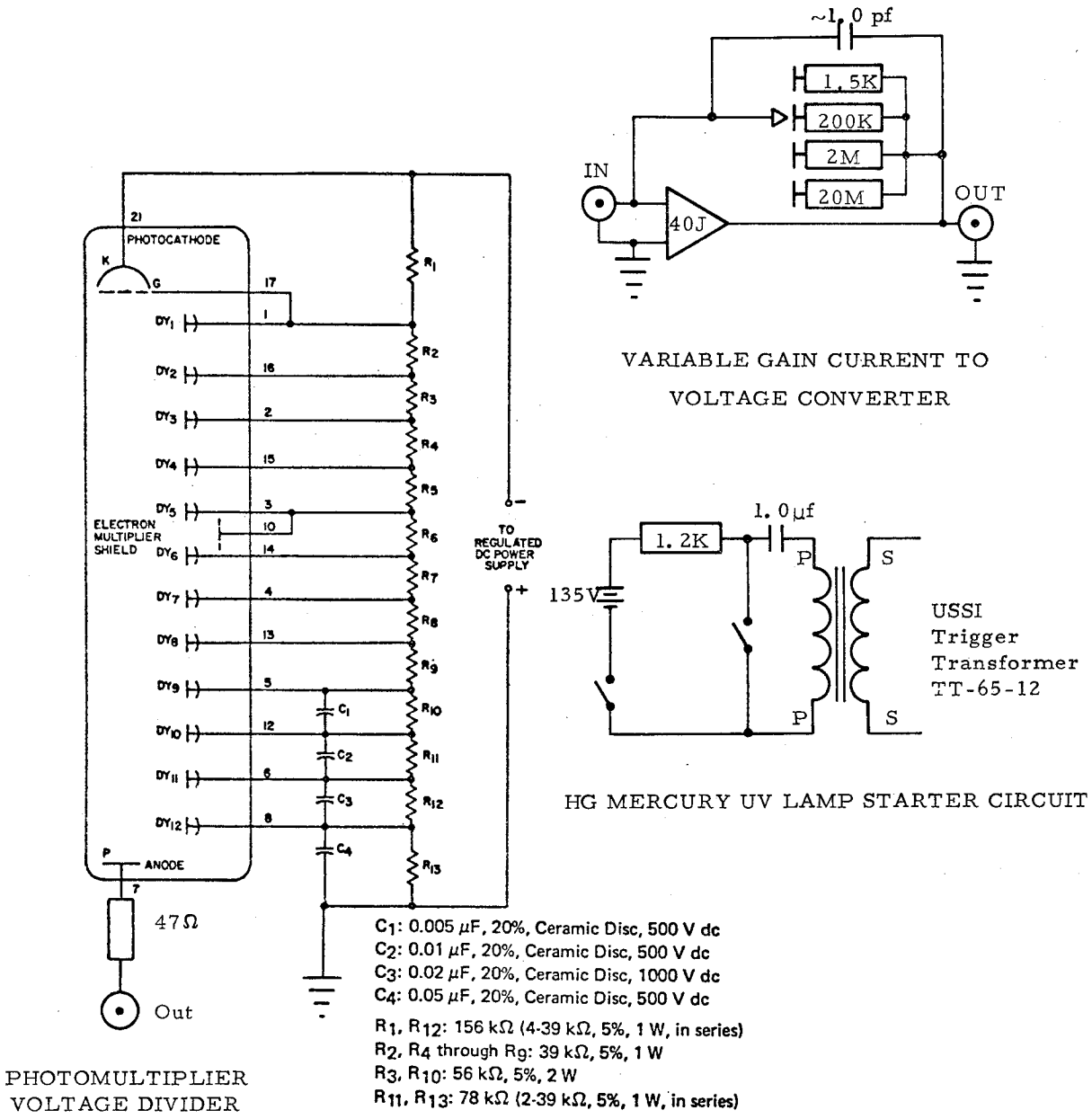


FIGURE 4-11. CIRCUITS FOR UV TEST SETUP

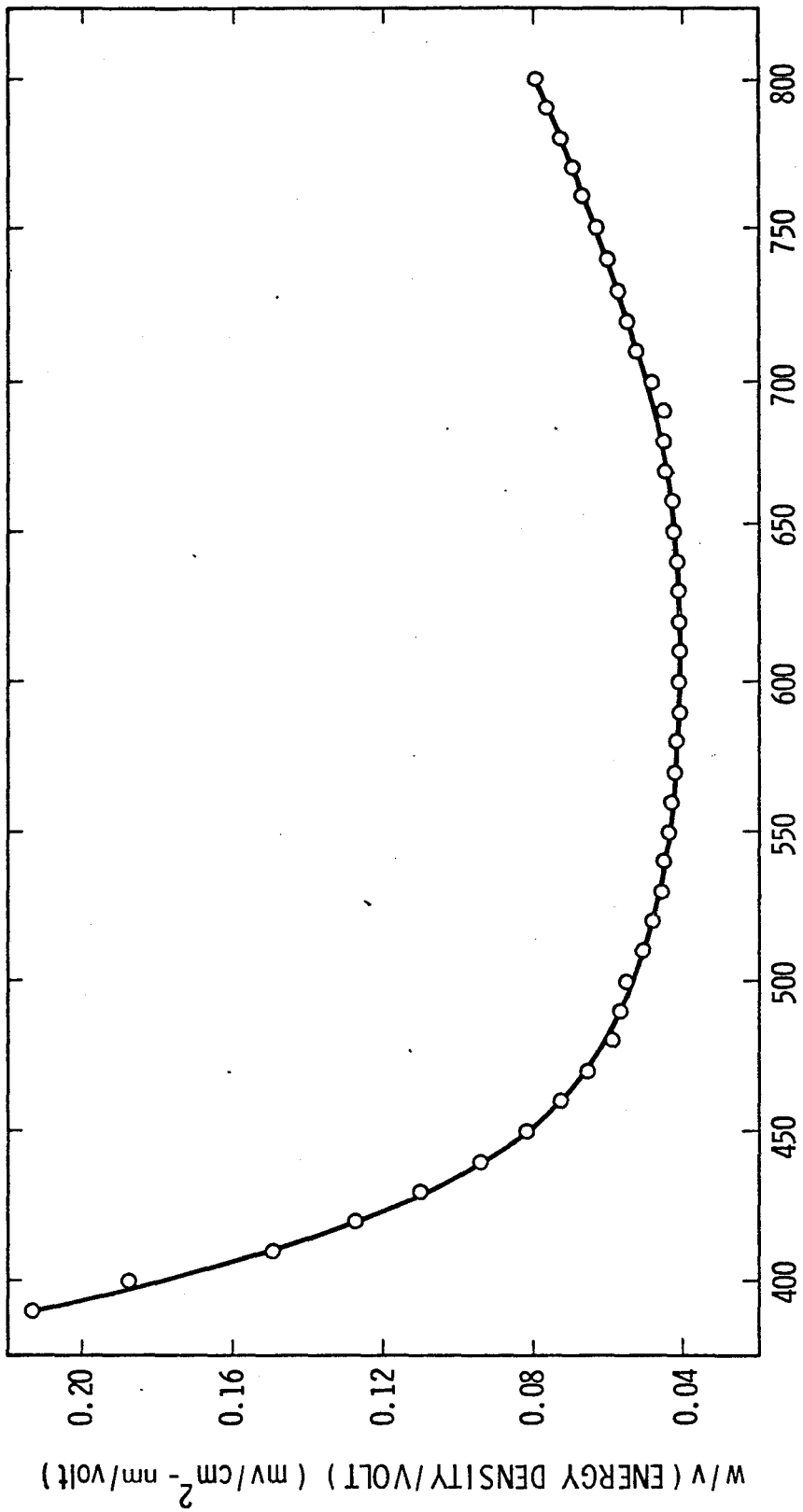


FIGURE 4-12. CALIBRATION CURVE FOR VISIBLE REGION

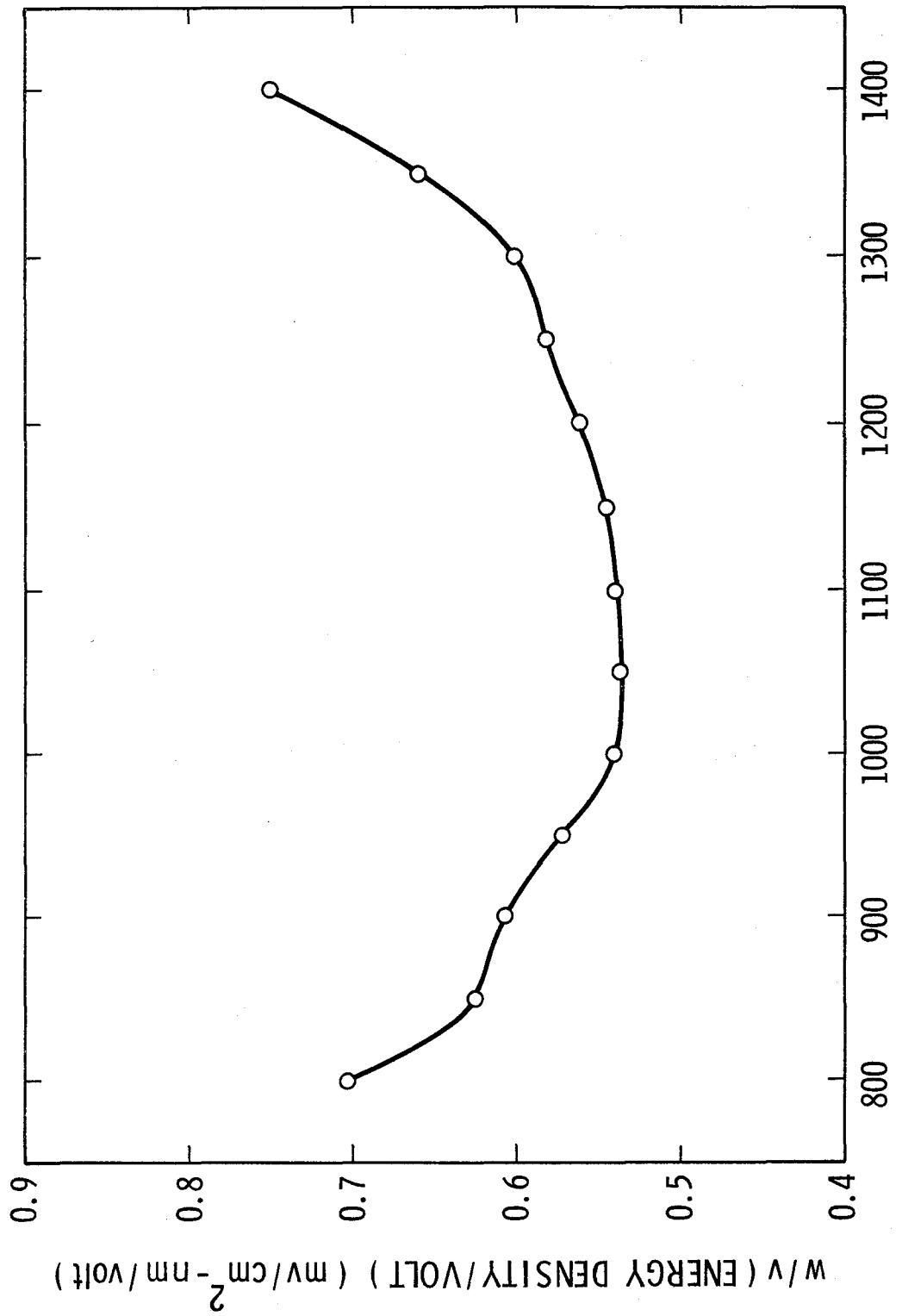


FIGURE 4-13. CALIBRATION CURVE FOR IR REGION

Calibration of the spectral measurement apparatus for the UV wavelengths was performed in the same fashion as the IR case except the calibration point was taken at 400 nm for the tungsten light source in this case. A relative calibration for the UV could also be obtained by measuring the relative "sensitivity" of the system to a mercury (Hg) arc lamp of known relative radiance. This arc lamp was started with a high voltage pulsing circuit and maintained when lit with a regulated DC power supply (Kepco Model SC-32-5) to give a constant spectral output in the UV. The UV calibration curve is seen in Figure 4-14.

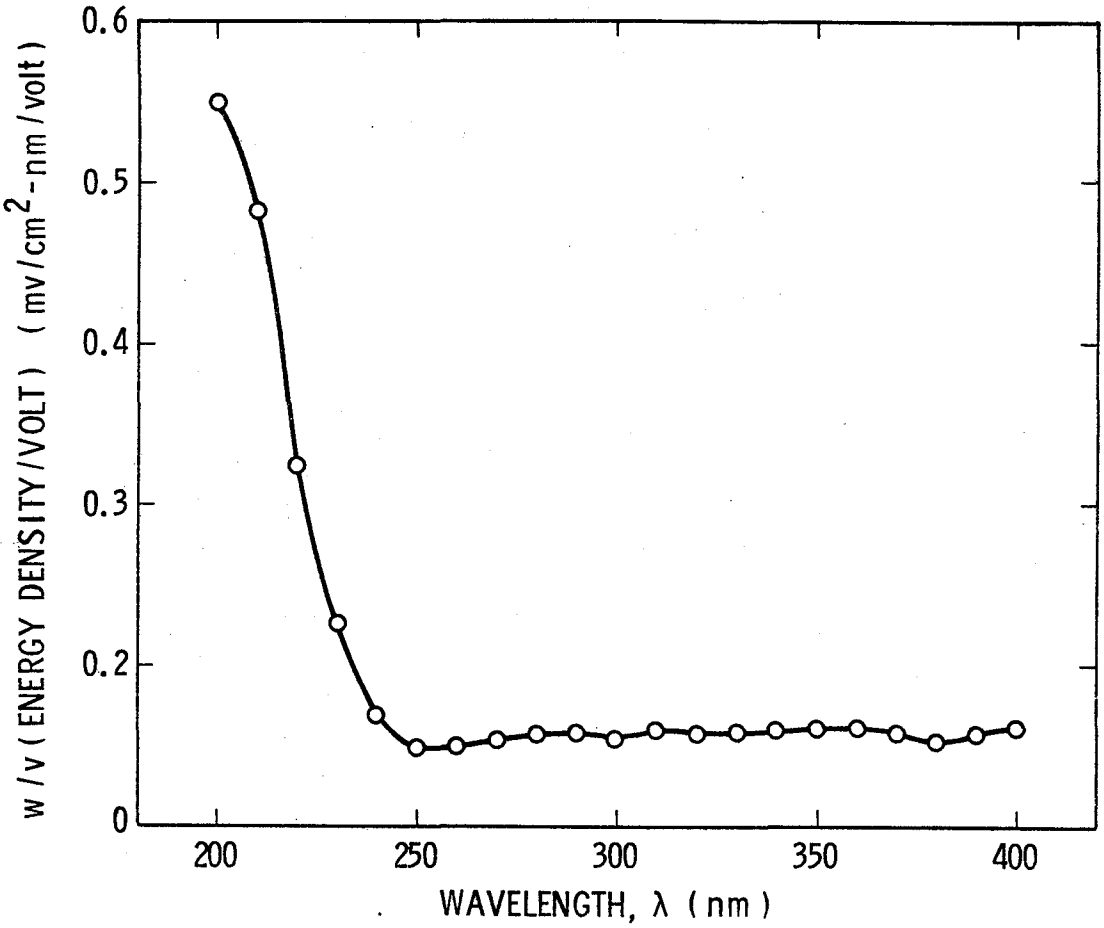


FIGURE 4-14. CALIBRATION CURVE FOR UV REGION

Plots of the experimental arc spectral irradiance data were obtained in the manner described above. These radiation profiles were then digitized on a Gerber digitizer. This raw data and the appropriate detector calibration curves and transmittance characteristics of the cover plates and/or filters used to protect the monochrometer-detector combination were input to a specially-written computer program. Plots of the arc spectral irradiance data are contained in Appendix D.

Caution should be taken when examining this data. Values below 200 nanometers were plotted to simplify the computer programming and should be disregarded since our calibration did not extend into this region. It should be noted that the scale divisions on the graphs vary frequently and should be examined independently in this regard. The computer program was written to optimize data presentation by taking into account the spread of the output values.

(5) Evaluation of Recommended Filter Shades

As cited earlier, the arc spectra for the processes that are called out in Tables 4-1 and 4-2 are contained in Appendix D. Apparent spectral data below 0.2 nm should be neglected, since these points are artifacts created by the computer program.

Based on (1) the processes and operating conditions that were defined at the beginning of this sub-section and (2) the filter selection guides in Table 4-3, the following table of recommended filter shades can be constructed

Process*	SN_D	SN_I
AAC-SS	14	12
AAC-CR	14	12
OFCA	3-4	5-6
E308-16	10	10
E308-15	10	10
E7018	12	10
E70S-4	12	12
E70T-1	12	10-12

It is obvious that a multiplicity of filter recommendations exists depending on whether the shade number selection is based on electrode diameter or arc amperage. The object of the remainder of this section is to evaluate the adequacy of these filter recommendations relative to their ability to reduce the spectral irradiance of the naked arc to sub-ocular damage levels. During this evaluation, reference will be made to the filter transmission table in Table 4-4.

Filter Shade Evaluation in the Ultraviolet Region

The keratitis inhibiting potential of these filters in the region from 200 to 315 nm was not evaluated because a deuterium source

*See table on Page 4.16 for process abbreviations. SS and CR denote stainless steel and cold-rolled carbon steel baseplates, respectively.

TABLE 4-3. APPROPRIATE FILTER LENSE FOR WELDING AND CUTTING OPERATIONS

(a) Governed by Amperage*

FILTER LENS SHADE NUMBERS FOR VARIOUS WELDING AND CUTTING OPERATIONS

Type of Operation	Shade Number
Resistance welding and for protection against stray light from nearby welding and cutting	Clear or filters up to No. 2
Torch brazing or soldering	3 to 4
Light oxygen cutting and gas welding (to ⅛ in.)	4 or 5
Oxygen cutting, medium gas welding (⅛ to ½ in.) and arc welding up to 30 amps	5 or 6
Heavy gas welding (over ½ in.) and arc welding and cutting from 30 to 75 amps	6 or 8
Arc welding and cutting from 75 to 200 amps	10
Arc welding and cutting from 200 to 400 amps	12
Arc welding and cutting exceeding 400 amps	14

NOTE: Flash goggles should be worn under all arc-welding helmets, particularly for gas-shielded metal arc welding.

Adapted from *Welding Handbook*, 5th ed. American Welding Society.

*Reproduced from the Accident Prevention Manual for Industrial Operations, 5th Edition.

(b) Governed by Electrode Diameter†

WELDING OPERATION	SHADE NUMBER
Shielded Metal-Arc Welding – 1/16, 3/32, 1/8, 5/32 inch electrodes	10
Gas-Shielded Arc Welding (Nonferrous) – 1/16, 3/32, 1/8, 5/32 inch electrodes	11
Gas-Shielded Arc Welding (Ferrous) – 1/16, 3/32, 1/8, 5/32 inch electrodes	12
Shielded Metal-Arc Welding – 3/16, 7/32, 1/4 inch electrodes	12
– 5/16, 3/8 inch electrodes	14
Atomic hydrogen welding	10-14
Carbon arc welding	14
Soldering	2
Torch Brazing	3 or 4
Light Cutting, up to 1 inch	3 or 4
Medium Cutting, 1 inch to 6 inches	4 or 5
Heavy Cutting, 6 inches and over	5 or 6
Gas Welding (Light) up to 1/8 inch	4 or 5
Gas Welding (Medium) 1/8 inch to 1/2 inch	5 or 6
Gas Welding (Heavy) 1/2 inch and over	6 or 8

NOTE: In gas welding or oxygen cutting where the torch produces a high yellow light, it is desirable to use a filter or lens that absorbs the yellow or sodium line in the visible light of the operation.

†Reproduced from USAS Z49.1, Safety in Welding and Cutting, 1967.

TABLE 4-4. TRANSMITTANCE AND TOLERANCES IN TRANSMITTANCE OF VARIOUS SHADES OF FILTER LENSES*

Shade Number	Optical Density			Luminous Transmittance			Maximum Infrared Transmittance	Maximum Spectral Transmittance in the Ultraviolet and Violet for Four Wavelengths (millimicrons) (or nanometers)†			
	Maximum	Standard	Minimum	Maximum	Standard	Minimum		313 mu	334 mu	365 mu	405 mu
				Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1.5	0.26	0.214	0.17	67	61.5	55	25	0.2	0.8	25	65
1.7	0.36	0.300	0.26	55	50.1	43	20	0.2	0.7	20	50
2.0	0.54	0.429	0.36	43	37.3	29	15	0.2	0.5	14	35
2.5	0.75	0.643	0.54	29	22.8	18.0	12	0.2	0.3	5	15
3.0	1.07	0.857	0.75	18.0	13.9	8.50	9.0	0.2	0.2	0.5	6
4.0	1.50	1.286	1.07	8.50	5.18	3.16	5.0	0.2	0.2	0.5	1.0
5.0	1.93	1.714	1.50	3.16	1.93	1.18	2.5	0.2	0.2	0.2	0.5
6.0	2.36	2.143	1.93	1.18	0.72	0.44	1.5	0.1	0.1	0.1	0.5
7.0	2.79	2.571	2.36	0.44	0.27	0.164	1.3	0.1	0.1	0.1	0.5
8.0	3.21	3.000	2.79	0.164	0.100	0.061	1.0	0.1	0.1	0.1	0.5
9.0	3.64	3.429	3.21	0.061	0.037	0.023	0.8	0.1	0.1	0.1	0.5
10.0	4.07	3.857	3.64	0.023	0.0139	0.0085	0.6	0.1	0.1	0.1	0.5
11.0	4.50	4.286	4.07	0.0085	0.0052	0.0032	0.5	0.05	0.05	0.05	0.1
12.0	4.93	4.714	4.50	0.0032	0.0019	0.0012	0.5	0.05	0.05	0.05	0.1
13.0	5.36	5.143	4.93	0.0012	0.00072	0.00044	0.4	0.05	0.05	0.05	0.1
14.0	5.79	5.571	5.36	0.00044	0.00027	0.00016	0.3	0.05	0.05	0.05	0.1

*Reproduced from USAS Z87.1, 1968.
†1 mu = 1 nm.

was not available with which to obtain accurate filter transmission spectra. Consequently, an estimation of the time required for these filters to exceed the UV action spectrum must be considered for future study.

Filter effectiveness in the near UV was evaluated as follows. For each process, spectral irradiance of the arc at the cornea was tabulated for wavelengths of 313, 334, 365 and 405 nm. The irradiance of 405 nm was obtained from the plots in the visible region-labeled VI. For each filter shade, the unfiltered spectral irradiance was multiplied by the appropriate filter spectral transmittance value to obtain a simulation of the filtered irradiance that is input to the cornea. The results of this manipulation are shown in Table 4-5.

For exposure times less than or equal to 1000 sec, the TLV dose is 1.0 J/cm^2. It is readily seen that every corneal irradiance value in Table 4-5 results in a 1000 sec corneal dose that is between 3 and 8 orders of magnitude below the threshold.

For exposure times greater than 1000 sec, the TLV is 10^{-3} Joules/cm^2-sec (1.0 m W/cm^2). Again, it is seen that the filtered corneal irradiance is significantly below the threshold. Consequently, on the basis of reciprocity of irradiance and dose, the corneal dose will not exceed the TLV for all exposure times that are greater than 1000 sec.

The conclusion is that the recommended filter shades ensure adequate protection against eye damage in the near UV independent of the extent of multiplicity in the recommendation.

Filter Shade Evaluation in the Visible Region

Evaluation of filter shade recommendations in the visible region, 400 to 750 nm, was based on the chorioretinal burn thresholds in Figure 4-2 and a modification of the analytical development that is contained in Figure 4-4. That modification is as follows.

The integrated or average retinal irradiance takes the form

$$\overline{H}_r = \overline{H}_c \frac{D_p^2 D^2}{F^2 D_s^2} \overline{k}$$

where all quantities are as defined in Figure 4-5. Theoretically, $\overline{H}_c$ is defined as

TABLE 4-5. FILTERED CORNEAL IRRADIANCE IN THE NEAR ULTRAVIOLET REGION

Process-Shade Number/λ (nm)	313	334	365	405
AAC-SS				
12	3500*	3100	4900	12000
14	3500	310	4900	12000
AAC-CR				
12	2400	1800	4100	11000
14	2400	1800	4100	11000
OFCA				
3	3.1	0.96	1.0	4.5
4	3.1	0.96	1.0	7.5
5	3.1	0.96	0.4	3.8
6	1.5	0.48	0.2	3.8
E308-16				
10	1900	2100	1000	2100
E308-15				
10	4500	850	2900	6500
E7018				
12	3900	2500	4800	13000
10	7800	5000	9500	66000
E70S-4				
12	48000	30000	40000	22000
E70T-1				
10	11000	9000	17600	80000
12	5600	4500	8800	16000

*Corneal irradiance, $H_c = H_{arc}(\lambda)\,\tau\,(\lambda) \times 10^{11}$ joules/cm^2-sec; e.g., 3500 is equivalent to 3.5×10^{-8}.

$$\overline{H}_c = \int_{400\ nm}^{750\ nm} H_{arc}(\lambda)\,\tau(\lambda)\,d\lambda$$

where $\tau(\lambda)$ is the transmission spectrum of the filter. Since filter transmission spectra were not available for all filters, the following assumptions were made

Assumption 1 $\overline{H}_c = \overline{H}_{arc}\ \overline{\tau}$; $\overline{\tau}$ = average non-Y corrected filter transmittance

Substitution of this approximation into the expression for retinal irradiance yields

$$\overline{H}_r = \overline{H}_{arc}\ \frac{D_p^2\ D^2}{F^2\ D_s^2}\ \overline{\tau}\,\overline{k}$$

The correction factor $\overline{k}$ accounts for the effect of light transmission through the ocular media, i.e., the Y-correction.

Assumption 2 $\overline{\tau}\,\overline{k} = \overline{\tau}_y$; $\overline{\tau}_y$ = Y-corrected, standard luminous transmittance factor from Table 4-4.

The cumulative effect of these assumptions results in the following expression, which was utilized in the filter evaluation.

$$\overline{H}_r = \overline{H}_{arc}\ \frac{D_p^2\ D^2}{F^2\ D_s^2}\ \overline{\tau}_y$$

The arc irradiance, $\overline{H}_{arc}$, was obtained by planimeter integration of the spectra in the visible region. A fully dilated eye was assumed; D_p = 7 mm represents the most critical retinal condition. A focal length of 17 mm was used through the analysis. The distance from the source to the corneal plane is process dependent.

$$D = L + \ell_f$$

where ℓ_f is 3.2 inches and L is the appropriate separation distance taken from the table on page 4.16. Van Someren and Rollason[4-17] suggest a source (arc) diameter of 0.3 cm for the SMAW processes. In this evaluation, the effect of source diameter was considered in parametric fashion: source diameters of 0.15, 0.3, and 1.0 cm were included. For these geometric conditions, retinal irradiance was calculated. Retinal dose, Q_r, was calculated from the retinal irradiance value for a representative 100 sec exposure assuming that reciprocity is valid for that exposure duration. The threshold dose as a function of image diameter at a 100 sec exposure was calculated from the following expression.

$$Q_r^T = \frac{19}{d_i^2} + \frac{51}{d_i} + 30$$

where d_i is the image diameter in mm, and Q_r^T is the retinal threshold dose in cal/cm^2. This expression resulted from an unpublished surface fit of the Miller and White[4-13] data and was furnished by personnel at Brooks School of Aerospace Medicine. Table 4-6 contains a summary of the calculations including a comparison with the threshold dose.

By comparing the retinal dose with the retinal burn threshold, it is concluded that the recommended filter shades provide satisfactory protection against radiation-induced retinal damage in the visible region given the assumptions upon which the calculations are based.

Filter Shade Evaluation in the Infrared Region

In the infrared region (beyond 750 nm) the following procedure was employed:

(1) The reduced monochrometer irradiance spectra for the naked arc were integrated with a planimeter between the limits of 750 to 800 nm from the graphs labeled VI and 800 to 1400 nm from the graphs labeled IR (of Appendix D). These quantities were then summed to give the integrated irradiance between 750 and 1400 nm.

(2) The thermopile readings, which reflect a high-pass wavelength of 800 nm, were subtracted from the integrated irradiance between 800 and 1400 nm to yield the radiation contribution beyond 1400 nm.

These data are summarized on page 4.37.

TABLE 4-6. RETINAL DOSE IN THE VISIBLE REGION

Process	Shade No.	D_s (cm)	d_j (mm)	$\overline{H}_{arc}\left(\frac{mW}{cm^2}\right)$	$\overline{H}_r\left(\frac{mW}{cm^2}\right)$	$\overline{Q}_r\left(\frac{cal}{cm^2}\right)$	$Q_r^T\left(\frac{cal}{cm^2}\right)$
AAC-SS	12	0.15	0.052	29.06	9.90	2370*	7951
	12	0.30	0.105	29.06	2.47	590	2254
	12	1.0	0.349	29.06	0.223	53.3	333
	14	0.15	0.052	29.06	1.41	337	7951
	14	0.30	0.105	29.06	0.351	83.9	2254
	14	1.0	0.349	29.06	0.032	7.58	333
AAC-CR	12	0.15	0.052	28.28	9.63	2300	7951
	12	0.30	0.105	28.28	2.41	576	2254
	12	1.0	0.349	28.28	1.37	51.9	333
	14	0.15	0.052	28.28	1.37	327	7951
	14	0.30	0.105	28.28	0.342	81.8	2254
	14	1.0	0.349	28.28	0.031	7.34	333
OFCA	3	0.15	0.055	0.02	44.55	10600	7189
	3	0.30	0.110	0.02	11.14	2660	2054
	3	1.0	0.368	0.02	1.0	239	309
	4	0.15	0.055	0.02	16.60	3970	7189
	4	0.30	0.110	0.02	4.15	992	2054
	4	1.0	0.368	0.02	0.374	89.4	309
	5	0.15	0.055	0.02	6.19	1480	7189
	5	0.30	0.110	0.02	1.55	370	2054
	5	1.0	0.368	0.02	0.139	33.2	309
	6	0.15	0.055	0.02	2.31	552	7189
	6	0.30	0.110	0.02	0.567	136	2654
	6	1.0	0.368	0.02	0.052	12.4	309
E308-15	10	0.15	0.052	3.05	7.59	1810	7951
	10	0.30	0.105	3.05	1.90	454	2254
	10	1.0	0.349	3.05	0.171	40.9	333
E7018	10	0.15	0.052	13.12	32.67	7810	7951
	10	0.30	0.105	13.12	8.17	1950	2254
	10	1.0	0.349	13.12	0.735	176	333
	12	0.15	0.052	13.12	4.47	1070	7951
	12	0.30	0.105	13.12	1.12	268	2254
	12	1.0	0.349	13.12	0.100	23.9	333
E70S-4	12	0.15	0.066	26.0	5.55	1330	5164
	12	0.30	0.132	26.0	1.39	332	1505
	12	1.0	0.440	26.0	0.125	29.9	243
E70T-1	10	0.15	0.066	17.84	27.86	6660	5164
	10	0.30	0.132	17.84	6.96	1660	1505
	10	1.0	0.440	17.84	0.627	150	243
	12	0.15	0.066	17.84	3.81	911	5164
	12	0.30	0.132	17.84	0.952	226	1505
	12	1.0	0.440	17.84	0.086	20.6	243

*$\overline{Q}_r \times 10^4$; e.g., 2370 is equivalent to 2.37×10^{-1}.

Process	$\overline{H}$* (750-1400 nm)	$\overline{H}$* (800-1400 nm)	$\overline{H}$*† (800 nm→)	$\overline{H}$* (1400 nm→)
AAC-SS	146.64	141.00	120.40	-20.6
AAC-CR	101.13	96.30	97.93	1.63
OFCA	5.60	5.59	5.95	0.36
E308-16	9.57	8.71	10.86	2.15
E308-15	10.71	10.30	10.33	0.03
E7018	27.13	25.65	19.12	-6.43
E70S-4	50.70	45.10	41.60	-3.50
E70T-1	24.71	22.95	24.54	1.59

The negative values for the integrated irradiance beyond 1400 nm suggests that the accuracy of the monochrometer data exceeded that of the thermopile. Justification for this statement is based on the fact that a thermopile has maximum accuracy for steady-state measurements, but the accuracy is reduced and the instrument cannot respond sufficiently to transient events such as a welding arc. The above data were then multiplied by the maximum IR transmittance values (Table 4-4) for the appropriate indicated filter plate. These data are contained in Table 4-7. The following conclusions and observations can be made:

(1) Beyond 1400 nm, there is no indication that ocular damage will result from corneal heating when the recommended filter shade is employed. The corneal irradiance is well below the 100 mW/cm^2 threshold.

(2) In the region between 750 and 1400 nm there is a high level of filter acceptibility; however, there are some marginal cases. The following criteria were used in assigning the M, A and M-A ratings.

(a) If t^+ was greater than the lower bound on t_n, the filter was acceptable.

(b) If t^+ was less moderately less than the lower bound on t_n, the filter was classed as marginal to acceptable.

(c) If t^+ was significantly less than the lower bound on t_n, a marginal rating was assigned.

These are subjective criteria, and their validity should be interpreted within the framework of the governing assumptions. A completely open eye for 30 to 70 seconds is unrealistic. To determine precisely the

*mw/cm^2 for naked arc.
†Thermopile.

TABLE 4-7. FILTER EVALUATION IN THE INFRARED REGION

Process	Shade No.	H_c* (750-1400)	t^+ (sec)	t_n (sec)	Comment	H_c** (1400→)
AAC-SS	12	7.33	17.5	30-60	M	n/a
	14	4.40	29	30-60	M-A	n/a
AAC-CR	12	5.06	25.5	30-60	M-A	8.15
	14	3.03	43.2	30-60	A	4.89
OFCA	3	5.04	25.5	30-60	M-A	32.4
	4	2.80	45.9	30-60	A	18.0
	5	1.40	91.0	30-60	A	5.40
	6	0.84	150	30-60	A	5.40
E308-15	10	0.582	∞	45-60	A	12.9
E308-16	10	0.643	≥200	45-60	A	0.18
E7018	10	1.63	80	70	A	n/a
	12	1.36	94.3	70	A	n/a
E70S-4	12	2.54	50.0	~60	M-A	n/a
E70T-1	10	1.48	84.8	~60	A	9.54
	12	1.24	100	~60	A	7.95

M - Marginal Filter Recommendation
A - Acceptable Filter Recommendation
M-A - Marginal to Acceptable Filter Resommendation
} 750 to 1400 nm

Corneal irradiance is for uninterrupted heating of an open eye, i.e., no blink reflex. The blink reflex will result in alternate heating and cooling, thus decreasing the time integrated irradiance with a corresponding increase in permissible exposure time, t^+.

t^+ = time to damage from Figure 4-5 (Figure 8, ANSI Z136.1)

t_n = nominal uninterrupted arc time based on representative job shop conditions

* = $W/cm^2 \times 10^4$; e.g., 7.33 is equivalent to 7.33×10^{-4}

** = $mW/cm^2 \times 10^3$; e.g., 8.15 is equivalent to 8.15×10^{-3}

n/a = not applicable due to negative calculated irradiance

validity of the M and M-A ratings would require an exact solution of a theoretical, time-dependent, thermodynamic heating model for the cornea. In all likelihood, the intermittent heating of the cornea due the blink reflex will reduce the time-averaged corneal irradiance to the point where the filters are totally acceptable, i.e., the cumulative heating of the cornea would not exceed the damage level. A second assumption concerns the application of the 750 nm laser TLV line as a precise delineator between injury and non-injury. A TLV is a guide rather than a demarcation time. Furthermore, the wavelength dependence of the corneal TLV for the IR-A band has not been fully substantiated experimentally. Consequently, a slight upward shift of the IR-A TLV would have a significant effect on the subjective rating that was applied to the data. Based on the above discussion an alteration of the filter recommendations or the IR filter transmittance for a given shade number cannot be justified at this time.

Regional Distribution of Arc Energy

For each arc configuration, the three regions of the optical radiation spectum, UV, visible and IR, were subjected to planimeter integration to determine the energy distribution of the naked arc. These distributions reflect the unfiltered, incident energy at the corneal plane for the separation distances and arc conditions were quoted earlier. The distribution results are shown in Table 4-8. Note that the IR contribution for all SMAW processes is consistent at approximately 60 percent as opposed to the 30 percent quoted by van Someren and Rollason. The distribution for the AAC processes is consistent even though the base metal was different in each case because the amperage-voltage parameters were the same. The distributions for the two gas shielded processes differ significantly because the required arc amperage is higher for the solid wire electrode (E70S-4: 1/16 inch).

TABLE 4-8. REGIONAL DISTRIBUTION OF ARC ENERGY

Process	UV H	UV %	V H	V %	IR H	IR %	H-Total
AAC-SS	19.40	9.94	29.06	14.89	146.64*	75.16	195.10
AAC-CR	18.50	12.37	28.28	18.91	102.76	68.72	149.54
OFCA	0.0068	0.11	0.0199	0.33	5.96	99.50	5.99
E308-16	2.83	14.74	4.65	24.22	11.72	61.04	19.20
E308-15	5.05	26.79	3.06	16.23	10.74	56.98	18.85
E7018	9.48	19.06	13.12	26.38	27.13*	54.55	49.73
E70S-4	153.50	66.68	26.00	11.29	50.70	22.02	230.20
E70T-1	14.45	24.66	17.84	30.54	26.30	44.89	58.59

H values in mW/cm^2

UV: 200 - 400 nm

V: 400 - 750 nm

IR: 750 nm

*Based on near IR (750 to 1400 nm) due to negative far IR contribution.

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TASK 5 - EVALUATION OF PLASTIC AND GLASS LENS PERFORMANCE

In accordance with the Scope of Work and the SwRI Technical Proposal for this project, the following items have been performed under this task:

(1) Mechanical Strength

a. impact testing
b. breakage from small objects moving at high speeds

(2) Abrasion Resistance

(3) Effect of Hot Materials

(4) Effect of Chemicals

(5) Susceptibility to Fogging

Table 5-1 provides a coded list of the eye and face protective equipment used in the performance of tests.

Each code number contains three or four positions (cf., below). The first position refers to the manufacturer, the second position refers to a particular type of device from the manufacturer given in position (1),the third position refers to a particular device of the type described in (1) and (2), and the fourth position refers to the number of devices of the type described by (1) and (2). The identification of a particular protective device is therefore accomplished using the first three positions:

Example:	(1)	(2)	(3)	(4)
	AA	A	1	7

(1) denotes the manufacturer

(2) denotes the type of device

(3) denotes a particular device

(4) denotes the number of devices of the type described in (1) and (2).

Therefore, AA A-3 is device #3 of type A of manufacturer AA. A description of the different types of protective devices and the number available are given in Table 5-1. Manufacturers' names have been deleted from the descriptions to eliminate any possible legal confrontations.

TABLE 5-1. LIST OF EYE AND FACE PROTECTIVE EQUIPMENT USED IN PERFORMANCE OF TESTS

SwRI Code #	Description
AA A-1-7	flex goggles, frame (non-glare vinyl) plastic, clear lens
AA B-1-7	flex goggles, frame (non-glare vinyl) plastic, clear lens (vinyl lens)
AA C-1-7	flex vinyl plastic goggles, filter plate sh #5 (glass) with plastic cover plate
AA D-1-7	flex vinyl plastic (clear) goggles, clear plastic safety plate
AA E-1-7	welding flexible jumbo lens goggles (vinyl plastic) with 50 mm fed spec. heat treated weld-safe lens
AA F-1-7	clear flex vinyl plastic goggles, jumbo lens (clear plastic safety plate)
AA G-1-6	safety glasses, charcoal color frame with plastic sideshield, glass lenses, S7-48 mm eyesize
AA J-1a-1b 2a-2b	clear safety lenses (quality ophthalmic glass), S7-49 mm eyesize
AA K-1-11	welding filter plate, ground and polished glass, shades #4 - 14 (except 7 and 13)
AA K-12	clear cover plate (plastic)
AA L-1-3	clear poly-type molded plastic faceshield
AA M-1-3	clear poly-type molded plastic faceshield
AA N-1	one-piece molded headgear
AA N-2	faceshield headgear
AA N-3	welding helmet, fibre

TABLE 5-1. LIST OF EYE AND FACE PROTECTIVE EQUIPMENT USED IN PERFORMANCE OF TESTS (Cont'd)

SwRI Code #	Description
AA N-4	welding helmet, fibre glass
AA N-5	welding helmet, fibre glass
AA P-1-7	safety spectacles, (glass lenses), S7-48 mm eyesize
BB A-1-9	spectacles with plastic frames and plastic (CR-39) lenses, S7-48 mm lenses
CC A-1	fibre helmets (vulcanized fibre) straight-front, stationary glassholder (welding helmet)
CC A-2	fibre helmet (vulcanized fibre) straight-front, liftfront glass holder (welding helmet)
CC A-3	fiberglass welding helmet, (welding helmet)
CC A-4	narrow front molded-on stationary fiberglass insulated glass holder
CC A-5	fiberglass welding helmet (welding helmet)
CC A-6	welding helmet liftfront, dowmetal glass holder
CC A-7	welding helmet with wide-vision shell, stationary molder-on insulated fiber glass holder
CC A-8	welding helmet, curved-bottom with liftfront glass holder, vulcanized fibre
CC A-9	thermoplastic welding helmet
CC A-10	thermoplastic welding helmet
CC B-1-3	faceshield, plastic deflection, polyethylene headband
CC C-1-3	clear window faceshield (plastic)

TABLE 5-1. LIST OF EYE AND FACE PROTECTIVE EQUIPMENT USED IN PERFORMANCE OF TESTS (Cont'd)

SwRI Code #	Description
CC D-1-3	clear window faceshield (plastic)
CC E-1-3	clear window faceshield (plastic)
CC F-1-3	medium green window faceshield (plastic)
CC G-1-3	clear window faceshield (plastic)
CC H-1	monarch welding plate, shade #10
DD A-1-7	flexible mask dust & splash goggle, polycarbonate lens, 4 indirect ventilating ports
DD B-1-7	neoprene frame, plastic lens, ventilating grommets of fine steel mesh, goggle
DD C-1-7	splash goggle, polycarbonate lens
DD D-1-3	chipper's cup type goggles, 50 mm round lenses
DD E-1-4	chipper's cup type goggles, 50 mm round lenses
DD F-1-7	welder's cover glass goggle, standard glass cover lenses, glass filter lenses, shade #5, 50 mm round lenses
DD G-1-7	goggle, standard glass cover lenses, glass filter lenses, shade #5, 50 mm round lenses
DD H-1-6	flexi-fit safety glasses with clear glass lenses and plastic frame, S7-48 mm lenses
DD J-1a-1b 4a-4b	6-curve glass lenses, S7-48, 6.00C
DD K-1a-1b 5a-5b	50 mm round flat filter lenses, shades # 3, 4, 5, 6, 8
DD L-1-3	2" x 4-1/4" heat-strengthened, filter plates, shades #4, 5, 6

TABLE 5-1. LIST OF EYE AND FACE PROTECTIVE EQUIPMENT USED IN PERFORMANCE OF TESTS (Cont'd)

SwRI Code #	Description
DD L-4	2" x 4-1/4" clear CR39 plastic cover plate
DD M-1	vulcanized fiber headgear
DD N-1-3	polycarbonate lens/8" x 11-1/2" x .050' clear, faceshield
DD P-1	curved chin fiber glass welding helmet
EE L-1	coverall goggles, plastic
EE L-2	coverall goggles, splash-gard vents
EE L-3	industrial safety spectacles, pink crystal frame, glass lenses, 48 mm eyesize, plastic frame
EE L-4	industrial safety spectacles, gray smoke, 46 mm eyesize, glass lenses, plastic frame
EE L-5	industrial safety spectacles, jet black, glass lenses, 48 mm eyesize, plastic frame
EE L-6	industrial safety spectacles, jet black, 48 mm eyesize, glass lenses, plastic frame
FF B-1-7	flex clear goggles, polycarbonate lens
FF C-1	flex welding goggles, plastic filter lens
FF D-1-6	clear heat treated safety lenses, black plastic frame
FF E-1-11	plastic welding lenses
FF E-12	clear welding cover plate
FF F-1a-3a	round plastic welding lenses
FF F-1b-3b	spectacles 6.000 D curve, clear, S7-48 mm lenses
FF H-1	complete headgear including sweat-band, spark deflector and headgear

TABLE 5-1. LIST OF EYE AND FACE PROTECTIVE EQUIPMENT USED IN PERFORMANCE OF TESTS (Cont'd)

SwRI Code #	Description
FF J-1-3	clear plastic faceshield
GG M-1-11	extra large wraparound, polycarbonate, clear, goggles
GG N-1-6	extra large wraparound, polycarbonate, green, goggles
GG P-1-12	regular wraparound, polycarbonate, clear, goggles
GG Q-1-5	regular wraparound, polycarbonate, green, goggles
HH A-1-4	nonvented soft frame goggles, clear body and clear lens
HH B-1a B-1b	pink crystal spectacles, with universal bridge, glass lenses, S7-48 mm eyesize
HH C-1a C-1b	pink crystal spectacles, with universal bridge, glass lenses, S7-48 mm eyesize
HH D-1a D-1b	pink crystal spectacles, with universal bridge, (no sideshields), glass lenses, S7-48 mm eyesize
HH E-11a E-1b	pink crystal spectacles, with universal bridge, (no sideshields), glass lenses, S7-48 mm eyesize
HH F-1-4	six-vent soft frame goggles, clear lens, clear frame
JJ R-1	clear plastic 6" x 15: x . 040" faceshield
JJ R-2	clear plastic 8" x 15: x . 060" faceshield
JJ R-3	clear plastic 8" x 15: x . 080" faceshield
JJ R-4	medium green plastic 6" x 15" x . 040" faceshield
JJ R-5	medium green plastic 6" x 15" x . 040" faceshield
JJ R-6	medium green plastic 6" x 15" x . 040" faceshield

TABLE 5-1. LIST OF EYE AND FACE PROTECTIVE EQUIPMENT USED IN PERFORMANCE OF TESTS (Cont'd)

SwRI Code #	Description
JJ S-1	front mounting for cap
JJ S-2	back mounting for cap
JJ S-3	front mounting for cap, plastic
KK A-1-7	chipper's cup goggles, plastic frame, clear heated treated lens
KK B-1-7	welder's cup goggles, plastic frame, clear cover plate (filter plate, shades 3-8)
KK C-1-7	chipper's coverall goggles, plastic frame, clear lens
KK D-1-7	welder's coverall goggles, plastic frame, cover cover plate, round filter shades #4 - 10
KK E-1-7	safety spectacles, plastic frame, glass lenses, S7-48 mm eyesize
KK F-1-7	safety spectacles, plastic frame, glass lenses, sideshields, S7-48 mm eyesize
KK G-1-7	safety spectacles, metal frames, green lenses, (glass), S7-48 mm eyesize
KK H-1-7	safety spectacles, metal frames, green lenses, (glass) sideshield, S7-48 mm eyesize
KK I-1-12	spectacles with plastic frames and plastic (CR-39) lenses, S7-48 mm lenses
LL A-1	visor-type, combination goggle and spectacle, clear
LL A-2	visor-type, combination goggle and spectacle, light green
LL A-3	visor-type, combination goggle and spectacle, med. green

TABLE 5-1. LIST OF EYE AND FACE PROTECTIVE EQUIPMENT USED IN PERFORMANCE OF TESTS (Cont'd)

SwRI Code #	Description
LL A-4	visor-type, combination goggle and spectacle, dark green
MM A-1-7	clear flex goggles, clear lens (acrylic), clear frame (covered vents)
MM B-1	clear flex goggle, clear lens (acrylic), clear frame (regular vent.)
MM C-1-7	clear flex goggles, clear lens, clear frames
MM D-1-7	clear flex goggles, clear lens (acrylic), clear frame (cover vents)
MM E-1	clear flex goggle, clear lens, clear frame, (regular)
MM F-1-7	safety spectacles, plastic frames, (charcoal), clear glass lenses, S7-48 mm eyesize
MM G-1	safety spectacles, plastic frame, (charcoal), clear glass lens, side-shields, S7-48 mm eyesize
MM H-1-7	safety spectacles, plastic frame (crystal), clear glass lenses, S7-48 mm eyesize
MM I-1	safety spectacles, plastic frame (charcoal), clear glass lenses, S7-48 mm eyesize
MM J-1	safety spectacles, plastic frame, clear plastic lenses, S7-48 mm eyesize
MM K-1	safety spectacles, plastic frame, clear plastic lenses, S7-48 mm eyesize
MM L-1	safety spectacles, plastic frame, clear plastic lenses, S7-48 mm eyesize
MM M-1	safety spectacles, plastic frame, clear plastic lenses , S7-48 mm eyesize
MM N-1	safety spectacles, plastic frame (crystal), glass lenses, S7-48 mm eyssize

TABLE 5-1. LIST OF EYE AND FACE PROTECTIVE EQUIPMENT USED IN PERFORMANCE OF TESTS (Cont'd)

SwRI Code #	Description
MM O-1	safety spectacles, plastic frame (crystal), glass lenses, S7-48 mm eyesize
NN A-1-7	basic cup type goggles, green circle lenses, 50 mm round lenses
NN B-1-7	adjustable coverall goggles, clear lens
NN C-1-7	welding cup-type goggles, clear cover lenses, shade #5
NN E-1-7	fog-ban goggles, clear plastic lens, clear flexible frames
NN F-1-7	flex welding coverall goggles, plastic frame, acetate lenses, shade #5
NN G-1-6	spectacles, plastic frame, sideshields (molded acetate), S7-48 mm glass lenses
NN H-1-7	spectacles, metal frame, sideshields (wire mesh), S7-48 mm glass lenses
NN I-1-8	clear lenses, 42 mm glass

(1) Mechanical Strength

There are basically three schools of thought for tests evaluating the mechanical or impact strength of eye and face protective devices. One group (e. g. United States in ANSI Z87. 1) advocates the drop ball test using a 1. 00" diameter steel ball dropped 50" onto the lens, a 7/8" diameter steel ball dropped 50" onto the lens, or a 5/8" diameter steel ball dropped 39" onto the lens, depending upon the type of lens being tested. Another group (e. g. Great Britain in standard #2092: 1967) advocates a high velocity ballistic impact test using a 6. 5 mm (1/4 in.) diameter steel ball travelling at a velocity of 12. 2m/sec (40 ft/sec), 45. 7 m/sec (150 ft/sec), or 119 m/sec (390 ft/sec), depending upon the type of protector being tested. Another group (e. g. : Australia in AS CZ7-1965) incorporates both a drop ball test using a 22mm (7/8 in.) diameter steel ball dropped 183 cm (72 in.) onto the lens, and a ballistic impact test using a 6. 0 mm (~0. 25 in) diameter steel ball travelling at a velocity of 42 ± 3m/sec (140 ± 10 ft/sec).

All of the standards mentioned above which contain a ballistic impact test incorporate a steel sphere rather than some other material or shape. The reason for this is that the kinetic energy imparted to the protector by the steel BB after impact is higher than for a BB made of a material such as lead because the lead BB deforms and part of the energy is absorbed by the missile when this occurs. Lead is also a bad representation of an actual particle produced from a normal machining operation because of this property. The use of a spherical object permits easy reproducability since the impact area is the same for any orientation. It is not, however, easy to determine what size BB and impact speed would be appropriate for a standard test.

Richard L. Williams in "Ballistic Studies in Eye Protection" determined that the ballistic limit for rabbit eyes, the point at which the eye was damaged beyond repair, using a 0. 172" (4. 4 mm) diameter steel BB was 249 ft/sec (76 m/sec). Particles of this size and velocity are therefore extremely dangerous to the eye, and for hazardous conditions, where a comparable particle size and velocity are present, it is imperative to have adequate eye protection. Eye and face protectors which are to protect against any hazard containing these parameters should be tested using a 4 mm to 5 mm diameter steel ball travelling at 100 m/sec or higher (The added velocity is to provide a margin of safety in the event a slightly weaker lens is produced or a higher velocity is produced in the hazardous area). A rough estimate of possible velocities attainable by particles in machining or grinding processes can be made by calculating the surface speed of the work or grinding surface. Some of these calculations will be presented later in this report.

E. C. Wigglesworth of the Australian Defense Scientific Service, in Melbourne, Australia has done extensive work in the area of drop ball and

ballistic impact testing. He states that different investigators using different test methods have come to different conclusions about the strength of the same materials. For example, "Newton[5-1] using a 6.3-mm steel ball in a ballistic system reported that allyl resin lenses (2 mm thick) had better impact resistance than thermally toughened glass lenses (3 mm thick), whereas, Wigglesworth[5-2] using a 22-mm steel ball in a drop tower system, investigated the same materials, but reported the superiority of glass!"[5-3] These conclusions imply that there is a need for both drop ball and ballistic impact tests in a new U.S. standard on eye and face protective equipment.

Wigglesworth mentions that Silberstein[5-4] "has demonstrated decreasing resistance with increasing lens life" due to multiple "minor impacts and abrasions"[5-3] sustained with aging. This conclusion, supported by work done by Wigglesworth[5-3] in which balls were dropped at increasing heights and balls the same increment between drops but different commencing heights and balls were dropped at different increments between drops but the same commencing height, supports the premise that it is improper to perform an impact strength on a lens before giving it to a wearer since this impact may weaken the lens. Perhaps a given number of lenses should be tested out of each production run in the manufacturing process and then discarded. Wigglesworth reasoned that the size and location of flaws in the surfaces of lenses are random and therefore normally distributed. In a normal distribution, "values which deviate from the mean by an amount exceeding twice the standard deviation (are) likely to arise only once in every twenty trials."[5-3] In the Australian standard (AS Z7-1967), however, only a ten unit sample size is used. A proof of Wigglesworth statement that values exceeding two standard deviations from the mean are likely to occur only 5% of the time in a normal distribution is as follows:

$$\text{Normal distribution: } f(x) = \left[\frac{1}{\sigma\sqrt{2\pi}}\right] \left[e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}\right]$$

where x = random variable
μ = mean
σ = standard deviation

The probability that x will be outside two standard deviations (i.e., outside $\mu \pm 2\sigma$) is given by

$$P\,[x<(\mu-2\sigma)\,;\,x>(\mu+2\sigma)] = 1 - P(\mu - 2\sigma < x < \mu + 2\sigma)$$

$$= 1 - \int_{\mu-2\sigma}^{\mu+2\sigma} \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} dx$$

When $t = \left(\frac{x - \mu}{\sigma}\right)$, then $dx = \sigma dt$

$$= 1 - \frac{1}{\sqrt{2\pi}} \int_{-2}^{+2} e^{-\frac{1}{2}t^2} \, dt$$

$$= 1 - (2)\left(\frac{1}{\sqrt{2\pi}}\right) \int_{0}^{2} e^{-t^2/2} \, dt$$

Normal Area (value can be found in mathematical tables)

$$= 1 - (2)(0.47725)$$

$$= 0.0455 \text{ (or } \simeq 5\%)$$

Hence, if the mean fracture strength of a lens is much higher than that to which it is exposed either in the working environment or in a standard test, the probability that it will break when subjected to these conditions is very minimal.

After impact testing with 19.1 mm (3/4 in.), 22.2 mm (7/8 in.), 25.4 mm (1 in.), and 28.6 (1-1/8 in.) diameter steel balls, Wigglesworth concludes that "the use of 2.0 mm or thinner allyl resin lenses is not recommended and the use of 2.0 mm or thinner thermally toughened glass lenses is strongly deprecated".[5-3] If tests in a standard are reliable, then lenses which are too thin will fail the tests and will not be manufactured. However, precautions must be made. According to various eye and face protective equipment manufacturers, there is a chemical treatment for glass lenses which greatly increases its impact strength. With this process, manufacturers may be tempted to produce non-heat treated, but chemically treated, glass lenses. Once the thin chemical layer is scratched, however, the lens becomes very susceptible to breakage upon impact. Hence, the new standard should establish that glass lenses be heat treated and possibly include a thickness requirement. The present requirement of 3.0 mm to 3.8 mm thickness is good for glass lenses. Glass lenses thicker than 3.8 mm tend to be too heavy to be comfortable for the wearer. As is shown in subsequent tables in this report, plastics used in goggles approximately 1.5 mm thick have excellent impact resistance. The surface area of the lens as well as the properties of the materials used in the goggle allow some recoil upon impact and thus bring about the greater strength. For some plastics, then, the thickness requirements may be too severe. To allow for any surface treatment for strength which may wear off with usage, it might be good to scratch the lenses before impact testing. This was done in some cases, and the results are presented in tables and discussed later in this report.

In spite of the above, glass lenses are not to be discounted. "Despite its inferior ballistic impact resistance (using 3.2 mm steel ball), cases of eye injury from the failure of thermally toughened glass are rarely reported."[5-5] (This could be due to poor accident statistics). In addition, thermally treated glass lenses are resistant to scratching and abrasion and are cosmetic in appearance and are thus more readily acceptable to the user than some of the other types of lenses.

According to Wigglesworth, the fracture velocity of 3 mm thermally toughened glass is 29 m/sec when using a 3.2 mm steel ball. Wigglesworth suggests the use of a 3 mm steel ball for ballistic testing since many particles of this size occur from machining operations. In the data he presents to arrive at this particle size, there are some particles larger than 3 mm. For instance, of 467 cases reported by Howsam[5-6] 402 had a maximum dimension of 3 mm or less, 30 were 4 mm or less, 27 were over 4 mm and the size of the remaining 8 were not recorded. Of this data, approximately 5.8% were over 4 mm in diameter. From these results, a steel ball size of 3 mm, 4 mm, 5 mm, or 6 mm (BSI 2092: 1967 and AS CZ7-1967 both use approximately 6 mm steel balls) should be good for a ballistic impact test. (We decided to use a 4.8 mm steel ball because it was in the 4 mm - 6 mm range (within range of approximately 5% occurrence), and could be propelled easily using a 22 caliber air pistol). Wigglesworth's recommendations for mechanical strength acceptance tests are summarized in Table 5-2.

TABLE 5-2. PROPOSED ACCEPTANCE TESTS FOR EYE PROTECTORS[5-5]

Ball Diameter	Ballistic Impact Test Velocity	Drop Ball Test Height*	Test Material
25 mm (1 in.)		1.25 m (50 in.)	Grade 1
3 mm (1/8 in.)	20 m/sec		Grade 1
3 mm (1/8 in.)	50 m/sec		Grade 2
3 mm (1/8 in.)	100 m/sec		Grade 3

*All grade materials must pass the drop ball test.

Grades 1, 2, and 3 designate protectors with increasing strength. The materials Wigglesworth tested produced the following results:

3 mm thermally toughened glass	Grade 1
3 mm allyl resin	Grade 2
1.4 mm cellulose acetate	Grade 2
1.9 mm polycarbonate	Grade 3

Tables 5-3 through 5-6 are copied from the 18th Edition of Machinery's Handbook: A Reference Book for the Mechanical Engineer, Draftsman, Toolmaker and Machinist by Erik Oberg and F. D. Jones. Normal cutting speeds of various machinery operations for different materials can be found in these tables. The highest normal tool speed in these tables is 3500 ft/min (17.8 m/sec) occurring when machining die-cast aluminum with a tantalum - carbide tool. The highest normal tool speed for machining steel is 1000 ft/min (5.08 m/sec) also occurring when machining with a tantalum - carbide tool. The density of steel ($\sim$0.29 lb/in^3) is almost three times that of aluminum ($\sim$0.098 lb/in^3). Therefore for an aluminum particle and a steel particle of the same volume, the ratio of the kinetic energies in the worst machining condition is

$$\frac{T_{Al}}{T_S} = \frac{\rho_{Al} v_{Al}^2}{\rho_s v_s^2}$$

where

T_{Al} = kinetic energy of aluminum particle

T_s = kinetic energy of steel particle

ρ_{Al} = density of aluminum

ρ_s = density of steel

v_A = velocity of aluminum particle

v_s = velocity of steel particle

$$\frac{T_{Al}}{T_s} \simeq \frac{0.098}{0.29} \times \frac{(17.8)^2}{(5.08)^2}$$

$$\frac{T_{Al}}{T_s} \simeq 4.15$$

The kinetic energy of the Aluminum particle is greater. The kinetic energies are equal, however, when

$$\frac{T_{Al}}{T_s} = \frac{\rho_{Al} v_{Al}^2}{\rho_s v_s^2} = 1$$

TABLE 5-3. CUTTING SPEEDS AND FEEDS FOR TURNING TOOLS

Steel — Standard ⅞-inch Tool					Cast Iron — Standard ⅞-inch Tool				
Depth of Cut in Inches	Feed in Inches	Speed in Feet per Minute for a Tool which is to last 1½ Hour before Re-grinding			Depth of Cut in Inches	Feed in Inches	Speed in Feet per Minute for a Tool which is to last 1½ Hour before Re-grinding		
		Soft Steel	Medium Steel	Hard Steel			Soft Cast Iron	Medium Cast Iron	Hard Cast Iron
3/32	1/64	476	238	108	3/32	1/16	122	61.2	35.7
	1/32	325	162	73.8		1/8	86.4	43.2	25.2
	1/16	222	111	50.4		3/16	70.1	35.1	20.5
	3/32	177	88.4	40.2	1/8	1/32	156	77.8	45.4
1/8	1/64	420	210	95.5		1/16	112	56.2	32.8
	1/32	286	143	65.0		1/8	79.3	39.7	23.2
	1/16	195	97.6	44.4		3/16	64.3	32.2	18.8
	1/8	133	66.4	30.2	3/16	1/32	137	63.6	40.1
3/16	1/64	352	176	80.0		1/16	99.4	49.7	29.0
	1/32	240	120	54.5		1/8	70.1	35.0	20.5
	1/16	164	82	37.3		3/16	56.8	28.4	16.6
	1/8	112	56	25.5	1/4	1/32	126	62.9	36.7
1/4	1/64	312	156	70.9		1/16	90.8	45.4	26.5
	1/32	213	107	48.4		1/8	64.1	32.0	18.7
	1/16	145	72.6	33.0		3/16	52	26.0	15.2
	3/32	116	58.1	26.4	3/8	1/32	111	55.4	32.3
3/8	1/64	264	132	60.0		1/16	80	40.0	23.4
	1/32	180	90.2	41.0		1/8	56.4	28.2	16.5
	1/16	122	61.1	27.8	1/2	1/32	104	52.1	30.4
1/2	1/64	237	118	53.8		1/16	75.2	37.6	22.0
	1/32	162	80.8	36.7		1/8	43.1	21.6	12.6

Steel — Standard ⅝-inch Tool					Cast Iron — Standard ⅝-inch Tool				
Depth of Cut	Feed	Soft Steel	Medium Steel	Hard Steel	Depth of Cut	Feed	Soft Cast Iron	Medium Cast Iron	Hard Cast Iron
1/16	1/64	548	274	125	3/32	1/32	160	80.0	46.6
	1/32	358	179	81.6		1/16	110	55.0	32.2
	1/16	235	117	53.3		1/8	75.4	37.7	22.0
3/32	1/64	467	234	106	1/8	1/32	148	74.0	43.3
	1/32	306	153	69.5		1/16	104	51.8	32.0
	1/16	200	100	45.5		1/8	69.6	34.8	20.3
	3/32	156	78	35.5	3/16	1/64	183	91.6	68.0
1/8	1/64	417	209	94.8		1/32	135	67.5	39.4
	1/32	273	136	62.0		1/16	94	47.0	27.4
	1/16	179	89.3	40.6		1/8	64.3	32.2	18.8
	3/32	140	69.8	31.7	1/4	1/64	171	85.7	50.1
3/16	1/64	362	181	82.2		1/32	126	63.2	36.9
	1/32	236	118	53.8		1/16	87.8	43.9	25.6
	1/16	155	77.4	35.2		3/32	70.4	35.2	20.6
1/4	1/64	328	164	74.5	3/8	1/64	156	77.8	45.4
	1/32	215	107	48.8		1/32	116	57.8	33.8
3/8	1/64	286	143	65.0		1/16	79.7	39.9	23.3

* Cutting speeds for tools of a good grade of high-speed steel, properly ground and heat-treated.

TABLE 5-4. CUTTING SPEEDS AND FEEDS FOR CEMENTED-CARBIDE TOOLS

Examples from Practice. Tantalum-carbide tools were used for materials marked with asterisks (*) Column 2. Tungsten carbide was used for all other examples. These speeds and feeds are intended as a general guide only. The rigidity of the machine and tool support, interrupted cuts, and other factors result in wide variations in practice.

Machining Operation	Kinds of Material	Cutting Speed, Ft. per Min.	Depth of Cut, Inch	Rate of Feed		
				Per Rev.	Inches per Min.	Inch per Tooth
Turning	Cast Iron	250	¼	0.070	...	...
	Cast Iron	210	3/8	0.062	...	...
	Cast Iron (1)	260	3/16	0.015	...	...
	Cast Iron (2)	150	¼–¾	0.050	...	...
	Semi-Steel (3)	280	⅛	0.012	...	...
	Semi-Steel	300	...	...	...	...
	*Semi-Steel	225	...	0.028	...	...
	*Semi-Steel	286	5/32	0.015	...	...
	*Chilled C.I.	62	5/8	.....	...	...
	*S.A.E. 52100	185	⅛–5/16	0.020	...	...
	*Tool Steel 1.10%	140	½	0.020	...	...
	Silicon Steel	500	...	...	...	...
	Carbon Steel 0.90%	500	...	...	...	...
	Bronze	400	...	0.020	...	...
	Bronze	425	3/16	0.024	...	...
	Bronze	550	⅛	0.031	...	...
	Brass Casting (4)	458	3/32	0.108	...	...
	Cast Aluminum	1000	...	...	...	...
	Aluminum Alloy	570	⅛	0.031	...	...
Face Milling	Cast Iron	226	1/16	...	24¾	0.014
	Cast Iron	276	1/16	...	24¾	0.012
	Cast Iron	205	⅛	...	14½	0.009
	Cast Iron	280	3/32	...	32½	...
	Cast Iron	288	⅛	...	26	...
	Cast Iron	307	⅛	...	21	0.009
	Cast Iron	370	⅛	...	52½	0.012
	Cast Iron (5)	227	⅛	...	11	...
	Cast Iron (5)	235	⅛	...	9.3	...
	Cast Iron (5)	236	⅛	...	23	...
	Cast Iron	225	...	...	32	...
	*S.A.E. 1020	375	1/16	...	42	...
	Cast Aluminum	1285	⅛	...	80	0.008
End Milling	Cast Iron	263	⅛	...	38	0.007
	Cast Iron	214	⅛	...	38	0.009
	Cast Iron	273	...	...	38	0.006
Boring	Cast Iron	250	...	...	...	...
	Brass	350	...	...	...	...
	Aluminum	1500	...	...	...	...

(1) Interrupted cut. (2) Much higher speed possible for lighter cut. (3) 9 to 17 hours between tool grindings. (4) Six days between tool grindings. (5) These milling cutters used from 16 to 19 hours without sharpening.

TABLE 5-5. CUTTING SPEEDS AND FEEDS FOR CEMENTED-CARBIDE MILLING CUTTERS

Material to be Milled	Roughing, Feet per Minute		Finishing
	Over ⅛-inch depth of cut	Under ⅛-inch depth of cut	Under ⅛-inch depth of cut
Cast Iron, soft	200– 250	250– 325	300– 400
Cast Iron, medium	150– 200	200– 250	250– 300
Cast Iron, hard	100– 125	125– 175	150– 250
†Malleable Iron	225– 300	250– 350	350– 450
†*Cast Steel	100– 200	150– 250	200– 300
†*Low-carbon Steel, soft	150– 200	175– 250	200– 350
†*Low-carbon Steel, medium	100– 150	150– 225	175– 250
†*Low-carbon Steel, hard	75– 100	100– 150	150– 200
Yellow Brass	300– 400	350– 500	400– 600
Ordinary Bronze	200– 300	250– 350	350– 500
†Aluminum	**	**	**

RECOMMENDED FEEDS IN INCH PER TOOTH PER CUTTER REVOLUTION

Material to be Milled	Roughing Depth ⅛–3/16 inch	Semi-finishing Depth 1/16–⅛ inch	Finishing Depth 1/16 inch or under
Cast Iron	0.008–0.010	0.009–0.014	0.006–0.008
Malleable Iron	0.008–0.010	0.009–0.014	0.006–0.008
Brass	0.010–0.012	0.012–0.016	0.008–0.010
Bronze	0.010–0.012	0.012–0.016	0.008–0.010
Aluminum	0.004–0.007	0.005–0.007	0.003–0.006
Steel	0.004–0.008	0.005–0.009	0.003–0.006

† Use Coolant. * Tantalum Carbide Cutters.

** Cutting speeds for turning or milling aluminum alloys with carbide cutters, may range from 500 to 15000 ft. per min. or even higher (in some "high cycle" milling) depending upon the machinability of the alloy and the maximum speed of available equipment. As a general rule, the highest speed obtainable may be employed, with the possible exception of alloys having a high silicon content.

Note: The feed in inches per minute equals the feed per tooth per revolution multiplied by the number of cutter teeth multiplied by R.P.M.

Example: Find the feed in inches per minute and the speed in R.P.M. for a 5-inch cutter having 10 teeth. The depth of cut is ⅛ inch and the operation rough-milling soft cast iron.

The table indicates that a speed of about 250 feet per minute applies in this case. Divide 250 by the circumference of the cutter in feet to obtain the revolutions per minute. Thus, 250 ÷ 1.31 feet = 191 R.P.M.

The table shows a recommended feed per tooth of 0.008 to 0.010 inch. Next multiply the "teeth per minute" by 0.008 thus obtaining a table feed of 15.3 inches per minute. (The "teeth per minute" is obtained by multiplying the number of cutter teeth by the number of revolutions per minute.) In this example we have 0.008 × 10 × 191 = 15.3.

TABLE 5-6. CUTTING SPEEDS FOR RIGIDLY MOUNTED TUNGSTEN-CARBIDE TOOLS

Material	Depth of Cut, Inch						
	1/32	1/16	3/32	⅛	5/32	3/16	¼
	Cutting Speed, Feet per Minute						
Cast Iron, Soft, Brinell up to 185	330	310	290	275	260	245	225
Cast Iron, Medium, Brinell up to 205	270	260	240	220	210	190	170
Malleable Iron	350	330	310	300	285	275	250
Yellow Brass	750	700	650	600	550	520	450
Ordinary Bronze	450	420	390	370	350	330	300
Cast Aluminum	1500	1400	1300	1200	1125	1050	900

If the machine is in good condition, the tool is of ample size and rigidly mounted with practically no overhang, and the part itself is of solid design, it will then be possible to use the cutting speeds listed in the table which covers materials most commonly used. Generally speaking, carbide tools operate from two to four times faster than high-speed steel tools.

Typical Average Speeds, Feeds and Depths of Cut for Tantalum-Carbide Tools

Material Machined — Straight Cutting	Speed in Feet per Minute	Feed per Rev. in Inches	Depth of Cut, in Inches
Aluminum, Die-Cast (94 Al 6Si)	1400 to 3500	0.002 to 0.020	0.062 to 0.125
Beryllium Bronze, Hardened	150 to 300	0.008 to 0.040	up to ⅜
Brass, Common Yellow	300 to 1000	0.008 to 0.040	up to 1¼
Gray Cast Iron up to 200 Brinell	165 to 400	0.040 to 0.080	0.040 to ⅜
Gray Cast Iron, 200 to 400 Brinell	130 to 260	0.008 to 0.080	0.040 to ⅜
Cast Iron, Malleable	250 to 400	0.008 to 0.080	0.040 to ½
Cast Iron, Copper Silicon	175 to 350	0.008 to 0.070	0.040 to ⅜
Chilled Cast Iron, 78 Scleroscope	15 to 40	0.125 to 0.320	0.040 to 3/16
Armature Copper	800 to 1200	0.008 to 0.040	0.008 to ¼
Electrode Carbon	150 to 300	0.020 to ⅜	0.040 to 1½
Bakelite, Durez, etc.	600 to 1000	0.012 to 0.050	0.004 to ¼
Paper Calender Rolls	300 to 800	0.012 to 0.050	0.008 to ¼
Steel, Soft S.A.E. 1015	200 to 1000	0.008 to 0.040	0.003 to ½
Steel, about 190 Brinell	200 to 1000	0.008 to 0.040	0.003 to ½
Steel, about 250 Brinell	175 to 600	0.008 to 0.040	0.003 to ⅜
Steel, S.A.E. 6150, 350 Brinell	175 to 300	0.008 to 0.040	0.003 to ¼
Steel, Cast, 0.60 C, 0.60 Mn	175 to 300	0.010 to 0.040	0.050 to ⅜
Steel, Stainless, 460 Brinell	175 to 400	0.004 to 0.040	0.003 to ¼
Steel, Stainless 18-8	125 to 400	0.004 to 0.040	0.003 to ¼
Steel, S.A.E. 4150, 325 Brinell	100 to 200	0.004 to 0.025	0.003 to ¼
Steel, 0.50 C, 0.80 Mn, 0.60 Mo, 477 Br.	85 to 125	0.004 to 0.040	0.003 to ⅛
Steel, 2.50 Mn, 0.45 C	100 to 175	0.004 to 0.040	0.003 to 3/16

While rather wide limits are given in this table, the higher speeds, in general, apply to the lighter, and the slower speeds to the heavier cuts. The speeds are dependent also upon the type of machine tools available and the rigidity of tool and work at the higher speeds.

The function of tantalum carbide is to resist the "cratering" action of chips. This resistance is due to certain fundamental differences between tantalum carbide and tool materials containing chiefly tungsten. The frictional resistance of tantalum carbide against metals is very low.

or $$v_s = v_{Al} \sqrt{\frac{\rho_{Al}}{\rho_s}}$$

$$v_s \sim 17.8 \sqrt{\frac{0.098}{0.29}}$$

$$v_s \sim 10.3 \text{ m/sec}$$

With this in mind, in order to provide adequate protection, lenses should be able to withstand ballistic impact by a steel ball, 4.8 mm in diameter (from above) travelling at a velocity of 10.3 m/sec or greater. The surface speed, however, of a 6" diameter, 3450 rpm, Rockwell Manufacturing Company Tool Grinder (Model #NE23-105B) found in our facilities is 27.5 m/sec. Seldom would one expect to see a 3 mm diameter or larger particle coming off of the surface of the grinding wheel and the protective shielding on this type of equipment is generally very good. With this in mind, the 4.8 mm diameter steel ball propelled at slightly higher than 10.3 m/sec would constitute a good test for grade 1, eye protectors and possibly an impact speed of greater than 27.5 m/sec would be good for grade 2 eye protectors (to be worn when using unshielded high rpm machines). A comparison of Wigglesworth's test criteria using a 3 mm diameter steel ball with other steel ball sizes is presented in Table 5-7.

TABLE 5-7. COMPARISON OF IMPACT PARAMETERS FOR VARIOUS STEEL BALL SIZES

Steel Ball Diameter	Mass (gm)	Impact Velocity (m/sec)	Momentum (kg-m/sec)	Kinetic Energy (joules)
25.4 mm (1 in)	68.0	5.0*	3.4×10^{-1}	8.5×10^{-1}
3.2 mm (0.125 in)	0.13	20	2.6×10^{-3}	2.6×10^{-2}
3.2 mm (0.125 in)	0.13	50	6.5×10^{-3}	1.6×10^{-1}
3.2 mm (0.125 in)	0.13	100	1.3×10^{-2}	6.5×10^{-1}
4.8 mm (0.188 in)	0.44	10.9†	4.8×10^{-3}	2.6×10^{-2}
4.8 mm (0.188 in)	0.44	20	8.8×10^{-3}	8.8×10^{-2}
4.8 mm (0.188 in)	0.44	27.0†	1.2×10^{-2}	1.6×10^{-1}
4.8 mm (0.188 in)	0.44	50	2.2×10^{-2}	5.5×10^{-1}
4.8 mm (0.188 in)	0.44	54.4†	2.4×10^{-2}	6.5×10^{-1}
4.8 mm (0.188 in)	0.44	100	4.4×10^{-2}	2.2

TABLE 5-7. COMPARISON OF IMPACT PARAMETERS FOR VARIOUS STEEL BALL SIZES (Cont'd)

Steel Ball Diameter	Mass (gm)	Impact Velocity (m/sec)	Momentum (kg-m/sec)	Kinetic Energy (joules)
6.5 mm (0.250 in)‡	0.99	12.2	1.2×10^{-2}	7.4×10^{-2}
6.5 mm (0.250 in)‡	0.99	45.7	4.5×10^{-2}	1.0
6.5 mm (0.250 in)‡	0.99	119	1.2×10^{-1}	7.0
6 mm (0.236 in)**	0.86	42	3.6×10^{-2}	7.6×10^{-1}

* Drop ball test $v = \sqrt{2a_y y}$

where v = impact velocity (m/sec)

a_y = acceleration due to gravity (9.8 m/sec^2)

y = drop height (1.27 meters)

† Velocities chosen so that impact energies are comparable to those given by Wigglesworth (Effect of contact area on lens by ball was ignored in comparison since the steel balls do not differ greatly in size).

‡ From BS 2092: 1967

** From AS Z7-1967

In summary then, there is a need for a ballistic impact test to insure protection against high velocity impact, and for a drop ball test to insure protection against blunt trauma. The use of a steel ball of 3 mm, 4 mm, 5 mm, or 6 mm diameter with an impact velocity of at least 10.3 m/sec should be used for ballistic impact testing. Precautions should be taken for lenses which may have some surface treatment which greatly increases impact strength but may break easily once they are slightly scratched.

With this in mind the following tests would be good to be used in evaluating lens acceptability:

1. Lenses of a particular model inserted within frames such that each frame is complete with lenses shall be drop ball and ballistic impact tested.

2. Each lens must pass first the drop ball test and then the appropriate (depending on grade of material) ballistic test. (See Table 5-8.)

3. Grades shall be permanently stamped on lens next to manufacturer's identification with the appropriate symbol "I", "II", or "III".

TABLE 5-8. EVALUATING LENS ACCEPTABILITY

Ball Diameter	Ballistic Impact Test Velocity (m/sec)	Drop Ball Test Height	Test Material
25 mm (1 in)		1.25 m(50 in)	Grade I, II, III
4.8 mm (0.188 in)	11 + 4 - 0*		Grade I
4.8 mm (0.188 in)	50 ± 3†		Grade II
4.8 mm (0.188 in)	100 ± 5†		Grade III

* 11 m/sec was chosen since it is greater than 10.3 m/sec calculated from equalizing the kinetic energy of a steel particle with that of a possible high speed aluminum particle and since it is comparable to the kinetic energy of Wigglesworth's Grade 1 impact particles.

† These velocities coincide with those selected by Wigglesworth using a smaller impact ball and are more arbitrary than that chosen by Grade 1 impact velocities.

Ballistic impact tests were performed with a 0.22 caliber Benjamin high compression air pistol, model # 132, with a rifled 8" long barrel. The test apparatus was inclined at a small angle such that a 0.188" (3/16" or 4.8 mm) steel ball could be muzzle loaded and shot from the gun. The velocity of the projectile was determined by allowing it to interrupt the light, supplied by two miniature focused lamps, shining on two photodiode spaced 6" apart. Each photodiode was connected to a Computer Measurements Company Time Interval Meter Model 915 accurate to the nearest microsecond such that the interruption of the light to the first photodiode would start the counter and the interruption of the light to the second photodiode would stop the counter. Time increments were recorded after each shot when available and the velocity of the projectile was calculated by dividing the distance between photodiodes by the time interval. When the counter was not triggered to start or stop, primarily due to the closeness of the sizes of the projectile diameter to the photodiode diameter, the average velocity ± the estimate of the standard deviation was recorded. The average velocity was determined by calculating the arithmetic mean velocity for a given number of pumps of the gun from the times that a time interval was shown on the counter. These data are presented in Table 5-9.

TABLE 5-9. NUMBER OF PUMPS OF AIR GUN VS VELOCITY OF 4.8 mm (0.188") PROJECTILE

No. of Pumps	Velocity (m/sec)	Sample Size
1	13.2 ± 1.2*	7
2	25.1 ± 4.3	7
3	39.2 ± 2.7	5
4	55.3 ± 2.8	22
5	63.4 ± 1.4	6
6	72.9 ± 0.7	7
7	79.5 ± 0.3	4
8	87.3	1
9	91.1 ± 2.0	3
10	96.9	1
11	100.6 ± 0.9	7

* Tolerances are an estimate of the standard deviation (i.e. $\sqrt{\frac{N}{N-1}}$ times the standard deviation where N is the sample size. An estimate of the standard deviation was used since this allows a larger spread in velocity and the sample size was considered as only a part of a larger sample size.

Shooting the steel ball in an oversized barrel (i.e. 0.188" diameter ball and 0.220" diameter barrel) provided good accuracy and fairly good velocity reproducability. A top view of our apparatus is shown in Figure 5-1. Eye protectors were mounted on the anthropomorphic head in the normal wearing position and impacted by the steel ball at the appropriate velocities.

Figure 5-2 shows the apparatus used for the ballistic impact test. Figure 5-3 shows the relative sizes of the 25.4 mm (1") and 4.8 mm (0.188") steel balls.

Table 5-10 contains the results of the ballistic impact test performed on spectacles with a commencing velocity of 55.3 m/sec ± 2.8 m/sec. The plastic lenses (CR-39) withstood much higher impact velocities than the glass lenses. Also, when the plastic lens failed, it was not as susceptible to spallation of the eye side of the lens as the glass lenses were. The approximate diameter of the spallations are recorded in the table and are quite large. In all cases where spallation occurred, extensive damage would undoubtedly have been done to the eye.

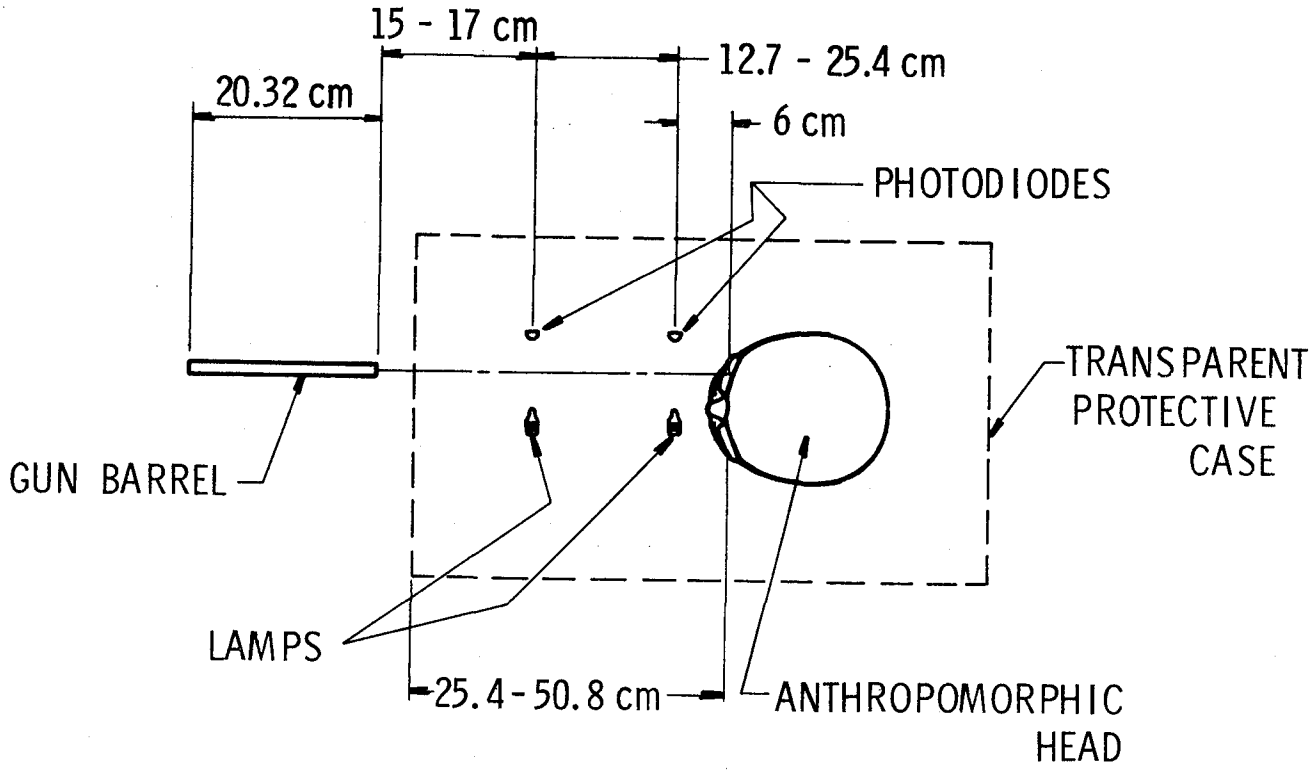


FIGURE 5-1. TOP VIEW OF BALLISTIC TEST APPARATUS

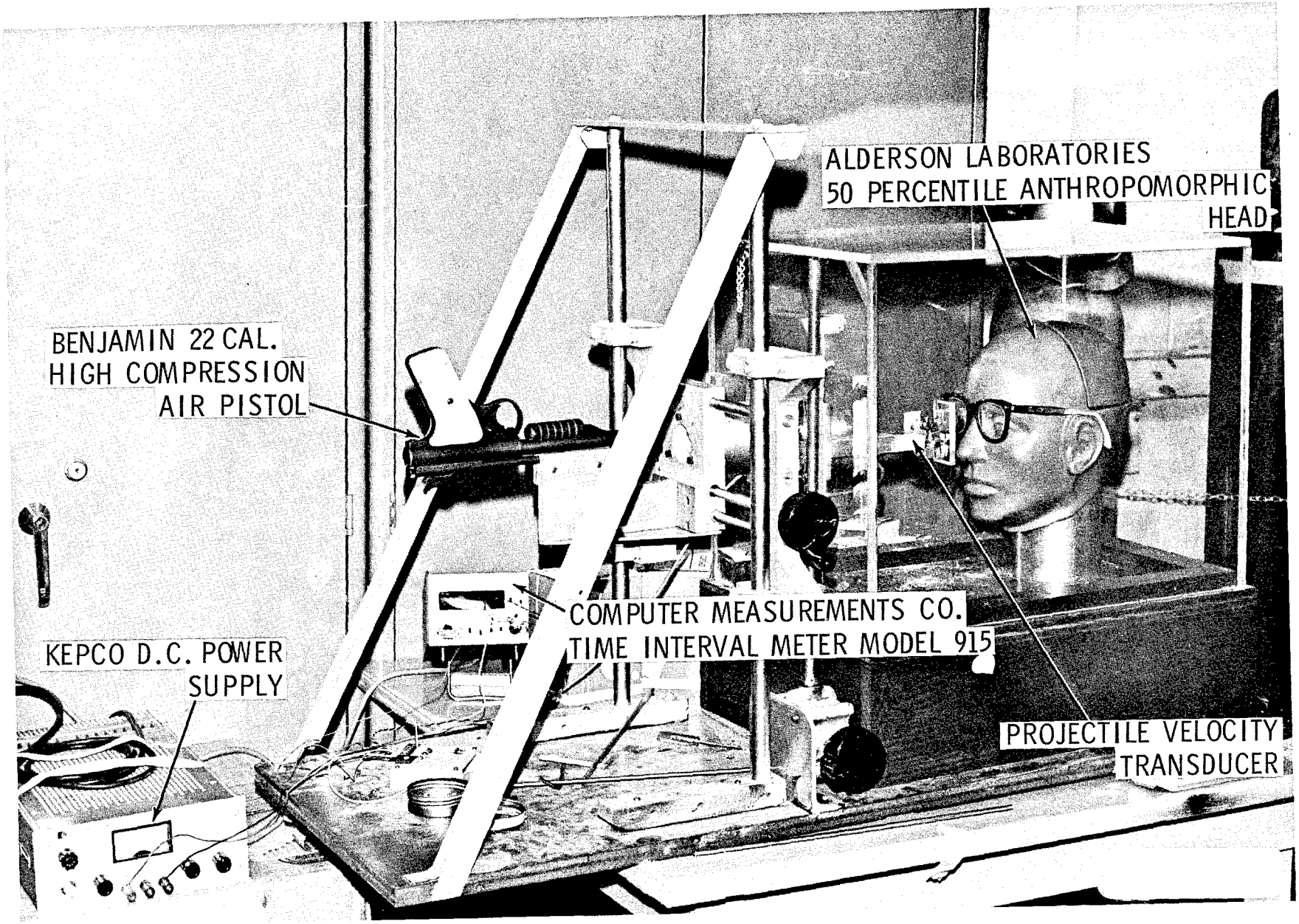


FIGURE 5-2. BALLISTIC TEST APPARATUS

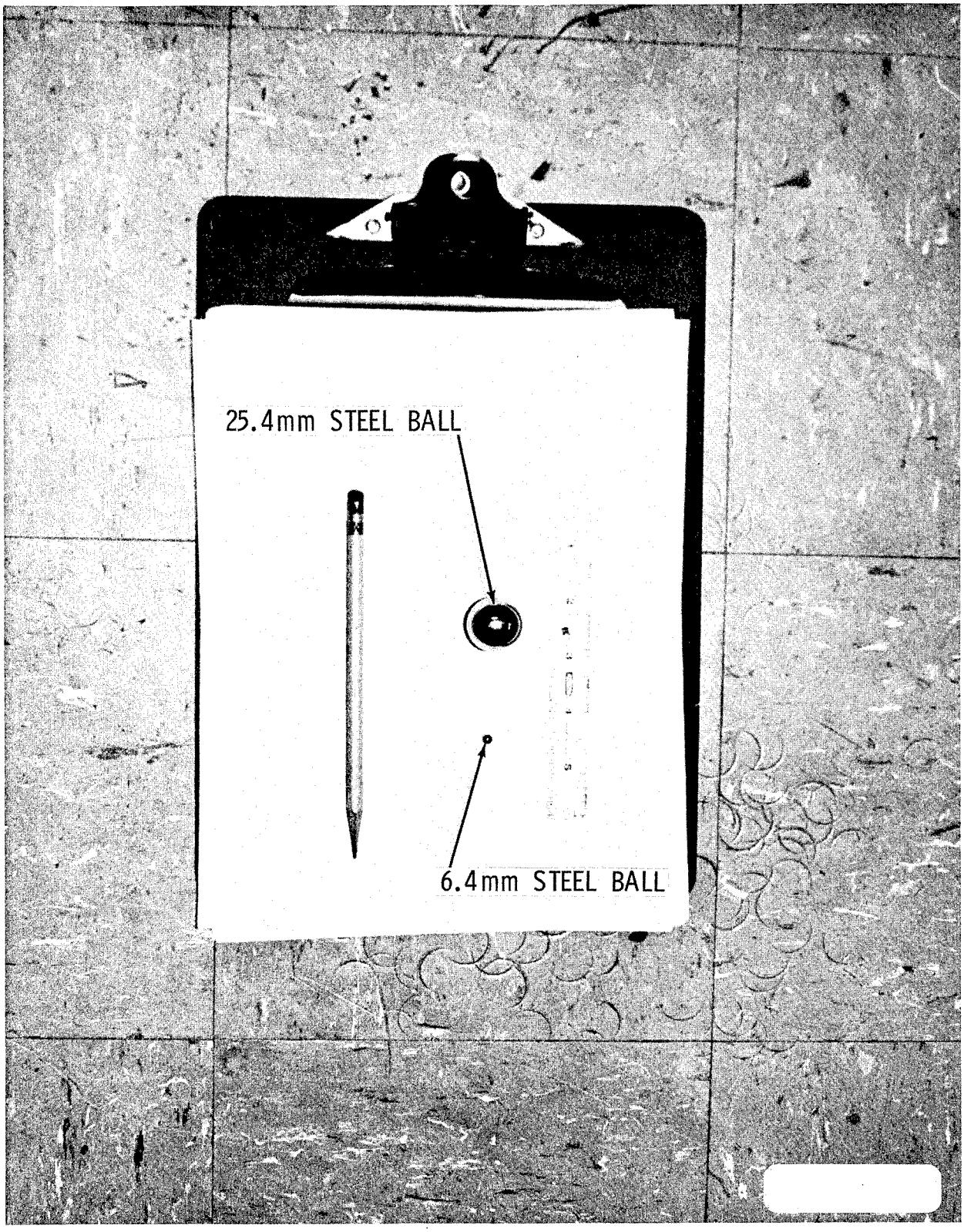


FIGURE 5-3. BALLISTIC IMPACT AND DROP BALL TEST PROJECTILES

TABLE 5-10. BALLISTIC IMPACT TEST ON SPECTACLES LENSES

Projectile: 4.8 mm (0.188") diameter steel ball
Propulsion System: 0.22 caliber air pistol

SwRI Code #	Description	Lens Designation	Lens Thickness	No of Pumps	Velocity* (m/sec)	Comments
AA H-5	plastic frame glass lenses S7-48 mm eyesize	right	3.1 mm (0.124")	4	54.8	lens shattered (3/8" dia. spall)
		left	3.1 mm (0.124")	4	55.9	lens shattered (1/2" dia. spall)
AA H-1	plastic frame glass lenses S7-48 mm eyesize	right	3.1 mm (0.122")	4	55.3 ± 2.8	lens shattered (1/2" dia. spall)
		left	3.1 mm (0.121")	4	53.6	lens shattered (1/2" dia. spall)
AA P-2	metal frame glass lenses S7-48 mm eyesize	right	3.1 mm (0.123")	4	55.3 ± 2.8	lens shattered (11/16" dia. spall)
		left	3.1 mm (0.121")	4	55.3 ± 2.8	lens shattered (1/2" dia. spall)
AA P-5	metal frame glass lenses S7-48 mm eyesize	right	3.1 mm (0.121")	4	55.3 ± 2.8	lens shattered (11/16" dia. spall)
		left	3.1 mm (0.122")	4	53.7	steel ball went through lens, lens shattered (13/16" dia. spall)
BB A-6	plastic frame plastic lenses (CR-39) S7-48 mm eyesize	right	3.1 mm (0.121")	4	52.5	
				5	60.6	
				6	73.2	
				7	79.5 ± 0.3	
				8	87.3	
				9	92.6	lens cracked
		left	3.1 mm (0.122")	4	56.4	
				5	63.4 ± 1.4	
				6	73.4	
				7	79.7	
				8	87.3	
				9	88.8	
				10	96.9	
				11	101.5	no damage

TABLE 5-10. BALLISTIC IMPACT TEST ON SPECTACLES LENSES (Cont'd)

SwRI Code #	Description	Lens Designation	Lens Thickness	No. of Pumps	Velocity (m/sec)*	Comments
BB A-7	plastic frame plastic lenses (CR-39) S7-48 mm eyesize	right	3.0 mm (0.120")	4	54.7	
				5	63.4 ± 1.4	lens cracked
		left	3.2 mm (0.125")	4	54.9	
				5	63.4 ± 1.4	
				6	73.9	lens cracked
DD H-4	plastic frame glass lenses S7-48 mm eyesize	right	2.9 mm (0.115")	4	55.3 ± 2.8	lens shattered (5/8" dia. spall)
		left	2.8 mm (0.112")	4	55.3 ± 2.8	lens shattered (5/8" dia. spall)
DD H-5	plastic frame glass lenses S7-48 mm eyesize	right	2.9 mm (0.113")	4	55.3 ± 2.8	lens shattered (5/8" dia. spall)
		left	2.9 mm (0.115")	4	55.3 ± 2.8	lens shattered (1/2" dia. spall)
EE L-6	plastic frame glass lenses S7-48 mm eyesize	right	3.1 mm (0.121")	4	55.3 ± 2.8	lens shattered (9/16" dia. spall)
		left	3.0 mm (0.119")	4	55.3 ± 2.8	lens shattered (9/16" dia. spall)
HH E-1a	plastic frame glass lenses S7-48 mm eyesize	right	3.1 mm (0.121")	4	54.9	lens shattered (3/4" dia. spall)
		left	3.1 mm (0.122")	4	55.3 ± 2.8	steel ball went through lens, lens shattered (5/8" dia. spall)
HH E-1b	plastic frame glass lenses S7-48 mm eyesize	right	3.1 mm (0.121")	4	55.3 ± 2.8	steel ball went through lens, lens shattered (5/8" dia. spall)
		left	3.1 mm (0.122")	4	54.7	steel ball went through lens, lens shattered (3/4" dia. spall)

TABLE 5-10. BALLISTIC IMPACT TEST ON SPECTACLES LENSES (Cont'd)

SwRI Code #	Description	Lens Designation	Lens Thickness	No. of Pumps	Velocity* (m/sec)	Comments
KK I-1	plastic frame plastic lenses (CR-39) S7-48 mm eyesize	right	2.8 mm (0.112")	4	55.3 ± 2.8	
				5	63.4 ± 1.4	
				6	73.3	shattered
				7	79.5 ± 0.3	lens (1/4" dia. spall)
		left	2.8 mm (0.112")	4	55.3 ± 2.8	
				5	64.7	
				6	72.3	lens cracked (no spalling)
KK I-8	plastic frame plastic lenses (CR-39) S7-48 mm eyesize	right	2.9 mm (0.114")	4	55.3 ± 2.8	
				5	63.7	
				6	72.9 ± 0.7	
				7	79.5 ± 0.3	
				8	87.3	
				9	91.8	lens & frame broke
		left	2.9 mm (0.114")	4	55.3 ± 2.8	lens cracked
KK E-7	plastic frame glass lenses S7-48 mm eyesize	right	2.8 mm (0.112")	4	55.3 ± 2.8	lens shattered (3/8" dia. spall)
		left	2.9 mm (0.115")	4	55.3 ± 2.8	lens shattered (1/2" dia. spall)
KK E-1	plastic frame glass lenses S7-48 mm eyesize	right	2.9 mm (0.115")	4	55.3 ± 2.8	lens shattered (3/8" dia. spall)
		left	2.8 mm (0.112")	4	54.1	lens shattered (3/8" dia. spall)
KK G-5	metal frame green glass lenses S7-48 mm eyesize	right	3.1 mm (0.121")	4	55.3 ± 2.8	lens shattered (1/2" dia. spall)
		left	3.0 mm (0.120)	4	55.3 ± 2.8	lens shattered (1/2" dia. spall)
KK G-1	metal frame green glass lenses S7-48 mm eyesize	right	3.1 mm (0.121")	4	55.3 ± 2.8	steel ball went through lens, lens shattered (7/8" dia. spall)
		left	3.0 mm (0.119)	4	54.8	lens shattered (1/2" dia. spall)

TABLE 5-10. BALLISTIC IMPACT TEST ON SPECTACLES LENSES (Cont'd)

SwRI Code #	Description	Lens Designation	Lens Thickness	No. of Pumps	Velocity* (m/sec)	Comments
MM H-1	plastic frame glass lenses S7-48 mm eyesize	right	2.7 mm (0.108")	4	55.0	lens shattered (1/2" dia. spall)
		left	2.7 mm (0.108")	4	55.3 ± 2.8	lens shattered (1/2" dia. spall)
MM H-4	plastic frame glass lenses S7-48 mm eyesize	right	2.7 mm (0.107")	4	54.5	steel ball went through lens, lens shattered (7/8" dia. spall)
		left (0.108")	2.7 mm (0.108")	4	54.3	lens shattered (5/8" dia. spall)
NN G-6	plastic frame glass lenses S7-48 mm eyesize	right	2.8 mm (0.109")	4	54.1	lens shattered (1/2" dia. spall)
		left	2.7 mm (0.108")	4	55.3 ± 2.8	lens shattered (11/16" dia. spall)
NN G-1	plastic frame glass lenses S7-48 mm eyesize	right	2.8 mm (0.110)	4	55.3 ± 2.8	lens shattered (11/16" dia. spall)
		left	2.8 mm (0.109")	4	55.3 ± 2.8	lens shattered (9/16" dia. spall)
NN H-5	metal frame glass lenses S7-48 mm eyesize	right	2.8 mm (0.111")	4	53.7	lens shattered (9/16" dia. spall)
		left	2.8 mm (0.110")	4	55.3 ± 2.8	lens shattered (no spall)
NN H-4	metal frame glass lenses S7-48 mm eyesize	right	2.8 mm (0.109")	4	64.4	lens shattered (no spall)
		left	2.8 mm (0.109")	4	54.9	lens shattered (lens crumbled before measuring spall)

* Average velocity and tolerances are given when no time interval was recorded.

Table 5-11 contains the results of the ballistic impact test performed on flexible goggles with plastic lenses. All of the goggles withstood an impact velocity of 100.6 m/sec ± 0.9 m/sec. The approximate diameter of the outline of the steel ball in the goggle is recorded to allow for calculations of the depth of penetration if needed.

Table 5-12 contains the results of the ballistic impact test performed on spectacles with a commencing velocity of 13.2 m/sec ± 1.2 m/sec. The left lens of each spectacle was scratched before impact testing. This was accomplished with the use of a carbide scribe placed through a hole drilled in a piece of plexiglass and held in place by a set screw such that the tip of the scribe projected 0.010" beyond a flat portion of the plexiglass. The 0.010" projection of the tip of the scribe beyond the plexiglas was determined by means of a low power optical microscope with a reticle at the focal point of its eyepiece. Two 1" long, 0.010" deep, perpendicularly crossed scribe lines were centered on the impact surface such that the scribe lines were parallel to the main axes of the lens. Due to the small sample size tested in this manner, no conclusions could be made about the weakening of the lens due to the scribe lines. All glass lenses withstood greater than 11 m/sec impact velocities but failed at slightly higher impact velocities. Plastic lenses withstood much higher impact velocities. Spallation of the eye side of glass lenses upon failure was severe.

Table 5-13 contains the results of the ballistic impact test performed on chipper's goggles with a commencing velocity of 13.2 m/sec ± 1.2 m/sec. The left lens of each goggle in this table was scribed in the same manner described above. There appears to be a tendency for the scratched lenses to have lower impact strength than unscratched lenses. Spallation of the eye side of all of these glass lenses was severe.

Table 5-14 contains the results of the ballistic impact test performed on a glass spectacle lens using a 0.22 caliber lead pellet projectile. The impact velocity before failure is much higher for the lead pellet than for the steel ball used in ballistic tests shown in previous tables. This is due to the energy absorption of the lead pellet upon impact.

Table 5-15 contains the results of the drop ball impact test performed on out-of-the-frame glass spectacle lenses with the left lens scratched in the manner described above. The balls were dropped 50" onto the lenses, and the drop ball diameter was increased until breakage of the lens. Plastic (CR-39) lenses and glass lenses appear to have equivalent impact strengths. This result is very significant. In the ballistic impact test the plastic (CR-39) had much higher impact strengths than glass lenses. This helps confirm the need for both ballistic impact and drop ball tests.

TABLE 5-11. BALLISTIC IMPACT TEST ON FLEXIBLE GOGGLES WITH PLASTIC LENSES

Projectile: 4.8 mm (0.188") diameter steel ball
Propulsion System: 0.22 caliber air pistol

SwRI Code #	Description	Lens Designation	Lens Thickness	No. of Pumps	Velocity* (m/sec)	Comments
AA A-3	flexible goggle dust & splash	right	1.5 mm (0.061")	11	100.6±0.9	slight indentation
		left	1.5 mm (0.061")	11	100.6±0.9	slight indentation
DD A-3	flexible goggle dust & splash	right	1.4 mm (0.055")	11	100.6±0.9	identation & bulging on inside (0.14" outline)
		left	1.4 mm (0.055")	11	100.3	identation & bulging on inside (0.14" outline)
FF B-7	flexible goggle dust & splash	right	1.5 mm (0.061")	11	100.6±0.9	indentation & bulging on inside (0.13" outline)
		left	1.7 mm (0.066")	11	99.4	indentation & bulging on inside (0.13" outline)
HH A-3	flexible goggle dust & splash	right	1.6 mm (0.063")	11	100.4	indentation & bulding on inside (0.13" outline)
		left	1.6 mm (0.062")	11	101.8	indentation & bulging on inside (0.13" outline)
MM D-2	flexible goggle dust & splash	right	1.3 mm (0.050")	11	100.6±0.9	slight indentation, slight bulging on inside
		left	1.3 mm (0.050")	11	100.6±0.9	slight indentation, slight bulging on inside
NN E-3	flexible goggle dust & splash (double molded lenses with air gap between lenses)	right	5.7 mm (0.223")	11	101.0	indentation of outside lens only (0.14" outline)
		left	5.9 mm (0.232")	11	99,9	indentation of outside lens only (0.13" outline)

* Average velocity and tolerances are given when no time interval was recorded.

TABLE 5-12. BALLISTIC IMPACT TEST ON SPECTACLE LENSES

Projectile: 4.8 mm (0.188") diameter steel ball
Propulsion System: 0.22 caliber air pistol
Other: Left lenses have two 1" long, 0.010" deep, perpendicularly crossed scribe lines centered on the impact surface such that the scribe lines are parallel to the main axes of the lens.

SwRI Code #	Description	Lens Designation	Lens Thickness	No. of Pumps	Velocity* (m/sec)	Comments
AA H-6	plastic frame glass lenses S7-48 mm eyesize	right	3.0 mm (0.118")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (3/8" dia. spall)
		left (scratched)	3.0 mm (0.120")	1	15.5	
				2	25.1 ± 4.3	
				3	36.7	lens shattered (5/8" dia. spall)
BB H-1	plastic frame plastic lenses S7-48 mm eyesize	right	2.4 mm (0.095")	1	13.2	
				2	25.1 ± 4.3	
				3	39.2 ± 2.7	
				4	53.7	
				5	63.6	
				6	72.1	
				7	79.2	lens cracked
		left (scratched)	2.5 mm (0.098")	1	12.8	
				2	25.1 ± 4.3	
				3	39.2 ± 2.7	
				4	55.3 ± 2.8	
				5	63.7	
				6	72.9 ± 0.7	
				7	79.8	lens cracked
DD H-2	plastic frame glass lenses	right	2.8 mm (0.111")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (3/8" dia. spall)
		left (scratched)	2.8 mm (0.110")	1	13.2 ± 1.2	
				2	27.1	
				3	39.2 ± 2.7	
				4	53.7	lens shattered (3/4" dia. spall)
FF D-1	plastic frame glass lenses	right	3.0 mm (0.117")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (5/8" dia. spall)
		left (scratched)	2.9 mm (0.116)	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (5/8" dia. spall)

TABLE 5-12. BALLISTIC IMPACT TEST ON SPECTACLE LENSES (Cont'd)

SwRI Code #	Description	Lens Designation	Lens Thickness	No. of Pumps	Velocity* (m/sec)	Comments
HH D-1b	plastic frame glass lenses	right	3.0 mm (0.120")	1	13.2 ± 1.2	
				2	27.1	lens shattered (3/8" dia. spall)
		left (scratched)	2.9 mm (0.115")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	
				3	41.3	lens shattered (3/8" dia. spall)
KK I-11	plastic frame plastic lenses	right	2.6 mm (0.101")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	
				3	39.2 ± 2.8	
				4	55.3 ± 2.8	
				5	63.6	
				6	72.0	
				7	79.3	lens shattered (1/4" dia. spall)
		left (scratched)	2.6 mm (0.102")	1	12.0	
				2	25.1 ± 4.3	
				3	41.3	
				4	55.3 ± 2.8	
				5	64.1	lens cracked
KK E-2	plastic frame glass lenses	right	2.9 mm (0.115")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	
				3	39.2 ± 2.7	lens shattered (1/2" dia. spall)
		left (scratched)	2.8 mm (0.112")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (1/2" dia. spall)
KK G-6	metal frame green glass lenses	right	3.0 mm (0.119")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	steel ball went through lens, lens shattered (3/8" dia. spall)
		left (scratched)	3.0 mm (0.120")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (1/2" dia. spall)
MM F-2	plastic frame glass lenses	right	3.0 mm (0.119")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	
				3	39.2 ± 2.7	steel ball went through lens, lens shattered (5/8" dia. spall)

TABLE 5-12. BALLISTIC IMPACT TEST ON SPECTACLE LENSES (Cont'd)

SwRI Code #	Description	Lens Designation	Lens Thickness	No. of Pumps	Velocity* (m/sec)	Comments
		left (scratched)	3.0 mm (0.118")	1	14.2	
				2	25.1 ± 4.3	lens shattered (3/8" dia. spall)
NN G-4	plastic frame glass lenses	right	2.7 mm (0.108")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	
				3	39.2 ± 2.7	lens shattered (5/8" dia. spall)
		left (scratched)	2.7 mm (0.109")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (1/4" dia. spall)

* Average velocity and tolerances are given when no time interval was recorded.

TABLE 5-13. BALLISTIC IMPACT TEST ON CHIPPER'S GOGGLES

Projectile: 4.8 mm (0.188") diameter steel ball
Propulsion System: 0.22 caliber air pistol
Comment: Left lenses have two 1" long, 0.010" deep, perpendicularly crossed scribe lines centered on the impact surface

SwRI Code #	Description	Lens Designation	Lens Thickness	No. of Pumps	Velocity (m/sec)	Comments
AA F-1	chipper's cover cup flexible fitting goggle, glass lenses, 50 mm round (flat)	right	2.7 mm (0.108")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	
				3	39.2 ± 2.7	lens shattered (3/8" dia. spall)
		left (scratched)	2.8 mm (0.110")	1	13.2 ± 1.2	
				2	29.1	lens shattered (3/8" dia. spall)
KK A-7	chipper's cup goggle, glass lenses, 50 mm round (flat)	right	3.0 mm (0.118")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (3/8" dia. spall)
		left (scratched)	3.0 mm (0.119")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (3/8" dia. spall)
KK C-1	chipper's cover cup goggle, glass lenses, 50 mm round (flat)	right	3.0 mm (0.118")	1	13.2 ± 1.2	
				2	18.3	
				3	40.8	lens shattered (1/2" dia. spall)
		left (scratched)	3.2 mm (0.126")	1	12.1	
				2	25.1 ± 4.3	
				3	39.2 ± 2.7	lens shattered (5/8" dia. spall)
NN A-6	chipper cup goggle, glass lenses, 50 mm round (curved)	right	2.8 mm (0.112")	1	13.2 ± 1.2	
				2	26.9	
				3	39.2 ± 2.7	lens shattered (5/8" dia. spall)
		left (scratched)	2.9 mm (0.114")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (3/8" dia. spall)
NN B-1	chipper cover cup goggle, glass lenses, 50 mm round (curved)	right	2.9 mm (0.113")	1	13.2 ± 1.2	
				2	19.7	lens shattered (1/2" dia. spall)
		left (scratched)	2.8 mm (0.109")	1	13.2 ± 1.2	
				2	25.1 ± 4.3	lens shattered (3/8" dia. spall)

TABLE 5-14. BALLISTIC IMPACT TEST ON SPECTACLE LENS

Projectile: 0.22 caliber lead pellet
Propulsion System: 0.22 caliber air pistol

SwRI Code #	Description	Lens Designation	Lens Thickness	No. of Pumps	Velocity (m/sec)	Comments
KK F-5	plastic frame glass lenses S7-48 mm eyesize	right	2.9 mm (0.115")	2	39.7	
				3	46.4	
				4	53.8	
				5	66.1	
				6	72.0	
				7	90.9	
				8	98.1	
				9	102.8	
				10	106.6	
				11	112.2	
				12	115.0	lens shattered (7/8" dia. spall)

TABLE 5-15. OUT-OF-THE-FRAME DROP BALL IMPACT TEST SPECTACLE LENSES

Comment: Left lenses have two 1" long, 0.010" deep, perpendicularly crossed scribe lines centered on the impact surface such that the scribe lines are parallel to the main axes of the lens

SwRI Code #	Description	Lens Designation	Lens Thickness	Ball Dia. & Drop Height	Comments
AA G-1	clear glass lenses S7-48 mm eyesize	right	3.0 mm (.120")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50", 1-1/2" @ 50"	shatter
		left (scratched)	3.0 mm (.120")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50", 1-1/2" @ 50"	shatter
BB A-2	clear plastic lenses (CR-39) S7-48 mm eyesize	right	3.1 mm (.123")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50" 1-1/2" @ 50", 1-3/4" @ 50"	cracked
		left (scratched)	3.0 mm (.119")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50", 1-1/2" @ 50", 1-3/4" @ 50", 2 @ 50"	cracked
FF D-6	clear glass lenses S7-48 mm eyesize	right	3.0 mm (.119")	1" @ 50", 1-1/8" @ 50", 1-1/2" @ 50"	shatter
		left (scratched)	2.9 mm (.116")	1" @ 50", 1-1/8" @ 50", 1-1/4 A 50", 1-1/2" @ 50"	shatter

TABLE 5-15. OUT-OF-THE-FRAME DROP BALL IMPACT TEST ON SPECTACLE LENSES (Cont'd)

SwRI Code #	Description	Lens Designation	Lens Thickness	Ball Dia. & Drop Height	Comments
HH C-1b	clear glass lenses S7-48 mm eyesize	right	2.9 mm (.116")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50", 1-1/2" @ 50"	shatter
		left (scratched)	2.9 mm (.114")	1" @ 50", 1-1/8" @ 50", 1-1/4 @ 50"	shatter
KK E-6	clear glass lenses S7-48 mm eyesize	right	2.9 mm (.114")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50" little chip on edge, 1-1/2" @ 50"	shatter
		left (scratched)	2.9 mm (.114")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50"	shatter
KK G-2	green glass lenses S7-48 mm eyesize	right	3.1 mm (.121")	1" @ 50", 1-1/8" @50", 1-1/4" @ 50", 1-1/2" @ 50"	shatter
		left (scratched)	3.0 mm (.119")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50", 1-1/2" @ 50"	shatter
KK I-12	clear plastic lenses (CR-39) S7-48 mm eyesize	right	2.8 mm (.111")	1" @ 50", 1-1/8" @ 50"	broke
		left (scratched)	2.8 mm (.112")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50"	shatter
MM F-5	clear glass lenses S7-48 mm eyesize	right	3.1 mm (.121")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50"	shatter
		left (scratched)	3.0 mm (.119")	1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50"	shatter

(2) Abrasion Resistance

Because of the natures of glass and plastic, glass lenses are generally accepted as being less likely to abrade than plastic lenses. A qualitative notion, however, does not constitute good grounds for downgrading plastics. With proper treatment of the surface of lenses, they too can resist substantial amounts of abrasion.

Several types of abrasive tests in Federal Standard 406, which contains methods for testing plastics, were examined. One of these was an "Abrasive Wear (Loss in Weight)" test (Test Method 1091) in which a 4" diameter plastic disk, with a 1/4" diameter hole in its center, or a 4" square plastic sheet, with a 1/4" diameter hole in its center is subjected to a "Taber Abraser" testing machine for a predetermined abrasion cycle. The average number of

milligrams removed per 1000 abrading revolutions is ultimately determined. This type of test was discarded because: (1) a specimen size larger than the normal eye protector size was needed, (2) the length of time needed to perform the test in order to establish sufficient accuracy was excessive and expensive in terms of labor time, and (3) plastic lens versus glass lens performance could not be examined due to the difficulty and effect of drilling a 1/4" diameter hole in a glass lens.

A "Surface Abrasion" test (Test Method 1092) was also examined. This method also used a "Taber Abraser" testing machine but the effect of the abrasion cycle, shorter than that above, was determined by noting the change in luminous transmittance and haze of transparent plastics. This approach was very appealing, but there still existed the problem of specimen size and the drilling of a hole through a glass lens.

Finally, a "Mar Resistance" test (Method 1093) was inspected. In this test, a 2" square specimen is needed, and the apparatus consisted of basically some No. 80 carborundum and a hopper, which allowed the abrasive to flow at a predetermined rate. The change in gloss of the specimen for a given amount of abrasive dropped on it was to be noted with the aid of the apparatus described in Test Method 3051 ("Gloss"). The type of apparatus employed here was appealing for testing plastic and glass lenses, but the measurement of gloss did not appear to be too appropriate.

Influenced by the tests mentioned above, a new simple abrasive wear test was fabricated in which the performance of both plastic and glass eye protective equipment could be examined. This test employed the use of 150 grit (powder) Carborundum abrasive, dropped 25" from a starting position stop clamp, positioned 7" below the base of a glass funnel and 1" below a flow rate control clamp, onto the center of the lens region of the eye protector which was at 45^{o} with respect to the vertical. The abrasive was guided to within 2" of the eye protector by means of a piece of 3/8" I. D. tygon tubing, thus producing a direct exposure area of the lens of approximately 1/2" diameter (Figure 5-4). The inside of the tygon tubing was allowed to obtain a thin coating of abrasive before the test was started to bring the system to equilibrium. A total of 1600 grams of abrasive was dropped on the same area of each lens in 200 gram quantities and at a flow rate of 200 gms + 50 gms - 15 gms per minute. Luminous transmittance measurements were made with a telephotometer before and after the abrasive wear test. (Luminous transmittance measurements after the abrasive wear test were taken in the most highly affected area, as determined by per cent luminous transmittance of regions in 1" diameter circle centered on the lens). It is suggested that no more than 1000 cycles of the same abrasive be used due to contamination.

Table 5-16 shows the effect of the abrasive wear test on the luminous transmittance of various types of eye protectors, glass and plastic. In

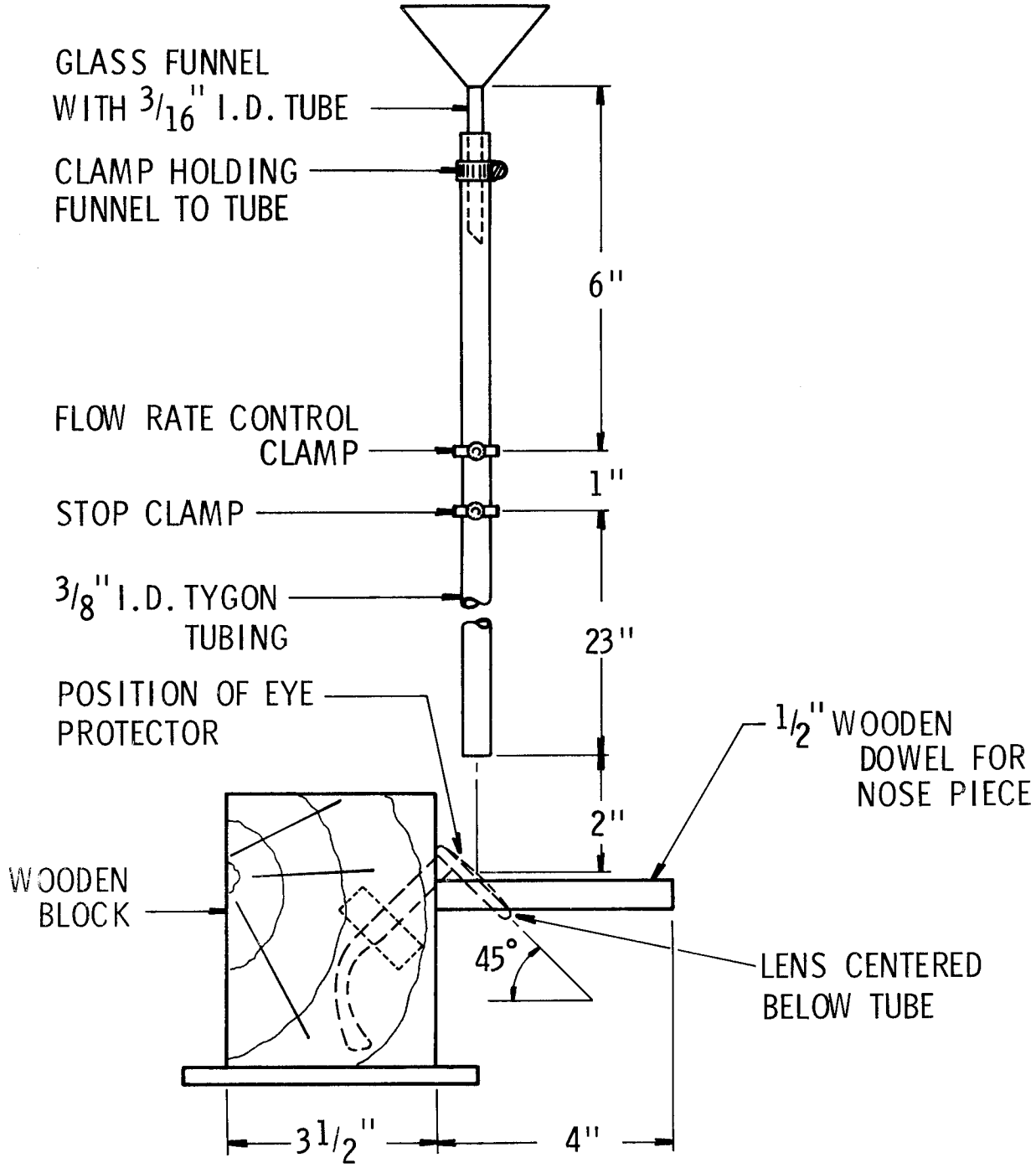


FIGURE 5-4. ABRASIVE TEST APPARATUS

TABLE 5-16. EFFECT OF ABRASIVE WEAR TEST ON LUMINOUS TRANSMITTANCE OF PLASTIC AND GLASS LENSES

Abrasive Cycle: 1600 total grams of 150 grit Carborundum abrasive in 200 gram increments and a flow rate of 200 gms + 50 gms - 15 gms per minute

SwRI Code #	Description	% Lum. Trans. before abrasion	% Lum. Trans. after abrasion	% Change in Lum. Trans.
AA H-4	clear glass spectacle lens, S7-48 mm	91.9	89.7	2.4
BB A-4	clear plastic spectacle lens (CR-39), S7-48 mm	85.9	66.9	22.1
KK I-2	clear plastic spectacle lens (CR-39), S7-48 mm	89.9	89.0	1.0
MM H-5	clear glass spectacle lens, S7-48 mm	90.2	89.2	1.1
AA B-3	clear plastic lens, flexible goggle	88.6	81.0	8.6
DD C-3	clear plastic lens, flexible goggle	87.3	74.0	15.2
NN D-1	clear plastic cover circle, goggle	91.4	88.4	3.3

all cases, the luminous transmittance was lower after the test than before it. The per cent decrease in luminous transmittance

(i.e. $\frac{\text{initial lum. trans. - final lum. trans.}}{\text{initial lum. trans.}} \times 100$) was, in most cases, greater for plastic lenses than for glass lenses. It should be noted that the luminous transmittance of window pane glass 1.7 mm (0.067") thick is

approximately 89% (measured in our laboratory). According to ANSI standard Z87. 1, any clear lens with less than 89% luminous transmittance is unacceptable. In the table, three of five plastic lenses are unacceptable before the abrasive wear test and four of five are unacceptable after the test. Of the two glass lenses tested, both are acceptable before and after the test. Thus, of the samples tested, glass lenses were more resistant to abrasive wear than plastic lenses. Some of the plastic lenses, however, showed substantial resistance to abrasive wear.

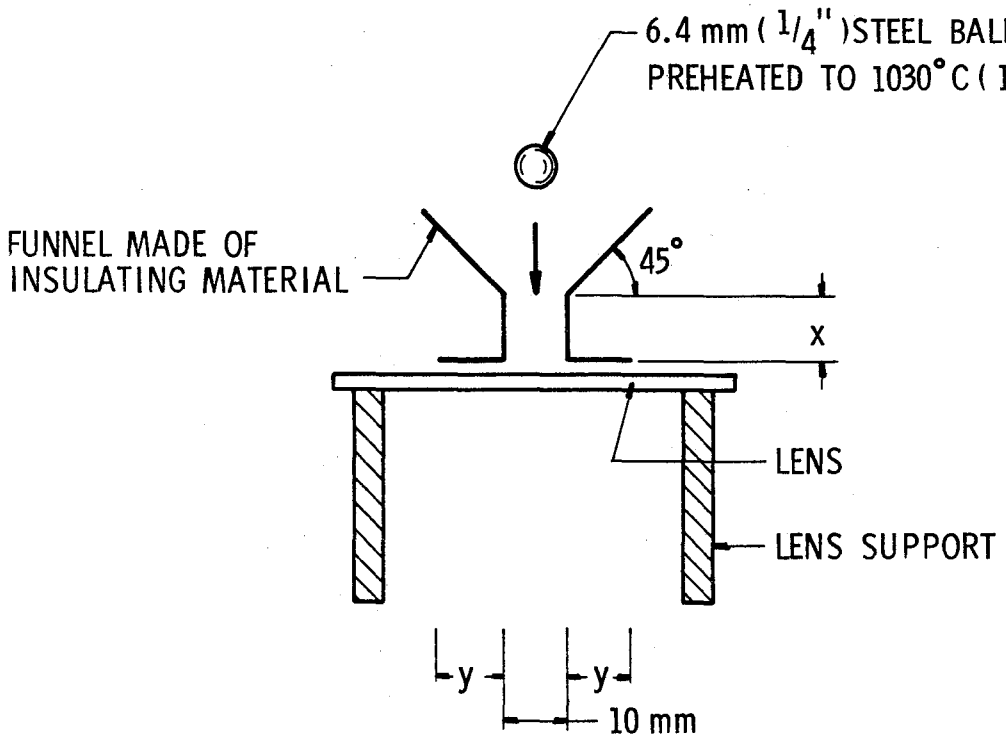
(3) Effect of Hot Materials

The effect of hot materials upon eye protectors was examined by subjecting eye protectors to a hot solid and also to molten metal. The penetration of a hot solid test affected plastic lenses more than glass lenses, but the adherence of molten metal test affected glass lenses more than plastic lenses.

The penetration of a hot solid test was patterned after Appendix L in the British Standard 2092: 1967, "Specification for Industrial Eye Protectors", and Appendix K in the Australian Standard AS Z7-1967, "Industrial Eye Protection". Our procedure for the test involved preheating a 6.4 mm (1/4") diameter steel ball to 1030°C (1886°F) in a furnace and, as rapidly as possible, dropping it through a funnel made out of an insulating material (alumina fire brick), and onto the lens positioned on a support such that the ball is free to drop completely through the lens if it should penetrate. The hot ball was left on the lens for two minutes before removal and inspection of the lens. A two minute test time was chosen since this was considered as approximately the longest length of time that a person who is stick welding above his head could have a hot particle on his protective lenses. Only lenses, such as welding cover lenses and dark colored lenses in goggles, having no cover lenses,were subjected to the test. Any dark shaded eye and face protector which could conceivably be used in a welding process should have its outermost lenses be tested if this test is adopted in a new standard. This includes dark colored (shade #5 and above) face shields and goggles. A failure would consist of complete penetration of any region of the lens by the hot solid or any breakage of the lens. Figure 5-5 shows the essential components of our test apparatus.

Table 5-17 shows the results of this test on various eye and face protective devices. Note that all failures were plastic lenses. This does not imply that plastic lenses should be excluded in welding operations, but that they should be of sufficient thickness for adequate protection.

The susceptibility of adherence of molten metal to eye protectors was examined by allowing the sparks, made in melting a piece of cold roll steel with an oxy-acetylene torch, to strike welding cover plates and



$10\ mm \leq x \leq y$

$10\ mm \leq y \leq 20\ mm$

FIGURE 5-5. ESSENTIAL COMPONENTS FOR PENETRATION OF HOT SOLID TEST

cover circles. Cold roll steel was chosen since it is used in many welding operations. The metal was in the form of a rectangular rod with cross sectional dimensions of 0.5" x 0.8". Approximately 100 gms (i.e. 1.95" long segment) was melted and sparks directed toward the cover lens for each cover lens tested. Figure 5-6 is a schematic of the test apparatus for adherence of molten metal to eye protective devices used in welding and cutting processes. The lens being tested was attached, with double sided tape, to a metal support inclined at 45°. A scribe line was made on the metal rod 1.95" from the edge and the portion of the rod to be melted (0.5" x 0.8" x 1.95") was placed 30 cm horizontally in front of the lens and 30 cm vertically above the center of the lens, such that the long (1.95") axis of the rod was parallel to the lens and centered with respect to the lens, and the intermediate (0.8") dimension was vertical. An oxy-acetylene torch was inclined at 45° to the horizontal and positioned behind the metal rod such that the sparks (tiny bits of molten metal) generated when melting the rod would strike the lens, and consequently, large masses of molten metal would fall harmlessly to the fire proof table supporting the apparatus. Figures 5-7 and 5-8 show the test being performed. Figure 5-9 shows the outcome of the test. Metal adhered only to glass lenses and not to plastic

TABLE 5-17. PENETRATION OF HOT SOLID

Exposure Time: 2 minutes
Passing Criteria: (1) Lens shall not crack (2) No portion of steel ball shall completely penetrate the lens

SwRI Code	Description	Comments	Damage
AA C-3	flexible welder's goggle, cover plate (plastic)	partial penetration into lens	pass
AA E-6	flexible welding goggle, cover plate (glass)	no apparent damage	pass
AA C-6	flexible welding goggle, cover plate (plastic	partial penetration into lens	pass
DD G-3	welder's cup goggle, cover lens (glass)	no apparent damage	pass
DD G-7	welder's cup goggle, cover circle (glass)	no apparent damage	pass
KK B-3	welder's cup goggle, cover lens (glass)	no apparent damage	pass
KK B-1	welder's cup goggle, cover circl (glass)	no apparent damage	pass
KK D-2	welder's cover cup goggle, cover circle (glass)	no apparent damage	pass
NN F-4	flexible goggle with shade #5 lens (plastic)	complete penetration (ball fell through lens in 7 seconds	fail
NN D-6	welder's cover cup goggle, cover circle (plastic)	complete penetration	fail
NN A-2	welder's cup goggle, cover circle (plastic)	complete penetration	fail

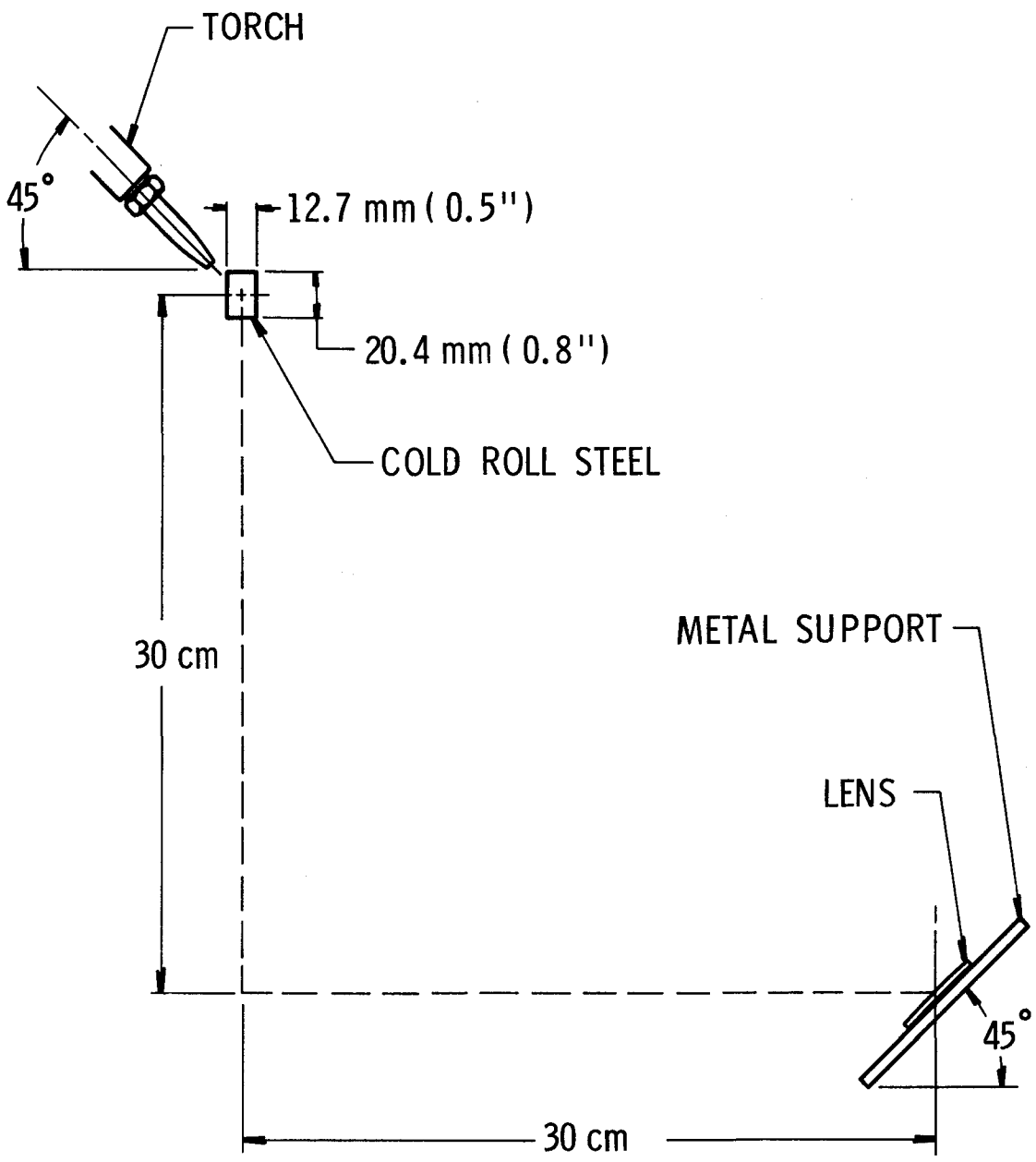


FIGURE 5-6. ESSENTIAL COMPONENTS FOR MOLTEN METAL ADHERENCE TEST

lenses. None of the lenses warped from exposure to heat, and none of the lenses cracked. The superior performance of plastic cover lenses over glass cover lenses in this test does not establish that glass cover lenses should be excluded from welding operations, but that they should be replaced more often than plastic cover lenses when exposed to molten metal of the type described in this test.

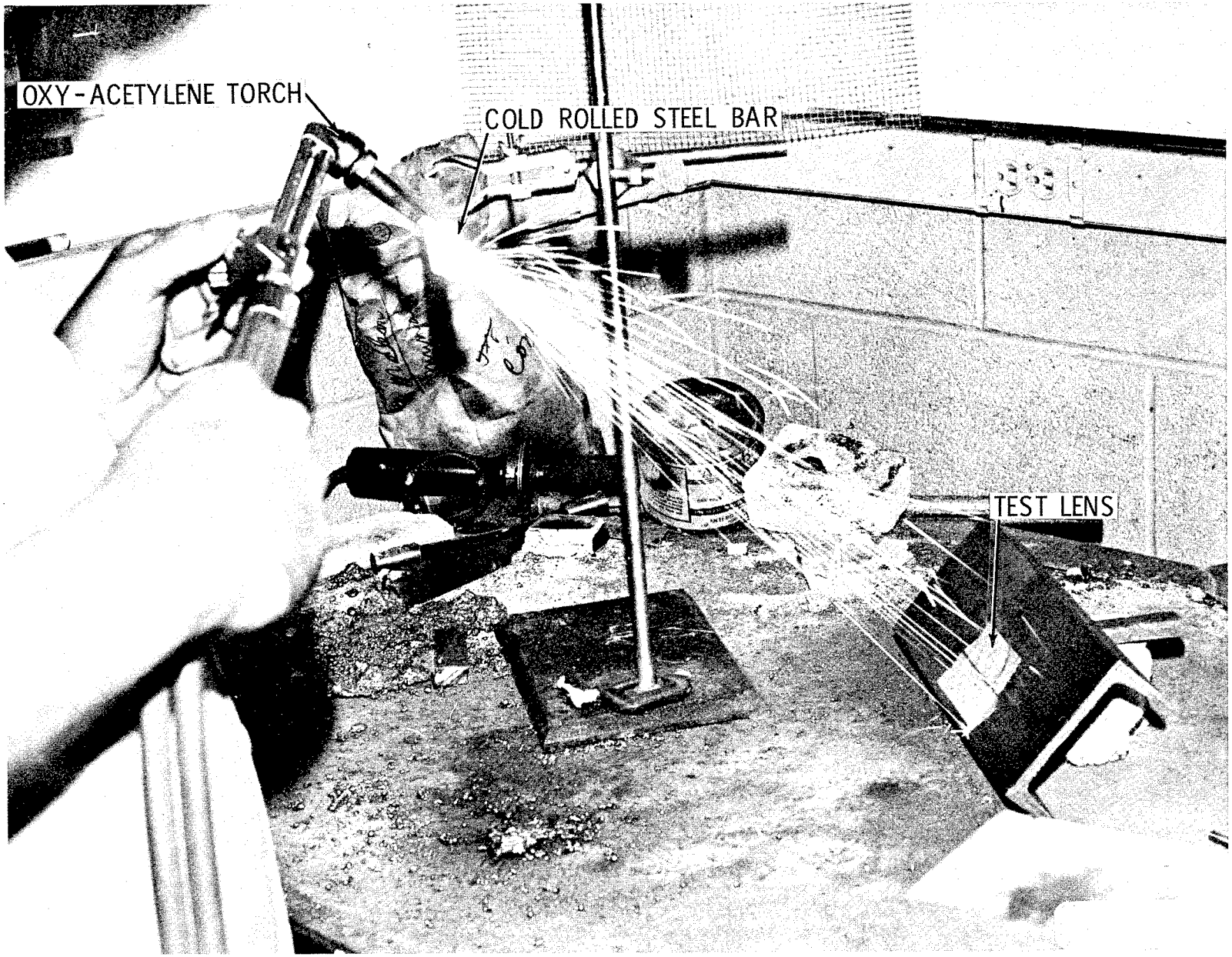


FIGURE 5-7. MOLTEN METAL ADHERENCE TEST

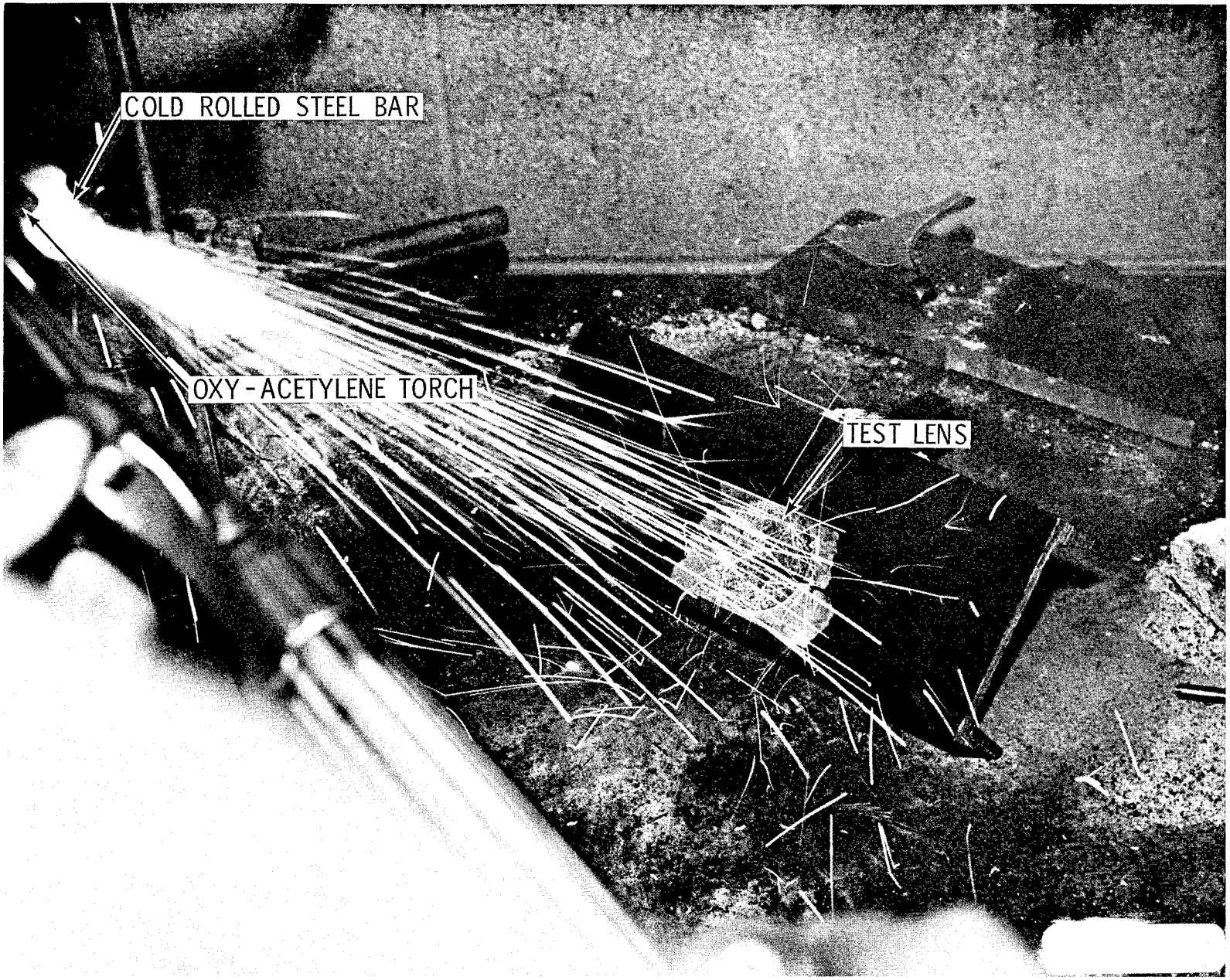


FIGURE 5-8. MOLTEN METAL ADHERENCE TEST

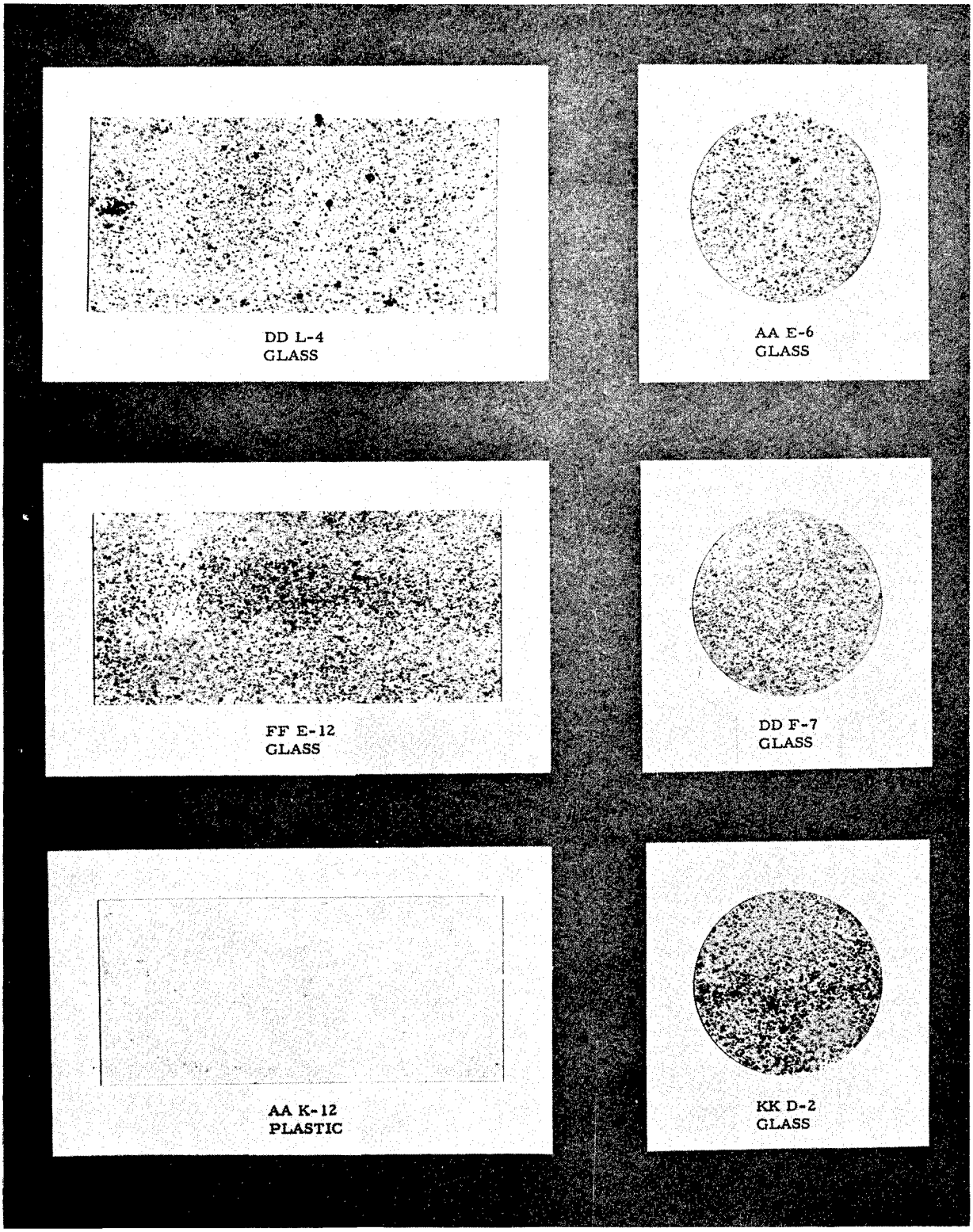


FIGURE 5-9. TEST RESULTS (MOLTEN METAL ADHERENCE TEST)

(4) Effect of Chemicals

The resistance of glass to chemical attack is one of its well known characteristics. In fact, many different chemicals are stored in glass containers. One rarely used, and very dangerous, chemical which attacks glass is hydroflouric (HF) acid. This acid in its liquid or vapor form etches glass. Because of the great chemical resistance of glass, no further comment needs to be made about glass on this aspect of the evaluation of plastic and glass lens performance. Instead, the emphasis in this section will be on plastics.

Federal Test Method Standard Number 406 on "Plastics: Methods of Testing" contains a "Resistance of Plastics to Chemical Reagents" (Method 7011) test. This test method contains a list of standard reagents and an immersion procedure to which plastics are to be exposed. However, the number (22) of chemical solutions is too large and the immersion time (7 days) is too long to be performed on each type of lens: This extensive work is unnecessary also because of the extensive data already available on properties of plastics. Table 5-18, Plastic Properties Chart, was found in Modern Plastics Encyclopedia, vol. 47:No. 104, October, 1970, McGraw-Hill, pp 768-787 is presented on the following pages. This table contains the processing, mechanical, thermal, electrical, optical, and resistance characteristics of various types of plastics. Many of the properties associated with these characteristics were determined using various reputable ASTM test methods. From this table, one can conclude that the chemical composition of cellulose nitrate is such that the burning rate is very fast, and hence should never be used in eye and face protective equipment.

The effect of different chemicals on some types of materials that may be used in eye protective equipment is as follows:

1. Methyl Methacrylate (Acrylic)

   (a) weak acids - nil
   (b) strong acids - attacked only by high concentration oxidizing acids
   (c) weak alkalies - nil
   (d) strong alkalies - attacked
   (e) organic solvents - soluble in ketones, esters, aromatic and chlorinated hydrocarbons

2. Cellulose Acetate (Cellulosic Molding Compounds)

   (a) weak acids - slight
   (b) strong acids - decomposes
   (c) weak alkalies - slight

TABLE 5-18. PLASTICS PROPERTIES CHART

ABS (acrylonitrile-butadiene-styrene)

Plastics properties chart

ABS (acrylonitrile-butadiene-styrene)

		A.S.T.M. test method	Extrusion grades	Molding Grades				
				High impact	High heat resistant	Medium impact	Self-extinguishing	20 to 40% glass filled
Processing	1. Molding qualities	—		Good to Excellent			Good	Fair to good
	2. Compression molding temp., °F.	—	300-450	300-450	325-500	300-450	—	—
	3. Comp. molding pressure, p.s.i.	—	—	1000 to 8000				—
	4. Injection molding temp., °F.	—	—	380-525	500-550	425-500	380-425	500-550
	5. Injection molding pressure, p.s.i.	—	—	8000 to 25000				15000-40000
	6. Compression ratio	—	—	1.1 to 1.2				—
	7. Mold (linear) shrinkage, in./in.	—	0.004-0.008	0.005 to 0.008			0.006-0.008	0.0010-0.0025
	8. Specific gravity (density)	D792	1.02-1.06	1.01-1.04	1.05-1.08	1.04-1.07	1.15-1.21	1.23-1.26
	9. Specific volume, cu. in./lb.	D792	28.0	27.0-26.0	28.0	28.0-27.0	—	22.5-20.4
	10. Machining qualities	—	Good to excellent					Good
Mechanical	11. Tensile strength, p.s.i.	D638, D651	4000-7000	3500-6200	6500-8000	5500-7000	4500-6000	8500-13000
	12. Elongation, %	D638	20.0-80.0	5.0-60.0	3.0-20.0	5.0-25.0	5.0-25.0	2.5-3.0
	13. Tensile modulus, 10^5 p.s.i.	D638	2.3-1.2	2.0-3.5	3.3-4.2	3.0-4.2	2.2-3.1	5.9-10.3
	14. Compressive strength, p.s.i.	D695	5700-10000	4500-8000	8800-10000	7800-12500	6500-7500	12000-22000
	15. Flexural yield strength, p.s.i.	D790	6000-14000	6000-10000	10000-12000	9500-13000	8000-10000	16000-27000
	16. Impact strength, ft. lb./in. of notch (⅛ x ½ in. notched bar, Izod test)	D256	1.0-10.0 @ 73° 0.6-4.0 @ −40° (⅛ x ½ in. bar)	6.0-8.0 @ 73° 2.0-4.0 @ −40° (⅛ x ½ in. bar)	2.0-4.5 @ 73° 0.7-1.5 @ −40° (⅛ x ½ in. bar)	3.0-6.0 @ 73° 1.0-2.0 @ −40° (⅛ x ½ in. bar)	1.6-4.0 @ 73° (⅛ x ½ in. bar)	1.0-2.4
	17. Hardness, Rockwell	D785	R75-115	R75-105	R107-115	R107-115	R75-98	M65-100
	18. Flexural modulus, p.s.i. x 10^5	D790	2.0-4.8	2.0-3.5	3.4-4.2	3.0-4.0	2.5-3.5	9.0-13.0
	19. Compressive modulus, p.s.i. x 10^5	D695	1.6-3.9	1.4-2.0	2.0-2.4	2.0-2.4	1.3-2.1	—
Thermal	20. Thermal conductivity, 10^{-4} cal./sec./sq.cm../(°C./cm.)	C177	4.5-8.0					—
	21. Specific heat, cal./°C./gm. (RT)	—	0.3 to 0.4					—
	22. Thermal expansion, 10^{-5}/in./in./°C.	D696	6.0-13.0	9.5-13.0	6.0-9.0	8.0-10.0	—	2.9-3.6
	23. Resistance to heat, °F. (continuous)	—	140-200	140-210	190-220	160-200	130-180	200-230
	24. Deflection temp., °F. @ 264 p.s.i. fiber stress	D648	(annealed) 200-224	(annealed) 200-218	(annealed) 215-245	(annealed) 199-215	(annealed) 200-215	210-240
	@ 66 p.s.i. fiber stress		210-230	210-225	225-252	210-225	210-220	220-250
Electrical	25. Volume resistivity, ohm/cm (50% RH and 23°C.)	D257	1.0-4.8 x 10^{16}	1.0-4.8 x 10^{16}	1.0-5.0 x 10^{16}	2.7 x 10^{16}	—	7.2-16.0 x 10^{9}
	26. Dielectric strength, short-time, ⅛-in. thickness, volts/mil	D149	350 to 500					—
	27. Dielectric strength, step-by-step, ⅛-in. thickness, volts/mil	D149	350-460	350-450	360-400	370-400	—	—
	28. Dielectric constant, 60 cyc.	D150	2.4 to 5.0					—
	29. Dielectric constant, 10^3 cyc.	D150	2.4 to 4.5					—
	30. Dielectric constant, 10^6 cyc.	D150	2.4 to 3.8					—
	31. Dissipation (power) factor, 60 cyc.	D150	0.003 to 0.008					—
	32. Dissipation (power) factor, 10^3 cyc.	D150	0.004 to 0.007					—
	33. Dissipation (power) factor, 10^6 cyc.	D150	0.007 to 0.015					—
	34. Arc resistance, sec.	D495	50 to 85				25-50	—
Optical	35. Refractive index, n_D	D542	—	—	—	—	—	—
	36. Clarity	—	Translucent in thin sections to opaque					
	37. Transmittance, %	—	33.3	28.0	33.3	33.3	—	—
	38. Haze, %		100	100	100	100	—	—
Resistance characteristics	39. Water absorp., 24 hr., ⅛-in. thick., %	D570	0.20 to 0.45				0.2-0.6	0.18-0.40
	40. Burning rate (flammability), in./min.	D635	Slow				Self-extinguishing	Slow
	41. Effect of sunlight	—	None to yellows slightly plus some embrittlement					
	42. Effect of weak acids	D543	None					
	43. Effect of strong acids	D543	Attacked by concentrated oxidizing acids					
	44. Effect of weak alkalies	D543	None					
	45. Effect of strong alkalies	D543	None					
	46. Effect of organic solvents	D543	Soluble in ketones, esters and some chlorinated hydrocarbons					

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TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

	Acetals					Acrylics				
						Methyl methacrylate				
	Homopolymer	Copolymer	20% glass filled	25% glass filled copolymer	TFE-fiber reinforced	Cast self-extinguishing	Cast	Molding	Impact acrylic, molding compound	MMA alpha-methylstyrene copolymer
1.	Excellent	Excellent	Good to excellent	Good to excellent	Excellent	—	—	Excellent	Excellent	Excellent
2.	—	340-400	—	—	—	—	—	300-425	300-400	325-400
3.	—	1000-5000	—	—	—	—	—	2000-10000	2000-5000	1000-10000
4.	380-470	360-480	350-480	380-480	370-410	—	—	325-500	400-490	350-525
5.	10000-20000	10000-20000	10000-20000	10000-20000	10000-20000	—	—	10000-20000	10000-20000	10000-20000
6.	—	—	—	—	—	—	—	1.6-2.0	—	—
7.	0.020-0.025	0.020-(Avg.)	0.013-0.028	0.002-0.006	0.02-0.025	—	—	0.001-0.004(C) 0.002-0.008(I)	0.004-0.008	0.002-0.008
8.	1.42	1.41	1.56	1.61	1.54	1.21-1.28	1.17-1.20	1.17-1.20	1.11-1.18	1.16
9.	19.6	19.7	18.7	—	18.9	—	23.7-23.1	23.7-23.1	25.6-23.3	24.0
10.	Excellent		Good to fair	Good to fair	Excellent	Good to excellent	Good to excellent	Good to excellent	Good to excellent	Good to excellent
11.	10000	8800	8500-11000	18000	6900 (73° F.)	8000-12500	8000-11000	7000-11000	5000-9000	10000
12.	25(Inj.); 75(Ext.)	60.0-75.0	2.0-7.0	3.0-4.0	12.0 (73° F)	3.8-5.1	2.0-7.0	2.0-10.0	20.0-40.0	2.5
13.	5.2	4.1	10.0	12.0	—	3.5-4.8	3.5-4.5	3.8-4.5	2.0-4.0	4.65
14.	18000 (10% defl.)	16000 (10% defl.)	18000 (10% defl.)	—	11000 (10% defl.)	11000-21000	11000-19000	12000-18000	4000-14000	18000
15.	14100	13000	15000 (5%)	26000	—	12000-18000	12000-17000	13000-19000	8000-13000	12000
16.	1.4(Inj.) 2.3(Ext.)	1.2-1.6 (⅛ x ½ in. bar)	0.8	1.5	0.7	0.3-0.4	0.3-0.4	0.3-0.5	0.8-2.5	0.3
17.	M94, R120	M78-M80	M75-M90	—	M78, R118	M61-M100	M80-M100	M85-M105	R105-R120	M104-M107
18.	4.1	3.75	8.8	11.0	4.0	3.5-4.5	3.90-4.75	4.2-4.6	2.6-3.8	5.0
19.	6.7	4.5	—	—	—	4.5	3.90-4.75	3.7-4.6	2.5-3.7	4.0
20.	5.5	5.5	—	—	—	4.0-6.0	4.0-6.0	4.0-6.0	4.0-5.0	4.0-6.0
21.	0.35	0.35	—	—	—	0.35	0.35	0.35	0.34	0.35
22.	8.1	8.5	3.6-8.1	—	7.5	—	5.0-9.0	5.0-9.0	6.0-8.0	5.4
23.	195 (8800 hr.)	220	185-220	220	195 (8800 hr.)	125-200	140-200	140-200	140-195	200-230
24.	255	230	315	—	212	155-205	160-215	165-210	165-190	221
	338	316	345	315	329	170-200	165-235	175-225	180-205	239
25.	1.0×10^{15}	1.0×10^{14}	1.2×10^{14}	—	—	$>10^{15}$	$>10^{15}$	$>10^{14}$	2.0×10^{16}	10^{16}
26.	380	500 (90 mil)	580	—	—	400-440	450-550	400-500	400-500	500
27.	320	—	—	—	—	—	431	350-400	400-500	—
28.	—	3.7	3.9	—	—	3.5-5.1	3.5-4.5	3.3-3.9	3.5-4.0	3.0
29.	3.7	3.7	3.9	—	—	3.1-4.3	3.0-3.5	3.0-3.6	2.8-3.5	2.7
30.	3.7	3.7	3.9	—	—	3.0-3.7	2.1-3.2	2.2-3.2	2.5-3.0	2.3
31.	—	—	—	—	—	0.04-0.09	0.05-0.06	0.04-0.06	0.04-0.05	0.04
32.	0.0048	0.0010 (40 mil)	0.0025	—	—	0.03-0.06	0.04-0.06	0.03-0.05	0.02-0.035	0.03
33.	0.0048	0.006	0.0062	—	—	0.02-0.05	0.02-0.03	0.02-0.03	0.004-0.02	0.02
34.	129 on 15 mil spec.	240 (burns)	136	—	—	No track	No track	No track	No track	169
35.	1.48	—	—	—	—	1.50	1.48-1.50	1.49	Not applicable	1.52
36.	Translucent to opaque		Opaque	Opaque	Brown opaque	Transparent, translucent and opaque			Transl. to opaq.	Transparent
37.	—	—	—	—	—	92	92	92	—	92
38.	—	—	—	—	—	1	1	<3	—	2-5
39.	0.25	0.22	0.25-0.29	0.23	0.20	0.3-0.4	0.2-0.4	0.1-0.4	0.2-0.7	0.2
40.	Slow (1.1)		0.8-1.0	0.8	Slow (0.8)	Non-burning	Slow (0.9-1.3)	Slow (0.6-1.2)	Slow (1.0-1.3)	Slow (1.3)
41.	Chalks slightly		Chalks slightly	Chalks slightly	Chalks slightly	—	Nil	Nil	Slight strength loss	Nil
42.	Resists some		Resists some	Resists some	Resists some	—	Nil	Nil	Practically nil	Nil
43.	Attacked		Attacked	Attacked	Attacked	—	Attacked only by high concentration oxidizing acids		Attacked only by high concentration oxidizing acids	Attacked by high concentration oxidizing acids
44.	Resists some	None	Copolymer resists some	None	Resists some	—	Nil	Nil	Practically nil	Nil
45.	Not recom.	None	Copolymer resists some	None	Not recom.	—	Attacked	Attacked	Practically nil	Nil
46.	Excellent resistance		Excellent resistance	Excellent resistance	Excellent resistance	—	Soluble in ketones, esters, aromatic and chlorinated hydrocarbons		Soluble in ketones, esters, aromatic and chlorinated hydrocarbons	

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Acrylics — Allyl resins and monomers

Plastics properties chart (continued)

		A.S.T.M. test method	Acrylic multi-polymer	Acrylic-PVC alloy: Sheet	Acrylic-PVC alloy: Molding	Cast allyl diglycol carbonate	Diallyl phthalate molding compounds: Glass filled	Diallyl phthalate molding compounds: Mineral filled	Diallyl phthalate molding compounds: Synthetic fiber filled
Processing	1. Molding qualities	—	Excellent	Good	Good	—	Excellent	Excellent	Good
	2. Compression molding temp., °F.	—	300-400	—	300-370	—	290-380	270-330	270-320
	3. Comp. molding pressure, p.s.i.	—	2000-6000	—	—	—	500-4000	500-4000	500-4000
	4. Injection molding temp., °F.	—	400-475	—	300-380	—	300-350	—	—
	5. Injection molding pressure, p.s.i.	—	10000-20000	—	—	—	2000-6000	—	—
	6. Compression ratio	—	—	—	—	—	1.9-10.0	1.2-2.3	1.2-3.2
	7. Mold (linear) shrinkage, in./in.	—	0.006-0.010	—	0.008	—	0.001-0.005	0.005-0.007	0.009-0.011
Mechanical	8. Specific gravity (density)	D792	1.09-1.14	1.35	1.30	1.30-1.40	1.61-1.78	1.65-1.68	1.34-1.39
	9. Specific volume, cu. in./lb.	D792	25.6-23.3	20.5	21.3	20.9-19.8	17.2-15.6	16.8-16.5	20.7-20.0
	10. Machining qualities	—	Good to excellent	Excellent	Excellent	Good	Fair	Fair	Excellent
	11. Tensile strength, p.s.i.	D638, D651	6000-8000	6300	5500	5000-6000	6000-11000	5000-8700	6000-8800
	12. Elongation, %	D638	3.0-10.0	100	150	—	—	—	—
	13. Tensile modulus, 10^5 p.s.i.	D638	3.1-4.3	3.35	2.75	3.0	14.0-22.0	12.0-22.0	6.0
	14. Compressive strength, p.s.i.	D695	8000-11500	8400	6200	21000-23000	25000-35000	20000-32000	25000-30000
	15. Flexural yield strength, p.s.i.	D790	9500-13000	10700	8700	6000-13000	11000-25000	8500-11000	No change
	16. Impact strength, ft. lb./in. of notch (½ x ½ in. notched bar, Izod test)	D256	1.0-3.0 @ 73° F. 0.9-1.6 @ −40° F.	15.0	15.0	0.2-0.4	0.4-15.0	0.3-0.45	0.55-8.0
	17. Hardness, Rockwell	D785	R108-119	R99-R105	R104	M95-M100	80-87 (E scale)	61 (E scale)	M108-M115
	18. Flexural modulus, p.s.i. x 10^5	D790	3.0-4.0	4.0	3.0	2.5-3.3	12.0-15.0	—	—
	19. Compressive modulus, p.s.i. x 10^5	D695	—	4.0	3.0	3.0	—	—	—
Thermal	20. Thermal conductivity, 10^{-4} cal./sec./sq.cm../(°C./cm.)	C177	5.3	—	—	4.8-5.0	5.0-15.0	7.0-25.0	5.0-6.0
	21. Specific heat, cal./°C./gm. (RT)	—	0.33	0.293	—	0.55	—	—	—
	22. Thermal expansion, 10^{-5}/in./in./°C.	D696	6.0-9.0	—	—	8.1-14.3	1.0-3.6	1.0-4.2	5.4-6.0
	23. Resistance to heat, °F. (continuous)	—	165-175	—	—	212	300-400	300-400	250-350
	24. Deflection temp., °F. @ 264 p.s.i. fiber stress	D648	185-195	160	171	140-190	330-540+	320-540+	320-400
	@ 66 p.s.i. fiber stress		—	177	180	—	—	—	—
Electrical	25. Volume resistivity, ohm/cm (50% RH and 23°C.)	D257	1.7×10^{16}	10^{14}-10^{16}	—	$>4 \times 10^{14}$	10^{13}-10^{16}+	10^{13}+	10^{13}-10^{16}+
	26. Dielectric strength, short-time, ⅛-in. thickness, volts/mil	D149	493	>400	400	380	395-450	395-420	390-400
	27. Dielectric strength, step-by-step, ⅛-in. thickness, volts/mil	D149	416	—	—	320	340-400	320-350	370-410
	28. Dielectric constant, 60 cyc.	D150	3.3-3.5	3.9	4.0	4.4	4.3-4.6	5.2	3.0-8.0
	29. Dielectric constant, 10^3 cyc.	D150	3.1-3.3	3.7	3.8	4.2-4.4	4.1-4.5	4.8-5.3	3.3-3.9
	30. Dielectric constant, 10^6 cyc.	D150	2.8-2.9	3.4	3.4	3.5-3.9	3.4-4.5	3.9-4.0	3.3-3.5
	31. Dissipation (power) factor, 60 cyc.	D150	0.02-0.03	0.02	0.04	0.006-0.019	0.01-0.05	0.03-0.06	0.026
	32. Dissipation (power) factor, 10^3 cyc.	D150	0.02-0.03	0.02	0.03	0.01	0.004-0.009	0.03-0.10	0.004-0.025
	33. Dissipation (power) factor, 10^6 cyc.	D150	0.02	0.03	0.03	0.04-0.06	0.009-0.014	0.02-0.04	0.012-0.020
	34. Arc resistance, sec.	D495	—	80	25	120-250	125-180	140-190	115-120
Optical	35. Refractive index, n_D	D542	1.52	—	—	1.50	Not applicable	Not applicable	Not applicable
	36. Clarity	—	Transparent	Opaque	Opaque	Transparent	Opaque	Opaque	Opaque
	37. Transmittance, %	—	87	—	—	90-92	—	—	—
	38. Haze, %	—	6-9	—	—	—	—	—	—
Resistance characteristics	39. Water absorp., 24 hr., ⅛-in. thick., %	D570	0.3	0.06	0.13	0.2	0.12-0.35	0.2-0.5	0.2
	40. Burning rate (flammability), in/min.	D635	Slow	Non-burning	Non-burning	0.35 to self-extinguishing	Self-exting. to nonburning	Self-exting. to nonburning	Self exting.
	41. Effect of sunlight	—	Slight color change, slight embrittlement	Nil	Nil	Yellows very slightly	None	None	None
	42. Effect of weak acids	D543	None	None	None	None	None	None	None
	43. Effect of strong acids	D543	Attacked by high concentration oxidizing acids	None	Slight	Attacked only by oxidizing acids	Slight	Slight	Slight
	44. Effect of weak alkalies	D543	None	None	None	None	None to slight	None to slight	Slight
	45. Effect of strong alkalies	D543	Very slight	None	None	None to slight	Slight	Slight	Slight
	46. Effect of organic solvents	D543	Attacked by esters, ketones, aromatic and chlorinated hydrocarbons	Attacked by ketones, esters, aromatic and chlorinated hydrocarbons		Resistant	None	None	None

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Cellulosic molding compounds and sheet

	Cellulosic molding compounds and sheet						
	Ethyl cellulose molding compounds and sheet	Cellulose acetate		Cellulose propionate molding compound	Cellulose acetate butyrate		Cellulose nitrate
		Sheet	Molding		Sheet	Molding	
1.	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Good
2.	250-390	—	260-420	265-400	—	265-390	185-250
3.	500-5000	—	100-5000	100-5000	—	100-5000	2000-5000
4.	350-500	—	335-490	335-515	—	335-480	—
5.	8000-32000	—	8000-32000	8000-32000	—	8000-32000	—
6.	1.8-2.4	—	1.8-2.6	1.8-2.4	—	1.8-2.4	—
7.	0.005-0.009	—	0.003-0.010(C) 0.003-0.008(I)	0.003-0.009(C) 0.003-0.006(I)	—	0.003-0.009(C) 0.003-0.006(I)	—
8.	1.09-1.17	1.28-1.32	1.22-1.34	1.17-1.24	1.15-1.22	1.15-1.22	1.35-1.40
9.	25.5-23.6	21.7-21.0	22.7-20.6	23.4-22.4	24.1-22.7	24.1-22.7	20.5-19.8
10.	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
11.	2000-8000	4500-8000	1900-9000	2000-7800	2600-6900	2600-6900	7000-8000
12.	5.0-40.0	20.0-50.0	6.0-70.0	29.0-100.0	50.0-100.0	40.0-88.0	40.0-45.0
13.	1.0-3.0	3.0-6.0	0.65-4.0	0.6-2.15	2.0-2.5	0.5-2.0	1.9-2.2
14.	10000-35000	—	2000-36000	2400-22000	—	2100-22000	22000-35000
15.	4000-12000	6000-10000	2000-16000	2900-11400	4000-9000	1800-9300	9000-11000
16.	2.0-8.5 0.3-1.7 @ -40° F.	—	0.4-5.2	0.5-11.5	—	0.8-6.3	5.0-7.0
17.	R50-R115	R85-R120	R34-R125	R10-R122	R30-R115	R31-R116	R95-R115
18.	—	—	—	1.5-3.4	—	—	—
19.	—	—	—	—	—	—	—
20.	3.8-7.0	4.0-8.0	4.0-8.0	4.0-8.0	4.0-8.0	4.0-8.0	5.5
21.	0.3-0.75	0.3-0.5	0.3-0.42	0.30-0.40	0.3-0.4	0.3-0.4	0.3-0.4
22.	10-20	10-15	8-18	11-17	11-17	11-17	8-12
23.	115-185	140-220	140-220	155-220	140-220	140-220	ca. 140
24.	115-190	—	111-195	111-228	—	113-202	140-160
	—	—	120-209	147-250	—	130-227	—
25.	10^{12}-10^{14}	10^{11}-10^{15}	10^{10}-10^{14}	10^{12}-10^{16}	10^{11}-10^{15}	10^{11}-10^{15}	10-15 x 10^{10}
26.	350-500	250-600	250-600	300-450	250-400	250-400	300-600
27.	300-500	200-520	200-520	230-385	225-320	225-320	250-550
28.	3.0-4.2	4.0-5.0	3.5-7.5	3.7-4.3	4.0-5.0	3.5-6.4	7.0-7.5
29.	3.0-4.1	4.0-5.0	3.4-7.0	3.6-4.3	4.0-5.0	3.4-6.4	7.0
30.	2.8-3.9	4.0-5.0	3.2-7.0	3.3-3.8	4.0-5.0	3.2-6.2	6.4
31.	0.005-0.020	0.01-0.02	0.01-0.06	0.01-0.04	0.01-0.02	0.01-0.04	0.09-0.12
32.	0.002-0.020	0.01-0.03	0.01-0.07	0.01-0.04	0.01-0.03	0.01-0.04	0.03
33.	0.010-0.060	0.03-0.04	0.01-0.10	0.01-0.05	0.02-0.04	0.01-0.04	0.06-0.09
34.	60-80	180-200	50-310	175-190	—	—	—
35.	1.47	1.49-1.50	1.46-1.50	1.46-1.49	1.46-1.49	1.46-1.49	1.49-1.51
36.	Transparent, translucent, opaque						
37.	—	88 (⅛-in. thick)	—	88 (⅛-in. thick)	88 (⅛-in. thick)	—	—
38.	—	<1 (film, thin sheet)	—	<1 (film, thin sheet)	<1 (film, thin sheet)	—	—
39.	0.8-1.8	2.0-7.0	1.7-6.5	1.2-2.8	0.9-2.2	0.9-2.2	1.0-2.0
40.	Slow	Slow to self-extinguishing		Slow (1.0-1.3)	Slow	Slow	Very fast
41.	Slight when properly stabilized	Slight	Slight	Slight	Slight	Slight	Discolors and becomes brittle
42.	Slight	Slight	Slight	Slight	Slight	Slight	Slight
43.	Decomposes	Decomposes	Decomposes	Decomposes	Decomposes	Decomposes	Decomposes
44.	None	Slight	Slight	Slight	Slight	Slight	Slight
45.	Slight	Swells	Decomposes	Decomposes	Decomposes	Decomposes	Decomposes
46.	Widely soluble	Soluble in liquid ketones and esters of lower alcohols. Softened or dissolved by chlorinated hydrocarbons and aromatic hydrocarbons. Little affected by aliphatic hydrocarbons.					Widely soluble

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Plastics properties chart (continued)

		A.S.T.M. test method	Chlorinated polyether	Cold molded and inorganic compounds: Cold molded		Cold molded and inorganic compounds: Inorganic molded plastics		Epoxy resins: Cast resins	
				Non-refractory (organic)	Refractory (inorganic)	Glass-bonded mica: Compression	Glass-bonded mica: Injection	No filler	Silica filler
Processing	1. Molding qualities	—	Excellent	Fair to good	Fair to good	Fair to good	Good	—	—
	2. Compression molding temp., °F.	—	400–420	—	—	1250	—	—	—
	3. Comp. molding pressure, p.s.i.	—	500–1000	2000–4000	1000–10000	2000–4000	—	—	—
	4. Injection molding temp., °F.	—	425–465	—	—	—	1200	—	—
	5. Injection molding pressure, p.s.i.	—	10000–20000	—	—	—	10000–20000	—	—
	6. Compression ratio	—	—	2.5	2.0–3.0	3.0–4.0	—	—	—
	7. Mold (linear) shrinkage, in./in.	—	0.004–0.008	0.010–0.017	0.000–0.010	0.000	0.000	0.001–0.004	0.0005–0.002
	8. Specific gravity (density)	D792	1.4	1.87–2.15	1.60–2.2	2.6–4.2	2.6–4.2	1.11–1.40	1.6–2.0
	9. Specific volume, cu. in./lb.	D792	19.8	14.8–12.9	17.3–12.7	9.1–8.6	10.5–7.4	24.9–20.0	17.3–13.9
	10. Machining qualities	—	Excellent	Poor to fair	Poor	Good	Fair to good	Good	Poor
Mechanical	11. Tensile strength, p.s.i.	D638, D651	6000	1400–3000	2200	5000–15000	4000–7000	4000–13000	7000–12000
	12. Elongation, %	D638	60.0–160.0	—	—	—	—	3.0–6.0	1.0–3.0
	13. Tensile modulus, 10^5 p.s.i.	D638	1.6	—	—	110.0–125.0	70.0–85.0	3.5	—
	14. Compressive strength, p.s.i.	D695	—	6000–15000	18000	35000–42000	25000–40000	15000–25000	15000–35000
	15. Flexural yield strength, p.s.i.	D790	5000	3700–10000	2000–7500	15000–21600	14000	13300–21000	8000–14000
	16. Impact strength, ft. lb./in. of notch (½ x ½ in. notched bar, Izod test)	D256	0.4	0.4	0.4	2.0–2.5 ½-in. dia. rod ft. lb./sq. in.	2.0–2.5 6 in. long, Charpy test	0.2–1.0	0.3–0.45
	17. Hardness, Rockwell	D785	R–100	M80–M90	M75–M95	M110–M120	M115–M125	M80–M110	M85–M120
	18. Flexural modulus, p.s.i. x 10^5	D790	—	—	—	—	—	—	—
	19. Compressive modulus, p.s.i. x 10^5	D695	—	—	—	—	—	—	—
Thermal	20. Thermal conductivity, 10^{-4} cal./sec./sq.cm../1(°C./cm.)	C177	3.1	—	—	9.5–12.0	10.0–15.0	4.0–5.0	10.0–20.0
	21. Specific heat, cal./°C./gm. (RT)	—	—	—	—	0.16	0.14	0.25	0.20–0.27
	22. Thermal expansion, 10^{-5}/in./in./°C.	D696	8.0	—	—	1.0–1.2	1.0–1.14	4.5–6.5	2.0–4.0
	23. Resistance to heat, °F. (continuous)	—	290	500	900–1300	700–1550	550–1000	250–550	250–550
	24. Deflection temp., °F. @ 264 p.s.i. fiber stress	D648	—	>800	>400	850–1360	690–870	115–550	160–550
	@ 66 p.s.i. fiber stress		285	—	—	—	—	—	—
Electrical	25. Volume resistivity, ohm/cm (50% RH and 23°C.)	D257	10^{15}	1.3×10^{12}	—	10^{14}–10^{17}	10^{14}–10^{17}	10^{13}–10^{17}	10^{13}–10^{16}
	26. Dielectric strength, short-time, ⅛-in. thickness, volts/mil	D149	400	85–115	45	250–500	350–400	400–500	400–550
	27. Dielectric strength, step-by-step, ⅛-in. thickness, volts/mil	D149	—	50–75	50–80	—	—	380	—
	28. Dielectric constant, 60 cyc.	D150	3.1	17.0–28.0	—	6.8–7.6	6.7–9.4	3.5–5.0	3.2–4.5
	29. Dielectric constant, 10^3 cyc.	D150	3.0	12.0–18.0	—	6.8–7.4	6.6–9.3	3.5–4.5	3.2–4.0
	30. Dielectric constant, 10^6 cyc.	D150	2.9	6.0	—	6.8–7.3	6.5–9.3	3.3–4.0	3.0–3.8
	31. Dissipation (power) factor, 60 cyc.	D150	0.01	0.20	—	0.0035–0.007	0.005–0.007	0.002–0.010	0.008–0.03
	32. Dissipation (power) factor, 10^3 cyc.	D150	0.01	—	—	0.0020–0.004	0.0020–0.0040	0.002–0.02	0.008–0.03
	33. Dissipation (power) factor, 10^6 cyc.	D150	0.01	0.07	—	0.0015–0.0018	0.0015–0.0030	0.030–0.050	0.02–0.04
	34. Arc resistance, sec.	D495	—	75–200	100–500	300	250	45–120	150–300
Optical	35. Refractive index, n_D	D542	—	—	—	—	—	1.55–1.61	—
	36. Clarity	—	Transl. to opaque	Opaque	Opaque	Opaque	Opaque	Transparent	Opaque
	37. Transmittance, %	—	—	—	—	—	—	—	—
	38. Haze, %	—	—	—	—	—	—	—	—
Resistance characteristics	39. Water absorp., 24 hr., ⅛-in. thick., %	D570	0.01	0.55–2.00	0.5–15.0	Nil	Nil	0.08–0.15	0.04–0.10
	40. Burning rate (flammability), in/min.	D635	Self-extinguishing	Nil	Nil	Nil	Nil	Slow	Self-extinguishing
	41. Effect of sunlight	—	Slight (loss in surface ductility)	—	Nil	Nil	Nil	None	None
	42. Effect of weak acids	D543	None	Slight	Slight	Slight	Slight	None	None
	43. Effect of strong acids	D543	Attacked by oxidizing acids	Decomposes	Decomposes	Decomposes	Decomposes	Attacked by some	Attacked by some
	44. Effect of weak alkalies	D543	None	None	None	Slight	Slight	None	None
	45. Effect of strong alkalies	D543	None	Decomposes	None	Decomposes	Decomposes	Slight	Slight
	46. Effect of organic solvents	D543	Resists most solvents	Attacked by some	None	None	None	Generally resistant	Generally resistant

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Epoxy resins

	Cast resins		Molding compounds			Encapsulating grades		Phenol novolac epoxy resins	Cycloaliphatic epoxy resins	Ortho cresol novolac epoxy resins
	Aluminum filled	Flexibilized	Glass fiber filled	Mineral filled	Low density[1]	Mineral filled	Glass filled			
1.	—	—	Excellent	Excellent	Good	Good to excel.	Good	—	—	—
2.	—	—	300-330	250-330	250-320	250-330 (Transf.)	280-330 (Transf.)	—	—	—
3.	—	—	300-5000	100-3000	100-2000	50-1000 (Transf.)	50-1000 (Transf.)	—	—	—
4.	—	—	—	—	250-300	—	—	—	—	—
5.	—	—	—	—	100-1500	—	—	—	—	—
6.	—	—	2.0-7.0	2.0-3.0	3.0-7.0	2.0	3.0	—	—	—
7.	0.001-0.005	0.001-0.004	0.001-0.005	0.002-0.008	0.006-0.010	0.004-0.010	0.004-0.008	—	—	—
8.	1.4-1.8	1.05-1.35	1.6-2.0	1.6-2.0	0.75-1.00	1.7-2.1	1.7-2.0	1.16-1.21	1.16-1.21	1.16-1.21
9.	—	20.5	15.4-14.0	14.2-13.4	—	14.0	14.0	—	—	—
10.	Excellent	Good	Fair to good	Fair	Good	Fair to good	Fair	Good	Good	Good
11.	7000-12000	2000-10000	10000-30000	5000-15000	2500-4000	4000-10000	5000-15000	6000-12000	9000-10000	—
12.	0.5-3.0	20.0-70.0	4.0	—	—	—	—	2.0-6.0	2.0-10.0	—
13.	—	0.01-3.5	30.4	—	—	—	—	—	—	—
14.	15000-33000	1000-14000	25000-40000	18000-40000	10000-15000	18000-30000	18000-30000	—	—	—
15.	8500-24000	1000-13000	10000-60000	8000-15000	5000-7000	6000-15000	8000-20000	—	10000-13000	—
16.	0.4-1.8	3.5-5.0	10.0-30.0	0.3-0.4	0.15-0.25	0.3-0.45	0.5-2.0	—	—	—
17.	M55-M85	—	M100-M110	M100-M110	—	M100-M112	M100-M112	—	—	—
18.	—	—	$2.5\text{-}4.5 \times 10^6$	$1.4\text{-}2.2 \times 10^6$	5.0-7.5	—	—	—	—	—
19.	—	—	—	—	—	—	—	—	—	—
20.	15-25	—	4.0-10.0	4.0-30.0	4.0-6.0	4.0-10.0	4.0-10.0	—	—	—
21.	—	—	0.19	—	—	—	—	—	—	—
22.	3.5×10^{-4}	2.0-10.0	1.1-3.5	2.0-5.0	—	3.0-6.0	3.0-5.0	—	—	—
23.	200-500	250-300	300-500	300-500	—	300-450	300-450	—	—	—
24.	190-600	RT-250	250-500	250-500	200-250	225-450	225-450	>464	>482	>572
	—	—	—	—	—	—	—	—	—	—
25.	<10	$1.3\text{-}15.0 \times 10^{14}$	$>10^{14}$	$>10^{14}$	$10^{13}\text{-}10^{15}$	$>10^{14}$	$>10^{14}$	0.38×10^{16}	$>10^{16}$	—
26.	—	235-400	300-400	300-400	380-420	250-400	250-400	—	—	—
27.	10-200	235-400	300-400	300-400	375-400	250-400	250-400	—	—	—
28.	>8	3.0-6.0	3.5-5.0	3.5-5.0	—	3.5-5.0	3.5-5.0	3.7	3.2	2.98
29.	—	3.0-5.0	3.5-5.0	3.5-5.0	—	3.5-5.0	3.5-5.0	3.7	—	2.95
30.	—	3.0-6.0	3.5-5.0	3.5-5.0	2.0-3.0	3.5-5.0	3.5-5.0	3.4	3.2	2.88
31.	>0.1	0.010-0.040	0.01	0.01	—	0.01	0.01	0.003	0.005	0.005
32.	—	0.012-0.050	0.01	0.01	—	0.01	0.01	0.012	—	0.007
33.	—	0.018-0.090	0.01	0.01	0.005-0.012	0.01	0.01	0.024	0.0016	0.010
34.	—	50-180	120-180	150-190	120-150	120-180+	120-180+	—	Excellent	—
35.	—	—	—	—	—	—	—	—	—	—
36.	Opaque	Transparent	Opaque	Opaque	Opaque	Opaque		Transparent	Transparent	Transparent
37.	—	—	—	—	—	—		—	—	—
38.	—	—	—	—	—	—		—	—	—
39.	0.1-4.0	0.27-0.50	0.05-0.20	0.04	0.10-0.20	0.03-0.20	0.04-0.20	Excellent	—	Good
40.	—	Slow	Self-exting.	Self-exting.	Self-exting.	Self-extinguishing to nonburning		—	—	—
41.	None	None	Slight	Slight	None	Slight	Slight	—	None	—
42.	None	None	None	None	None	None	None	None	None	None
43.	Attacked by some	Attacked by some	Negligible	None	Slight	Slight	Slight	—	Attacked by some	Attacked by some
44.	None	None	None	None	Slight	Slight		None	None	None
45.	Some	Slight	None	Slight	Slight to attacked	Slight to attacked		None	Attacked by some	Attacked by some
46.	Chlorinated affects	Generally resistant	None	None	Slight	Slight	Slight	None	None	None

[1] Filled with Microballoons or other hollow spheres.

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Fluoroplastics | Furane molding compounds | Ionomers

Plastics properties chart (continued)

		A.S.T.M. test method	Fluoroplastics: Polychlorotrifluoroethylene	Fluoroplastics: Polytetrafluoroethylene molding compound	Fluoroplastics: FEP fluoroplastic	Fluoroplastics: Polyvinylidene fluoride	Furane molding compounds: Asbestos filler	Ionomers
Processing	1. Molding qualities	—	Excellent	—	Excellent	Excellent	Good	Excellent
	2. Compression molding temp., °F.	—	460-550	—	600-750	400-550	275-300	200-350
	3. Comp. molding pressure, p.s.i.	—	500-15000	2000-5000	1000-2000	500-15000	100-500	100-800
	4. Injection molding temp., °F.	—	500-600	—	625-760	450-550	—	300-550
	5. Injection molding pressure, p.s.i.	—	20000-60000	—	5000-20000	15000-20000	—	2000-20000
	6. Compression ratio	—	2.0	3.0-4.0	2.0	1.8 plts. 3.6 pdr.	—	2.0
	7. Mold (linear) shrinkage, in./in.	—	0.010-0.015	—	0.03-0.06	0.030	—	0.003-0.02
	8. Specific gravity (density)	D792	2.1-2.2	2.14-2.20	2.12-2.17	1.75-1.78	1.75	0.93-0.96
	9. Specific volume, cu. in./lb.	D792	13.2-12.7	12.9-12.5	13.0-12.8	15.7-15.6	15.8	30.0-29.0
	10. Machining qualities	—	Excellent	Excellent	Excellent	Excellent	Fair to good	Fair to good
Mechanical	11. Tensile strength, p.s.i.	D638, D651	4500-6000	2000-5000	2700-3100	5500-7400	3000-4500	3500-5000
	12. Elongation, %	D638	80.0-250.0	200.0-400.0	250.0-330.0	100.0-300.0	—	350.0-450.0
	13. Tensile modulus, 10^5 p.s.i.	D638	1.5-3.0	0.58	0.5	1.2	15.8	0.2-0.6
	14. Compressive strength, p.s.i.	D695	4600-7400	1700	2200	8580	10000-13000	—
	15. Flexural yield strength, p.s.i.	D790	7400-9300	—	—	—	6000-9000	No yield
	16. Impact strength, ft. lb./in. of notch (½ x ½ in. notched bar, Izod test)	D256	2.5-2.7	3.0	No break	3.6-4.0	—	6.0-15.0
	17. Hardness, Rockwell	D785	R75-R95	D50-D65 (Shore)	R25	D80 (Shore)	R110	D50-D65 (Shore)
	18. Flexural modulus, p.s.i. x 10^5	D790	—	—	—	2.0	—	0.3
	19. Compressive modulus, p.s.i. x 10^5	D695	—	—	—	1.2	—	—
Thermal	20. Thermal conductivity, 10^{-4} cal./sec./sq.cm../1(°C./cm.)	C117	4.7-5.3	6.0	6.0	3.0	—	5.8
	21. Specific heat, cal./°C./gm. (RT)	—	0.22	0.25	0.28	0.33	—	0.55
	22. Thermal expansion, 10^{-5}/in./in./°C.	D696	4.5-7.0	10.0	8.3-10.5	8.5	—	12.0
	23. Resistance to heat, °F. (continuous)	—	350-390	550	400	300	265-330	160-220
	24. Deflection temp., °F. @ 264 p.s.i. fiber stress	D648	—	—	—	193	—	100-120
	@ 66 p.s.i. fiber stress		258	250	158	300	—	110
Electrical	25. Volume resistivity, ohm/cm (50% RH and 23°C.)	D257	1.2×10^{15}	$>10^{18}$	$>2.0 \times 10^{18}$	2.0×10^{14}	—	$>10^{16}$
	26. Dielectric strength, short-time, ⅛-in. thickness, volts/mil	D149	500-600	480	500-600	260	—	900-1100
	27. Dielectric strength, step-by-step, ⅛-in. thickness, volts/mil	D149	450-550	430	—	—	—	2.4-2.5
	28. Dielectric constant, 60 cyc.	D150	2.24-2.8	<2.1	2.1	8.4	—	2.4-2.5
	29. Dielectric constant, 10^3 cyc.	D150	2.3-2.7	<2.1	2.1	7.72	—	—
	30. Dielectric constant, 10^6 cyc.	D150	2.3-2.5	<2.1	2.1	6.43	—	—
	31. Dissipation (power) factor, 60 cyc.	D150	0.0012	<0.0002	<0.0003	0.049	—	0.001-0.003
	32. Dissipation (power) factor, 10^3 cyc.	D150	0.023-0.027	<0.0002	<0.0003	0.018	—	0.0015
	33. Dissipation (power) factor, 10^6 cyc.	D150	0.009-0.017	<0.0002	<0.0007	0.17	—	0.0019
	34. Arc resistance, sec.	D495	>360	>300	>165	50-70	—	<90
Optical	35. Refractive index, nD	D542	1.425	1.35	1.338	1.42	—	1.51
	36. Clarity	—	Transl. to opaque	Opaque	Transp. to transl.	Transp. to transl.	Opaque	Transparent
	37. Transmittance, %	—	—	—	—	—	—	75-85 (125 mil)
	38. Haze, %	—	—	—	—	—	—	3-17 (125 mil)
Resistance characteristics	39. Water absorp., 24 hr., ⅛-in. thick., %	D570	0.00	0.00	0.01	0.04	0.01-0.20	0.1-1.4
	40. Burning rate (flammability), in/min.	D635	None	None	None	Self-extinguishing	Slow	Very slow 1 in./min.
	41. Effect of sunlight	—	None	None	None	Slight bleaching on long exposure	None	Requires UV stabilizer
	42. Effect of weak acids	D543	None	None	None	None	None to slight	Slow attack
	43. Effect of strong acids	D543	None	None	None	Attacked by fuming sulfuric	Attacked by oxidizing acids	Attacked by oxidizing acids
	44. Effect of weak alkalies	D543	None	None	None	None	None	Very resistant
	45. Effect of strong alkalies	D543	None	None	None	None	None to slight	Very resistant
	46. Effect of organic solvents	D543	Hologenated compounds cause slight swelling	None	None	Resists most solvents	Resistant	Very resistant @ 75° F.

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

	Melamine-formaldehyde molding compounds									Methyl-pentene polymer
	No filler	Alpha cellulose filler	Cellulose filler	Flock filler	Asbestos filler	Macerated fabric filler	Macerated fabric filler (phenolic modified)	Glass fiber filler (including nodular)	Melamine-phenol molding compounds	
1.	Good	Excellent	Good	Good	Good	Good	Good	Good	Good	Excellent
2.	300-330	280-370	290-360	275-330	280-340	275-330	300-350	280-340	300-350	540-555
3.	2000-5000	1500-8000	1500-6000	4000-8000	1000-7000	4000-8000	4000-8000	2000-8000	2000-5000	500-1000
4.	—	—	—	—	—	—	—	—	350-400	500-570
5.	—	—	—	—	—	—	—	—	15000-20000	8000-20000
6.	2.0	2.1-3.1	2.2-2.5	4.0-7.0	2.1-2.5	5.0-10.0	5.0-10.0	—	2.1-4.4	2.0-2.5
7.	0.011-0.012	0.005-0.015	0.006-0.008	0.006-0.007	0.005-0.007	0.003-0.004	0.003-0.006	0.001-0.004	0.004-0.010	0.015-0.030
8.	1.48	1.47-1.52	1.45-1.52	1.50-1.55	1.70-2.0	1.5	1.5	1.8-2.0	1.5-1.7	0.83
9.	18.7	18.8-18.2	20.0-19.1	18.5-17.8	16.3-13.8	18.5	18.5	13.8-10.0	20.9-17.8	33.3
10.	—	Fair	Good	Good	Fair	Good	Good	Good	Fair	Good
11.	—	7000-13000	5000-9000	7000-9000	5500-7000	8000-10500	6000-10500	5000-10000	6000-8000	4000
12.	—	0.6-0.9	0.6	—	0.30-0.45	0.6-0.8	0.6	—	0.4-0.8	15.0
13.	—	12.0-14.0	11.0	—	19.5	14.0-16.0	16.0	24.0	8.0-17.0	2.1
14.	40000-45000	40000-45000	33500	30000-35000	30000	30000-35000	25000-30000	20000-35000	26000-30000	—
15.	11000-14000	10000-16000	9000-11500	13000	9000-11000	12000-15000	14000-17000	15000-23000	8000-10000	—
16.	—	0.24-0.35	0.27-0.36	0.40-0.45	0.28-0.40	0.6-1.0	1.1-1.4	0.6-18.0	0.27-0.38	0.8
17.	—	M115-M125	M115-M125	—	M110	M120	M115	—	E95-100	L67-74
18.	—	—	—	—	—	—	—	—	10.0-12.0	—
19.	—	—	—	—	—	—	—	—	—	—
20.	—	7.0-10.0	6.5-8.5	—	13.0-17.0	10.6	10.1	11.5	4.0-7.0	4.0
21.	—	0.4	—	—	—	—	—	—	0.35-0.40	0.52
22.	—	4.0	4.5	—	2.0-4.5	2.5-2.8	1.8-2.8	1.5-1.7	1.0-4.0	11.7
23.	210	210	250	250	250-400	250	250	300-400	275-325	250-320
24.	298	350-370	268	—	265	310	375	400	285-310	—
	—	—	—	—	—	—	—	—	—	—
25.	—	$0.8\text{-}2.0 \times 10^{12}$	—	—	1.22×10^{12}	$10^{9}\text{-}10^{10}$	—	2.0×10^{11}	—	10^{16}
26.	—	270-300	350-400	300-330	410-430	250-350	130-370	170-300	220-325	—
27.	—	240-270	250-350	—	280-320	200-300	—	170-240	—	700
28.	—	7.9-9.5	6.2-7.6	—	6.4-10.2	7.6-12.6	10.5-15.5	9.7-11.1	7.0-7.7	2.12
29.	—	7.8-9.2	6.0-7.5	—	9.0	7.1-7.8	7.9-9.7	—	—	2.12
30.	—	7.2-8.4	4.7-7.0	—	6.1-6.7	6.5-6.9	6.1-6.7	6.6-7.5	5.2-6.0	2.12
31.	—	0.030-0.083	0.019-0.033	—	0.07-0.17	0.07-0.34	0.10-0.16	0.14-0.23	0.02-0.04	0.00007
32.	—	0.015-0.036	0.013-0.034	—	0.07	0.03-0.05	0.10-0.16	—	—	0.00003
33.	—	0.027-0.045	0.032-0.060	—	0.041-0.050	0.036-0.041	0.050-0.055	0.013-0.015	0.04-0.06	0.000025
34.	100-145	110-140	95-135	110-150	120-180	115-125	100-200	180	130-180	—
35.	—	—	—	—	—	—	—	—	—	1.465
36.	Opalescent	Translucent	Opaque	Opaque	Opaque	Opaque	Opaque	Opaque	Opaque	Transp., opaq.
37.	—	29.9 (0.50 in.)	—	—	—	—	—	—	—	>90
38.	—	—	—	—	—	—	—	—	—	<5.0
39.	0.3-0.5	0.1-0.6	0.34-0.80	0.16-0.30	0.08-0.14	0.3-0.6	0.2-1.3	0.09-0.21	0.30-0.65	0.01
40.	Self-ext.	Nonburning	Self-ext.	None	Self-ext.	Self-ext.	Very low	Self-ext.	Nonburning	1.0
41.	Colors may fade	Slight color change	Slight color change	Slight color change	Slight color change	Slight discoloration	Color darkens	Slight	Nil	Unprotected material crazes rapidly; requires black for protection
42.	None	None	None to slight	None to slight	None to slight	None	None	None	Good	None
43.	—	Decomposes	Decomposes	Decomposes	Decomposes	Decomposes	Decomposes	Decomposes	Fair	Attacked slowly by oxidizing acids
44.	None	None	None	None	Very slight attack	None	None	None	Fair-good	None
45.	—	Attacked	Decomposes	Decomposes	Slight attack	Attacked	Attacked	None to slight	Poor-fair	Very resistant
46.	None	None	None	None on bleed-proof colors	None	None on bleed-proof colors	None on bleed-proof colors	None	Good	Attacked by chlorinated aromatic solvents

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TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Nylons

Plastics properties chart (continued)

		A.S.T.M. test method	Nylons: Type 6/6 Unfilled	Nylons: Type 6/6 30% glass filled	Nylons: Type 6 Molding	Nylons: Type 6 Cast	Nylons: Type 6 Crystalline modified	Nylons: Type 6 6% Glass	Nylons: Type 6 Copolymer
Processing	1. Molding qualities	—	Excellent	Excellent	Excellent	—	Excellent	Excellent	Excellent
	2. Compression molding temp., °F.	—	—	—	—	—	—	—	—
	3. Comp. molding pressure, p.s.i.	—	—	—	—	—	—	—	—
	4. Injection molding temp., °F.	—	520-720	520-650	400-600	—	440-600	440-600	440-600
	5. Injection molding pressure, p.s.i.	—	10000-25000	10000-25000	10000-25000	—	10000-25000	—	—
	6. Compression ratio	—	2.1-2.2	—	—	—	—	—	—
	7. Mold (linear) shrinkage, in./in.	—	0.015	0.002-0.007	0.006-0.014	—	0.010-0.015	0.010	0.018
	8. Specific gravity (density)	D792	1.13-1.15	1.34-1.37	1.12-1.14	1.15-1.17	1.12-1.14	1.17-1.18	1.035
	9. Specific volume, cu. in./lb.	D792	24.5-24.1	—	24.8-24.2	24.1-23.6	24.8-24.2	25.6	23.5
	10. Machining qualities	—	Excellent						
Mechanical	11. Tensile strength, p.s.i.	D638, D651	9000-12000	19300-28000	7000-12400	11000-14000	10000-13000	13000	9500
	12. Elongation, %	D638	60.0-300.0	5.0-10.0	100-300[1] 20-30[2]	10.0-60.0	30.0-320.0	10.0-100.0	200.0-320.0
	13. Tensile modulus, 10^5 p.s.i.	D638	1.75-4.15	10.0-12.5	1.1 (Wet)-4.5 (dry)	3.5-4.5	1.75-4.70	2.00-5.10	—
	14. Compressive strength, p.s.i.	D695	6700-12500	18500-20000	6700-13000	12000	16000	13000	—
	15. Flexural yield strength, p.s.i.	D790	No break	28000-30000	7000-15000	7000-17500	7000-16000	7000-17000	5000-12000
	16. Impact strength, ft. lb./in. of notch (½ x ½ in. notched bar, Izod test)	D256	1.0-2.0	1.7-2.1 (½ x ½ in. bar)	0.8-5.5[2] 2.0-N.B.[1]	0.8-3.0 (½ x ⅛" bar)	0.8-5.5	0.8-1.8	2.4-no break
	17. Hardness, Rockwell	D785	R108-R120	R118-R120	R103-R119	R95-R120	R120	R120	R108
	18. Flexural modulus, p.s.i. x 10^5	D790	1.75[1] 4.10[2]	10.0-12.5	0.8-1.4[1] 3.7-4.0[2]	0.8-1.6[1] 1.1-4.5[2]	1.2-1.8[1] 4.0-4.7[2]	1.95[1] 5.00[2]	0.70-3.2
	19. Compressive modulus, p.s.i. x 10^5	D695	—	—	2.45-2.48	—	—	—	—
Thermal	20. Thermal conductivity, 10^{-4} cal./sec./sq.cm../1(°C./cm.)	C177	5.85	—	5.85	—	5.85	5.65	5.0
	21. Specific heat, cal./°C./gm. (RT)	—	0.4	0.3	0.38	—	0.4	0.38	0.4
	22. Thermal expansion, 10^{-5}/in./in./°C.	D696	8.0	1.5-2.0	8.3	9.0	8.0	3.3	—
	23. Resistance to heat, °F. (continuous)	—	180-300	—	175-250	180-250	180-300	180-300	250
	24. Deflection temp., °F. @ 264 p.s.i. fiber stress	D648	150-220	470-490	140-155	200-425	160-180	300-400	130-350
	@ 66 p.s.i. fiber stress		350-470	489	300-365	400-425	370	—	—
Electrical	25. Volume resistivity, ohm/cm (50% RH and 23°C.)	D257	10^{14}-10^{15}	10^{16}	10^{12}-10^{13}	—	10^{14}-10^{15}	10^{13}	10^{15}
	26. Dielectric strength, short-time, ⅛-in. thickness, volts/mil	D149	385-470	365-480	440-510	300-400	440-500	410-490	460-490
	27. Dielectric strength, step-by-step, ¼-in. thickness, volts/mil	D149	340-410	400	300-440	—	300-410	320-380	370-410
	28. Dielectric constant, 60 cyc.	D150	4.0-4.6	4.0-4.3	3.9-5.5	3.7	3.7-5.5	4.6	3.8
	29. Dielectric constant, 10^3 cyc.	D150	3.9-4.5	3.9-4.7	4.0-4.9	3.7	4.0-4.9	—	—
	30. Dielectric constant, 10^6 cyc.	D150	3.4-3.6	—	3.5-4.7	3.7	3.5-4.7	3.8	3.3
	31. Dissipation (power) factor, 60 cyc.	D150	0.014-0.040	0.006	0.040-0.060	0.02	0.020-0.050	0.017	0.010
	32. Dissipation (power) factor, 10^3 cyc.	D150	0.02-0.04	0.009	0.011-0.060	0.02	0.025-0.055	0.019	0.010
	33. Dissipation (power) factor, 10^6 cyc.	D150	0.04	—	0.03-0.04	0.02	0.040	0.040	0.025
	34. Arc resistance, sec.	D495	130-140	—	—	—	—	—	—
Optical	35. Refractive index, n_D	D542	1.53	—	—	—	—	—	—
	36. Clarity	—	Translucent to opaque						
	37. Transmittance, %	—	—						
	38. Haze, %	—	—						
Resistance characteristics	39. Water absorp., 24 hr., ¼-in. thick., %	D570	1.5	0.65-0.75	1.3-1.9	0.6-1.2	1.5	1.5	1.3
	40. Burning rate (flammability), in/min.	D635	Self-ext.	Slow	Self-extinguishing			Slow to self ext.	Slow
	41. Effect of sunlight	—	Discolors slightly						
	42. Effect of weak acids	D543	Resistant						
	43. Effect of strong acids	D543	Attacked						
	44. Effect of weak alkalies	D543	None						
	45. Effect of strong alkalies	D543	Resistant						
	46. Effect of organic solvents	D543	Resistant to common solvents but dissolved by phenols and formic acid						

[1] 2.5% H_2O [2] 0.2% H_2O

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

	Nylons							Phenol-formaldehyde and phenol-furfural molding compounds			
	Type 6/10		Type 11		Type 12						
	Unfilled	20 to 40% Glass filled	Unfilled	Glass-filled	Unfilled	Glass-filled	6/12 Copolymer	No filler	Woodflour and cotton flock filler	Asbestos filler	Mica filler
1.	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Fair	Excellent	Excellent	Good
2.	—	—	—	—	—	—	—	270-320	290-380	290-380	270-350
3.	—	—	—	—	—	—	—	2000-4000	2000-5000	2000-5000	2000-5000
4.	440-720	500-670	390-520	480-535	360-525	450-535	280-495	—	330-400	330-400	360-390
5.	10000-20000	15000-40000	8500-12800	14200-21300	9200-12800	—	—	—	10000-20000	10000-20000	8000-19000
6.	—	2.2	>2.5	>2.5	2.5	—	—	2.0-2.5	1.0-1.5	1.0-1.5	2.1-2.7
7.	0.010	0.003-0.014	0.012	0.003	0.003-0.015	0.003	0.015	0.010-0.012	0.004-0.009	0.002-0.009	0.0005-0.005
8.	1.09	1.17-1.52	1.04-1.05	1.26	1.01-1.02	1.23	1.04	1.25-1.30	1.34-1.45	1.45-2.00	1.65-1.92
9.	25.4	25.4-18.2	27.2	21.9	27.4-27.1	22.5	27.2	22.2-21.3	20.9-17.8	20.9-11.9	15.8-14.3
10.	Fair		Excellent	Fair	Excellent			Fair to good	Fair to good	Good to poor	Poor
11.	8500-8500	13000-35000	7850	12800	6680-8250	17400	5120	7000-8000	5000-9000	4500-7500	5500-7000
12.	85.0-300.0	1.5-10.0	300.0	4.0	120-350	3.0	350	1.0-1.5	0.4-0.8	0.18-0.50	0.13-0.50
13.	2.8-1.6	5.0-18.0	1.85	3.56	1.84-1.92	—	—	7.5-10.0	8.0-17.0	10.0-30.0	25.0-50.0
14.	—	13000-24000	7800	12800	—	—	—	10000-30000	22000-36000	20000-35000	25000-30000
15.	No break	15500-40000	No break	—	No break	22300	No break	12000-15000	7000-12000	7000-10000	8000-12000
16.	1.2	1.2-6.0	1.8	2.4	2.0-5.5	3.0	—	0.20-0.36	0.24-0.60	0.26-3.50	0.27-0.38
17.	R111	M94, E75	R108	R114	M31, R106	—	—	M124-128	M100-115	M105-115	E88
18.	1.6[1] 2.8[2]	7.0[1] 11.4[2]	1.42	3.56	1.7-1.8	10.0	—	—	10.0-12.0	10.0-22.0	—
19.	—	—	1.85	5.0	—	—	—	—	—	—	—
20.	5.15	5.15	7.0	8.8	5.3	3.9	5.3	3.0-6.0	4.0-8.2	6.0-22.0	10.0-14.0
21.	0.4	0.3-0.35	0.58	0.42	0.28	—	—	0.38-0.42	0.32-0.40	0.28-0.32	0.28-0.32
22.	9.0	1.2-3.2	15.0	3.2	10.4	7.5	13.0	2.5-6.0	3.0-4.5	0.8-4.0	1.9-2.6
23.	180-250	300-400	180-300	250-340	175-260	250-300	221	250	300-350	350-500	250-300
24.	—	320-502	130	343	120-131	203-345	91	240-260	300-370	300-500	300-350
	300	400-510	302	356	—	—	—	—	—	—	—
25.	10^{12}-10^{15}	1.53-5.5×10^{15}	4.3×10^{12}	10^{15}	2.5×10^{15}	—	—	10^{11}-10^{12}	10^{9}-10^{12}	10^{10}-10^{13}	10^{12}->10^{14}
26.	—	400-500	425	485	452	—	—	300-400	260-400	260-360	350-400
27.	—	375-450	—	—	409	—	—	250-350	250-350	230-310	250-390
28.	3.9	4.0-4.6	—	—	4.2	—	—	5.0-6.5	5.0-13.0	5.0-20.0	4.7-6.0
29.	3.6	3.9-4.4	3.7	3.8	3.8	—	—	4.5-6.0	4.4-9.0	6.0-16.0	4.4-5.5
30.	3.5	3.4-3.9	3.2	—	3.1	—	—	4.5-5.0	4.0-6.0	5.0-10.0	4.2-5.2
31.	0.01	0.001-0.025	—	—	0.04	—	—	0.06-0.10	0.05-0.30	0.05-0.20	0.03-0.05
32.	0.04	0.009-0.040	—	—	0.05	—	—	0.03-0.08	0.04-0.20	0.05-0.20	0.025-0.04
33.	0.04	0.011-0.022	—	—	0.03	—	—	0.015-0.03	0.03-0.07	0.35-0.80	0.005-0.013
34.	—	92-148	—	—	109	—	—	Tracks	Tracks	10-190	Tracks
35.	—	—	1.52	—	—	—	—	1.5-1.7	—	—	—
36.	Transl. to opaque		Translucent		Transp. to transl.	Transl. to opaque	Transparent	Transp. to transl.	Opaque	Opaque	Opaque
37.		—	—			—		—	—	—	—
38.		—	—			—		—	—	—	—
39.	0.4	0.2-2.0	<0.40	0.54	0.25	0.07	—	0.1-0.2	0.3-1.2	0.10-0.5	0.01-0.05
40.	Self ext.	Slow-burning to self-exting.	Self-extinguishing	1.7.	Slow burn. to self-ext.	—	Self-ext.	Very low	Self-exting.	None	None
41.	Discolors slightly							Surface darkens	General darkening		
42.	Resistant				None			None to slight, depending on acid			
43.	Attacked							Decomposed by oxidizing acids; reducing and organic acids, none to slight effect			
44.	None							Slight	Slight to marked, depending on alkalinity		
45.	None	Surface only	None					Decomposes	Attacked by strong alkalis		
46.	Resistant to common solvents but dissolved by phenols		Resistant to common solvents but dissolved by phenols					Fairly resistant	Fairly resistant on bleed-proof materials		

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Phenol-formaldehyde and phenol-furfural molding compounds

Plastics properties chart (continued)		Phenol-formaldehyde and phenol-furfural molding compounds							
		A.S.T.M. test method	Glass fiber filler	Macerated fabric and cord filler	Pulp preformed and molding board	Compounded with butadiene-acrylonitrile copolymer			Metal filled (iron, lead)
						Woodflour and cotton flock filler	Asbestos filler	Rag filler	
Processing	1. Molding qualities	—	Good to excel.	Good to fair	Good	Fair to good	Fair to good	Fair to good	Good
	2. Compression molding temp., °F.	—	280-350	280-380	290-350	300-360	310-360	310-360	280-320
	3. Comp. molding pressure, p.s.i.	—	1000-6000	2000-4000	2000-4000	2000-4000	2000-4000	2000-4000	2000-5000
	4. Injection molding temp., °F.	—	360-390	—	—	—	—	—	—
	5. Injection molding pressure, p.s.i.	—	8000-14000	—	—	—	—	—	—
	6. Compression ratio	—	2.0-10.0	3.5-18.0	1.5-3.5	2.5-3.2	2.4	3.8-5.2	—
	7. Mold (linear) shrinkage, in./in.	—	0.0001-0.004	0.002-0.009	0.0018-0.008	0.004-0.009	0.004-0.007	0.002-0.004	0.003-0.004
	8. Specific gravity (density)	D792	1.69-1.95	1.36-1.43	1.36-1.42	1.29-1.35	1.57-1.65	1.30-1.35	2.0-4.2
	9. Specific volume, cu. in./lb.	D792	15.8-14.1	20.4-19.4	20.4-19.6	22.3-20.5	17.3-16.8	21.3-21.0	—
	10. Machining qualities	—	—	Fair to good		Good			
Mechanical	11. Tensile strength, p.s.i.	D638, D651	5000-18000	3000-9000	4300-12000	3500-5000	4000-5000	3000-5000	4000-7600
	12. Elongation, %	D638	0.2	0.37-0.57	0.3-0.7	0.75-2.25	—	—	—
	13. Tensile modulus, 10^3 p.s.i.	D638	19.0-33.0	9.0-14.0	9.0-13.0	—	—	—	—
	14. Compressive strength, p.s.i.	D695	16000-70000	15000-30000	16000-35000	15000-20000	10000-20000	15000-20000	15000-30000
	15. Flexural yield strength, p.s.i.	D700	10000-60000	8500-15000	7000-18500	5000-7000	6000-8000	7000-9000	7000-12000
	16. Impact strength, ft. lb./in. of notch (½ x ½ in. notched bar, Izod test)	D256	0.3-18.0	0.75-8.00	0.5-4.5	0.40-0.90	0.34-0.40	2.0-2.3	0.3-0.5
	17. Hardness, Rockwell	D785	E54-E101	E79-E82	E50-E85	M45-M60	M50	M50-M70	M80-M115
	18. Flexural modulus, p.s.i. x 10^3	D790	20.0-33.0	10.0-14.0	—	3.0-5.0	5.0-6.0	3.5-5.5	18.0-26.0
	19. Compressive modulus, p.s.i. x 10^3	D695	—	—	—	—	—	—	—
Thermal	20. Thermal conductivity, 10^{-4} cal./sec./sq.cm./1(°C./cm.)	C177	8.2-14.5	4.0-9.0	4.0-7.0	5.0-6.0	4.6	4.9	14.0-20.0
	21. Specific heat, cal./°C./gm. (RT)	—		0.30-0.35	0.34-0.36	0.33	—	—	—
	22. Thermal expansion, 10^{-5}/in./in./°C.	D696	0.8-2.05	1.0-4.0	3.0-4.5	1.5-3.5	4.0	2.1	—
	23. Resistance to heat, °F. (continuous)	—	350-550	220-250	300-400	200	225	200	—
	24. Deflection temp., °F. @ 264 p.s.i. fiber stress	D648	300-600	250-330	260-340	200-230	250	225-250	350-425
	@ 66 p.s.i. fiber stress		—	—	—	—	—	—	—
Electrical	25. Volume resistivity, ohm/cm (50% RH and 23°C.)	D257	10^{12}-10^{13}	10^{11}-10^{12}	10^{10}-10^{13}	10^{10}	2.5 x 10^{11}	10^{10}-10^{11}	—
	26. Dielectric strength, short-time, ⅛-in. thickness, volts/mil	D149	140-400	200-400	250-550	275-325	275-350	225-175	—
	27. Dielectric strength, step-by-step, ⅛-in. thickness, volts/mil	D149	120-400	150-300	200-450	225-275	250-300	175-225	—
	28. Dielectric constant, 60 cyc.	D150	5.0-7.1	5.2-21.0	5.0-8.0	9.0-15.0	15.0	13.0-17.0	—
	29. Dielectric constant, 10^3 cyc.	D150	5.0-6.9	4.9-11.0	5.0-8.0	—	—	—	—
	30. Dielectric constant, 10^6 cyc.	D150	4.5-6.6	4.5-7.0	4.0-7.0	5.0	5.0	4.0-6.0	—
	31. Dissipation (power) factor, 60 cyc.	D150	0.04-0.05	0.08-0.64	0.04-0.30	0.14-0.50	0.15	0.30-0.5	—
	32. Dissipation (power) factor, 10^3 cyc.	D150	0.012-0.027	0.04-0.20	0.02-0.20	—	—	—	—
	33. Dissipation (power) factor, 10^6 cyc.	D150	0.010-0.026	0.03-0.09	0.03-0.7	0.08-0.10	0.010	0.08-0.15	—
	34. Arc resistance, sec.	D495	4-190	Tracks	2-130	Tracks	Tracks	Tracks	—
Optical	35. Refractive index, n_D	D542				—			
	36. Clarity	—		Opaque					
	37. Transmittance, %	—				—			
	38. Haze, %	—				—			
Resistance characteristics	39. Water absorp., 24 hr., ⅛-in. thick., %	D570	0.03-1.20	0.40-1.75	0.6-1.8	1.0-2.0	0.15-0.20	1.0-2.0	0.03-0.15
	40. Burning rate (flammability), in/min.	D635	None	Almost none	Very low to self-exting.	Slow	Very slow	Slow	None
	41. Effect of sunlight	—	General darkening						
	42. Effect of weak acids	D543	None to slight depending on acid						
	43. Effect of strong acids	D543	Decomposed by oxidizing acids; reducing and organic acids, none to slight effect						
	44. Effect of weak alkalies	D543	Slight to marked, depending on alkalinity						
	45. Effect of strong alkalies	D543	Attacked						
	46. Effect of organic solvents	D543	Fairly resistant on bleed-proof materials						

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

	Phenolic cast resins			Modified phenylene oxides		Poly-allomer	Poly-aryl ether	Poly-aryl-sulfone	Poly-butylene
	No filler	Mineral filler	Asbestos filler	Unfilled	20 to 30% glass filled				
1.	—	—	—	Excellent	Very good	Excellent	Excellent	Excellent	Good
2.	—	—	—	400-460	—	—	—	720-750	300-350
3.	—	—	—	500-1000	—	—	—	1000-2000	500-1000
4.	—	—	—	425-600	500-650	430-445	540-590	600-800	290-380
5.	—	—	—	14000-20000	15000-40000	1000-2000	10000-20000	20000-50000	10000-30000
6.	—	—	—	1.3-2.2	—	—	2.6-1.8	2.5	2.5
7.	—	—	—	0.006	0.001-0.004	0.01-0.02	0.007	0.007-0.009	0.003 unaged-0.026 aged
8.	1.236-1.320	1.68-1.70	1.70	1.06-1.10	1.21-1.36	0.896-0.899	1.14	1.36	0.910-0.915
9.	21.3-20.9	16.5-16.3	16.3	26.1-25.2	22.9-20.2	—	25.2	20.4	30.4-30.2
10.	Excellent	Good to fair	Fair to good	Excellent	Excellent	Good	Excellent	Excellent	Poor
11.	5000-9000	4000-9000	3000-6000	7800-9600	14500-17000	3050-3850	7500	13000	3800-4400
12.	1.5-2.0	—	—	20.0-30.0	4.0-6.0	400.0-500.0	25.0-90.0	13.0	300.0-380.0
13.	4.0-7.0	—	18.8	3.55-3.80	9.25-12.0	—	3.2	3.7	0.26
14.	12000-15000	29000-34000	10500-12500	16000-16400	17600-17900	—	—	17900	—
15.	11000-17000	9000-12000	5000-8000	12800-13500	18500-20000	—	11000	17200	—
16.	0.24-0.40	0.35-0.50	—	1.7-1.8 (½ x ⅛ in. bar)	1.4-1.5 (½ x ⅛ in. bar)	1.7C-6.0P	8.0 (½ x ⅛ in. bar)	5.0 @ 73° F.	No break
17.	M93-M120	M85-M120	R110	R115-119	L106-108	R50-85	R117	M110	65 (Shore D)
18.	—	—	—	3.6-4.0	7.5-11.0	0.70-1.10	3.0	3.95	0.49
19.	—	—	—	3.7	9.0-13.0	—	—	3.4	0.31
20.	3.5	—	8.4	5.16	3.8	2.0-4.0	7.13	4.55	—
21.	0.3-0.4	—	0.3	0.32	—	0.5	0.35	—	0.45
22.	6.8	7.5	3.3	5.2	2.2	8.3-10.0	6.5	4.7	15.0
23.	160	160	300	175-220	240-265	—	250-270	500	225
24.	165-175	150-175	—	212-265	270-300	124-133	300	525	130-140
	—	—	—	230-280	280-310	165-192	320	—	215-235
25.	10^{12}-10^{13}	10^{9}-10^{13}	—	$>10^{16}$->10^{17}	$>10^{17}$	$>10^{15}$	1.5×10^{16}	3.2×10^{16}	—
26.	250-400	100-250	—	400-550	420-600	800-950	430	350	—
27.	130-300	75-200	—	400-550	420-600	—	—	—	—
28.	6.5-17.5	—	—	2.64	2.93	2.3	3.14	3.94	—
29.	5.5-12.0	14.0-30.0	—	2.64	2.93	2.3	2.85	3.80	2.25
30.	4.0-5.5	9.0-15.0	—	2.64	2.92	2.3	3.10	3.70	2.25
31.	0.10-0.15	—	—	0.0004	0.0009	$<5 \times 10^{-4}$	0.006	0.003	—
32.	0.01-0.055	0.10-0.30	—	0.0004	0.0010	—	0.004	0.0035	0.005
33.	0.04-0.05	0.07-0.20	—	0.0009	0.0015	$<5 \times 10^{-4}$	0.007	0.013	0.005
34.	—	—	—	75	70-120	—	180+	67	—
35.	158.1.66	—	—	—	—	1.492	—	—	1.50
36.	Transp., transl., opaq.	Opaque	Opaque	Opaque	—	Transp. to transl.	Transl. to opaque	Opaque	Translucent
37.	—	—	—	—	—	—	—	—	—
38.	—	—	—	—	—	—	—	—	—
39.	0.2-0.4	0.12-0.36	—	0.066	0.08	<0.01	0.25	1.8	<0.01-0.026
40.	Very slow	Almost none	Almost none	Self-ext., non-drip	Self-ext., non-drip	Slow	Slow	Self-ext.	1.08
41.	Colors may fade	Darkens	Darkens slightly	Colors may fade	Colors may fade	Crazes; can be protected	None to yellows; slight embrittlement	Slight darkening	Crazes rapidly
42.	None	None to slight		None	None	None	None	None	Resistant
43.	None	Attacked by oxidizing acids		None	None	Attacked slowly by oxid. acids	Resists some	None	Attacked by oxidizing
44.	Moderate to none	Nil	None	None	None	None	None	None	Very resistant
45.	Strong	Decomposes		None	None	Very resistant	None	None	Very resistant
46.	Moderate to none		Generally resistant	Soluble or swells in some aromatics and chlorinated aliphatics. Resistant to alcohols	Softens in some aromatics and chlorinated aliphatics. Resistant to alcohols	Resistant below 80° C.	Soluble in chlorinated aromatics, esters, ketones	Soluble in highly polar solvents, unaffected by most common solvents, fuel, lubricants	—

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Plastics properties chart (continued)

			Polycarbonates			Polyesters		
			Polycarbonates			Polyesters		
		A.S.T.M. test method	Unfilled	Less than 10% glass filled	10 to 40% glass filled	ABS-poly-carbonate alloy	Thermo-plastic polyester	Thermo-plastic polyester 18% glass filled	Sheet molding compound
Processing	1. Molding qualities	—	Good to excel.	Excellent	Very good	Good	Good	Very good	Good
	2. Compression molding temp., °F.	—	460-620	—	—	Not rec.	—	—	270-350
	3. Comp. molding pressure, p.s.i.	—	1000-2000	—	—	—	—	—	300-1200
	4. Injection molding temp., °F.	—	480-650	520-650	575-650	490-540	500-540	500-540	—
	5. Injection molding pressure, p.s.i.	—	10000-20000	10000-20000	15000-40000	8000-25000	8000-23000	8000-23000	—
	6. Compression ratio	—	1.74-5.5	—	—	—	—	—	—
	7. Mold (linear) shrinkage, in./in.	—	0.005-0.007	0.002-0.003	0.001-0.003	0.005-0.009	0.018	0.003	0.001-0.004
Mechanical	8. Specific gravity (density)	D792	1.2	1.25	1.24-1.52	1.10-1.20	1.37-1.38	1.48-1.50	1.65-2.50
	9. Specific volume, cu. in./lb.	D792	23.0	22.2	22.4-18.2	26.0-24.0	20.2-20.0	18.9-18.7	—
	10. Machining qualities	—	Excellent	Fair to good	Fair	Good to excellent	Excellent		Good
	11. Tensile strength, p.s.i.	D638, D651	8000-9500	9600	12000-25000	7500-8300	10400	10900	8000-20000
	12. Elongation, %	D638	100.0-130.0	10.0	0.9-5.0	10.0-150.0	100.0-300.0	5.0	—
	13. Tensile modulus, 10^5 p.s.i.	D638	3.0-3.5	4.5	5.0-17.0	3.0-3.8	—	—	—
	14. Compressive strength, p.s.i.	D695	10300-10800	14000	13000-21000	8500-11000	18600	19500	15000-30000
	15. Flexural yield strength, p.s.i.	D790	12200-12700	15000	17000-32000	10500-14500	16700	26500	10000-36000
	16. Impact strength, ft. lb./in. of notch (½ x ½ in. notched bar, Izod test)	D256	12.0-18.0 (½ x ⅛ in. bar)	4.0-5.0 (½ x ⅛ in. bar)	1.2-4.0 1.9-6.5 (¼ x ½ in.)	8.0-13.0 @ 73° F. 1.5-3.5 @ -40° F. (½ x ⅛ in. bar)	0.8	1.2	7.0-22.0
	17. Hardness, Rockwell	D785	M73-78, R115-125	M85	M88-95	R106-120	R120, M94	M109	50-70 (Barcol)
	18. Flexural modulus, p.s.i. x 10^5	D790	3.2-3.5	5.0	5.0-14.0	3.0-4.2	4.01	9.3	10.0-22.0
	19. Compressive modulus, p.s.i. x 10^5	D695	3.45	5.2	5.0-15.0	—	—	—	—
Thermal	20. Thermal conductivity, 10^{-4} cal./sec./sq.cm../1(°C./cm.)	C177	4.6	4.8	4.9-5.2	6.0-9.0	6.9	7.0	—
	21. Specific heat, cal./°C./gm. (RT)	—	0.28-0.30.	—	—	—	0.28	0.25	—
	22. Thermal expansion, 10^{-5}/in./in./°C.	D696	6.6	3.42	1.7-4.0	6.2-8.5	6.0	2.5	2.0
	23. Resistance to heat, °F. (continuous)	—	250	275	275	220-250	175-250	250	—
	24. Deflection temp., °F. @ 264 p.s.i. fiber stress	D648	265-285	288	289-300	annealed 220-260	185	394	375-500
	@ 66 p.s.i. fiber stress		270-290	295	300-310	235-265	240	—	—
Electrical	25. Volume resistivity, ohm/cm (50% RH and 23°C.)	D257	2.1 x 10^{16}	3 x 10^{16}	4.0-5.0 x 10^{16}	2.2-4.0 x 10^{16}	3.0 x 10^{16}	20 x 10^{16}	10^{14}-10^{15}
	26. Dielectric strength, short-time, ⅛-in. thickness, volts/mil	D149	400	450	450	350-500	—	—	350-450
	27. Dielectric strength, step-by-step, ⅛-in. thickness, volts/mil	D149	364	450	400	350-460	400(1.1mm)	550 (2.0mm)	350-400
	28. Dielectric constant, 60 cyc.	D150	2.97-3.17	3.10	3.0-3.53	2.4-5.0	3.65	3.70	4.4-6.3
	29. Dielectric constant, 10^3 cyc.	D150	3.02	—	—	2.4-4.5	3.55	3.60	4.4-6.1
	30. Dielectric constant, 10^6 cyc.	D150	2.92-2.93	3.05	3.0-3.48	2.4-3.8	3.37	3.50	4.2-5.5
	31. Dissipation (power) factor, 60 cyc.	D150	0.0009	0.0008	0.0009-0.0013	0.003-0.007	0.0055	0.005	0.007-0.021
	32. Dissipation (power) factor, 10^3 cyc.	D150	0.0021	—	—	0.003-0.006	0.0187	0.017	0.007-0.015
	33. Dissipation (power) factor, 10^6 cyc.	D150	0.010	0.0075	0.0087-0.0075	0.006-0.013	0.0208	0.020	0.016-0.024
	34. Arc resistance, sec.	D495	10-120	5-120	5-120	70-120	—	—	121-243
Optical	35. Refractive index, n_D	D542	1.586	—	—	—	—	—	—
	36. Clarity	—	Transp. to opaque	Translucent to opaque		—	—	—	Opaque
	37. Transmittance, %	—	82-90	—	—	—	—	—	—
	38. Haze, %	—	1-4	—	—	—	—	—	—
Resistance characteristics	39. Water absorp., 24 hr., ¼-in. thick., %	D570	0.15-0.18	0.12	0.07-0.20	0.20-0.35	0.02	0.02	0.10-0.15
	40. Burning rate (flammability), in/min.	D635	Self-ext. UL class I & II	Self-ext. UL class I		Slow (0.8-1.2)	Slow burning	Slow burning	Slow to self-extin
	41. Effect of sunlight	—	Slight color change, slight embrittlement			None to slight yellowing, some embrittlement	Discolors very slightly	Discolors very slightly	None
	42. Effect of weak acids	D543	None			None	Resistant		None
	43. Effect of strong acids	D543	Attacked slowly	Attacked by oxidizing acids		Attacked by conc. oxidizing acids	Attacked slowly by high conc. oxidizing acids		—
	44. Effect of weak alkalies	D543	Limited resistance			None	Resistant		Slight
	45. Effect of strong alkalies	D543	Attacked			Slight	Attacked by high conc.		Attacked
	46. Effect of organic solvents	D543	Resistant to paraffinics; soluble in aromatic and chlorinated hydrocarbons	Soluble in chlorinated hydrocarbons		Soluble in ketones, esters and some chlorinated hydrocarbons	Resistant to common solvents. Slightly attacked by halogen-hydrocarbons		Slight

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Polyesters and alkyds

	Polyesters and alkyds										
		Cast polyester		Glass reinforced polyester			Alkyd				
	Low shrink	Rigid	Flexible	Preformed chopped roving	Premix chopped glass	Woven cloth	Granular and putty types, mineral filled	Asbestos filled	Glass filled	Synthetic fiber filled	Vinyl ester thermoset (Derakane®)
1.	Good	—	—	Excellent	Excellent	Hand lay-up	Excellent	Excellent	Excellent	Excellent	Excellent
2.	270-330	—	—	170-320	280-350	Rm. temp.-250	270-350	280-320	330-350	280-350	270-300
3.	>100	—	—	250-2000	500-2000	0-300	100-4000	500-2000	2000-6000	500-3000	100-200
4.	270-330	—	—	—	—	—	280-390	—	280-320	280-320	—
5.	2000	—	—	—	—	—	2000-14000	—	2500-10000	2000-8000	—
6.	1.0	—	—	—	—	—	1.8-2.5	2.0-2.5	>1.0-11.0	>1.0-5.0	—
7.	0.0001	—	—	0.000-0.002	0.001-0.012	0.000-0.002	0.003-0.010	0.004-0.007	0.002-0.008	0.005-0.0010	—
8.	1.67	1.10-1.46	1.01-1.20	1.35-2.30	1.65-2.30	1.50-2.10	1.60-2.30	1.65	2.12-2.15	1.24-2.10	1.03-1.083
9.	—	25.2-19.0	27.4-23.0	20.5-13.9	—	18.5-13.2	17.3-12.0	16.8	13.2	22.4-13.2	—
10.	Good to excel.	Good	Fair	Good	Good	Good	Poor to fair	Good	Poor	Fair to excellent	—
11.	4500-20000	6000-13000	800-1800	25000-30000	4000-10000	30000-50000	3000-9000	4500-7000	4000-9500	4500-7000	10500
12.	—	<5.0	40.0-310.0	0.5-5.0	—	0.5-2.0	—	—	—	—	3.5-5.5
13.	15.6-18.0	3.0-6.4	—	8.0-20.0	16.0-25.0	15.0-45.0	5.0-30.0	—	20.0-28.0	20.0	—
14.	15000-50000	13000-36500	—	15000-30000	20000-30000	25000-50000	12000-38000	22500	15000-32000	20000-30000	—
15.	9000-35000	8500-23000	—	10000-40000	12000-20000	40000-80000	6000-17000	8000-10000	15000	10000-20000	17800-18400
16.	2.5-15.0	0.2-0.4	>7.0	2.0-10.0	1.5-16.0	5.0-30.0	0.30-0.50	0.45-0.50	0.60-10.0	0.50-4.50	—
17.	—	M70-M115	84-94(Shore)	M70-M120	60-80(Barcol)	M80-M120	60-70 (Barcol) 98 (E scale)	M99	55-80 (Barcol) 95 (E scale)	95 (M scale) 76 (E scale)	—
18.	16.5-19.0	—	—	—	—	—	20	—	20.0	17.0	4.7-4.9
19.	—	—	—	—	—	—	—	—	—	—	—
20.	—	4.0	—	—	10.0-16.0	—	12.2-25.0	—	15.0-25.0	7.0-16.5	—
21.	—	—	—	—	0.25	—	0.25	—	—	—	—
22.	0.66-1.09	5.5-10.0	—	1.2-5.0	2.0-3.3	1.5-3.0	2.0-5.0	—	1.5-2.5	3.0-5.5	—
23.	—	250	250	300-350	300-350	300-350	300-450	450	450	300-430	—
24.	>400	140-400	—	—	>400	—	350-500	315	400-500	245-430	—
	—	—	—	—		—	—	—	—	—	185-215
25.	3×10^{14}	10^{15}	—	10^{14}	10^{13}-10^{15}	10^{14}	10^{13}-10^{15}	6.6×10^{8}	10^{15}	10^{8}-10^{16}	2.5×10^{15}
26.	—	380-500	250-400	350-500	345-420	350-500	350-450	380	250-530	365-500	445-541
27.	—	280-420	277	—	275-390	—	300-375	290	200-400	325-450	—
28.	5.3	3.00-4.36	4.4-8.1	3.8-6.0	5.3-7.3	4.1-5.5	5.1-7.5	—	5.7	3.8-5.0	4.38-4.88
29.	5.0	2.8-5.2	4.5-7.1	4.0-6.0	4.68	4.2-6.0	5.0-6.4	5.2	5.4-7.4	3.7-4.9	4.35-4.72
30.	4.7	2.8-4.1	4.1-5.9	3.5-5.5	5.2-6.4	4.0-5.5	4.6-6.1	4.5	5.2-6.8	3.6-4.7	4.15-4.27
31.	0.019	0.003-0.028	0.026-0.310	0.01-0.04	0.011-0.041	0.01-0.04	0.009-0.06	—	0.010	0.012-0.026	0.0097-0.0210
32.	0.018	0.005-0.025	0.016-0.050	0.01-0.05	—	0.01-0.06	0.007-0.040	0.11	0.007-0.04	0.001-0.03	0.0055-0.0210
33.	0.019	0.006-0.026	0.023-0.060	0.01-0.03	0.008-0.022	0.01-0.03	0.006-0.040	0.01-0.06	0.008-0.023	0.010-0.016	0.013-0.019
34.	—	125	135	120-180	120-240	60-120	75-190	138	150-210	85-185	—
35.	—	1.523-1.570	1.537-1.550	—	—	—	—	—	—	—	—
36.	Opaque	Transparent to opaque		Transl. to opaq.	Opaque	Transl. to opaq.	Opaque	Opaque	Opaque	Opaque	—
37.	—	—		—	—	—	—	—	—	—	—
38.	—	—		—	—	—	—	—	—	—	—
39.	0.1	0.15-0.60	0.50-2.50	0.01-1.00	0.06-0.28	0.05-0.50	0.05-0.50	0.14	0.05-0.25	0.05-0.20	0.2
40.	Slow to self-exting.	Conventional burns; Fire Retardant type self-extinguishing Conventional 0.7-2.0 in./min.; Fire Retardant <0.2					Slow to nonburning	Self-extinguishing	Slow to nonburning	Self-extinguishing and nonburning	—
41.	Slight	Yellows slightly	—	Slight	Depends on pigmentation	Slight	None	None	None	None	—
42.	None	Ortho & Gen. Purp. Iso resis. some at RT; Chem. Resis. Iso resis. to 170° F.; Bis. & HBPA to 210° F.; Chlor. Anhyd. resis. most at RT, some to 250° F.					None	None	Poor to fair	None	—
43.	Attacked by high conc.	Ortho & Gen. Purp. not resis. strong or oxidizing; Chem. Resis. Iso resis. strong to 170° F., not resis. low-concen. oxidizing at RT; Bis. & HBPA resis. strong to 210° F., oxidizing to 170° F.; Chlor. Anhyd. resis. most at RT, some to 250° F.					Attacked	Slight	Poor to fair	Slight	—
44.	Slight	Ortho & Gen. Purp. resis. some at RT; Chem. Resis. Iso to 170° F. and Bis. & HBPA to 210° F.; Chlor. Anhyd. resis. some to 210° F.					Attacked	None	Poor to fair	None	—
45.	Attacked	Ortho & Gen. Purp. Iso & Chem. Resis. Iso not resis.; Chem Resis. Bis. resis. to 170° F.; Chlor. Anhyd. resis. some to 170° F.					Decomposes	Slight	Poor to fair	Slight	—
46.	Resistant to slight	Ortho & Gen. Purp. Iso not resis.; Chem. Resis. Iso resis. some & Bis. & HBPA most at RT; Chlor. Anhyd. resis. most at RT, some to 200° F. Effect of salts: Ortho & Gen. Purp. Iso resis. some at RT; Chem. Resis. Iso resis. to 170° F., Bis. & HBPA to 210° F.; Chlor. Anhyd. resis. most to 250° F.					Fair to good	None	Fair to good	Fair to good	—

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Polyethylenes and ethylene copolymers

Plastics properties chart (continued)

		A.S.T.M. test method	Polyethylenes and ethylene copolymers							
			Low density	Medium density	High density	Polyethylene cross-linkable compounds: Molding grades	Polyethylene cross-linkable compounds: Wire and cable grades	Ethylene-ethyl acrylate copolymer	Ethylene vinyl acetate copolymer	High molecular weight
Processing	1. Molding qualities	—	Excellent	Excellent	Excellent	Excellent	—	Excellent	Excellent	Fair
	2. Compression molding temp., °F.	—	275-350	300-375	300-450	240-450	—	200-300	200-300	400-500
	3. Comp. molding pressure, p.s.i.	—	100-800	100-800	500-800	100-800	—	50-1000	50-2500	800-1200
	4. Injection molding temp., °F.	—	300-500	300-500	300-600	250-300	—	250-600	250-400	—
	5. Injection molding pressure, p.s.i.	—	8000-30000	8000-30000	10000-20000	—	—	8000-20000	8000-20000	—
	6. Compression ratio	—	1.8-3.6	1.8-2.2	2.0	—		—	—	—
	7. Mold (linear) shrinkage, in./in.	—	0.015-0.050	0.015-0.050	0.02-0.05	0.007-0.090	0.020-0.050	0.015-0.035	0.007-0.011	—
	8. Specific gravity (density)	D792	0.910-0.925	0.926-0.940	0.941-0.965	0.95-1.45	0.93-1.40	0.93	0.925-0.950	0.94
	9. Specific volume, cu. in./lb.	D792	30.5-30.0	30.0-29.6	29.6-28.8	—	—	—	—	29.8
	10. Machining qualities	—	Good	Good	Excellent	Good to excellent		Fair	Fair	Good to excellent
Mechanical	11. Tensile strength, p.s.i.	D638, D651	600-2300	1200-3500	3100-5500	1600-4600	1500-3100	800-2000	1440-2800	2500-3500
	12. Elongation, %	D638	90.0-800.0	50.0-600.0	20.0-1000.0	10.0-440.0	180.0-600.0	300.0-700.0	750.0-900.0	300.0-500.0
	13. Tensile modulus, 10^5 p.s.i.	D638	0.14-0.38	0.25-0.55	0.6-1.8	0.5-5.0	—	0.046-0.067	0.02-0.12	0.20-1.10
	14. Compressive strength, p.s.i.	D695	—	—	2700-3600	2000-5500	—	—	—	—
	15. Flexural yield strength, p.s.i.	D790	—	4800-7000	—	2000-6500	—	3000-3600	—	—
	16. Impact strength, ft. lb./in. of notch (½ x ½ in. notched bar, Izod test)	D256	No break	0.5->16.0	0.5-20.0	1.0-20.0	—	No break	No break	No break
	17. Hardness, Rockwell	D785	D41-D46 (Shore), R10	D50-D60 (Shore), R15	D60-70 (Shore)	55-80 (Shore D)	33-57 (Shore D)	D27-36 (Shore)	D17-38 (Shore)	D60-70 (Shore)
	18. Flexural modulus, p.s.i. x 10^5	D790	0.08-0.60	0.60-1.15	1.0-2.6	0.7-3.5	—	—	0.01-0.20	1.30-1.40
	19. Compressive modulus, p.s.i. x 10^5	D695	—	—	—	0.5-1.5	—	—	—	—
Thermal	20. Thermal conductivity, 10^{-4} cal./sec./sq.cm./1(°C./cm.)	C177	8.0	8.0-10.0	11.0-12.4	—	—	—	—	—
	21. Specific heat, cal./°C./gm. (RT)	—	0.55	0.55	0.55	—	—	0.55	0.55	—
	22. Thermal expansion, 10^{-5}/in./in./°C.	D696	10.0-20.0	14.0-16.0	11.0-13.0	10.0-35.0	10.0-35.0	16.0-23.0	16.0-20.0	7.2
	23. Resistance to heat, °F. (continuous)	—	180-212	220-250	250	275	275	190-200	—	—
	24. Deflection temp., °F. @ 264 p.s.i. fiber stress	D648	90-105	105-120	110-130	105-145	100-175	—	93	105-120
	@ 66 p.s.i. fiber stress		100-121	120-165	140-190	130-225	—	—	140-147	155-180
Electrical	25. Volume resistivity, ohm/cm (50% RH and 23°C.)	D257	$>10^{16}$	$>10^{16}$	$>10^{16}$	<200->15 x 10^8	—	2.4 x 10^9	1.5 x 10^4	$>10^{16}$
	26. Dielectric strength, short-time, ⅛-in. thickness, volts/mil	D149	450-1000	450-1000	450-500	—	230-1420	450-550	620-780	710
	27. Dielectric strength, step-by-step, ⅛-in. thickness, volts/mil	D149	420-700	500-700	440-600	—	—	—	620-780	680
	28. Dielectric constant, 60 cyc.	D150	2.25-2.35	2.25-2.35	2.30-2.35	—	2.28-7.60	2.7-2.9	2.50-3.16	—
	29. Dielectric constant, 10^3 cyc.	D150	2.25-2.35	2.25-2.35	2.30-2.35	—	2.27-7.40	2.7-2.9	2.60-2.98	—
	30. Dielectric constant, 10^6 cyc.	D150	2.25-2.35	2.25-2.35	2.30-2.35	2.63-3.11	—	2.7-2.8	2.5-3.2	2.30
	31. Dissipation (power) factor, 60 cyc.	D150	<0.0005	<0.0005	<0.0005	—	0.003-0.044	0.01-0.02	0.003-0.020	—
	32. Dissipation (power) factor, 10^3 cyc.	D150	<0.0005	<0.0003	<0.0005	—	0.00048-0.04900	0.01-0.02	0.011-0.017	—
	33. Dissipation (power) factor, 10^6 cyc.	D150	<0.0005	<0.0005	<0.0005	0.001-0.002	—	0.01-0.02	0.03-0.05	0.0002
	34. Arc resistance, sec.	D495	135-160	200-235	—	—	—	—	—	—
Optical	35. Refractive index, n_D	D542	1.51	1.52	1.54	—	—	—	—	—
	36. Clarity	—	Transparent to opaque			Transparent to opaque		Translucent	Transp.-opaq.	Transl.-opaque
	37. Transmittance, %	—	0-75	10-80	0-40	—		—	0-80	—
	38. Haze, %	—	4-50	2-40	10-50	—		—	2-40	—
	39. Water absorp., 24 hr., ⅛-in. thick., %	D570	<0.015	<0.01	<0.01	<0.01-0.06	<0.01-0.05	0.04	0.05-0.13	<0.01
Resistance characteristics	40. Burning rate (flammability), in/min.	D635	Very slow (1.04)	Very slow (1.00-1.04)	Very slow (1.00-1.04)	Very slow to self-exting.	Slow	Very slow	Very slow	Very slow
	41. Effect of sunlight	—	Unprotected material crazes rapidly. Requires black for complete protection but weather resistant grades available in natural and colors.			Same as for polyethylene		Very slight yellowing	Very slight yellowing	—
	42. Effect of weak acids	D543	Resistant	Very resistant	Very resistant	Very resistant		Resistant	Resistant	Very resistant
	43. Effect of strong acids	D543	Attacked by oxidizing acids	Attacked slowly by oxidizing acids	Attacked slowly by oxidizing acids	Attacked slowly by oxidizing acids		Attacked by oxidizing acids	Attacked	Attacked by oxidizing acids
	44. Effect of weak alkalies	D543	Resistant	Very resistant	Very resistant	Very resistant		Resistant	Resistant	Very resistant
	45. Effect of strong alkalies	D543	Resistant	Very resistant	Very resistant	Very resistant		Resistant	Resistant	Very resistant
	46. Effect of organic solvents	D543	Resistant (below 60° C.)	Resistant (below 60° C.)	Resistant (below 80° C.)	Resistant below 80° C.		Attacked by chlorinated solvents; soluble in aromatic solvents above 50° C.	Soluble in chlorinated and aromatic solvents over 50° C.	Resists many solvents below 80° C.

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

	Poly-imides aro-matic	Polyphenylene sulphides			Polypropylenes				
	Poly-imides aro-matic	Polyphenylene sulphides			Polypropylenes				
		Unfilled	25% asbestos filled	40% glass filled	Unmodified	Copolymer	Inert-filled	Glass-reinforced	Impact (rubber-modified)
1.	—	Excellent	Good	Very good	Excellent	Excellent	Excellent	Excellent	Excellent
2.	—	600-650	600-650	600-650	340-450	340-550	340-550	—	340-450
3.	—	1000-2000	1000-2000	1000-2000	500-1000	500-1000	500-1000	—	500-1000
4.	—	600-700	600-700	600-700	400-550	400-600	375-600	450-550	400-500
5.	—	5000-15000	10000-20000	10000-20000	10000-20000	10000-20000	10000-20000	10000-20000	15000
6.	—	—	—	—	2.0-2.4	2.0-2.4	—	—	2.0-2.4
7.	—	0.001	—	—	0.010-0.025	0.009-0.020	0.005-0.015	0.004-0.008	0.01-0.02
8.	1.43	1.34	—	—	0.902-0.906	0.890-0.905	1.0-1.3	1.05-1.24	0.90-0.91
9.	19.3	20.6	—	—	30.8-30.4	31.2-30.5	26.0	24.5	30.8-30.5
10.	Excellent	Excellent	Excellent	Excellent	Good	Good	Fair-good	Fair	Good
11.	10500	10800	11700	21400	4300-5500	2900-4500	4500-8200	6000-9000	2800-4400
12.	5.0-6.0	3.0	2.0	3.0	200.0-700.0	200-700 (at break)	3.0-20.0 (at break)	2.0-3.6	350.0->500.0
13.	4.5	4.8	7.0	11.2	1.60-2.25	1.0-1.7	4.0-8.0	4.5-9.0	1.0-1.7
14.	>24000	—	—	—	5500-8000	<3700-8000	—	5500-7000	4000-6500
15.	15000	20000 (at break)	18000 (at break)	37000 (at break)	6000-8000	5000-7000	8000-9000	7000-11000	—
16.	0.9	0.3 @ 75° F. 1.0 @ 300° F. (½ x ¼ in. bar)	0.6 @ 75° F. 1.2 @ 300° F. (¼ x ¼ in. bar)	0.8 @ 75° F. 1.8 @ 300° F. (½ x ¼ in. bar)	0.5-2.0 @ 73° F.	1.1-20.0 @ 73° F.	0.4-3.0 @ 73° F.	1.0-5.0 @ 73° F.	1.0-15.0 @ 73° F.
17.	E40-60	R124	R123	R123	R85-110	R50-96	R94-100	R90	R50-R85
18.	4.6	6.0	9.7	22.0	2.0-2.4	1.3-1.8	3.0-6.5	3.8-7.5	1.2-1.8
19.	—	—	—	—	1.5-3.0	—	2.4	—	—
20.	—	6.84	—	—	2.8	2.0-4.0	—	—	3.0-4.0
21.	0.27	—	—	—	0.46	0.5	—	—	0.5
22.	4.0-5.0	5.5	5.3	4.0	5.8-10.2	8.0-9.5	2.9	2.9-5.2	6.0-8.5
23.	500	400-500	400-500	400-500	225-300	190-240	290-310	300-320	200-250
24.	680	278	400	>425	125-140	115-140	140-200	230-300	120-135
	—	—	—	—	200-230	185-230	210-290	305-310	160-200
25.	$>10^{16}$	—	—	—	$>10^{16}$	10^{17}	$1.5\text{-}2.8 \times 10^{16}$	—	$>10^{15}$
26.	560	595	—	490	500-660	500-660	450-650	—	500-650
27.	—	—	—	—	450-650	450-600	—	—	450-600
28.	3.4	—	—	—	2.2-2.6	2.25-2.30	2.50-2.75	2.37	2.3
29.	3.4	3.11	—	3.79	2.2-2.6	2.24-2.30	2.50-2.65	2.36	2.3
30.	3.4	3.22	—	3.88	2.2-2.6	2.24-2.30	2.50-2.60	2.38	2.3
31.	—	—	—	—	<0.0005	<0.0001-0.0005	0.0054-0.0070	0.0022	>0.0003
32.	0.002	0.0004	—	0.0037	<0.0005-0.0018	<0.0001-0.0008	0.0036-0.0050	0.0017	>0.0003
33.	0.005	0.0007	—	0.0041	<0.0005-0.0018	<0.0001-0.0018	0.0021	0.0035	>0.0003
34.	230	—	—	—	138-185	136	121	74	—
35.	—	—	—	—	1.49	—	—	—	—
36.	Opaque	Opaque	Opaque	Opaque	Transp., transl., op.		Opaque	Opaque	Translucent
37.	—	—	—	—	55-90 (film)	—	—	—	—
38.	—	—	—	—	1.0-3.5	—	—	—	—
39.	0.32	—	—	—	<0.01	<0.01-0.03	0.02-0.10	0.01-0.05	<0.01
40.	Non-burning	Nonburning			Slow	Slow	Slow to nonburning	—	Slow
41.	—	—			Unprotected material crazes rapidly. Requires black for complete protection, but weather-resistant grades available in natural and colors				
42.	Resistant	None			None				
43.	Resistant	Attacked slowly by oxidizing acids			Attacked slowly by oxidizing acids			—	Attacked slowly by oxidizing acids
44.	Slow attack	None			None	None	None	—	None
45.	Attack	None			Very resistant		Very resistant	—	Very resistant
46.	Very resistant	Resistant below 375-400° F.			Resistant below 80°C.			—	Attacked by hydrocarbons and chlorinated hydrocarbons

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Polystyrenes

Plastics properties chart (continued)

		A.S.T.M. test method	Polystyrene molding compounds and sheet		Special heat and chemical resistant type	20 to 30% glass filled	Styrene-acrylonitrile copolymer	
			Unfilled free-flowing general-purpose heat-resistant	Impact-resistant medium-impact high-impact (heat-resistant)			Unfilled	20 to 33% glass filled
Processing	1. Molding qualities	—	Excellent	Excellent	Good	Excellent	Good	Excellent
	2. Compression molding temp., °F.	—	265–400	250–400	300–400	—	300–400	—
	3. Comp. molding pressure, p.s.i.	—	1000–10000	1000–10000	1000–5000	—	1000–10000	—
	4. Injection molding temp., °F.	—	325–500	350–500	350–700	450–625	375–575	450–575
	5. Injection molding pressure, p.s.i.	—	10000–30000	10000–30000	10000–30000	15000–40000	10000–33000	15000–40000
	6. Compression ratio	—	1.6–4.0	1.6–4.0	1.6–40	1.6–4.0	1.6–4.0	1.6–4.0
	7. Mold (linear) shrinkage, in./in.	—	0.001–0.006 (C) 0.002–0.008 (I)	0.002–0.008	0.001–0.008	0.001–0.002	0.002–0.007	0.001–0.002
	8. Specific gravity (density)	D792	1.04–1.09	1.04–1.10	1.04–1.10	1.20–1.33	1.075–1.100	1.20–1.46
	9. Specific volume, cu. in./lb.	D792	26.4–26.0	28.1–25.2	26.2–24.8	22.2–20.9	25.8–25.2	23.0–19.0
	10. Machining qualities	—	Fair to good	Good	Fair to good	Good	Good	Fair
Mechanical	11. Tensile strength, p.s.i.	D638, D651	5000–12000	1500–7000	6500–12000	9000–15000	9000–12000	8500–20000
	12. Elongation, %	D638	1.0–2.5	2.0–80.0	1.4–2.5	0.75–1.30	1.5–3.7	1.1–3.3
	13. Tensile modulus, 10^5 p.s.i.	D638	4.0–6.0	1.5–3.0	4.0–6.0	8.4–12.9	4.0–5.6	4.0–14.0
	14. Compressive strength, p.s.i.	D695	11500–16000	4000–9000	11500–16000	13500–15000	14000–17000	22000
	15. Flexural yield strength, p.s.i.	D790	8700–14000	5000–12000	10000–17000	10500–20000	14000–19000	22000–26000
	16. Impact strength, ft. lb./in. of notch (½ x ½ in. notched bar, Izod test)	D256	0.25–0.40 (¼ in. bar)	0.5–11.0 0.5–8.0 (23° C.) 0.4–2.5 (−25° C.)	0.35–0.60 (¼ in. bar)	0.4–4.5	0.35–0.50	0.4–4.0
	17. Hardness, Rockwell	D785	M65–M80	M20–80; R50–100	M65–M90	M70–M95	M80–M90	M100, E80
	18. Flexural modulus, p.s.i. x 10^5	D790	4.3–4.7	3.3–4.0	—	8.0–10.0	to 5.5	8.0–18.0
	19. Compressive modulus, p.s.i. x 10^5	D695	—	—	—	—	5.3	
Thermal	20. Thermal conductivity, 10^{-4} cal./sec./sq.cm./1(°C./cm.)	C177	2.4–3.3	1.0–3.0	1.9–3.0	—	2.9	—
	21. Specific heat, cal./°C./gm. (RT)	—	0.32	0.32–0.35	0.32–0.35	0.23–0.27	0.32–0.34	—
	22. Thermal expansion, 10^{-5}/in./in./°C.	D696	6.0–8.0	3.4–21.0	6.0–8.0	1.8–4.5	3.6–3.8	2.7–3.8
	23. Resistance to heat, °F. (continuous)	—	150–170	140–175	170–200	180–200	140–205	200–220
	24. Deflection temp., °F. @ 264 p.s.i. fiber stress	D648	220 max.	210 max.	180–235	195–220	190–220	190–220
	@ 66 p.s.i. fiber stress		—	—	—	207–231	—	215–240
Electrical	25. Volume resistivity, ohm/cm (50% RH and 23°C.)	D257	$>10^{16}$	$>10^{16}$	10^{13}–10^{17}	3.2×10^{16}	$>10^{16}$	$1.4\text{–}2.1 \times 10^{17}$
	26. Dielectric strength, short-time, ⅛-in. thickness, volts/mil	D149	500–700	300–600	400–600	350–425	400–500	510
	27. Dielectric strength, step-by-step, ⅛-in. thickness, volts/mil	D149	400–600	300–600	300–500	350–430	300–600	410
	28. Dielectric constant, 60 cyc.	D150	2.45–2.65	2.45–4.75	2.45–3.4	—	2.6–3.4	3.6
	29. Dielectric constant, 10^3 cyc.	D150	2.40–2.65	2.4–4.5	2.4–3.2	—	2.6–3.3	3.5
	30. Dielectric constant, 10^6 cyc.	D150	2.40–2.65	2.4–3.8	2.4–3.1	—	2.6–3.1	3.4
	31. Dissipation (power) factor, 60 cyc.	D150	0.0001–0.0003	0.0004–0.0020	0.0005–0.0030	0.004–0.014	0.006–0.008	0.00645
	32. Dissipation (power) factor, 10^3 cyc.	D150	0.0001–0.0003	0.0004–0.0020	0.0005–0.0030	0.001–0.004	0.007–0.012	0.00652
	33. Dissipation (power) factor, 10^6 cyc.	D150	0.0001–0.0004	0.0004–0.0020	0.0005–0.0050	0.001–0.003	0.007–0.010	0.00668
	34. Arc resistance, sec.	D495	60–80	20–100	60–135	25–40	100–150	16
Optical	35. Refractive index, n_D	D542	1.59–1.60	—	1.57–1.60	—	1.56–1.57	—
	36. Clarity	—	Transparent	Transl., opaque	Transparent	Transl., opaque	Transparent	Transl., opaque
	37. Transmittance, %	—	88–92	35–55	88–90	—	78–88	—
	38. Haze, %	—	<0.1–3.0	>77	—	—	0.4–0.1	—
Resistance characteristics	39. Water absorp., 24 hr., ⅛-in. thick., %	D570	0.03–0.10	0.05–0.6	0.05–0.40	0.05–0.10	0.20–0.30	0.08–0.22
	40. Burning rate (flammability), in/min.	D635	Slow	Slow	Slow	Nonburning to 1	Slow	Nonburning to 1
	41. Effect of sunlight	—	Yellows slightly	Some strength loss. Yellows slightly	Yellows slightly	Yellows slightly	Yellows slightly	Yellows slightly
	42. Effect of weak acids	D543	None	None	None	None	None	Resistant
	43. Effect of strong acids	D543	Attacked by oxidizing acids	Attacked by oxidizing acids	Attacked by oxidizing acids	Attacked by oxidizing acids	Attacked by oxidizing acids	Attacked by oxidizing acids
	44. Effect of weak alkalies	D543	None	None	None	Resistant	None	None
	45. Effect of strong alkalies	D543	None	None	None	Surface only	None	Surface only
	46. Effect of organic solvents	D543	Soluble in aromatic and chlorinated hydrocarbons	Soluble in aromatic and chlorinated hydrocarbons	Soluble in aromatic and chlorinated hydrocarbons	Soluble in aromatic and chlorinated hydrocarbons	Soluble in ketones, esters & some chlorinated hydrocarbons	Soluble in ketones, esters & some chlorinated hydrocarbons

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

	Poly-sulfone	Silicones				Styrene-butadiene thermo-plastic elastomers	Urea-formaldehyde molding compound
		Cast resins	Molding compounds				
		Flexible (including RTV)	Asbestos filler	Glass fiber filler	Mineral filler		Alpha cellulose filler
1.	Excellent	Excellent	Good	Good	Excellent	Good	Excellent
2.	550-600	—	300-350	310-360	310-375	250-325	275-350
3.	1000	—	1000-8000	1000-5000	200-5000	100-3000	2000-8000
4.	650-750	—	—	—	—	300-425	—
5.	15000-20000	—	—	—	—	15000-30000	—
6.	1.8-2.2	—	6.0-8.0	6.0-9.0	1.7-2.0	2.0	2.2-3.0
7.	0.007	0-0.006	—	0-0.005	0.003-0.006	0.001-0.005	0.006-0.014
8.	1.24	0.99-1.50	1.6-1.9	1.68-2.0	1.81-2.82	0.93-1.10	1.47-1.52
9.	22.3	—	17.3-14.4	16.5-13.8	—	37.4-27.5	18.8-18.2
10.	Excellent	—	Fair to good	Fair	Fair to good	Poor	Fair
11.	10200 (at yield)	350-1000	28000-35000	4000-6500	4000-6000	600-3000	5500-13000
12.	80.0-100.0 (at break)	100-1000	—	—	—	300.0-1000.0	0.5-1.0
13.	3.6	900.0	25.0-30.0	—	—	0.008-0.500	10.0-15.0
14.	13900 (at yield)	100	—	10000-15000	13000-18000	Max. stress 5000 no break	25000-45000
15.	15400 (at yield)	—	30000-35000	10000-14000	7000-10000	Max. stress 60-900 no break	10000-18000
16.	1.3 (¼ in. bar) 1.2 (⅛ in. bar) (—40° F.)	—	—	3.0-15.0	0.26-0.35	No break	0.25-0.40
17.	M69, R120	15-65 (Shore A)	—	M84	M71-M95	40-90 (Shore A)	M110-M120
18.	3.7-3.9	—	—	11.6	—	0.04-1.50	13-15
19.	3.4-3.7	—	—	—	—	0.036-1.200	—
20.	—	3.5-7.5	—	7.51-7.54	11.0-13.0	3.6	7.0-10.0
21.	0.31	—	—	0.24-0.30	—	0.45-0.50	0.4
22.	5.2-5.6	8.0-30.0	—	0.8	2.0-4.0	13.0-13.7	2.2-3.6
23.	300-345	500	—	>600	>600	130-150	170
24.	345	—	—	>900	>900	Sub zero—150	260-290
	358	—	—		—	Sub zero—120	—
25.	5.0×10^{16}	10^{14}-10^{16}	—	10^{16}-10^{14}	10^{14}	5.0×10^{13} —2.5×10^{16}	10^{12}-10^{13}
26.	425	550	—	200-400	200-400	420-520	300-400
27.	400	550	—	125-300	380	420-540	220-300
28.	3.14	2.75-4.20	—	3.3-5.2	3.5-3.6	2.5-3.4	7.0-9.5
29.	3.13	—	—	3.2-5.0	—	2.5-3.4	7.0-7.5
30.	3.10	2.6-2.7	—	3.2-4.7	3.4-6.3	2.5-3.4	6.8
31.	0.0008	0.001-0.025	—	0.004-0.030	0.004-0.005	0.002-0.003	0.035-0.043
32.	0.0010	—	—	0.0035-0.0200	—	0.001-0.003	0.025-0.035
33.	0.0034	0.001-0.002	—	0.002-0.020	0.002-0.005	0.001-0.003	0.25-0.35
34.	75-122	115-130	—	150-250	250-420	95	80-150
35.	1.633	1.43	—	—	—	1.52-1.55	1.54-1.56
36.	Transp., opaque	Clear grades available	Opaque	Opaque	Opaque	Transp., opaque	Transl., opaque
37.	—	—	—	—	—	—	39.4 (0.50 in.)
38.	5.0	—	—	—	—	—	—
39.	0.22	0.12 (7 days @ 77° F.)	—	0.1-0.2	0.08-0.13	0.19-0.39	0.4-0.8
40.	Self-extinguishing	Self-extinguishing	None to slow	None to slow	None to slow	Slow	Self-exting.
41.	Strength loss, slight yellowing	None	None to slight	None to slight	None to slight	Slight color change	Pastels grey
42.	None	Little or none	None to slight	None to slight	None	None	None to slight
43.	None	Slight to severe	Slight	Slight	Slight	Attacked by oxidizing acids	Decomposed or surface attacked
44.	None	Little or none	None to slight	None to slight	None to slight	None	Slight to marked
45.	None	Moderate to severe	None to marked	Slight to marked	Slight to marked	Slight	Decomposes
46.	Aliphatic—none Aromatic—partly soluble	Insoluble but swells in some	Attacked by some	Attacked by some	Attacked by some	Dissolves	None to slight

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

Plastics properties chart (continued)		Urethanes			Vinyl polymers and copolymers		
					Vinyl chloride and vinyl chloride-acetate molding compounds and sheets, rods and tubes		
		A.S.T.M. test method	Cast liquid urethane	Urethane elastomers	Rigid	Flexible unfilled	Flexible filled
Processing	1. Molding qualities	—	Good	Good to excellent	Fair to good	Good	Good
	2. Compression molding temp., °F.	—	—	293-400	285-400	285-350	285-350
	3. Comp. molding pressure, p.s.i.	—	—	100-5000	750-2000	500-2000	500-2000
	4. Injection molding temp., °F.	—	—	320-460	300-415	320-385	320-385
	5. Injection molding pressure, p.s.i.	—	—	5000-20000	10000-40000	8000-25000	8000-25000
	6. Compression ratio	—	—	2.4	2.0-2.3	2.0-2.3	2.0-2.3
	7. Mold (linear) shrinkage, in./in.	—	0-0.015	0.009-0.030	0.001-0.005	0.010-0.050 (Varies with plasticizer)	0.008-0.035
	8. Specific gravity (density)	D792	1.10-1.50	1.11-1.25	1.35-1.45	1.16-1.35	1.3-1.7
	9. Specific volume, cu. in./lb.	D792	27.0-22.0	24.0-22.0	20.5-19.1	23.8-20.5	21.3-16.3
	10. Machining qualities	—	Excellent	Fair to excellent	Excellent	—	—
Mechanical	11. Tensile strength, p.s.i.	D638, D651	175-10000	4500-8400	5000-9000	1500-3500	1000-3500
	12. Elongation, %	D638	100-1000	10-650	2.0-40.0	200.0-450.0	200.0-400.0
	13. Tensile modulus, 10^5 p.s.i.	D638	1.0-10.0	0.1-3.5	3.5-6.0	—	—
	14. Compressive strength, p.s.i.	D695	20000	20000	8000-13000	900-1700	1000-1800
	15. Flexural yield strength, p.s.i.	D790	—	700-9000	10000-16000	—	—
	16. Impact strength, ft. lb./in. of notch (½ x ½ in. notched bar, Izod test)	D256	5.0 to flexible	Does not break	0.4-20.0	Varies depending on type and amount of plasticizer	
	17. Hardness, Rockwell	D785	10A-90D (Shore)	30A-70D (Shore) M28, R60	65-85 (Shore D)	50-100 (Shore A)	50-100 (Shore A)
	18. Flexural modulus, p.s.i. x 10^5	D790	0.1-1.0	0.3-1.3	—	—	—
	19. Compressive modulus, p.s.i. x 10^5	D695	0.1-1.0	0.04-0.09	—	—	—
Thermal	20. Thermal conductivity, 10^{-4} cal./sec./sq.cm./(°C./cm.)	C177	5.0	1.7-7.4	3.0-7.0	3.0-4.0	3.0-4.0
	21. Specific heat, cal./°C./gm. (RT)	—	0.42-0.44	0.40-0.45	0.2-0.28	0.3-0.5	0.3-0.5
	22. Thermal expansion, 10^{-5}/in./in./°C.	D696	10.0-20.0	10.0-20.0	5.0-18.5	7.0-25.0	—
	23. Resistance to heat, °F. (continuous)	—	190-250	190	150-175	150-175	150-175
	24. Deflection temp., °F. @ 264 p.s.i. fiber stress	D648	Varies over wide range	Varies over wide range	130-175	—	—
	@ 66 p.s.i. fiber stress				135-180	—	—
Electrical	25. Volume resistivity, ohm/cm (50% RH and 23°C.)	D257	2.0×10^{11}-10^{13}	2.0×10^{11}-0.11×10^{16}	$>10^{16}$	10^{11}-10^{13}	10^{11}-10^{14}
	26. Dielectric strength, short-time, ⅛-in. thickness, volts/mil	D149	400-500	330-900	425-1300	300-1000	250-800
	27. Dielectric strength, step-by-step, ⅛-in. thickness, volts/mil	D149	400-500	460	375-750	275-290	225-750
	28. Dielectric constant, 60 cyc.	D150	4.0-7.5	5.4-7.6	3.2-3.6	5.0-9.0	5.0-6.0
	29. Dielectric constant, 10^3 cyc.	D150	4.0-7.5	5.59-7.60	3.0-3.3	4.0-8.0	4.0-5.0
	30. Dielectric constant, 10^6 cyc.	D150	6.5-7.1	4.21-5.10	2.8-3.1	3.3-4.5	3.5-4.5
	31. Dissipation (power) factor, 60 cyc.	D150	0.015-0.017	0.015-0.048	0.007-0.020	0.08-0.15	0.10-0.15
	32. Dissipation (power) factor, 10^3 cyc.	D150	0.050-0.060	0.043-0.060	0.009-0.017	0.07-0.16	0.09-0.16
	33. Dissipation (power) factor, 10^6 cyc.	D150	—	0.050-0.075	0.006-0.019	0.04-0.14	0.09-0.10
	34. Arc resistance, sec.	D495	0.1-0.6	122	60-80	—	—
Optical	35. Refractive index, n_D	D542	1.50-1.60	—	1.52-1.55	—	—
	36. Clarity	—	Clear to opaque	Transparent to opaque colors	Transparent to opaque		
	37. Transmittance, %	—	—	—	—		
	38. Haze, %	—	—	—	—		
Resistance characteristics	39. Water absorp., 24 hr., ¼-in. thick., %	D570	0.02-1.5	0.7-0.9	0.07-0.4	0.15-0.75	0.50-1.0
	40. Burning rate (flammability), in/min.	D635	Slow to self-exting.	Slow to self-extinguishing	Self-exting.	Slow to self-extinguishing	Slow to self-extinguishing
	41. Effect of sunlight	—	None to yellow	None to yellows slightly	—	Slight	—
	42. Effect of weak acids	D543	Slight	Slight to dissolves	None	None	None
	43. Effect of strong acids	D543	Attacked (moderate)	Moderate to dissolves	None to slight	None to slight	None to slight
	44. Effect of weak alkalies	D543	Slight	Slight to dissolves	None	None	None
	45. Effect of strong alkalies	D543	Slight to attacked	Moderate to dissolves	None	None	None
	46. Effect of organic solvents	D543	None to slight	Resists most solvents	Resists alcohols, aliphatic hydrocarbons and oils. Soluble or swells in ketones and esters; swells in aromatic hydrocarbons		

TABLE 5-18. PLASTICS PROPERTIES CHART (Cont'd)

	Vinyl polymers and copolymers				ABS-modified vinyl-chloride		Polypropylene modified vinyl chloride
	Vinylidene chloride molding compounds	Vinyl formal molding compound	Chlorinated polyvinyl chloride compound	Vinyl butyral molding compounds			
				Flexible unfilled	Rigid	Flexible	Rigid
1.	Excellent	Good	Good	Good	Good to excellent		Excellent
2.	220-350	300-350	350-400	280-320	300-350		290-360
3.	250-5000	1000-10000	1500-2000	100-3000	1000-2000		1000-2000
4.	300-400	300-400	375-425	250-340	350-390		330-375
5.	10000-30000	10000-30000	15000-40000	15000-30000	8000-25000		8000-16000
6.	2.0	—	2.0-2.5	—	—		1.7-2.0
7.	0.005-0.025	0.0015-0.0030	0.003-0.007	—	0.004-0.015		0.002-0.005 (Inj.)
8.	1.65-1.72	1.2-1.4	1.49-1.58	1.05	1.10-1.21		1.28-1.58
9.	16.8-16.1	23.0-19.8	18.4-17.8	26.2	—		21.4-18.05
10.	Good	Good to poor	Excellent	—	Good to excellent	—	Excellent
11.	3000-5000	10000-12000	7500-9000	500-3000	5400-6000	2600-3200	5000-8000
12.	Up to 250.0	5.0-20.0	4.5-65.0	150.0-450.0	20.0-100.0	250.0	100.0-140.0
13.	0.5-0.8	3.5-6.0	3.60-4.75	—	3.2	—	3.5-4.5
14.	2000-2700	—	9000-22000	—	—	—	7750-11700
15.	4200-6200	17000-18000	14500-17000	—	7500	—	10000-15400
16.	0.3-1.0	0.8-1.4	1.0-5.6	Varies depending on type and amount of plasticizer	10.0-15.0	—	0.36-32.00
17.	M50-M65	M85	R117-122	10-100 (Shore A)	R102	93 (Shore A)	M18-55 R107-119
18.	—	—	3.8-4.5	—	3.0-3.5	—	3.52-5.04
19.	—	—	3.35-6.00	—	—	—	—
20.	3.0	3.7	3.3	—	—	—	—
21.	6.32	—	0.33	—	—	—	—
22.	19.0	6.4	6.8-7.6	—	—	—	—
23.	160-200	120-150	230	—	—	—	150-175
24.	130-150	150-170	202-234	—	Annealed 154-180	—	150-170
	—	—	215-247	—	169-190	—	
25.	10^{14}-10^{16}	—	10^{16}	5.0×10^{15}	—	—	$>10^{16}$
26.	400-600	490	1220-1500	350	600	—	—
27.	400-600	455	—	325	—	—	335-380
28.	4.5-6.0	3.7	3.08	5.60	—	—	3.1-3.7
29.	3.5-5.0	3.6	2.8-3.6	5.10	—	—	3.1-3.6
30.	3.0-4.0	3.0	3.2-3.6	3.92	—	—	2.8-3.3
31.	0.030-0.045	0.013	0.01887-0.02060	0.115	—	—	0.008-0.010
32.	0.060-0.075	0.019	0.0092-0.0108	0.057	—	—	0.01-0.02
33.	0.05-0.08	0.023	0.020	0.061	—	—	0.01-0.02
34.	—	—	—	—	—	—	—
35.	1.60-1.63	1.50	—	1.47-1.49	—	—	—
36.	Transparent to opaque				—	—	Transp.-opaq.
37.	—	—	—	—	—	—	—
38.	—	—	—	—	—	—	—
39.	0.1	0.5-3.0	0.02-0.15	1.0-2.0	0.20	—	0.07-0.4
40.	Self-exting.	Slow	Non-burning	Slow	Self-exting.	Slow	Self-exting.
41.	Slight	Slight	—	Slight	Slight		—
42.	None	Attacked	None	Slight	None		None
43.	Resistant	Attacked	None	Slight	None to slight		None to slight
44.	Resistant	Resistant	None	Slight	None		None
45.	Resistant	Resistant	None	Slight	None		None
46.	None to slight	Attacked by some	Resists most	Resists aliph. hydro., most oils. Swells in ketones, esters and arom. hydro.: dis. in alcohols	Soluble or swells in ketones or esters		Same as for vinyl chloride

(d) strong alkalies - decomposes
(e) organic solvents - soluble in liquid, ketones and esters of lower alcohols; softened or dissolved by chlorinated hydrocarbons and aromatic hydrocarbons; little affected by aliphatic hydrocarbons.

3. Cellulose Acetate Butyrate (Cellulosic Molding Compounds)

Same as 2 above

4. Polycarbonates

(a) weak acids - none
(b) strong acids - attacked slowly
(c) weak alkalies - limited resistance
(d) strong alkalies - attacked
(e) organic solvents - resistant to paraffinics; soluble in aromatic and chlorinated hydrocarbons

5. Polyethylene

(a) weak acids - resistant
(b) strong acids - attacked by oxidizing acids
(c) weak alkalies - resistant
(d) strong alkalies - resistant
(e) organic solvents - resistant (below $60^{\circ}C$)

6. Polypropylene

(a) weak acids - none
(b) strong acids - attacked slowly by oxidizing acids
(c) weak alkalies - none
(d) strong alkalies - very resistant
(e) organic solvents - resistant (below $80^{\circ}C$)

7. Polystyrene

(a) weak acids - none
(b) strong acids - attacked by oxidizing acids
(c) weak alkalies - none
(d) strong alkalies - none
(e) organic solvents - soluble in aromatic and chlorinated hydrocarbons

8. Styrene - Butadiene Thermoplastic Elastomers

(a) weak acids - none
(b) strong acids - attacked by oxidizing acids

(c) weak alkalies - none
(d) strong alkalies - slight
(e) organic solvents - dissolves

9. Urethanes

(a) weak acids - slight
(b) strong acids - attacked (moderate)
(c) weak alkalies - slight
(d) strong alkalies - slight to attacked
(e) organic solvents - none to slight

10. Vinyl Polymers and Copolymers

(a) weak acids - none to attacked depending on type
(b) strong acids - none to attacked depending on type
(c) weak alkalies - none to slight depending on type
(d) strong alkalies - none to slight depending on type
(e) organic solvents -none to slight and attacked by some depending on type

The effect of exposure of plastics to sunlight is also presented in the enclosed table and is worth examination by manufacturers of eye and face protective equipment.

The effect of different chemicals on eye protectors used for chemical protection should be included with each eye protector and read by the user before he begins to wear the protective equipment.

(5) Susceptibility to Fogging

An attempt was made to examine the susceptibility of glass and plastic lenses to fogging. Since no test method was located, we established a method of producing fog on lenses. Protectors were placed in an upright position in a temperature controlled freezer at 14°F. A plastic bucket with a tight fitting lid and large enough to hold one of the protectors at a time was also placed in the freezer. After two hours one protector was placed in the bucket and the lid secured. The assembly was taken to a temperature and humidity controlled room approximately 10 meters away (walking distance) and removed from the bucket. Immediately after the protector was removed from the bucket, the bucket was returned to the freezer and the process was repeated after five minutes. Exposure of the interior of the freezer to the ambient atmosphere was kept as minimal as possible.

When the protector was removed from the carrying bucket in the temperature and humidity controlled environment, the length of time for

the lens to fog and the length of time after fogging for the lens to defog was recorded. During the defog period spectacles were placed on a flat surface in their upright position, and goggles were suspended by their headband near the edge of one lens such that the front surface of the lens was downward and at approximately 45° (i. e. support was near one temple side of the lens and the other temple side was downward). If defogging of goggles was nonuniform, the protector was reversed from left end downmost to right end downmost or vice versa. A lens was considered as being free of fog when no more than 6. 4 mm (1/4") fog bordered the edge of the lens.

Table 5-19 shows the results of this fog test. The fog time was much too rapid for meaningful conclusions and the defog time did not seem to depend on whether the lens was plastic or glass, but seemed to depend more on the thickness of the lens. Glass lens surfaces appeared to have a tendency of getting wetter than plastic lens surfaces during the test. All in all, this type of procedure does not appear to establish the relative fog resistance of glass and plastic lenses.

Luminous transmittance and/or haze measurements of the fogged lenses was considered but deemed impracticable since the same environmental exposure of each lens would be irreproducible unless extreme care was taken. No useful results were expected for the effort involved, so this attempt was not made.

TABLE 5-19. FOG TEST

Test Parameters: Protectors in freezer @ 14°F for >2 hours & then exposed to controlled environment.

SwRI Code #	Description	Temp.	Humidity	Fog time(sec)	Defog time(sec)	Comments
AA H-6	spectacles, glass lenses ~3.1 mm (0.124") thick	72°F	52%	< 1	600	could barely see through fogged lenses, lenses were wet
BB A-5	spectacles, plastic lenses ~3.2 mm (0.125" thick)	72°F	50%	< 1	532	could barely see through fogged lenses
MM H-6	spectacles, glass lenses ~2.7 mm (0.108") thick	73°F	50%	< 1	860	could barely see through fogged lenses, lenses very wet
MM I-1	spectacles, plastic lenses ~2.6 mm (0.102") thick	72°F	53%	< 1	580	could barely see through fogged lenses
AA B-3	flex. dust & splash goggle, vinyl lens ~1.6 mm (.062") thick	76°F	49%	< 1	265	could barely see through fogged lens
AA F-1	chipper's goggle, glass lenses ~2.8 mm (0.109") thick	72°F	53%	< 1	510	could barely see through fogged lenses, lenses very wet
DD A-3	flex. dust & splash goggle, polycarbonate lens ~1.5 mm (0.059") thick	76°F	49%	< 1	261	could barely see through fogged lens
FF B-6	flex. dust & splash goggle, polycarbonate lens ~1.6 mm (0.064") thick	76°F	49%	< 1	300	could barely see through fogged lens
MM C-2	flex. dust & splash goggle, plastic non-fog double lenses ~5.1 mm (0.200") thick	76°F	51%	< 1	480	could barely see through fogged lenses
NN E-1	flex. dust & splash goggle, plastic fog-ban double lenses ~5.7 mm (0.223") thick	76°F	51%	< 1	570	could barely see through fogged lenses

LIST OF REFERENCES

5-1. Newton, A. W., Industrial Eye Protection - An Appraisal of Some Current Safety Lens Materials, J. Inst. Eng. Australia, 39(9): 163-170, 1967.

5-2. Wigglesworth, E. C., Evaluation of Eye Protector Lens Materials, Australian J. Optom., 50(12): 343-352, 1967.

5-3. Wigglesworth, E. C., "The Impact Resistance of Eye Protector Materials", American Journal of Optometry and Archives of American Academy of Optometry, March, 1971.

5-4. Silberstein, Irwin W., The fracture resistance of industrially damaged safety glass lenses, plano and prescription - an expanded study, American Journal of Optometry and Archives of American Academy of Optometry, 41 (4): 199-221, 1964.

5-5. Wigglesworth, E. C., "A Comparative Assessment of Eye Protective Devices and a Proposed System of Acceptance Testing and Grading", American Journal of Optometry and Archives of American Academy of Optometry, 49 (4): April 1972.

5-6. Howsam, K. G., Localization of Ocular Foreign Bodies: Removal of Difficult Foreign Bodies. Trans. Ophth. Soc. Australia 24: 27-39, 1965.

TASK 6 - EVALUATION OF CURRENT STANDARDS AND SPECIFICATIONS DERIVATIONS

The following items have been performed under this task:

(1) Assessment of the Origin of and the Rationale Behind the Table I, Filter Transmittance Standard for Optical Radiation, USAS Z87. 1.

(2) Evaluation of the Optical Standards of Z87. 1

(3) Measurements Related to Physical Optics

(4) Physical Testing Apparatus for Z87. 1

(5) Examination of Various Tests in Z87. 1

(1) Assessment of Z87. 1, Table I, Filter Transmittance Standard for Optical Radiation

The present manufacturing standard for filter transmittance as contained in Z87. 1 is shown in Table 6-1. Selection of an appropriate filter shade number (left-hand column) is empirically related to the welding/cutting process, electrode diameter and/or arc amperage, c.f., ANSI Z49. 1 - Safety in Welding and Cutting, The Accident Prevention Manual for Industrial Applications, Welding Handbook and Task 4 of this report. Idealistically, these transmittance values (luminous, ultraviolet and infrared) should be based on scientifically determined ocular Threshold Limit Values. Realistically, however, this is not the case. The transmittances in this table were developed empirically[6-1] and have remained essentially unchanged since they were generated by Coblentz and Stair, et al., at the Bureau of Standards. The luminous transmittance, optical density and filter shade system for the majority of the filters in this table first appeared in a 1928 Bureau of Standards publication [6-2] in which the optical density was related to shade number by

$$SN = 3D + 1 \quad \text{and} \quad D = -\log_{10} LTF_{STD}$$

where SN is the shade number, D is the optical density of the filter medium and LTF_{STD} is the standard luminous transmittance factor.

TABLE 6-1. TRANSMITTANCES AND TOLERANCES IN TRANSMITTANCE OF VARIOUS SHADES OF ABSORPTIVE LENSES, FILTER LENSES, AND PLATES

Shade Number	Optical Density			Luminous Transmittance			Maximum Infrared Transmittance	Maximum Spectral Transmittance in the Ultraviolet and Violet for Four Wavelengths (millimicrons) (or nanometers)*			
	Maximum	Standard	Minimum	Maximum	Standard	Minimum		313 mu	334 mu	365 mu	405 mu
				Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1.5	0.26	0.214	0.17	67	61.5	55	25	0.2	0.8	25	65
1.7	0.36	0.300	0.26	55	50.1	43	20	0.2	0.7	20	50
2.0	0.54	0.429	0.36	43	37.3	29	15	0.2	0.5	14	35
2.5	0.75	0.643	0.54	29	22.8	18.0	12	0.2	0.3	5	15
3.0	1.07	0.857	0.75	18.0	13.9	8.50	9.0	0.2	0.2	0.5	6
4.0	1.50	1.286	1.07	8.50	5.18	3.16	5.0	0.2	0.2	0.5	1.0
5.0	1.93	1.714	1.50	3.16	1.93	1.18	2.5	0.2	0.2	0.2	0.5
6.0	2.36	2.143	1.93	1.18	0.72	0.44	1.5	0.1	0.1	0.1	0.5
7.0	2.79	2.571	2.36	0.44	0.27	0.164	1.3	0.1	0.1	0.1	0.5
8.0	3.21	3.000	2.79	0.164	0.100	0.061	1.0	0.1	0.1	0.1	0.5
9.0	3.64	3.429	3.21	0.061	0.037	0.023	0.8	0.1	0.1	0.1	0.5
10.0	4.07	3.857	3.64	0.023	0.0139	0.0085	0.6	0.1	0.1	0.1	0.5
11.0	4.50	4.286	4.07	0.0085	0.0052	0.0032	0.5	0.05	0.05	0.05	0.1
12.0	4.93	4.714	4.50	0.0032	0.0019	0.0012	0.5	0.05	0.05	0.05	0.1
13.0	5.36	5.143	4.93	0.0012	0.00072	0.00044	0.4	0.05	0.05	0.05	0.1
14.0	5.79	5.571	5.36	0.00044	0.00027	0.00016	0.3	0.05	0.05	0.05	0.1

*1 mu = 1 nm.

Permissible UV and IR transmittances also appeared for the first time in that 1928 publication. Two years later[6-3], the optical density relationship was modified to read

$$SN = \frac{7}{3} D + 1$$

and uniform tolerances on optical density (± 0.214) were adopted. In 1938, Coblentz and Stair published NBS Circular 421[6-1] which contained specifications for additional filter shade numbers. The original 1928 specifications were carried over verbatim into NBS Circular 421. In 1948, this table was republished in NBS Circular 471[6-5]. Selected transmittances were modified slightly in the fourth and fifth decimal places, e.g., standard luminous transmittance factor (LTF) for shade number 14 was changed from 0.0003 to 0.00027 percent. Optical density tolerances also underwent minor modification. In its present form, Table I of Z87.1 is identical to the table that was presented in NBS Circular 471. Therefore, without loss of generality, we conclude that the filter transmittance specifications that are in existence today were set by Coblentz and Stair in 1928. The entire table to the left of the maximum IR transmittance is defined by the two equations given above.

Earlier it was stated that the filter transmittance table was empirical and was based on experience. The rationale for the initial specification was contained in a recent communication with Ralph Stair[6-6].

> "At that time we had no medical information, except that a lot of welders had received great injury from ultraviolet, and possibly infrared. We, therefore, set the ultraviolet and infrared values as low as practicable for the manufacture of the glass and for certification by our laboratory that it met the standards we had set up. Maybe that does not sound too scientific in this day, but we had no other guide. The range of shades from No. 1.5 to No. 14 will cover the requirements of most individuals for 'Best Seeing' with all sources from the weakest available to above 3000 degrees. In our papers and in the Federal Specifications there are suggestions that certain shades are 'intended' for certain operations. But the final answer rests with the operator to choose the proper shade for 'Best Seeing'. Hence all source strengths were included in covering the range from shade 1.5 to 14. Although the infrared values were arrived at in a rather unscientific manner, it still appears that they are rational—possibly set at much lower values than necessary, at least for most sources. Since the human eye had its origin in sunlight in the remote past we have used sunlight as sort of a standard in deciding reasonable tolerances. Hence, our decision for setting these ultraviolet

tolerances below that for sunlight, but high enough to measure and certify does have some real sense."

This commentary corroborates the observations of Sliney[6-1] that when the recommended filter is used for a given process (within selection limits), retinal and corneal hazards are effectively eliminated.

(2) Evaluation of the Optical Standards of Z87.1

General

The function of this task is to evaluate the current standard (Z87.1) in terms of its basis of derivation and applicability to eye and face protection. The standard requires a number of optical tests for certain characteristics of the eye and face protective devices some of which are delineated in detail in terms of procedure and some of which are not. The standard gives specific instructions on how the luminous transmission test, the UV transmission test, the haze test, etc. are to be run, for instance; but no specific instructions are given for measurement of lens defects, lens curvature, etc. Some tests which are described in detail, such as the test for prism effects in lenses, are nonetheless not detailed enough in covering some specifics (such as how a lens with curvature should be mounted in front of the telescope objective for the prism test, an important feature of the test!).

In the following discussion of the optical tests and standards of Z87.1, we will limit ourselves to the specific tests and standards delineated in detail in Z87.1, and we will discuss suggested added tests for those situations not covered in detail in Z87.1 under Task 8. Furthermore, the lens prism and refraction tests and standards will be discussed under Task 7, where they properly belong.

In order to make the evaluations of Task 6 in terms of the optical tests and standards, we have concentrated on setting up the test apparatus as described in Z87.1 (for the tests which are delineated in some detail), and performing these tests on lenses from various manufacturing sources. The following section will describe how we have performed these tests (i.e., test system setup), and present some of the data taken on lenses (the data are limited in quantity in some cases because we are still getting more samples from manufacturers to test). We will describe problems and suggested improvements on these tests resulting from our experience in performing them.

Optical Tests for Z87.1

Measurements Related to Radiant Energy

In this area, Z87.1 requires two broad types of measurement, integrated-spectral measurements over some specified wave-

length band and spectral measurements at some specific wavelength. Among the first type of test is the luminous transmittance test (6.3.4.6.2), the IR transmittance test (6.3.4.6.3), and the haze test (6.3.4.4). Among the second type of test is the UV transmittance test (6.3.4.6.1), an alternate suggested way to perform the luminous transmittance test (6.3.4.6.2., par. 3), and an alternate for the IR transmittance test (6.3.4.6.3, par.1).

Figure 6-1 shows the test setups used to perform the integrated spectral measurements of the Z87.1 tests. The luminous transmittance measurements were made with a telephotometer with digital readout corrected for the photopic sensitivity of the eye (Gamma Scientific Model IC-2-001 and Spectra Physics Pritchard Model 1970-R). These are integrated-spectral measurements in the visible range $400 \leq \lambda \leq 800$ nm. The light source was a No. T-8 projection lamp (tungsten filament) operated at a color temperature of 2854°K as described in the Z87.1, section 6.3.4.6.2. Suggested improvements on this test are described in the following section.

The IR transmittance measurements (Z87.1 - 6.3.4.6.3, par.2) were made with the apparatus shown in Figure 6-1, where the thermopile is the 14-junction copper-bismuth Eppley thermopile described under Task 4 (calibration traceable to the NBS), and the IR pass filter passes wavelengths of 800 nm and above (Rolyn Optics 65.1395). The output of the thermopile was measured with a precision potentiometer (Leeds & Northrup Model 8662). Suggested improvements on this test are described in the following section.

The haze measurements (Z87.1 - 6.3.3.4, and Appendix A1) were made with the apparatus also shown in Figure 6-1 (some changes were made later and are discussed in Task 8). The detector was a photopic corrected PIN photodiode (UDT-PIN-10) with the current-to-voltage converter described under Task 4. The output of this system was read with a digital voltmeter.

Spectral transmittance measurements for the UV, visible, and IR ranges were made with the test setups shown in the line diagrams of Figures 4-7 , 4-8, and 4-10 of Task 4. The filters under investigation were inserted between the tungsten light source and the monochromator in the case of the visible and IR transmission data, and between the Hg light source and the monochromator for the UV data. Figure 6-2 shows the test setup for the visible transmittance. To obtain the luminous transmittance from the visible transmittance curves each point must be multiplied by the point at a corresponding wavelength of the photopic curve. Figure 6-3 shows the test setup for measuring the UV transmittance at the discrete wavelengths required by Z87.1 (i.e., 313, 334, 365, and 405 nm). Figures 6-4 through 6-14 show the visible transmittance plots for typical welders filter plates (see Table 6-2). Suggested improvements in the spectral measurements are given below.

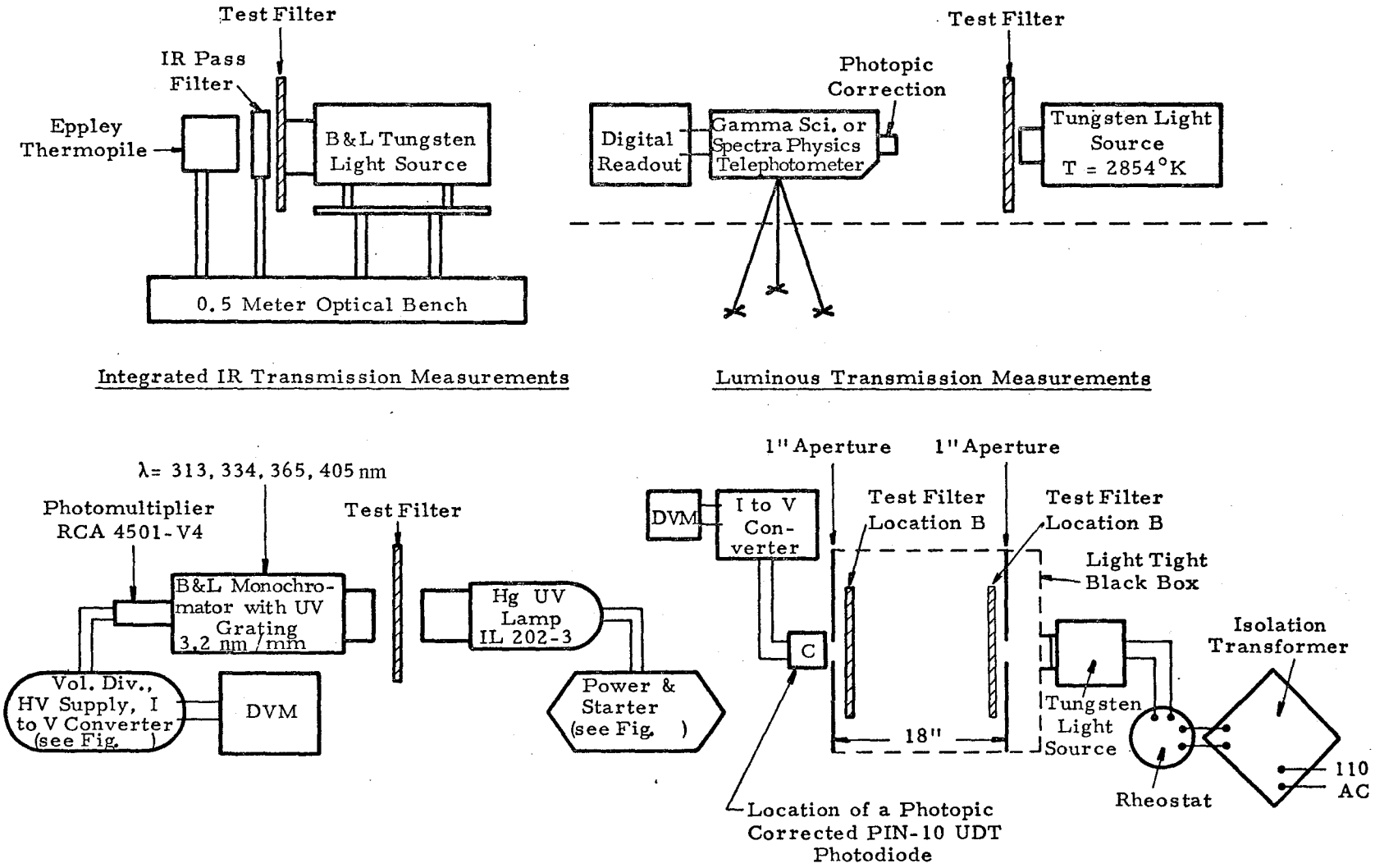

FIGURE 6-1. RADIANT MEASUREMENTS FOR Z87: TEST SETUPS

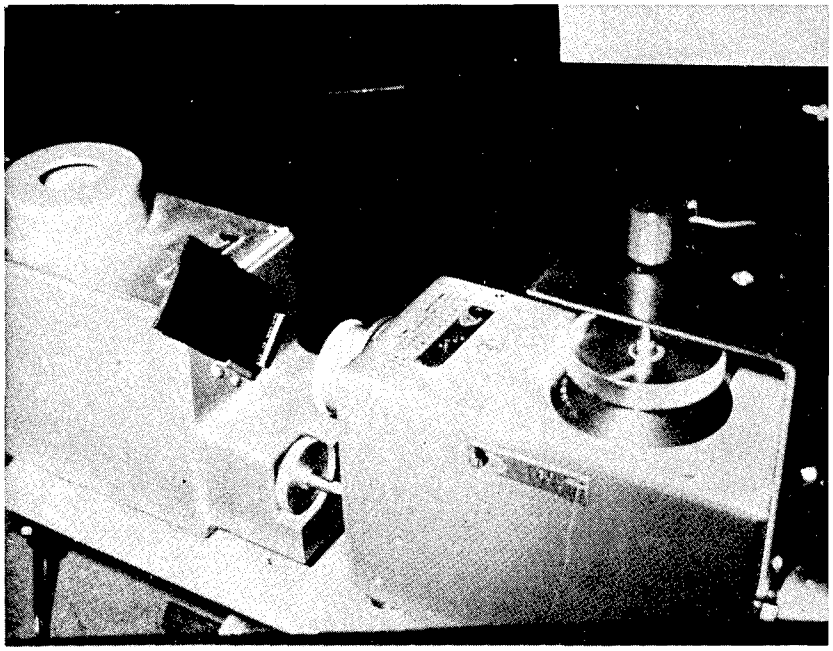

FIGURE 6-2. VISIBLE TRANSMITTANCE APPARATUS

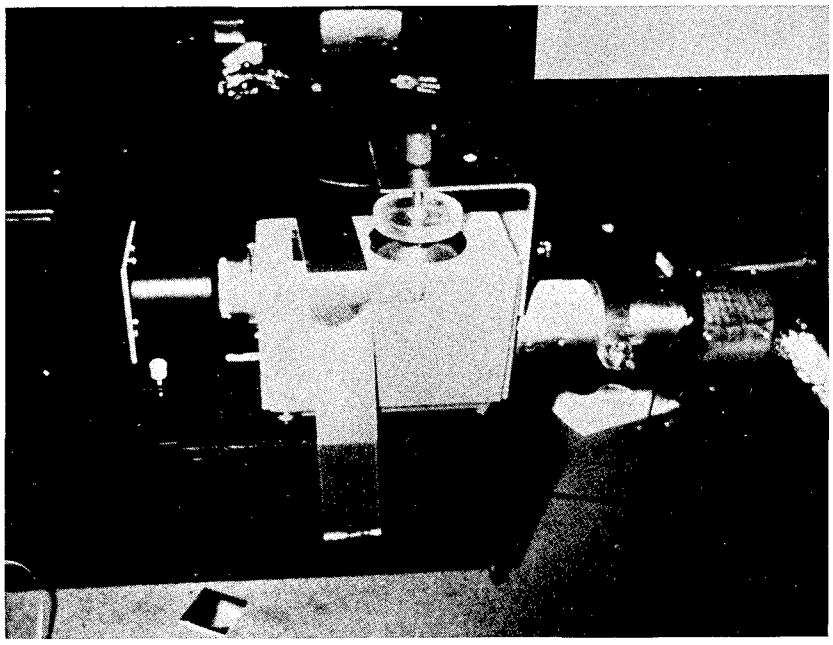

FIGURE 6-3. UV TRANSMITTANCE APPARATUS

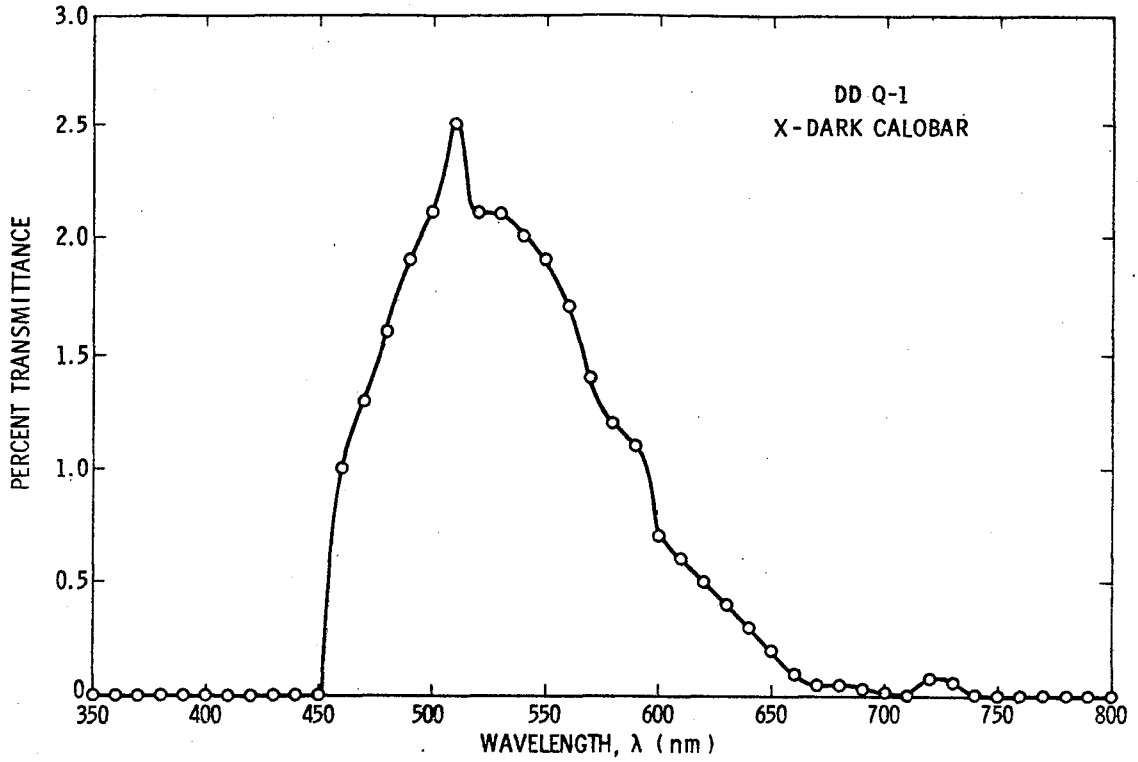

FIGURE 6-4. TRANSMITTANCE VERSUS WAVELENGTH

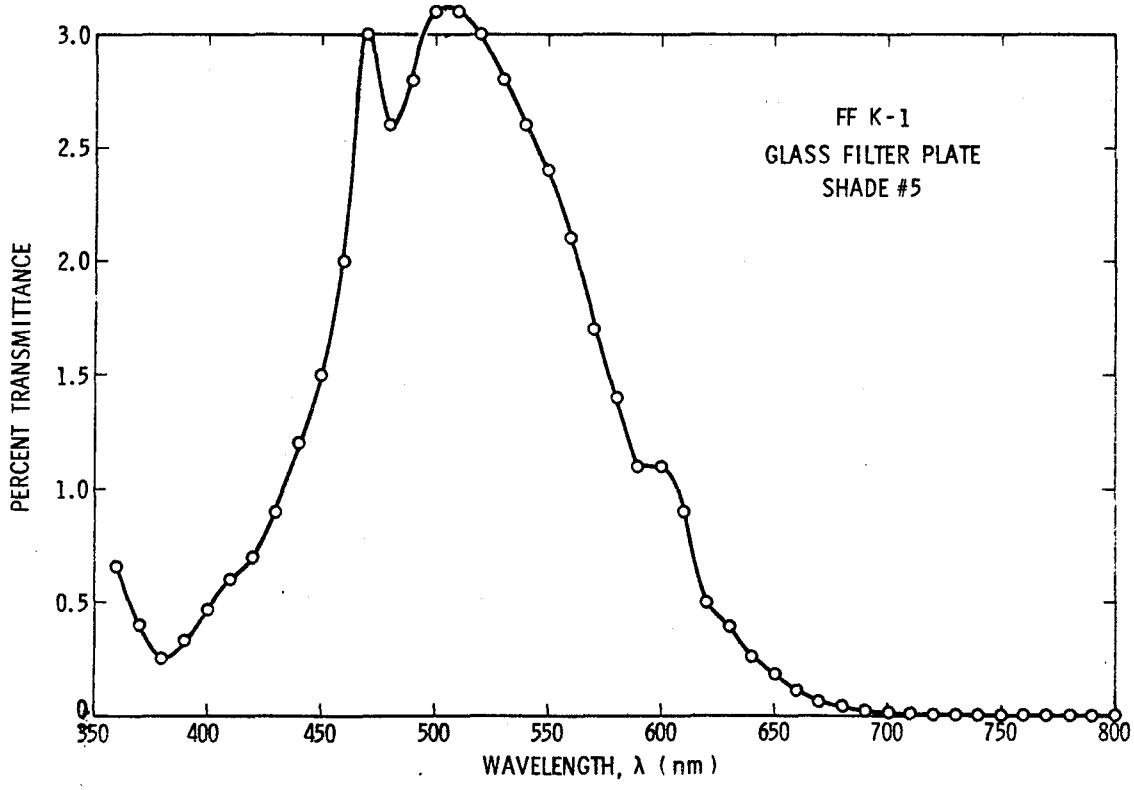

FIGURE 6-5. TRANSMITTANCE VERSUS WAVELENGTH

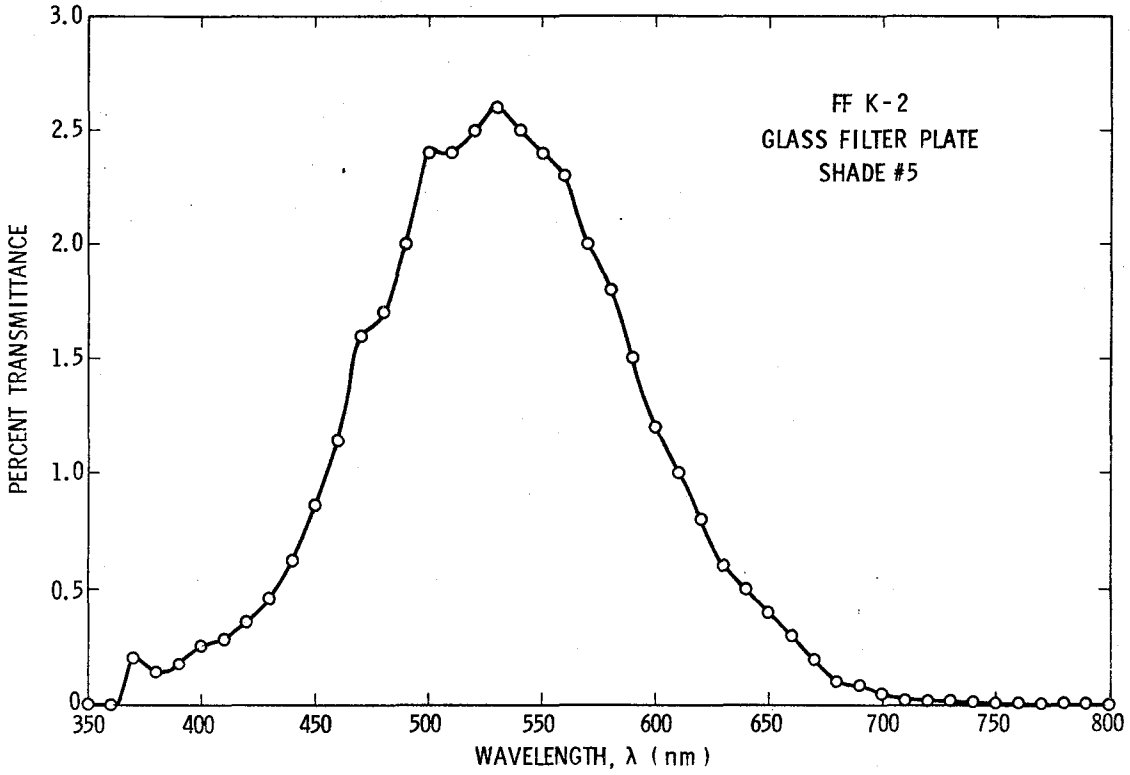

FIGURE 6-6. TRANSMITTANCE VERSUS WAVELENGTH

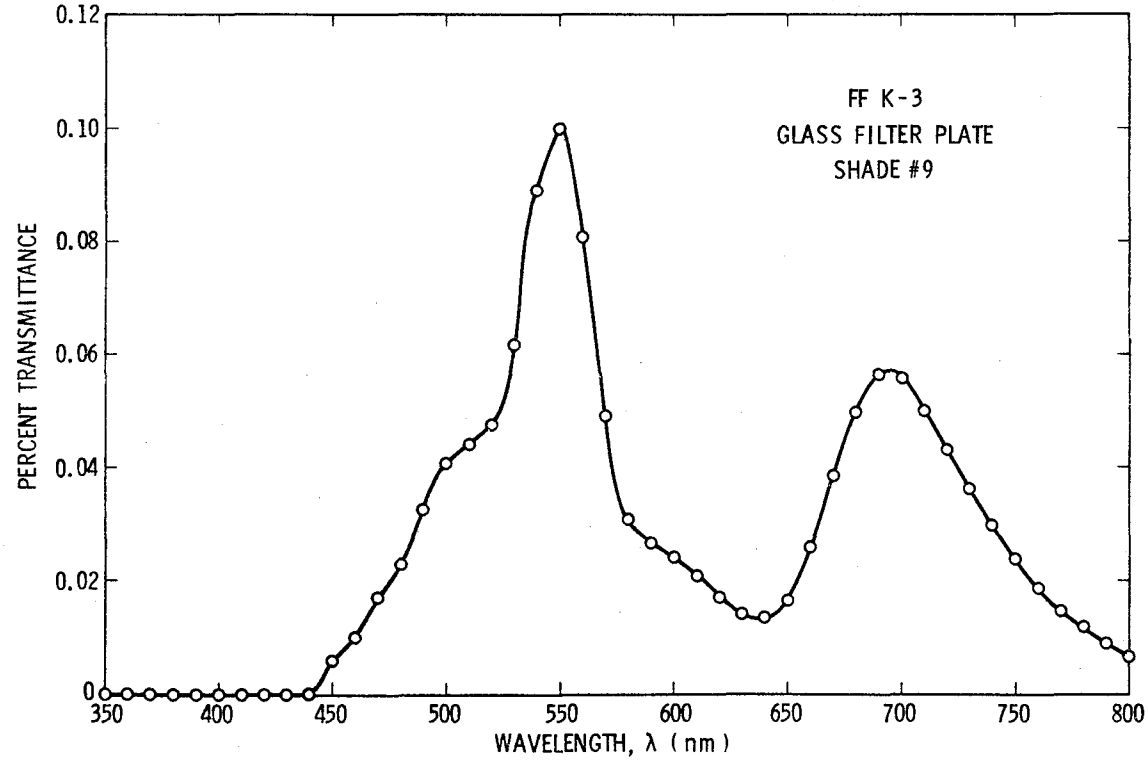

FIGURE 6-7. TRANSMITTANCE VERSUS WAVELENGTH

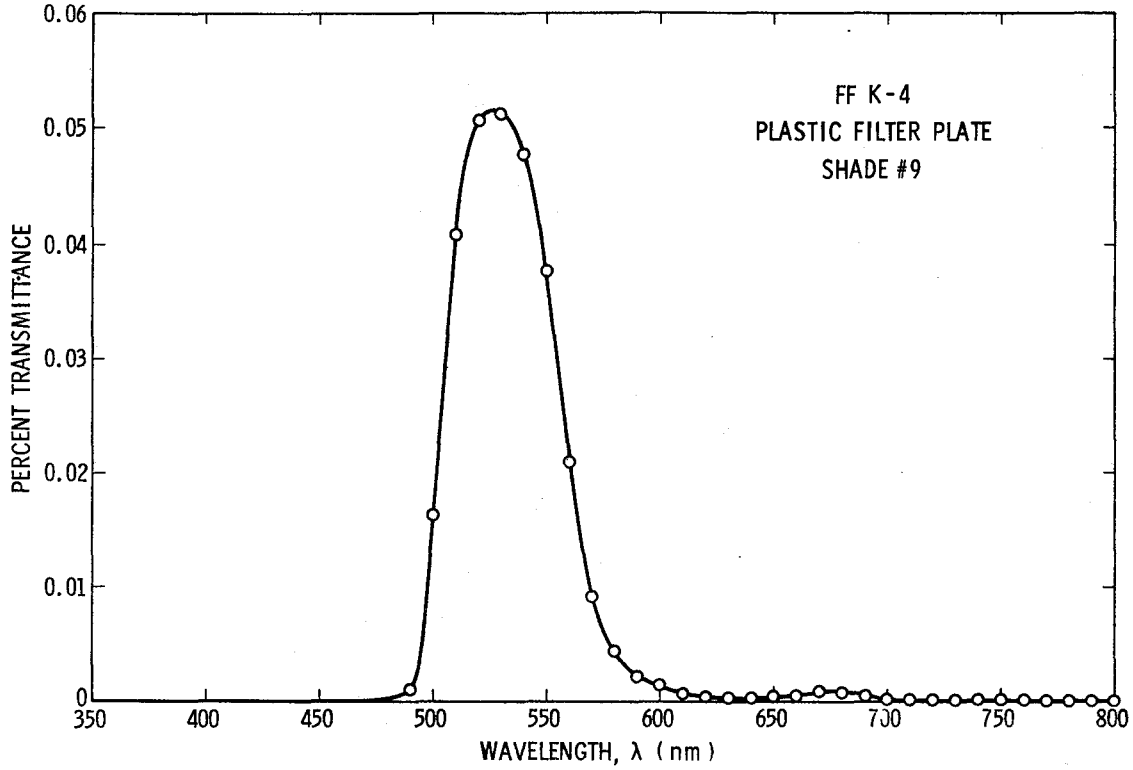

FIGURE 6-8. TRANSMITTANCE VERSUS WAVELENGTH

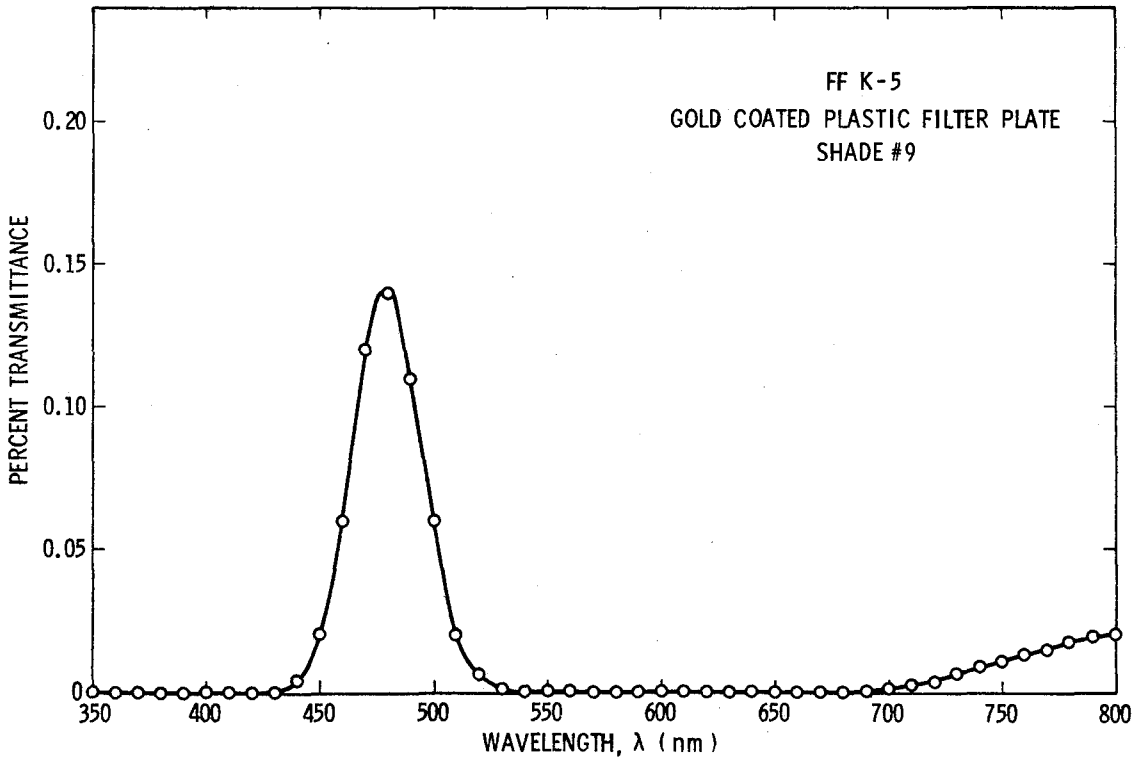

FIGURE 6-9. TRANSMITTANCE VERSUS WAVELENGTH

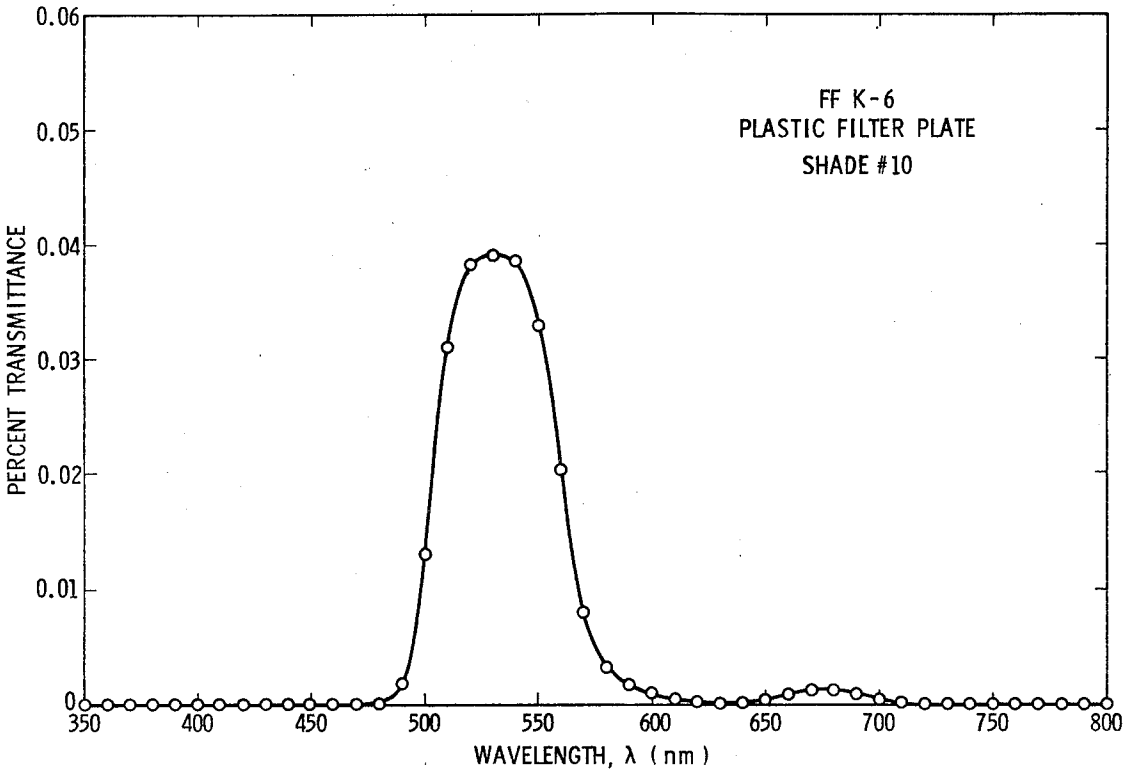

FIGURE 6-10. TRANSMITTANCE VERSUS WAVELENGTH

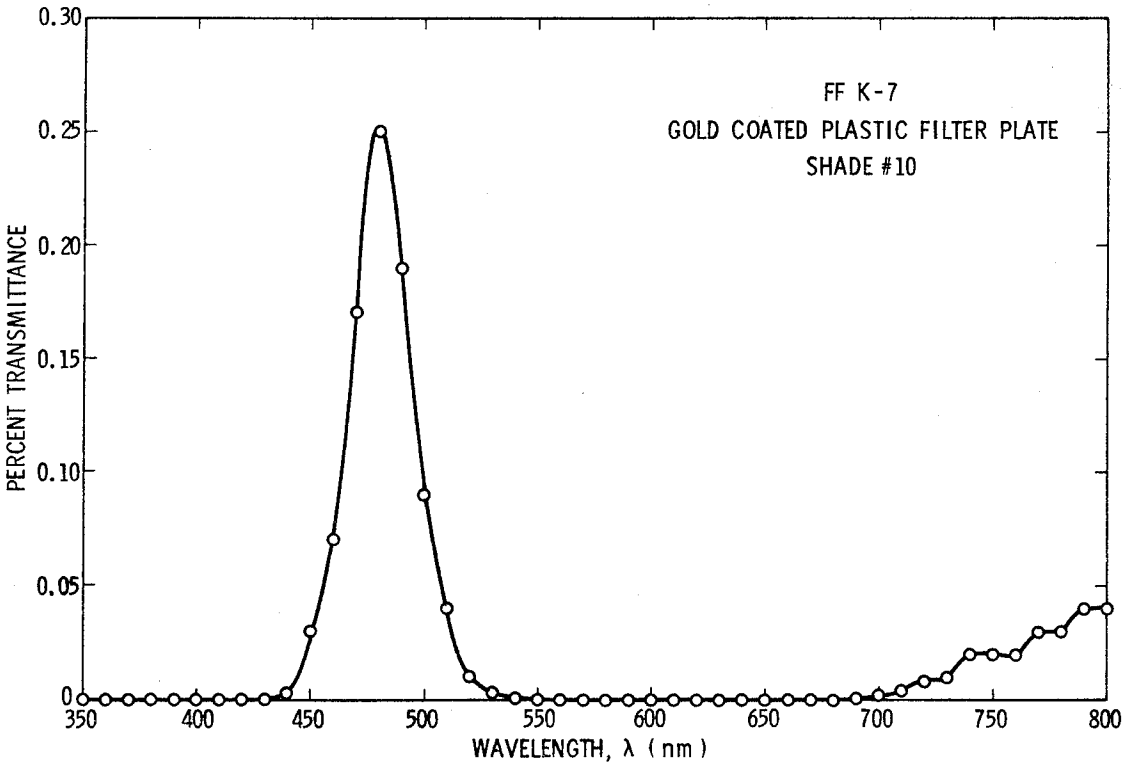

FIGURE 6-11. TRANSMITTANCE VERSUS WAVELENGTH

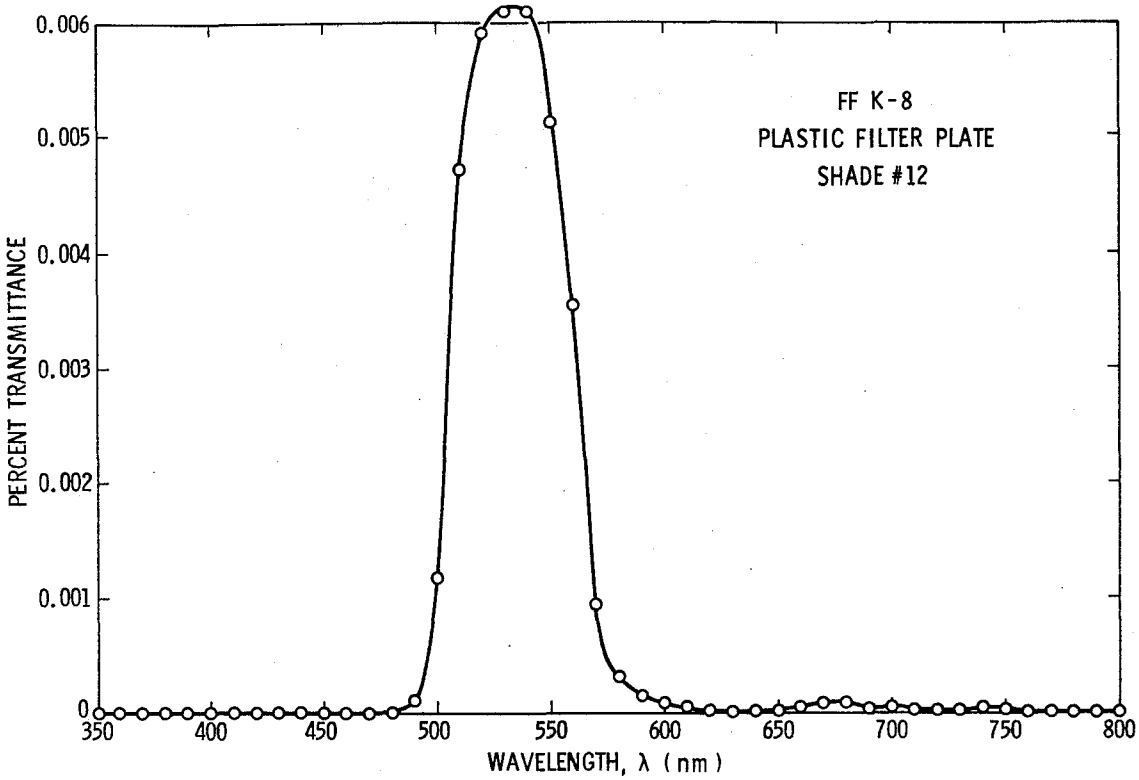

FIGURE 6-12. TRANSMITTANCE VERSUS WAVELENGTH

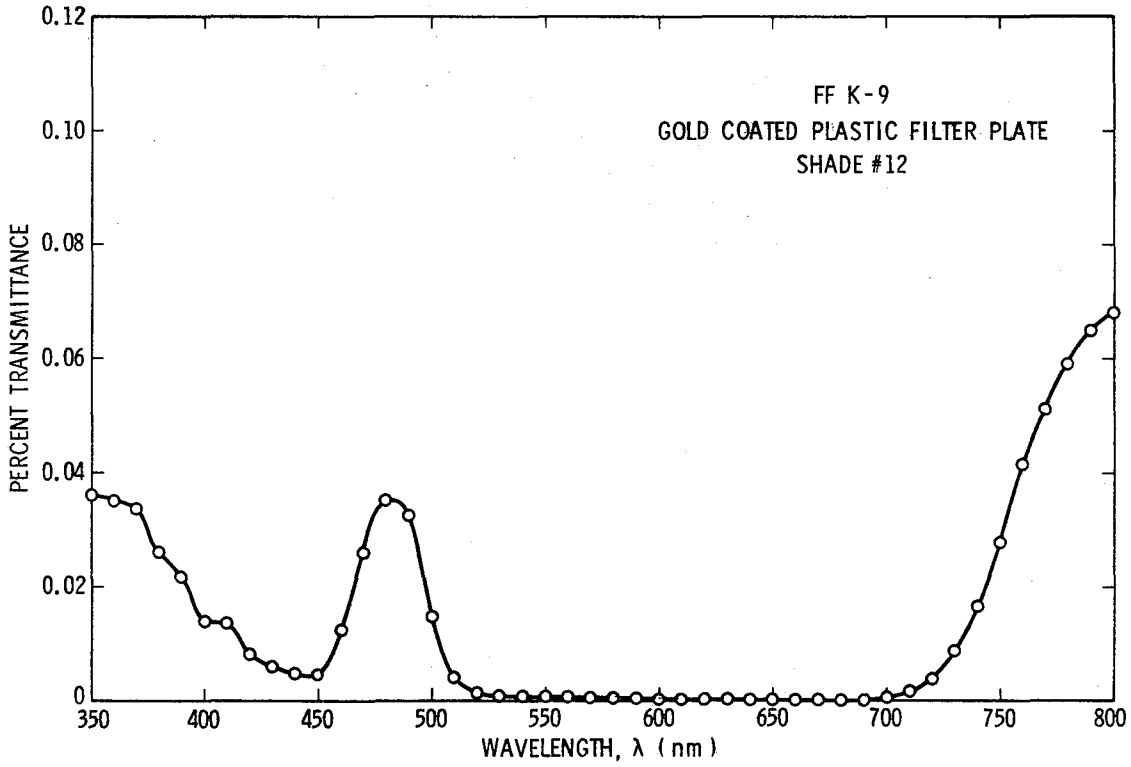

FIGURE 6-13. TRANSMITTANCE VERSUS WAVELENGTH

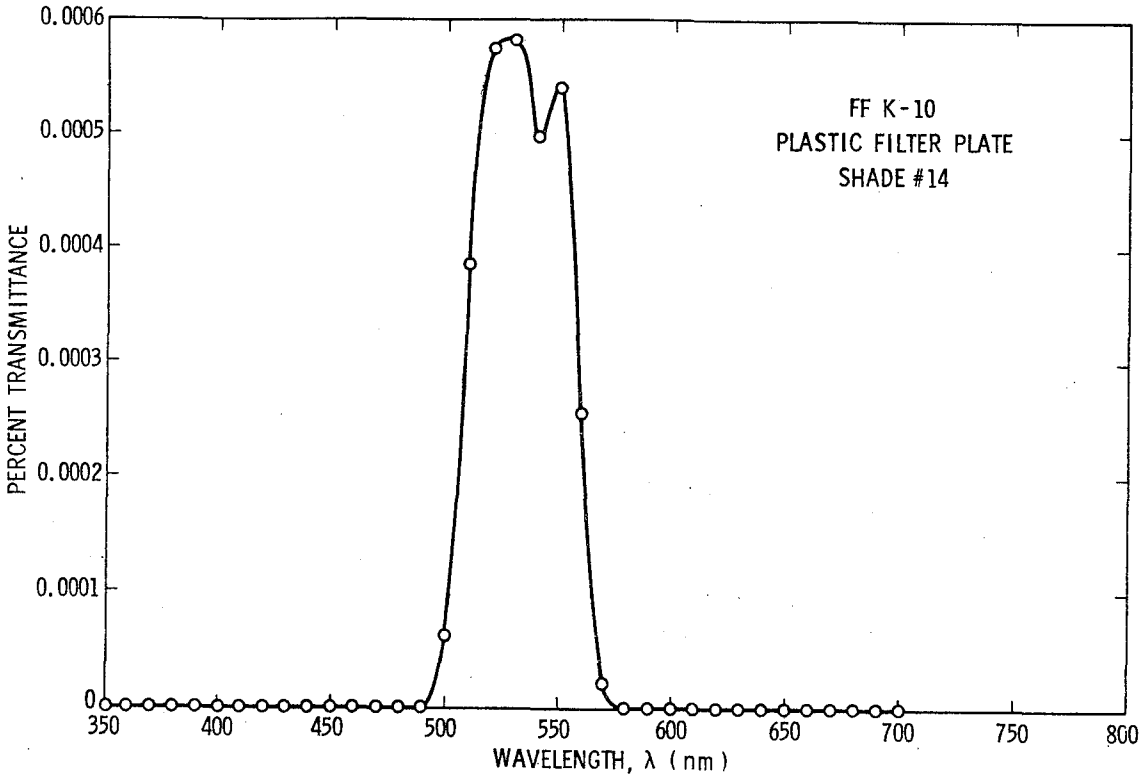

FIGURE 6-14. TRANSMITTANCE VERSUS WAVELENGTH

TABLE 6-2. LIST OF FILTER PLATES USED FOR VISIBLE SPECTRAL TRANSMITTANCE MEASUREMENTS

SwRI Code No.	Description
DD Q-1	X-Dark Caolbar filter plate
FF K-1	Glass filter plate, shade #5
FF K-2	Glass filter plate, shade #5
FF K-3	Glass filter plate, shade #9
FF K-4	Plastic filter plate, shade #9
FF K-5	Gold coated plastic filter plate, shade #9
FF K-6	Plastic filter plate, shade #10
FF K-7	Gold coated plastic filter plate, shade #10
FF K-8	Plastic filter plate, shade #12
FF K-9	Gold coated plastic filter plate, shade #12
FF K-10	Plastic filter plate, shade #14

Evaluations of Tests Related to Radiant Energy

After performing the various tests described in Z87.1, requiring radiant energy measurements, the following evaluations may be made:

Luminous Transmittance Test (6.3.4.6.2)

The standard says nothing about lens homogeneity. Thus, a lens or filter plate which meets the standard for a given luminous transmittance at one point on the lens may have significant different luminous transmittance at another point. Lens inhomogeneity with regard to luminous transmittance would be especially important where the transmittance lies considerably above or below the "standard" value of Z87.1 Table 1, for a given shade number but nonetheless within the tolerances stated in that table for at least one point on the lens.

The standard does not specify a cleaning technique for the lenses before transmittance measurements. For high shade numbers where the transmitted luminous flux density is low, we found significant error could be introduced into the luminous transmittance measurement if "foreign" substances (finger prints, etc.) were on the lens.

Lenses with a high shade number (optical density) tended to absorb so much radiant energy that they heated up during the test. For the case of plastic filter plates this caused near melting and a possible change in the filter's characteristics.

The location of detector, filter, and light source relative to one another is important for transmittance measurements because of the difference between direct transmittance and total transmittance. This location for the luminous transmittance measurements is not specified in Z87.1.

The signal-to-noise level (S/N) for the detection system used in the luminous transmission measurement is not specified in Z87.1. Thus, for measurements on high shade number filters, the dark current noise of the detector or detection system used could be a significant percent of the luminous transmittance measurement with the filter in place. This was not the case in our test setup because we used a telephotometer with a photomultiplier tube having an extremely low dark current. Other systems might not have that characteristic.

The specification of the S/N level is even more important when the luminous transmittance is measured spectrally, especially for high shade number filters. In this case the spectral measurements

at any given center wavelength and wavelength band are being made on irradiance levels that are considerably less than those measured with a spectral-integrating device such as a photopically corrected thermopile or photometer. The dark current of the detector becomes more significant when measuring these lower irradiance levels.

IR Transmittance Test (6.3.4.6.3)

The IR transmittance test should specify lens homogeneity, cleaning procedure, temperature; the geometry of the test setup; and the minimum acceptable S/N just as in the case for the luminous measurements.

The IR transmittance measurement will be affected by the filter characteristic of the IR pass filter used. An acceptable filter characteristic and tolerances should be specified rather than simply suggesting some manufacturer's particular filter (the Corning 2404 is suggested in Z87.1).

The IR transmittance test is essentially a null test, i.e., it proves that a given eye protective lens or filter does not pass more than a certain percentage of IR but it does not require that the experimenter necessarily measure what percentage of IR the lens actually does pass. In this kind of null experiment, where one is proving what the lens or filter does not do, measuring low signal levels (i.e., low irradiance received by the detector), is inherent in the experimental design. Thus, the S/N ratio of the measuring apparatus is particularly significant for these measurements.*

Haze Test (6.3.4.4, and Appendix A1)

There is a conflict in Z87.1 between paragraph 6.3.4.4, which states that "Plastic lenses of all types" should be tested for haze, and Appendix A1, which describes the haze test and which states "test specimens shall be 2 inches in diameter minimum... the surfaces... shall be substantially flat and parallel." Not all types of plastic lenses are either a minimum of 2 inches in diameter nor do they all have flat and parallel surfaces. The haze test as described in Appendix A1 is not suitable for lenses which have correction and probably not suitable for lenses with curvature. This conflict in the test specifications should be resolved.

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*If the S/N ratio is less than 3×10^{-2} times the signal measured without the test lens in place, then the spectral-integrated IR transmittance test would not be valid by the present Z87.1 Standard (Table 6-1) for Shade Number 14, for instance.

The haze test described in Appendix A1 requires an instrument manufactured by one manufacturer (Weston Photronic, cell Type I or II). The aperture, dimensions, and light source to detector dimension given for this test are based on the diameter of the sensing area of this particular detector. What is important in the haze test, however, is the ratio of scattered radiation transmitted through the test filter to the total radiation transmitted. This ratio may be obtained from measurements made from detectors with any diameter sensing surface so long as a particular solid angle is specified as the standard one subtended by the detector at the light source location. Aperture sizes should be adjusted to the detector diameter for this test. The haze test as described should, therefore, be expressed in terms more cogent to the lens property being measured and a wider selection of test apparatus be allowed where they meet specifications.

Cleaning specifications for test lenses are of obvious importance in a haze test as in the minimum S/N ratio of the test apparatus. One of the inherent assumptions of the haze test as described in Appendix A1 of Z87.1 is that radiation scattered in transmittance through the test lenses has an equal probability of scattering for any given angle of scatter with the normal to the lens (i.e., axial symmetry of scatter). This would not necessarily be so for inhomogeneous lenses. No tolerances are put on lens homogeneity by Z87.1 for this test.

UV Spectral Test (6.3.4.6.1)

In general, all the spectral tests suggested or required by Z87.1 could be improved as described previously.

Since the UV action spectra extends continuously through the UV region, 200 nm and above, it seems clear that these tests required measurements at the major UV lines of an Hg arc source purely for convenience (Hg sources are readily available). A better test would be made using a deuterium light source, which has a continuous output in the UV range of interest, and measuring the UV spectral transmittance continuously with wavelength. This type of data would be necessary to assure that filters would be applicable in reducing arc emissions below the TLV for UV damage to the eye. The test setup and methods used for obtaining such data are not much more complex than the present Z87.1 requirements.

(3) Measurements Related to Physical Optics

The tests required for measurement of the refraction and prismatic power of lenses are delineated in detail in Z87.1 but are discussed under Task 7. Other tests related to the physical optics properties of

lenses are not described at all by Z87.1, i.e., there is no test procedure for measurement of lens curvature, lens defects, lens size, etc. Test procedures for these characteristics is suggested in the discussion of Task 8.

(4) Physical Testing Apparatus for Z87.1

Although all of the apparatus has been constructed to perform the Z87.1 tests, photographs of selected pieces of apparatus are shown.

The drop ball test (Figure 6-15) is comprised of an electromagnetic device insulated from the steel ball to reduce residual magnetism in the ball when it is being dropped. The electromagnet was made by modifying a solenoid and carving out the end of a solenoid with a curved surface. The electromagnet is controlled by normally opened push-button. Additional apparatus are:

- Drop Ball Test - Filter Plate Holder (Figure 6-16)
- Drop Ball Test - Circular Cover Plate Holder (Figure 6-17)
- Drop Ball Test - Spectacle Lens Support Anvil with 40 Durometer Rubber Around the Outside Rim of the Recessed Lens Cavity (Figure 6-18)

It is important to note that many suppliers of neoprene rubber will ship orders stating that it is 40 durometer when in actual practice it is not 40 durometer. For example, we had to return approximately 6 shipments of neoprene rubber in which the supplier claimed that it was 40 durometer; however, when it was actually tested with a durometer, the rubber turned out to be either 50 or 60 durometer.

The face shield penetration test support (Figure 6-19) shows a spear consisting of a specified Singer sewing needle mounted in a phenolic stabilization shaft of specified weight. The stabilization guide is a stainless steel tube. The internal diameter of the guide tube is such that it will not effectively alter the normal free-fall impact velocity of the spear.

Figure 6-20 shows the heat deformation test support for the welder's cup goggle. When the test was actually performed, a wire was used to hold the goggle in place instead of the beaded eyecup holder shown in Figure 6-20.

(5) Examination of Various Tests in Z87.1

Many tests in Z87.1 or similar tests can be found in previous standards. The "American Standard Safety Code for the Protection of Heads, Eyes, and

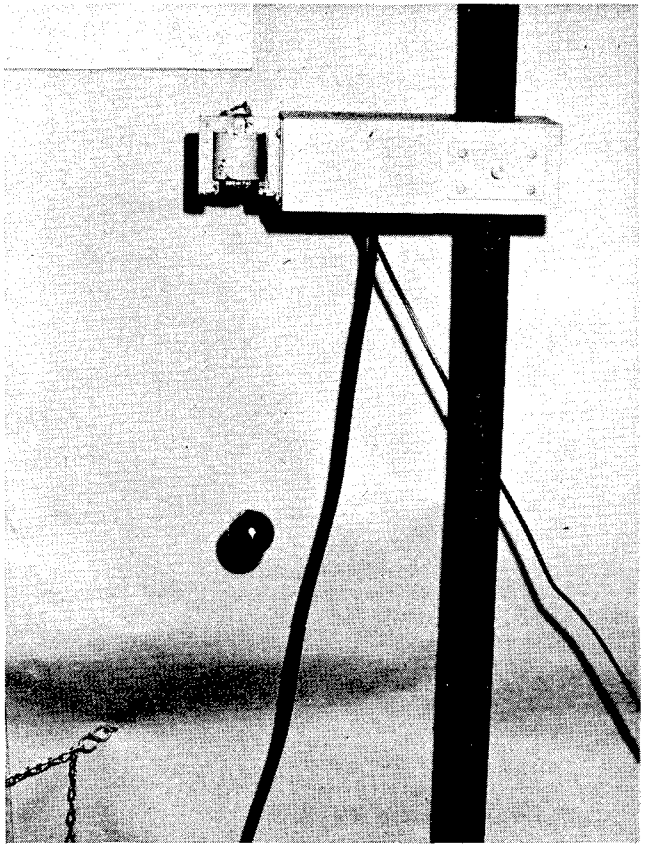

FIGURE 6-15. DROP BALL TEST APPARATUS

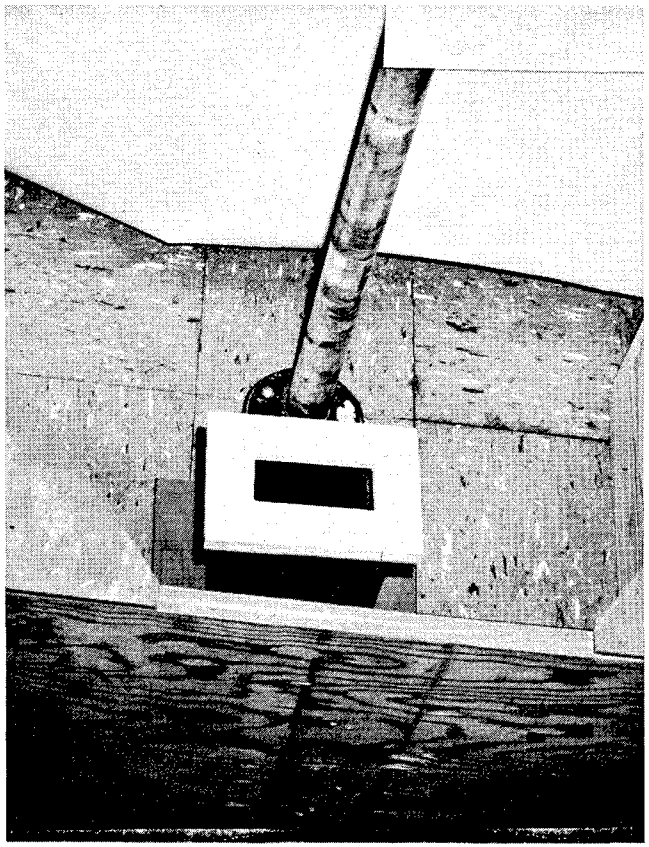

FIGURE 6-16. FILTER PLATE HOLDER FOR DROP BALL TEST

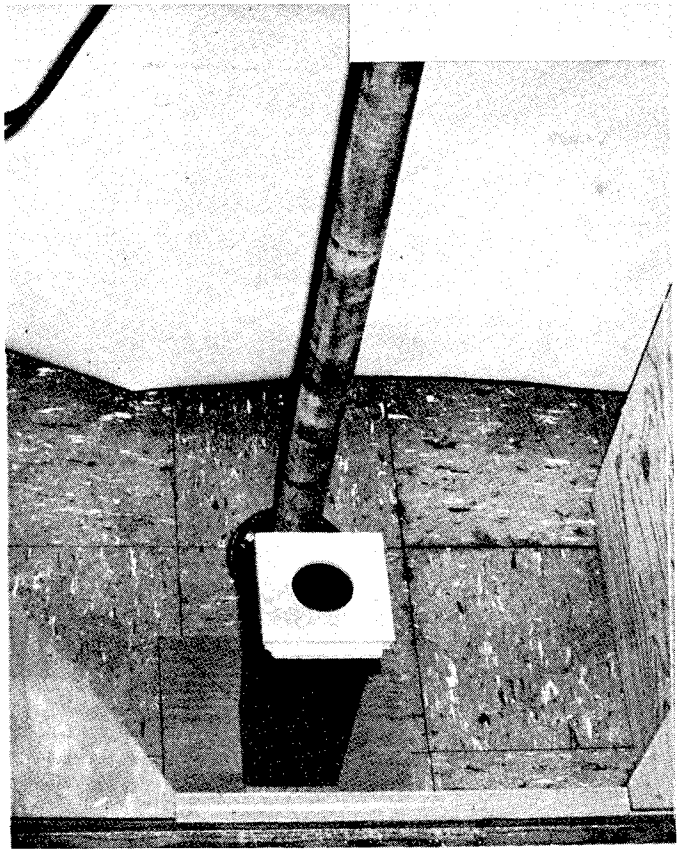

FIGURE 6-17. CIRCULAR COVER PLATE HOLDER FOR DROP BALL TEST

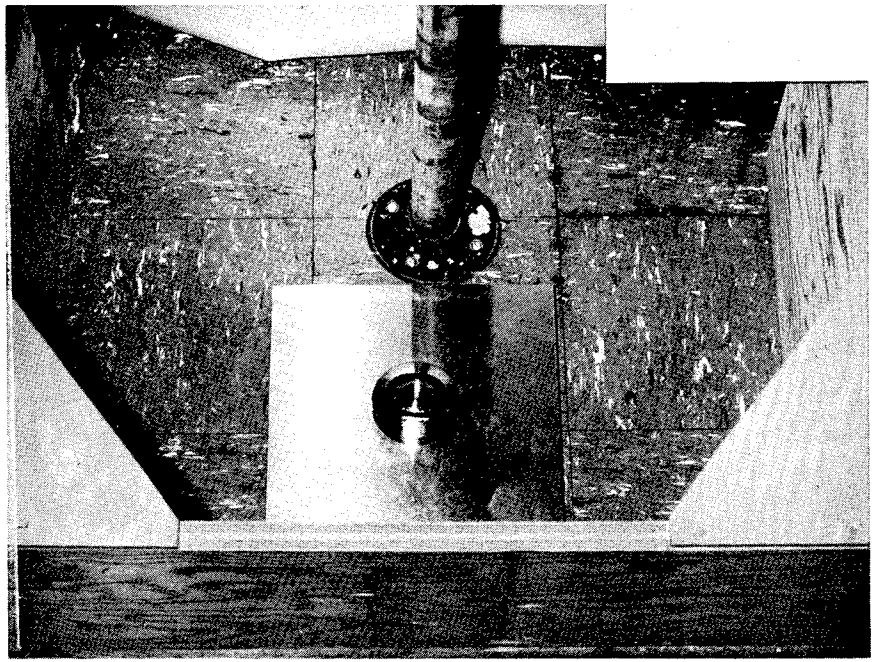

FIGURE 6-18. LENS SUPPORT ANVIL WITH 40 DUROMETER NEOPRENE RUBBER GASKET

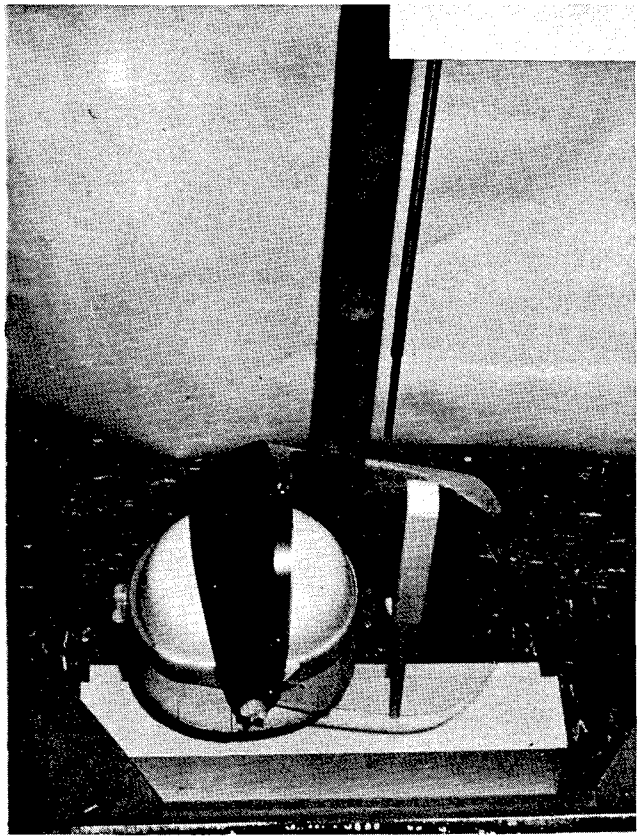

FIGURE 6-19. FACE SHIELD PENETRATION TEST APPARATUS

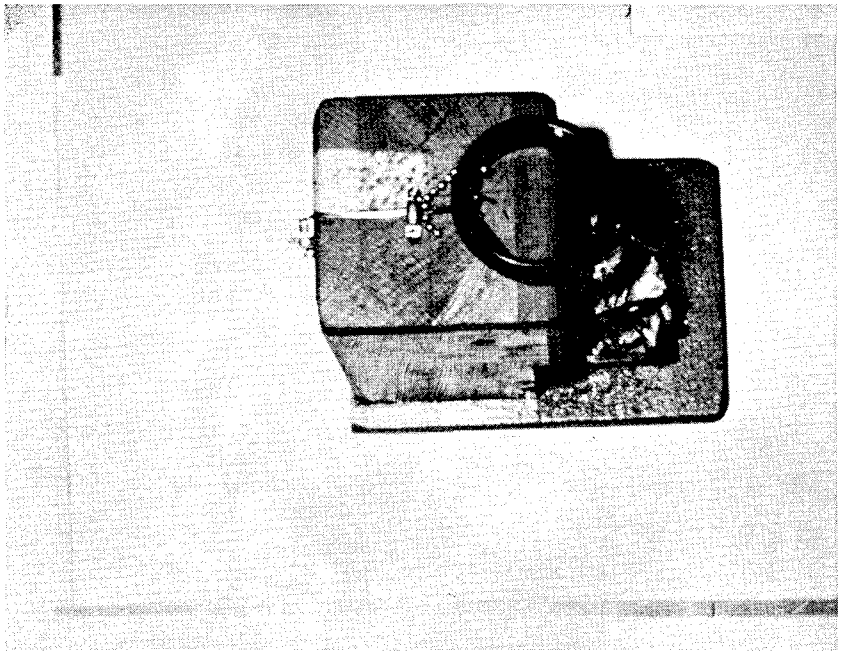

FIGURE 6-20. WELDER'S CUP GOGGLE HEAT DEFORMATION TEST APPARATUS

Respiratory Organs," issued on November 1, 1938 contains some tests similar to those in Z87.1. Undoubtedly, many of the tests in this 1938 standard were preceded by earlier standards. This 1938 standard contains a flat transverse test, edge transverse test and strength of joints test which are similar to those in Z87.1. The test for corrosion in the 1938 standard is identical to that in the British Standard 2092:1967 and Australian Standard AS Z7-1967. We, incidentally, performed this test on a 2-in. × 2-in. × 1/16-in. piece of cold rolled steel and compared the results with another piece of cold rolled steel subjected to a 48-hour exposure to the corrosion test in Z87.1. The specimen subjected to the Z87.1 salt fog corrosion test was much more corroded than the one subjected to the salt solution corrosion test. The 1938 standard contains a drop ball test in which a steel ball 0.625 in. (1.59/cm) in diameter is dropped 39.4 in. (1 m) onto the lens. The lens support is different from that in Z87.1. Many of the Z87.1 tests can also be found in other more recent test specifications. Some examples are the corrosion resistance test (Z118.1 - 1966) and the water absorption test (Method 7031 of Federal Test Methods Standard 406, October 5, 1961). The flammability tests in Z87.1 can be found in Methods 2021 and 2022 of Federal Test Methods Standard 406, October 5, 1961. Members of the Industrial Safety Equipment Association, ISEA (cf, Task 1), whom we questioned and who were responsible for writing previous standards, told us that many of the Z87.1 tests were updated as the state-of-the-art improved or the tests were taken in their entirety from previous standards. Most, if not all, of the tests were <u>not</u> based on actual user conditions. Some tests, such as the corrosion resistance test, were accelerated tests and some, such as the drop ball tests, were chosen for their practicality. This approach is not objectionable provided there are assurances that the protectors will provide adequate protection in actual use. After testing several lenses, the results of which are given in Task 5 and Task 8, it appears that the protective devices are generally quite good. It is felt, by members of the ISEA and to some extent by ourselves, that a major area of concern is user acceptability. No eye protector can be effective unless it is worn.

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6-2. Coblentz, W. W., and Stair, R., "Transmissive Properties of Eye-Protective Glasses and Other Substances," Bureau of Standards Technologic Paper No. 369, June 1928.

6-3. Coblentz, W. W., and Stair, R., "Correlation of the Shade Numbers and Densities of Eye-Protective Glasses," Journal of the Optical Society of America, Vol. 20, November 1930.

6-4. Coblentz, W. W., and Stair, R., NBS Circular C421, 1938.

6-5. Stair, R., "Spectral-Transmissive Properties and Use of Eye-Protective Glasses," NBS Circular 471, October 1948.

6-6. Private Communication, Ralph Stair, Newberg, Oregon, November 26, 1973.

TASK 7 - STUDY OF LENS DISTORTION AND/OR PRISM EFFECTS

In accordance with the Scope of Work and the SwRI Technical Proposal for this project, the following items have been performed under this task:

(1) Apparatus for Refractive and Prismatic Effects (6.3.4.1)

(2) Improvements on Tests for Lens Distortion of Prism Effects

(3) Recommended Limits on the Nonparallelism Between the Two Faces of Plano Lenses - Prismatic Power

(4) Recommended Limits on the Refractive Power of Plano Lenses

(1) Apparatus for Refractive and Prismatic Effects (6.3.4.1)

Figure 7-1 shows the apparatus constructed to measure the prismatic power and refractive power of lenses as required by Z87.1, section 6.3.4.1. The telescope consists of a 54-mm diameter coated achromatic objective lens with a focal length of 254 mm which has been stopped down by an entrance aperture of 191-mm diameter immediately before the objective. The objective has been mounted in a tube of suitable length with a rack and pinion eyepiece mount. The eyepiece is a 1.25-inch compound lens set of the Kellner type with a crossline reticule at its 27-mm focal length. The overall power of the telescope is 9.4 X with an effective aperture of 0.75 inch. The rack and pinion mount was modified with a micrometer head and stop such that the travel of the eyepiece could be measured to the thousandth of an inch. The targets were obtained from NBS Special Publication No. 374 which supersedes the old NBS Circular 533 entitled "Method for Determining the Resolving Power of Photographic Lenses." The telescope has been mounted on a tripod with a biaxial micrometer-adjusted mount for lenses before the objective lens. This mount allows a tested lens to be rotated around a vertical and horizontal axis through its optic center. Flat lenses or filter plates may be aligned so that the normal to one of their surfaces is parallel to the optic axis of the telescope, and lenses with curvature may be aligned so that the center of curvature falls on the optic axis of the telescope.

(2) Improvements on Tests for Lens Distortion of Prism Effects

The micrometer adjustments noted above are improvements on the suggested test apparatus as described in Z87.1. The alignment of

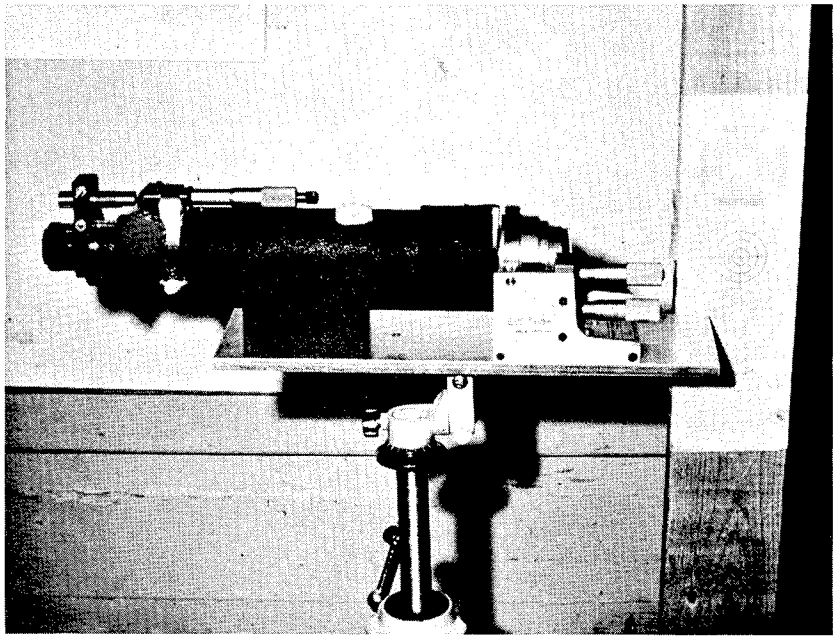

FIGURE 7-1. TELESCOPE (9.4X) WITH BARREL MICROMETERS

test lenses before the telescope is critical to the proper measurement of the prismatic effect. This alignment is not specified in Z87.1 or the suggested NBS Circular 533 publication which describes the required test in more detail. The micrometer adjust on the rack and pinion eyepiece mount permits a continuous measurement of the refractive power of the tested lens with an accuracy that is limited by the experimenter's ability to focus the telescope. This feature also permits the telescope to be calibrated with a standard lens other than the 1/16 prism diopter lens required by Z87.1. The advantage of this is that a calibration with a lens of greater prism diopter means a greater displacement of the eyepiece in calibration and therefore a more accurate displacement measurement and calibration.

We have performed the lens definition test (Z87.1, section 6.3.4.1.3) with this telescope and NBS Resolution Test Chart 1952 (the standard does not specify if the high contrast or low contrast test chart should be used). Since the detector in this test system is the experimenter's eye, the accuracy of the resolution measurement is a function of the percentage contrast in the light and dark regions of the target as well as the retinal illuminous level (a function of the lighting of the target), and eye adaptation. Some specification should be made for these quantities in an improved version of the test. The resolving power of the lenses used in the test apparatus is also an important factor in this test. Minimums should be specified to insure that the test apparatus has an order

of magnitude better resolving power than the maximum resolution required of the test lenses.

Other resolution tests require the use of photographic detectors (microdensitometer and negatives), photomultiplier detectors, or solid state electronic detectors as substitutes for the human eye. The techniques for measuring resolution with these devices are more complicated, but they present the possibility of automating the testing procedure, and they make it easier to quantify the tolerances on the testing apparatus. Eliminating the eye as a detector could also be an improvement on the test for lens refractive power because the focus of a test pattern with and without the test lens in the optic system may be better quantified with the use of the inanimate detectors mentioned above.

Figure 7-2 shows a possible test setup which could be used to measure prismatic power, refractive power, and definition or resolution of eye and face protective lenses. The advantage of this system would be compactness (i.e., the 35-foot optical arm of the Z87.1 test would not be necessary) and less subjectively would be involved in the measurements since the human eye as a detector is replaced with a photomultiplier tube. The system is a modification of the "Electronic Optical Bench" system described by F. E. Washer for testing the resolution of photographic lenses(7-1).

In this system, a grid of sinusoidally varying transmittance is back-lit by a columnated white light source. A high-resolution objective lens produces a real image of the grid at the image plane which is

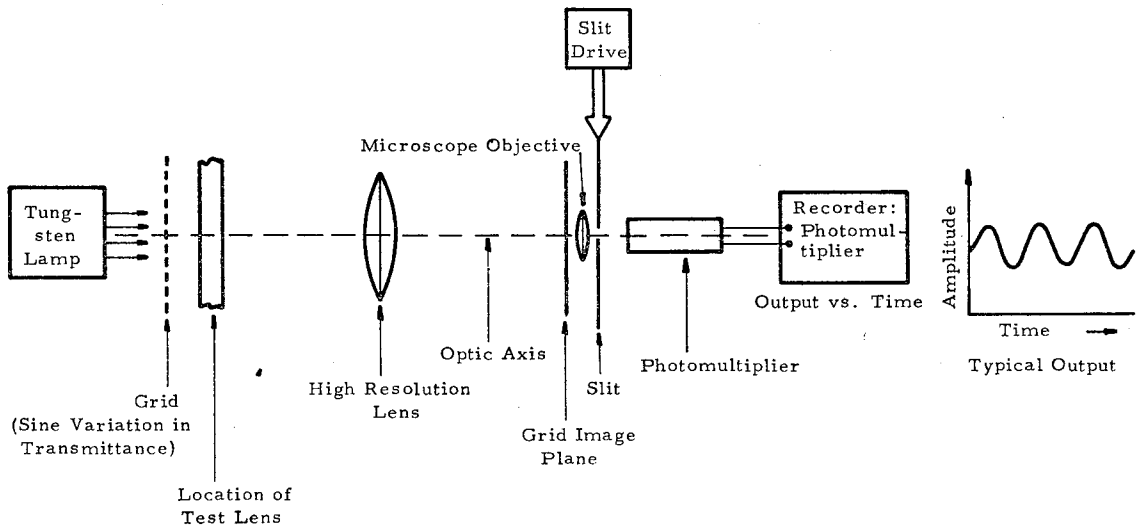

FIGURE 7-2. SUGGESTED APPARATUS FOR IMPROVED MEASUREMENT OF PRISMATIC POWER, REFRACTIVE POWER, AND DEFINITION (RESOLUTION) OF TESTED EYE AND FACE PROTECTIVE LENSES

magnified by a microscope objective and focused on a slit plane. A slit in this plane, which is narrow with respect to the wavelength of the intensity distribution of the grid imaged on that plane, is connected to a drive which moves the slit perpendicular to the grid "lines" with a constant speed. A photomultiplier tube senses the output of the slit at any time, t; its output amplitude is recorded with respect to t. A typical output is seen in the figure and is a sinewave modulated signal with a DC component. The ratio of the sinewave modulation amplitude with and without the test lens in the system is the so-called sine-wave response factor of the test lens (Ref. 7-1, pp 772 to 776). The sinewave response factor is a way of quantifying the resolution of the test lens for grids of various frequency of sine variation in transmittance; i.e., this is a test for definition.

The phase difference between the recorded sine wave amplitude versus time with and without the test lens in the system (for a constant V) is a measure of the prismatic power of the lens.

$$\theta p = 2 \tan^{-1} \frac{\Delta\theta\lambda g}{2\pi x}$$

where θp is the prism angle, λg is the wavelength of the sine wave transmittance of the grid, and x is the optic arm of the system.

The ratio of the amplitude of the sine wave component to constant component for the system output is maximized for any given λg for the best focus of the system. If the position of the microscope objective is measured with a vernier and this objective is used to refocus with the test lens in and out of the system, then focus can be maximized by measuring the system output, and the microscope objective vernier may be calibrated in terms of lens refractive power using a standard 1/16 or 1/8 diopter lens. Thus, this system may also be calibrated for measuring lens refractive power for test lenses.

(3) Recommended Limits on the Nonparallelism between the Two Faces of Plano Lenses - Prismatic Power

We have not found any literature stating the effect different prismatic powers in plano lenses have upon the worker. The eye and face protective devices manufacturers with whom we discussed the problem felt that the tolerances presently given in the ANSI Z87.1 standard were very stringent but good. Most manufacturers could meet these requirements with proper precautions taken while grinding the surfaces of the lenses. The tolerance for plano lenses, excluding filter plates, in the Z87.1 standard is 1/16 diopter. It is 1/8 diopter for filter plates. Federal Specification GGG-S-720B, April 10, 1972

on "Spectacles, Industrial; and Lenses (Ophthalmic, Plano and Prescription, Glare and Impact Resistant)" has only a 1/8-diopter prismatic power tolerance for plano lenses. It should be noted that this is twice the tolerance for spectacle lenses in the Z87.1 standard. Thus, for a pair of spectacles, with a 1/16-diopter prismatic power tolerance, the maximum prismatic effect possible for the two lenses is 1/8 diopter (i.e. One lense could have +1/16 diopter prismatic power and the other -1/16 diopter prismatic power, thus creating a difference of +1/8 diopter prismatic power (i.e., +1/16 - (-1/16 = +1/8)). This result is why the prismatic power tolerance for filter plates is 1/8 diopter. A tolerance of 1/8 diopter incidentally represents an angular deviation of only 4 minutes of arc or only a movement (due to the presence of the lens) of only 1/2 inch, perpendicular to the line of sight, of an object 35 feet away from the observer. This variation is small indeed when one considers that workers generally require protection from objects located only a few feet away (e.g., 0.06 inch movement for object 4 feet away). From these considerations and because of the lack of information found by us which states the effect of different prismatic powers in lenses upon workers, we conclude that the present tolerances on prismatic power are acceptable.

If the prismatic power of a lens is to be determined by using an 8 power telescope and the target and distance between target and telescope described in the Z87.1 standard, it is recommended that the lenses be mounted in the frames and on a suitable anthropomorphic head. The telescope objective lens should be located at the position of the front surface of the eye in the anthropomorphic head and should be positioned with its optic axis coinciding with the optic axis of the eye looking straight ahead while making measurements. This will end the age-old problem of the current position of the lens in front of the telescope and will simulate actual user conditions.

(4) Recommended Limits on the Refractive Power of Plano Lenses

We have not found any literature stating the effect different refractive power in plano lenses have upon the worker. Most manufacturers of eye and face protective devices with whom we discussed the problem believed that the tolerances presently in the Z87.1 standard were good for the worker and attainable by the manufacturer. These tolerances state that for plano lenses the refractive power shall not exceed plus or minus 1/16 diopter and the difference in refractive power of any two meridians shall not exceed 1/16 diopter. Federal Specification GGG-S-620B, April 10, 1972 on "Spectacles, Industrial; and Lenses (Ophthalmic, Plano and Prescription, Glare and Impact Resistant)" specifies that for plano lenses the refractive power at the optical center of the lens should be 1/16 diopter. Where cylindrical power is involved, the refractive power of each of the two principal meridians of the lens shall not exceed

1/16 diopter. Therefore, in this case, the Z87.1 standard is more stringent since it prescribes that the difference in refractive power of any two meridians shall not exceed 1/16 diopter. A lens with +1/16 diopter refractive power in one meridian and -1/16 diopter refractive power in another meridian would pass the GGG-S-620B Federal Specification but would not pass the Z87.1 standard. Therefore, since there is no indication that the present tolerances in refractive power specified in Z87.1 are inadequate and since they are even more stringent than the GGG-S-620B Federal Specification, we feel that the tolerances on refractive power in the existing Z87.1 standard should be adopted.

A question arises as to what portion of the lens should be viewed if the telescope method as described in the Z87.1 standard is used to measure refractive power. Ideally the optical center of the lens should be in line with the optic axis center of the telescope. The optical center of the lens, however, should also be located so that when the lens is worn the optical center of the lens is in line with the optical center of eye (when looking straight ahead). Measurements of the refractive power of lenses should therefore be taken with the lenses inserted in their proper frame, and the frames placed on a suitable anthropomorphic head in the normal wearing position. The telescope objective lens should be at the normal position of the eye such that the optic axis of the telescope is pointed in the same direction as the eyes looking "straight ahead". To examine differences in refractive power along different meridians, the anthropomorphic head with lenses in place should be capable of being rotated with respect to each other about the optic axis of the telescope. This type of test set-up will insure that lenses will be worn in a position such that the optical center of the lens is in line with the optic axis of the eye when the eye is looking "straight ahead".

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TASK 8 - IDENTIFICATION AND DEVELOPMENT OF APPLICABLE EYE AND FACE PROTECTIVE DEVICES ATTRIBUTES

In accordance with the Scope of Work and the SwRI Technical Proposal for this project, the following items have been performed under this task:

(1) Identification of attributes of eye and face protective devices

(2) Performance and evaluation of Z87.1 tests

(3) Development of new tests

(1) Identification of Attributes of Eye and Face Protective Devices

Dimension Measurements

The Z87.1 requires dimension measurements for thickness, width, and length of eye and face protective optical components, i.e., filter plates, cover plates, goggle and spectacle lenses, etc. (see paragraphs 5.1.4.1.5, 5.1.4.1.6, 5.1.4.1.7, 5.1.4.2, 5.2.6.1, 6.1.1.4.2, 6.1.2.1.3, 6.1.3.4, 6.1.3.5, 6.3.2.3, 6.3.2.6, and 6.3.3.1). In most cases, the measurement is a straight-forward linear measurement, but tolerances to the measurements are assigned only the case of paragraphs 5.1.4.1.6 (welders filter plates) and 6.3.2.3 (circumferential tolerance of lenses). For consistency, tolerances should be specified for all dimension measurements, even if these tolerances are relatively loose, so that the accuracy of the measuring devices used meet certain minimum standards.

Paragraphs 5.1.4.1.5, 5.1.4.2, 6.1.1.4.2, and 6.1.3.4 require measurements of effective angle of vision or lens distance from the eye and lens dimensions (which determine effective angle of vision). The maximum lens distance to the pupil of the eye should be specified in all cases so that the minimum effective angle of vision may be obtained from lens dimensions.

Paragraph 6.1.2.1.3 requires plano-lenses to be flat or have a 6.00 diopter curvature (6.58-inch radius of curvature). The radius of curvature, 4, may be measured with a device which measures the length of a chord, ℓ, on a meridian through the lens simultaneously with the distance from the chord along its perpendicular bisector to the intercept with the lens, h. Then,

$$r = \left(\frac{h}{2} + \frac{\ell 2}{2h}\right) = 6.58 \text{ inches}$$

A mechanical depth measuring device which measures a chord length of 1.5 inches (approximate maximum dimension of a lens) would measure an h of 85 mils, i.e., a micrometer with 1 mil least unit would produce a curvature measurement with approximately 1% error. A more accurate measurement would probably have to be made by optical means. Thus, tolerance specifications on the 6.0-diopter curvature requirement should be stated in order to prescribe the test procedure for its measurement as well as standardize the minimum accuracy for the specification.

Lens Quality Measurements

There are no tests for lens quality in Z87.1 except the statements of paragraph 6.3.2.1 which require lenses to be "free from visible defects" and paragraph 6.4.1.2 admonishing the user to replace "pitted and scratched" lenses and a maintenance procedure. Before a more technical approach to lens quality measurement can be taken a reasonable working definition of lens "quality" for the applications of eye and face protective lenses must be settled upon. One way it may be defined is as a maximum limit of the areal density of local distortions in a lens caused by pits, scratches, striae bubbles, waves, discolorations, etc. Local distortions would be defined as impairment of transmittance in regions small compared to the characteristic dimension of the lens. With this as an appropriate definition, further investigations into a testing procedure for lens quality will be made as the project progresses.

Opacity Measurements

The Z87.1 standard requires that the eyecups for welders' and cutters' goggles (6.1.1.4.3 and 6.1.3.2) be opaque for $190 \leq \lambda \leq 1200$ nm. No test procedure is delineated nor is the term opacity defined. We suggest that an appropriate definition of opacity would be that the transmittance of the cup material be less than 0.05 percent for all wavelengths $190 \leq \lambda \leq 1200$ nm. This is reasonable since this is a spectral transmittance lower than that allowed for the highest shade number filter at any wavelength as given in Z87.1, Table 1. If a correction in this table is made lowering the spectral transmittance for the highest number filter at any wavelength, then the opacity limit could be adjusted appropriately to the lower transmittance value.

With opacity defined in terms of transmittance this way, a spectral transmittance characteristic for the cup material may be run using the techniques described under Task 6 which were used to investigate filter spectral transmittance characteristics. For materials whose maximum spectral transmittance per unit thickness of material is well known in the wavelength band of interest, a requirement might be put on the minimum thickness of cup material to be used in the goggle manufacture to assure the required opacity.

Optical Definitions and Test Procedure Descriptions

In general, the Z87.1 standard needs some improvement in the definition of optical terms. For instance, the term "optical density" should be defined as minus the log to the base 10 of the luminous spectral transmittance integrated over the visible wavelengths. This is how this term is used in Z87.1, Table 1, as opposed to "optical density" as the minus log of total transmittance.

The standard often requires tests of "lenses" without specifying whether this term includes all types of lenses, corrective, plano 6.0 diopter curved, filters, glass and plastic, etc., or only some types. The result is that while some of the tests suggested are not possible for all lenses (the haze test, for instance), the user is at a loss to know which lenses are referred to and which are not (in the case of the haze test, there appears to even be a contradition between what lenses are meant when it is described in one place, 6.3.4.4, and in another, Appendix A1). Terms such as "6.0 diopter curvature" should be defined in a more physical sense, i.e., radius of curvature of the lens in linear measure, so that the physical property of the lens being specified is emphasized. This is also true of the term "prism diopter," which should be expressed at least alternately in terms of the included angle of a prism or the deviation angle of a transmitted light ray. The term "diopter" as applied to refractive power of a lens should be expressed in terms of focal length. In the examples above, we see one word, "diopter," used for three different physical properties of a lens, not a situation conducive to clarity!

A suggested test procedure should be given for all the required optical parameters to be measured. We have seen that this has been done in Z87.1 for some of the parameters and not for others. But the suggested tests should be an example of how the optical parameters may be measured within the stated tolerances, not a required set of test procedures. Thus, a proper method of testing will be available to those who do not necessarily understand the physics of the test situation, but a knowledgeable experimenter may design a test setup of his own so long as his method is a valid one for measuring the pertinent physical parameter of the test lenses. To this end, the physical parameters of the test lenses which are being tested, such as the ratio of scattered to total transmittance of the haze test, should be clearly defined and emphasized, and vague terms such as "haze" de-emphasized. The physically pertinent quantities, such as the solid angle subtended by the detector in the haze test, should be emphasized in each test procedure description rather than specific distances and detector sizes.

Additional Attributes

Other attributes which are discussed in this report are:

(1) Strength (section (2) of Task 8)

(2) Impact resistance (section (1) of Task 5 and section (2) of Task 8)

(3) Corrosion resistance (section (2) of Task 8)

(4) Abrasion resistance (section (2) of Task 5)

(5) Reaction to chemicals (section (4) of Task 5)

(6) Flame resistance (section (2) of Task 8)

(7) Resistance to hot materials (section (3) of Task 5)

(8) Heat deformation (section (2) of Task 8)

(9) Water absorption (section (2) of Task 8)

(10) Susceptibility to foggin (section (5) of Task 5)

(11) Transmissive properties (Task 4 and section (2) of Task 8)

(12) Haze (Task 6 and section (2) of Task 8)

(13) Ability to be disinfected (section (2) of Task 8)

(14) General observations (section (2) of Task 8)

Comfort of wearing eye and face protective devices is highly subjective and was not discussed extensively. This attribute and the general appearance of the device while worn determine to a great extent the user acceptability of the eye and face protective device.

(2) Performance and Evaluation of Z87.1 Tests

The objects of conducting these tests were to examine the manner in which the standard is written and note the ambiguities, to become familiar with the test apparatus and note any deficiencies in the standard in the explanation of this apparatus and of the test procedures, to note the completeness and practicality of the tests, and to determine the need for the addition and/or exclusion of tests.

OBSERVATIONS, MARKING, OPTICAL QUALITY, DIMENSIONS FILTER PLATES AND COVER PLATES

Note: Numbers in margin indicate appropriate Z87.1 section numbers.

Filter Plates Observations: 6.3.2.4	Edges. The edges of the lenses shall be smooth and, where required, lenses shall be bevelled and such bevelled edges shall be dull-finished.
Marking: 5.1.4.1.6(5)	All filter plates shall be marked with the shade designation and a permanent and legible marking by which the manufacturer may be readily identified. In addition, all glass filter plates, when treated for impact resistance, shall be marked with the letter "H".
6.3.3.2	Each lens shall be distinctly marked in a permanent and legible manner with the manufacturer's monogram. Such marking shall be so placed as not to interfere with the vision of the wearer. Each filter lens shall be marked with the shade designation. Each glass filter lens shall be marked with the letter "H" to indicate treatment for impact resistance.
Optical Quality: 5.1.4.1.6(2)	Both surfaces of filter plates shall be <u>well polished</u>, and shall be free from striae, waves, or other defects which would impair their optical quality. Filter-plate surfaces shall be flat and substantially parallel; prismatic effects shall not exceed <u>1/8 prism diopter</u> (4 minutes of angular deviation).
6.3.2.1	All lenses shall be made of material suitable for ophthalmic use and both surfaces of the lenses shall be well polished and free from visible surface defects. The lenses shall be free from striae, bubbles, waves, and other visible defects and flaws which would impair their optical quality.
Dimensions: 5.1.4.1.6(1)	The filter plate shall be of such dimensions as to fit suitably into the frame and to cover the window; the filter plate shall be <u>not less than</u> 0.080 inch (2 millimeters) <u>nor more than</u> 0.150 inch (3.8 millimeters) thick; shall measure not less than 2 inches ± 0.03 inch wide by 4.25 inches ± 0.03 inch long.

Cover Plates: 5.1.4.1.7

Cover plates, made of plain glass, of glass coated on one or on both sides with plastic, or of a slow-burning solid plastic sheet shall be used to protect the filter plates from damage. The cover plates shall be the same peripheral size and shape as filter plates, and the thickness of cover plates shall not be less than 0.050 inches. They shall transmit not less than 75 percent of the luminous radiation and shall be substantially free from optical imperfections. Cover plates shall not be heat treated for impact resistance.

Table 8-1 shows the results of observation, marking, and optical quality examinations made of filter plates. The prismatic power test [mentioned in 5.1.4.1.6(2)] is not included here but in another part of the report. Sections 5.1.4.1.6(4) and 5.1.4.1.6(5) imply that when a manufacturer specifies that a filter plate is impact resistant, it must pass an impact resistance test. If a manufacturer does not specify that a filter plate is impact resistant, then it does not have to pass an impact resistant test. The inferred conclusion is that both impact resistant and non-impact resistant filter plates are able to pass the Z87.1 standard.

Table 8-2 contains the thickness, length, and width dimensions made of selected filter plates. Measurements were made using a micrometer with an accuracy better than 0.001 inch. Three measurements of each dimension were made in three different locations on the filter plate.

Table 8-3 shows the results of observation and optical quality examinations made of cover plates. Section 5.1.4.1.7 specifies that "cover plates shall <u>not</u> be heat treated for 'impact resistance'." To provide adquate protection to the eyes of the welder from flying objects either the filter plate must be impact resistant or the welder should wear impact resistant eyewear beneath the helmet or both. This author suggests that at least the filter plates be impact resistant. The only type of safety eyewear that can easily fit inside the helmets are spectacles.

Table 8-4 contains the thickness, length, and width dimensions made of selected cover plates. These measurements were made in the same manner as those taken of the filter plates.

FACE SHIELDS

Observations: 5.2.5.1

Assembly. Face shields shall consist essentially of a detachable transparent plastic window, wire-screen window, or opaque frame with window; a tilting support, and adjustable headgear, and, as required, a crown protector and chin protector.

TABLE 8-1. OBSERVATIONS, MARKING, OPTICAL QUALITY - FILTER PLATES

SwRI Code #	Description	Type of Test	Z87.1 Number	Results
AA K-1	green glass shade #4	Observation	6.3.2.4	pass
		Marking	6.3.2.2	pass
		Optical Quality	6.3.2.1	fail *
AA K-2	green glass shade #5	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
AA K-3	green glass shade #6	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
AA K-4	green glass shade #8	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
AA K-5	green glass shade #9	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
AA K-6	green glass shade #10	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
AA K-7	green glass shade #11	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
AA K-8	green glass shade #12	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
AA K-9	green glass shade #14	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
DD L-1	green glass shade #4	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
DD L-2	green glass shade #5	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
DD L-3	green glass shade #6	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
FF E-1	green plastic shade #4	Observation	6.3.2.4	fail†
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass

TABLE 8-1. OBSERVATIONS, MARKING, OPTICAL QUALITY - FILTER PLATES (Cont'd)

SwRI Code #	Description	Type of Test	Z87.1 Number	Results
FF E-2	green plastic shade #5	Observation	6.3.2.4	fail†
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
FF E-3	green plastic shade #6	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
FF E-4	green plastic shade #7	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
FF E-5	green plastic shade #8	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
FF E-6	green plastic shade #9	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
FF E-7	green plastic shade #10	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
FF E-8	green plastic shade #11	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
FF E-9	green plastic shade #12	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
FF E-10	green plastic shade #13	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass
FF E-11	green glass shade #14	Observation	6.3.2.4	pass
		Marking	6.3.3.2	pass
		Optical Quality	6.3.2.1	pass

*Failure due to pits on surface near two edges.
†Failure doe to lack of smooth edges.

TABLE 8-2. DIMENSIONS - FILTER PLATES [5.1.4.1.6(1)]

SwRI Code #	Description	Thickness (.080"-.150")	Width (2.00" ± .03")	Length (4.25" ± .03")	Results
AA K-1	glass shade #4	.107 .106 .105	2.017 2.019 2.023	4.231 4.232 4.234	pass
AA K-2	glass shade #5	.139 .139 .138	2.009 2.006 2.001	4.255 4.255 4.257	pass
AA K-3	glass shade #6	.127 .127 .128	2.005 2.014 2.022	4.258 4.266 4.263	pass
AA K-4	glass shade #8	.109 .109 .109	2.013 2.006 2.006	4.260 4.261 4.257	pass
AA K-5	glass shade #9	.102 .102 .102	2.006 2.010 2.012	4.262 4.260 4.260	pass
AA K-6	glass shade #10	.118 .117 .118	2.012 2.017 2.017	4.261 4.262 4.268	pass
AA K-7	glass shade #11	.122 .122 .121	2.001 2.002 2.004	4.254 4.256 4.255	pass
AA K-8	glass shade #14	.122 .123 .122	2.003 2.001 2.003	4.254 4.261 4.252	pass
DD L-1	glass shade #4	.128 .127 .126	2.001 2.000 1.994	4.241 4.240 4.238	pass
DD L-2	glass shade #5	.122 .122 .122	1.994 1.997 2.000	4.222 4.214 4.253	fail
DD L-3	glass shade #6	.119 .118 .119	1.991 1.988 1.990	4.274 4.273 4.266	pass
FF E-1	plastic shade #4	.108 .106 .107	1.989 1.995 1.990	4.228 4.242 4.238	pass
FF E-2	plastic shade #5	.103 .101 .102	1.999 1.997 2.002	4.200 4.200 4.200	fail

TABLE 8-2. DIMENSIONS - FILTER PLATES [5.1.4.1.6(1)] (Cont'd)

SwRI Code #	Description	Thickness (.080"-.150")	Width (2.00±.03")	Length (4.25"±.03")	Results
FF E-3	plastic shade #6	.122	2.002	4.192	fail
		.127	1.986	4.194	
		.124	1.989	4.188	
FF E-4	plastic shade #7	.115	1.996	4.212	fail
		.114	1.997	4.213	
		.114	1.996	4.212	
FF E-5	plastic shade #8	.110	2.022	4.201	fail
		.111	2.019	4.200	
		.111	2.015	4.201	
FF E-6	plastic shade #9	.107	1.990	4.198	fail
		.106	1.994	4.199	
		.107	1.993	4.198	
FF E-7	plastic shade #10	.121	1.940	4.212	fail
		.119	1.790	4.208	
		.118	1.930	4.203	
FF E-8	plastic shade #11	.130	1.940	4.198	fail
		.131	1.928	4.202	
		.131	1.920	4.201	
FF E-9	plastic shade #12	.116	1.983	4.198	fail
		.118	1.983	4.196	
		.121	1.985	4.200	
FF E-10	plastic shade #13	.134	2.024	4.174	fail
		.136	2.023	4.173	
		.138	2.031	4.172	
FF E-11	plastic shade #14	.148	2.003	4.208	fail
		.143	2.003	4.208	
		.140	2.008	4.209	

TABLE 8-3. OBSERVATIONS, OPTICAL QUALITY - COVER PLATES (5.1.4.1.7)

SwRI Code #	Description	Type of Test	Z87.1 Number	Results
AA K-12	clear plastic	Observation	6.3.2.4	pass
		Optical Quality	6.3.2.1	pass
DD L-4	clear glass	Observation	6.3.2.4	pass
		Optical Quality	6.3.2.1	pass
FF E-12	clear glass	Observation	6.3.2.4	pass
		Optical Quality	6.3.2.1	pass

TABLE 8-4. DIMENSIONS - COVER PLATES [5.1.4.1.7, 5.1.4.1.6(1)]

SwRI Code #	Description	Thickness (≥ 0.050")	Width (2.00" ± .03")	Length (4.25" ± .03")	Results
AA K-12	plastic	.057	1.998	4.209	fail
		.056	2.002	4.211	
		.055	1.997	4.211	
DD L-4	glass	.061	2.009	4.202	fail
		.061	2.009	4.205	
		.061	2.014	4.206	
FF E-12	glass	.090	2.003	4.213	fail
		.089	2.006	4.203	
		.089	2.003	4.208	

5.2.5.2 Window Shape. The windows shall be designed to fit the contour of the window support.

5.2.5.3 Window Support. There shall be attached to the headgear a window-supporting or window-holding member which shall be a band or crown protector. The window support shall position the window in front of the face in such a manner as to provide clearance for the nose and eyeglasses of the wearer.

5.2.5.4 Window Attachment. The attachment of the window to the window support shall be such as to permit easy removal and replacement. The several sizes and types of windows for a particular face shield shall be interchangeable for attachment to the window support.

5.2.5.5 Headgear. The headgear shall consist of at least a headband and a crown strap. The headgear shall be made from materials having low heat conductivity. The design shall be such as to hold the window and window support comfortably and firmly in place on the wearer's head, and shall provide for tilting the window away from the face.

5.2.5.6 Crown Protector. The crown protector shall be shaped to cover at least the frontal portion of the head and shall extend around each side at least to a vertical line at the front of the ears. It may be designed to be an integral part of the window support, or it may be a separate assembly. The design shall be such as to provide a comfortable clearance over the forehead and head of the wearer.

5.2.5.7 Chin Protector. The chin protector shall be shaped to cover at least the chin and upper part of the neck. The design shall be such as to provide a comfortable clearance under the chin of the wearer.

5.2.6.2 Wire-Screen Window. The exposed borders of wire-screen windows shall be suitably bound or otherwise finished in such a manner as to eliminate any sharp, rough or unfinished edges, using not less than 20-mesh screen.

5.2.6.3 Window Support. The window support shall be made of vulcanized fiber, plastic, or other suitable material. It shall be pivotally attached to the sides of the headgear to permit easy tilting, either upward or downward, of the supporting member and of the window attached thereto. The window shall be capable of being tilted sufficiently upward so that the center of its bottom edge shall be out of the line of horizontal vision. The tension of the tilting mechanism shall be sufficient to hold the window without slippage in either the up or the down position.

5.2.6.4 Headgear. The headgear shall be readily adjustable to head sizes from 6-1/2 to 7-5/8 without the use of tools. Adjusting devices, if used, shall hold firmly in place after being so adjusted. The crown strap or band shall be attached to, and extend between, the front and rear centers or from the middle sides of the headband. It shall form an arc over the head to assist in positioning and holding the headgear in place. Adjusting devices, if used, shall be positive and shall hold firmly in place after being so adjusted. All mechanisms and movements shall be protected so that the wearer's hair cannot catch in the adjusting devices. If required, not less than the forehead portion of the headband shall be provided with a removable and replaceable cushioned sweatband that shall be non-irritating and non-toxic.

5.2.6.5 Crown Protector and Chin Protector. The crown protector and chin protector shall be made of vulcanized fiber, plastic, or other suitable material having an impact resistance not less than that of the plastic window. When the crown protector is used in conjunction with the chin protector for protection against sprays of hazardous liquids, the assembly of the crown protector and window support and the assembly of the chin protector and window shall be splash-proof, that is, shall

not allow liquids to pass through any openings in the assembly and reach the face, forehead, or chin of the wearer.

Marking: 5.2.7

Marking. Each headgear and each plastic window shall bear a permanent and legible marking by which the manufacturer may be readily identified. In addition, each window offered for protection against glare shall bear its shade designation.

Optical Quality: 6.3.2.1

All lenses shall be made of material suitable for ophthalmic use and both surfaces of the lenses shall be well polished and free from visible surface defects. The lenses shall be free from striae, bubbles, waves, and other visible defects and flaws which would impair their optical quality.

Dimensions: 5.2.6.1

Window Dimensions. Plastic or wire-screen windows without frames shall be not less than 9-1/2 inches wide at the top and 8-1/2 inches wide at the bottom, measured over their curved surfaces when attached and in position on the window support, and not less than 6 inches high. Windows, when used in frames, shall be not less than 4 inches wide and 2 inches high, and the frames shall conform to the dimensions specified for windows without frames.

Plastic windows shall be not less than 0.040 inch nominal thickness.

Table 8-5 shows the results of observation, marking, and optical quality using the Z87.1 criterions quoted above.

Wire-screen window face shields mentioned in Section 5.2.6.2 have certain severe disadvantages. In the April, 1972 issue of the American Journal of Optometry and Archives of American Academy of Optometry, E. C. Wigglesworth of the Australian Defense Scientific Service submitted an article entitled "A Comparative Assessment of Eye Protective Devices and a Proposed System of Acceptance Testing and Grading" in which he stated that

> ". . . wire gauze is hazardous in the presence of molten metal, rapidly becomes clogged with dirt, and has obviously poor optical qualities. On the only occasion when I wore them, I volunteered to test them for a two-hour period during which time I was engaged in breaking scrap metal castings with a 14 lb sledge hammer. The close

TABLE 8-5. OBSERVATIONS, MARKING, OPTICAL QUALITY - FACE SHIELDS

SwRI Code #	Description	Type of Test	Results	Comments
AA L-1	clear plastic	Observation	pass	
		Marking	pass	
		Optical Quality	pass	
AA M-1	clear plastic	Observation	pass	
		Marking	pass	
		Optical Quality	pass	
DD N-1	clear plastic	Observation	pass	
		Marking	pass	
		Optical Quality	pass	
JJ R-1	clear plastic	Observation	pass	
		Marking	pass	
		Optical Quality	pass	
JJ R-2	clear plastic	Observation	pass	
		Marking	pass	
		Optical Quality	pass	
JJ R-3	clear plastic	Observation	pass	
		Marking	pass	
		Optical Quality	pass	
JJ R-4	dark green plastic	Observation	pass	
		Marking	pass	
		Optical Quality	pass	
JJ R-5	clear plastic	Observation	pass	
		Marking	fail	5.2.7
		Optical Quality	pass	
JJ R-6	dark green plastic	Observation	pass	
		Marking	fail	5.2.7
		Optical Quality	pass	

proximity of the interstices produced a claustrophobic effect that increased with time. It became so consciously annoying that, had there been no prior agreement for a two-hour test, I would have terminated it earlier. I persisted for the full duration of the planned test and received an acute headache that persisted until the next day.

The physical reaction and consequent opinion of one person who was indulging in unaccustomed physical activity can hardly be considered an objective report on this type

of protection. However, the test was made precisely because the regular operators had asked for suitable eye protection for their work and had reacted unfavorably to the suggestion that wire gauze goggles would be suitable. Allegations of severe vision disturbance, dust penetration and headache were made and the test was carried out to examine the validity of these claims. All were substantiated.

For these reasons, and for their potentially hazardous characteristics, gauze goggles cannot be recommended."

Restrictions should be made on the use of wire mesh goggles in dusty environments or areas where there is exposure to chemicals or molten metal unless other eye and face protective devices are used in conjunction with the wire screen protector.

Section 5.2.6.5 specifies that "the crown protector and chin protector shall be made of vulcanized fiber, plastic, or other suitable material having an impact resistance not less than that of the plastic window," yet there is no impact test mentioned in the Z87.1 standard for crown protectors and chin protectors.

Table 8-6 contains the thickness measurements and overall window dimensions examinations specified in 5.2.6.1. Thickness measurements were made using a micrometer with an accuracy of less than 0.001 inch. Thickness measurements were taken in three different regions of each faceshield.

SPECTACLES

Observations: 6.1.2.1

Description. Safety spectacles require special frames. Therefore combinations of street-wear frames with safety lenses meeting this standard are definitely not in compliance.

Spectacles shall consist of two lenses in a frame which supports the lenses around their entire periphery, of suitable size and shape for the purpose intended, connected by a nose bridge, and retained on the face by temples or other suitable means. The spectacles shall be furnished with or without sideshields depending upon their intended use. The frames, temples, and sideshields can be of metal or plastic construction and when made of plastic shall be of the slow-burning type.

TABLE 8-6. DIMENSIONS - FACE SHIELDS (5.2.6.1)

SwRI Code #	Description	Thickness ($\geq$ 0.040")	Other Window Dimensions	Results
AA L-1	clear plastic	.042 .041 .041	good	pass
AA M-1	clear plastic	.040 .039 .038	good	fail
CC C-1	clear plastic	.042 .043 .042	good	pass
CC D-1	clear plastic	.043 .041 .041	good	pass
CC E-1	clear plastic	.042 .045 .040	good	pass
CC F-1	green plastic	.060 .061 .061	good	pass
CC G-1	clear plastic	.059 .061 .061	good	pass
DD N-1	clear plastic	.040 .041 .040	good	pass
JJ R-5	clear plastic	.040 .040 .040	good	pass
JJ R-2	clear plastic	.061 .061 .061	good	pass
JJ R-3	clear plastic	.084 .085 .086	good	pass
JJ R-4	green plastic	.043 .041 .040	good	pass
JJ R-6	green plastic	.043 .041 .040	good	pass
JJ R-5	clear plastic	.042 .040 .043	good	pass

6.1.2.1.3	Frame and Lens Sizes. Spectacle frame and lenses shall be of identical shape and configuration and of such dimensions to assure support of the lens by the lens frame around its entire periphery.
6.1.2.1.4	Temples. Temples may be of the cable or spatula type as specified, and shall be of such design as to permit adjustment and fit comfortably and securely on the wearer. The size of the temples shall be clearly marked.
6.1.2.2.1	cf ANSI Z87.1
6.1.2.2.2	cf ANSI Z87.1
6.2.2.3	cf ANSI Z87.1
Marking: 6.1.2.1.2	These frames shall be designed for industrial exposure and shall bear a trademark identifying the manufacturer on both fronts and temples. The frame front shall carry a designation of the eye size and bridge size (where applicable). Temples will be marked as to the overall length or fitting value.
6.3.3.2	Each lens shall be distinctly marked in a permanent and legible manner with the manufacturer's monogram. Such marking shall be so placed as not to interfere with the vision of the wearer. Each filter lens shall be marked with the shade designation. Each glass filter lens shall be marked with the letter "H" to indicate treatment for impact resistance.
Optical Quality: 6.3.2.1	All lenses shall be made of material suitable for ophthalmic use and both surfaces of the lenses shall be well polished and free from visible surface defects. The lenses shall be free from striae, bubbles, waves, and other visible defects and flaws which would impair their optical quality.
Dimensions: 6.3.3.1	Lens Thickness. Glass or plastic lenses for use in eyecup goggles, metal- or plastic-frame or metal-plastic combination-frame spectacles, or foundrymen's goggles shall be not less than 3.0 millimeters, nor more than 3.8 millimeters in thickness.

Table 8-7 shows the results of observations, marking, and optical quality examinations made of safety spectacles. As regards to 6.1.2.1, sideshields should be worn whenever there is a need to wear safety spectacles since any

TABLE 8-7. OBSERVATIONS, MARKING, OPTICAL QUALITY, SPECTACLES (FRAME AND LENSES)

SwRI Code #	Description	Type of Test	Results
AA G-2	clear glass plastic frame sideshield	Observation Marking Optical Quality	pass pass pass
AA H-2	clear glass plastic frame	Observation Marking Optical Quality	pass pass pass
AA C-1b	clear glass plastic frame sideshield	Observation Marking Optical Quality	pass pass pass
AA B-1b	clear glass plastic frame sideshield	Observation Marking Optical Quality	pass pass pass
DD H-2	clear glass plastic frame	Observation Marking Optical Quality	pass pass pass
EE L-3	clear glass plastic frame	Observation Marking Optical Quality	pass pass pass
EE L-4	clear glass plastic field sideshield	Observation Marking Optical Quality	pass pass pass
EE L-6	clear glass plastic frame sideshield	Observation Marking Optical Quality	pass pass pass
FF D-2	clear glass plastic frame	Observation Marking Optical Quality	pass pass pass
GG P-2	clear plastic plastic frame	Observation Marking Optical Quality	fail (6.1.2.1.3)* fail (6.1.2.1.2)† pass
GG M-2	clear plastic plastic frame	Observation Marking Optical Quality	fail (6.1.2.1.3)* fail (6.1.2.1.2)† pass
GG Q-2	dr. green plastic plastic frame	Observation Marking Optical Quality	fail (6.1.2.1.3)* fail (6.1.2.1.2)† pass
GG N-2	dr. green plastic plastic frame	Observation Marking Optical Quality	fail (6.1.2.1.3)* fail (6.1.2.1.2)† pass

TABLE 8-7. OBSERVATIONS, MARKING, OPTICAL QUALITY, SPECTACLES (FRAME AND LENSES) (Cont'd)

SwRI Code #	Description	Type of Test	Results
HH D-1b	clear glass plastic frame	Observation	pass
		Marking	pass
		Optical Quality	pass
HH E-1b	clear glass plastic frame	Observation	pass
		Marking	pass
		Optical Quality	pass
MM I-1	clear glass plastic frame	Observation	pass
		Marking	pass
		Optical Quality	pass
MM G-1	clear glass plastic frame sideshield	Observation	pass
		Marking	pass
		Optical Quality	pass
MM N-1	clear glass plastic frame	Observation	pass
		Marking	pass
		Optical Quality	pass
MM F-2	clear glass plastic frame	Observation	pass
		Marking	pass
		Optical Quality	pass
NN H-2	clear glass metal frame sideshield	Observation	pass
		Marking	pass
		Optical Quality	pass
NN G-2	clear glass plastic frame sideshield	Observation	pass
		Marking	pass
		Optical Quality	pass

*Lens not supported around entire periphery.
†No manufacturer's identification; no eyesize or bridge size.

distractions causing the wearer to turn his head from his work presents potentially dangerous exposure to the eye of the worker if he is not wearing sideshields with his spectacles. Only the first paragraph of section 6.1.2.1.3 is presented in Table 8-7.

Table 8-8 contains the thickness readings made of spectacle lenses. Measurements were made using a micrometer with an accuracy of less than 0.001 inch. Three measurements of each dimension were made in three different locations on each spectacle lens.

TABLE 8-8. DIMENSIONS - SPECTACLE LENSES (6.3.3.1)

SwRI Code #	Description	Thickness (.118" - .150")	Results
AA H-2	clear glass	.144	pass
	plastic frame	.143	
	right lens	.142	
	left lens	.144	pass
		.143	
		.144	
AA G-2	clear glass	.144	pass
	plastic frame	.145	
	right lens	.144	
	left lens	.144	pass
		.146	
		.147	
DD H-2	clear glass	.139	pass
	plastic frame	.140	
	right lens	.139	
	left lens	.140	pass
		.145	
		.143	
EE L-3	clear glass	.144	pass
	plastic frame	.143	
	right lens	.146	
	left lens	.147	pass
		.145	
		.141	
EE L-4	clear glass	.127	pass
	plastic frame	.126	
	right lens	.125	
	left lens	.122	pass
		.125	
		.132	
EE L-6	clear glass	.145	pass
	plastic frame	.144	
	right lens	.144	
	left lens	.142	pass
		.143	
		.143	
FF D-2	clear glass	.138	pass
	plastic frame	.139	
	right lens	.138	
	left lens	.140	pass
		.140	
		.141	

TABLE 8-8. DIMENSIONS - SPECTACLE LENSES (6. 3. 3. 1) (Cont'd)

SwRI Code #	Description	Thickness (. 118" - . 150")	Results
GG P-2	clear plastic	. 100	fail
	plastic frame	. 095	
	right lens	. 098	
	left lens	. 095	fail
		. 095	
		. 091	
GG M-2	clear plastic	. 081	fail
	plastic frame	. 078	
	right lens	. 082	
	left lens	. 076	fail
		. 082	
		. 079	
GG Q-2	clear plastic	. 081	fail
	plastic frame	. 087	
	right lens	. 086	
	left lens	. 085	fail
		. 081	
		. 087	
GG N-2	clear plastic	. 082	fail
	plastic frame	. 085	
	right lens	. 083	
	left lens	. 083	fail
		. 085	
		. 087	
HH D-1b	clear glass	. 138	pass
	plastic frame	. 138	
	right lens	. 138	
	left lens	. 139	pass
		. 138	
		. 139	
HH E-1b	clear glass	. 138	pass
	plastic frame	. 138	
	right lens	. 138	
	left lens	. 138	pass
		. 137	
		. 138	
HH B-1b	clear glass	. 138	pass
	plastic frame	. 133	
	right lens	. 132	
	left lens	. 131	pass
		. 130	
		. 130	

TABLE 8-8. DIMENSIONS - SPECTACLE LENSES (6.3.3.1) (Cont'd)

SwRI Code #	Description	Thickness (.118" - .150")	Results
HH C-1b	clear glass	.139	pass
	plastic frame	.139	
	right lens	.138	
	left lens	.137	pass
		.132	
		.131	
MM I-1	clear glass	.144	pass
	plastic frame	.146	
	right lens	.145	
	left lens	.131	pass
		.136	
		.140	
MM G-1	clear glass	.143	pass
	plastic frame	.144	
	right lens	.147	
	left lens	.143	pass
		.143	
		.143	
MM N-1	clear glass	.143	pass
	plastic frame	.142	
	right lens	.143	
	left lens	.141	pass
		.141	
		.143	
MM F-2	clear glass	.143	pass
	plastic frame	.142	
	right lens	.142	
	left lens	.140	pass
		.141	
		.142	
NN H-2	clear glass	.132	pass
	plastic frame	.132	
	right lens	.133	
	left lens	.132	pass
		.137	
		.134	
NN G-2	clear glass	.131	pass
	plastic frame	.132	
	right lens	.134	
	left lens	.131	pass
		.132	
		.132	

Observations

Eyecup Goggles:

6.1.1.3 Eyecup goggles shall consist of two eyecups, with lenses and lens retainers, connected by an adjustable bridge, and a replaceable and adjustable headband or other means for retaining the eyecups comfortably in front of the eyes.

6.1.1.4.2(1) Cup-Type Goggles. Eyecups shall be right and left in pairs and shall permit an effective angle of vision not less than 105 degrees, assuming that the pupil of the eye is located 17 millimeters behind the inner surface of the lens. The edge of the eyecup which bears against the face shall have a smooth surface free from roughness or irregularities which might exert undue pressure or cause discomfort to the wearer. The eyecups shall be of such shape and size as to protect completely the entire eye sockets.

6.1.1.4.2(2) Cover-Cup Type Goggles. Eyecups shall be right and left in pairs and shall permit an effective angle of vision not less than 90 degrees. The goggles shall be designed to provide ample clearance and will not interfere with the spectacles of the wearer. The edges of the goggles which bear against the face shall have a smooth surface free from roughness or irregularities which might exert undue pressure or cause discomfort to the wearer.

6.1.1.4.4 Lens-Retaining Ring. Each eyecup shall be provided with a rigidly constructed lens-retaining ring of metal or of plastic designed to accommodate lenses and to permit their ready removal and replacement without damage to the eyecup or to the lenses and without the use of tools. The ring shall provide a complete clamping action against the lens. Lens retainers for welder's and cutter's models shall be such as to accommodate a filter lens, fiber gasket, and cover lens.

6.1.1.4.5 Lens Seat. Each eyecup shall have a lens seat sufficiently wide to support the lens and to resist the falling inward of the broken lens when the lens is subjected to the impact test specified in 6.1.1.4.6.

Flexible or Cushioned Fitting Goggles:

6.1.3.1 Description. Goggles shall consist of a wholly flexible frame, forming a lens holder, or with separable lens

holder; or a rigid frame with integral lens or lenses, having a separate, cushioned fitting surface on the full periphery of the facial contact area. Materials used shall be chemical-resistant, nontoxic, nonirritating and slow-burning. There shall be a positive means of support on the face, such as an adjustable headband of suitable means of support to retain the frame comfortably and snugly in place in front of the eyes. When the frame is a lens holder or has a separable lens holder, it should be such that the lens or lenses are held firmly and tightly and may be removed or replaced without the use of tools. The goggles may be ventilated or not, as required by their intended use. Where chemical goggles are ventilated, the openings shall be such as to render the goggles splashproof.

6.1.3.2(1) Models. Chipper's models shall provide protection against impact.

6.1.3.2(2) Dust and Splash models shall provide protection from fine dusts, fumes, liquids, splashes, mists, and spray, alone or with reflected light or glare, wind, and impact.

6.1.3.2(3) Welder's and Cutter's models shall provide protection against glare, injurious radiations, and impact. Eye cups and lens holders shall be opaque from 1,900 to 12,000 angstrom units.

6.1.3.4 Goggles shall be so designed as to protect completely the eye sockets and the facial area immediately adjacent to and surrounding the eyes of the wearer to protect the eye from side exposure. Where required, the design shall be such that the goggles will fit over ordinary spectacles worn by the wearer. Goggles shall be so designed as to afford an effective angle of vision of not less than 90 degrees. Where the goggle consists of an opaque frame and is designed for protection against radiant energy, the angle of vision is not applicable. The methods of attachment to frame shall be such that the lens will not be inwardly dislodged from its seat when it is subjected to the impact resistance or penetration tests specified in 6.3.4.2, 6.3.4.3, or 6.1.1.4.6(4), whichever is applicable. Where a rigid frame design is used, the cushioned fitting substance affixed for peripheral contact shall be of sufficient thickness or diameter to maintain a seal with comfort and conformity to normal facial contours.

Marking

Eyecup Goggles:

6.1.1.4.7 Marking. All filter lenses shall be marked with the shade designation and a permanent and legible marking by which the manufacturer may be readily identified. In addition, all glass filter lenses, when treated for impact resistance, shall be marked with the letter "H".

Flexible or Cushioned Fitting Goggles:

6.1.3.6(1) Frames shall bear a trademark or name identifying the manufacturer.

6.1.3.6(2) Each separate lens shall be distinctly marked in a manner by which the manufacturer may be identified.

6.1.3.6(3) In addition, all heat-treated glass filter plates or lenses shall be marked with the shade designation and the letter "H".

6.1.3.6(4) Such marking shall be clear cut and permanent and so placed as not to interfere with the vision of the wearer.

Optical Quality

6.3.2.1 All lenses shall be made of material suitable for ophthalmic use and both surfaces of the lenses shall be well polished and free from visible surface defects. The lenses shall be free from striae, bubbles, waves, and other visible defects and flaws which would impair their optical quality.

Dimensions

Eyecup Goggles:

6.1.1.4.3(1) Chipper's Models. Eyecups shall be ventilated in a manner to permit circulation of air. Ventilation openings shall be such as to exclude a spherical particle 0.040 inch (1 millimeter) in diameter.

The equivalent area of opening for ventilation in each eyecup through the side shall be not less than the area of a 5/8-inch (15.0 millimeter) diameter hole. The equivalent area of opening in each eyecup through or around a lens-retaining ring shall be not less than the area of a 5/16-inch

(7.9 millimeter) diameter hole. The openings in the side shields shall be such as to exclude any particle that will not pass through an opening 0.040 inch (1 millimeter) in diameter. The openings in or around the lens-retaining rings shall be such as to exclude any particle that will not pass through an opening 0.080 inch (2.03 millimeters).

6.1.1.4.3(2) Dust and Splash Models. Eyecups shall be ventilated in a manner to permit circulation of air. The ventilation openings shall be baffled or screened to prevent the direct passage of dust or liquids into the interior of the eyecups.

The equivalent area of openings of ventilation in each eyecup shall be not less than the area of 1/4-inch (6.35 millimeter) diameter hole.

6.1.1.4.3(3) Welder's and Cutter's Models. Eyecups shall be ventilated in a manner to permit circulation of air and shall be opaque from 1,900 to 12,000 angstrom units. The ventilation opening shall be baffled to prevent the passage of light rays into the interior of the eyecups.

The equivalent area of openings of ventilation in each eyecup shall be not less than the area of a 1/4-inch (6.35 millimeter) diameter hole.

6.3.3.1 Lens Thickness. Glass or plastic lenses for use in eyecup goggles, metal- or plastic-frame or metal-plastic combination frame spectacles or foundrymen's goggles shall be not less than 3.0 millimeters, nor more than 3.8 millimeters in thickness.

Flexible or Cushioned Fitting Goggles:

6.1.3.5 Plastic lenses used in flexible-fitting goggles and lens areas of cushioned-fitting goggles shall be not less than 0.050 inch in thickness. Materials used shall be capable of withstanding the disinfection, corrosion-resistance, water-absorption, and flammability tests outlined in 6.2.

Table 8-9 shows the results of observations, marking, and optical quality examinations made of safety goggles. The effective angle of vision observations specified in 6.1.1.4.2(1), 6.1.1.4.2(2), and 6.1.3.4 were performed by placing the observer wearing the goggle to be tested with his eyes three feet from a wall directly in front of a mark at eye level. Two sets of marks, 3 feet and 3 feet 10.9 inches, were placed on either side of the centerline. With the observer wearing the test goggle and focusing on the centerline, and using his peripheral vision, the effective angle of vision of the goggles would be at least 90°

TABLE 8-9. OBSERVATIONS, MARKING, OPTICAL QUALITY - GOGGLES

SwRI Code #	Description	Type of Test	Results
AA A-2	flexible or cushioned fitting, dust and splash, clear plastic	Observation Marking Optical Quality	pass pass
AA B-2	flexible or cushioned fitting, dust and splash, clear plastic	Observation Marking Optical Quality	pass pass
AA C-2	flexible or cushioned fitting, welder's and cutter's, green glass	Observation Marking Optical Quality	pass pass pass
AA D-2	flexible or cushioned fitting, chipper's clear plastic	Observation Marking Optical Quality	pass pass
AA E-2	green glass (welders) flexible or cushioned cover cup	Observation Marking Optical Quality	fail (6. 1. 1. 4. 2: $< 90^{\circ}$) pass pass
AA F-2	flexible (chippers) clear glass	Observation Marking Optical Quality	fail (6. 1. 1. 4. 2: hindrance 85° - 90° pass
DD A-2	flexible or cushioned fitting, dust and splash, clear plastic	Observation Marking Optical Quality	pass pass
DD B-2	flexible or cushioned fitting, dust and splash, clear plastic	Observation Marking Optical Quality	pass pass
DD C-2	flexible or cushioned fitting, dust and splash, clear plastic	Observation Marking Optical Quality	pass pass
DD D-2	cup type (chippers) clear glass	Observation Marking Optical Quality	fail (6. 1. 1. 4. 2: $< 105^{\circ}$) pass
DD E-2	cup type (chippers), clear glass	Observation Marking Optical Quality	fail (6. 1. 1. 4. 2: $< 105^{\circ}$) pass
DD G-2	cup type (cutter's) dark green glass	Observation Marking Optical Quality	pass pass pass
EE L-2	flexible or cushioned fitting, dust and splash, clear plastic	Observation Marking Optical Quality	pass pass

TABLE 8-9. OBSERVATIONS, MARKING, OPTICAL QUALITY - GOGGLES (Cont'd)

SwRI Code #	Description	Type of Test	Results
FF B-2	flexible or cushioned fitting, dust and splash, clear plastic	Observation	pass
		Marking	
		Optical Quality	pass
HH A-2	flexible fitting, dust and splash, clear plasticq	Observation	pass
		Marking	
		Optical Quality	pass
LL A-2	light green plastic	Observation	fail - 6.1.1.4.4, 6.1.1.4.5, 6.1.3.1, 6.1.3.4
		Marking	fail - 6.1.1.4.7
		Optical Quality	pass
MM A-2	flexible (dust and splash) clear plastic	Observation	pass
		Marking	
		Optical Quality	pass
MM C-2	flexible (dust and splash) clear plastic	Observation	pass
		Marking	
		Optical Quality	pass
MM D-2	flexible (dust and splash) clear plastic	Observation	pass
		Marking	
		Optical Quality	pass
NN A-2	cup type (cutter) dark green glass	Observation	pass
		Marking	pass
		Optical Quality	pass
NN B-2	cover cup type eye-cup, clear glass	Observation	pass
		Marking	
		Optical Quality	pass
NN D-2	cover cup type eye-cup, dark green glass	Observation	pass
		Marking	pass
		Optical Quality	pass
NN F-2	flexible fitting (welders) dark green plastic shade #5	Observation	pass
		Marking	pass
		Optical Quality	pass
NN E-2	flexible fitting (dust) clear plastic	Observation	pass
		Marking	pass
		Optical Quality	pass
NN C-2	cup type (chippers) clear glass	Observation	pass
		Marking	
		Optical Quality	pass

if he could see the first set of lines placed 3 feet to either side of the centerline, and at least 105° if he could see the second set of lines placed 3 feet 10.9 inches to either side of the centerline. The field of vision, whether upward and downward or peripherally or both, should be better defined.

Table 8-10 contains the thicknesses of the goggles' lenses measured to within 0.001 inch using a micrometer, and the size of the ventilation openings measured with a ruler accurate to within 0.01 inch. A drill blank would also be good to use to measure the size of ventilation openings, especially for those which are round. Section 6.1.3.1 states that for flexible or cushioned fitting goggles "the goggles may be ventilated or not, as required by their intended use," but no mention is made as regards to the maximum ventilation hole size or the minimum ventilation area for those goggles that are ventilated. To remedy this paradox, we followed the ventilation requirements specified in 6.1.1.4.3(1), 6.1.1.4.3(2), and 6.1.1.4.3(3) for eyecup goggles when there were ventilation holes. Only under the most adverse conditions can it be conceived that there be no ventilation openings. Whenever possible, ventilated goggles should be worn to decrease irritation from wearing goggles.

TABLE 8-10. DIMENSIONS - GOGGLES

Minimum Ventilation Areas:

6.1.1.4.3(1) Chipper's Models
Through side: 0.307 in^2
Around Lens Returning Ring: 0.074 in^2

6.1.1.4.3(2) Dust and Splash Models:
In each eyecup: 0.087 in^2

6.1.1.4.3(3) Welder's Models
In each eyecup: 0.087 in^2

1. When 6.1.3.5 occurs, lenses must be $\geq$ 0.050" thick
2. When 6.3.3.1 occurs, lenses must be 3.0 mm - 3.8 mm
3. When 5.1.4.1.7 occurs, lenses must be $\geq$ 0.050" thick

NOTE: Chippers's Goggles (6.1.1.4.3(1))
(a) Sideshields shall exclude 0.040" diameter particle
(b) Lens retaining rings shall exclude 0.080" diameter particle

SwRI Code #	Description	Z87.1#	Dimensions	Results
AA A-2	flexible or cushioned fitting, chipper's model, clear plastic	6.1.3.5	0.062" 0.062" 0.072"	pass
		6.1.1.4.3(1)		pass
AA B-2	flexible or cushioned fitting, dust and splash model, clear plastic	6.1.3.5	0.059" 0.060" 0.059"	pass
		6.1.1.4.3(2)		pass
AA C-2	flexible or cushioned fitting, welders model, weld plate #5	6.1.1.4.3(3)	.062", .062" .062" (cover) .138", .138" .139" (sh #5)	pass pass
AA D-2	flexible or cushioned fitting, cutters model, clear plastic	6.1.3.5	Front 0.057" 0.059" 0.062"	pass
			Back 0.110" 0.111" 0.111"	pass
		6.1.1.4.3(3)		pass
AA E-2	flexible or cushioned fitting, welder's, cover cup	6.1.3.5	rt front 0.060" rt back 0.145" lt front 0.062" lt back 0.145"	pass
		6.1.1.4.3(3)		pass
AA F-2	flexible or cushioned fitting, chipper, cover cup, clear plastic	6.1.3.5	rt lens 0.130" lt lens 0.130"	pass
		6.1.1.4.3(2)		pass

TABLE 8-10. DIMENSIONS - GOGGLES (Cont'd)

SwRI Code #	Description	Z87.1 #	Dimensions	Results
DD A-2	flexible or cushioned-ed fitting, dust and splash, clear plastic	6.1.3.5	0.055" 0.054" 0.053"	pass
		6.1.1.4.3(2)		pass
DD B-2	flexible or cushion-ed fitting, chipper, clear plastic	6.1.3.5	0.050" 0.051" 0.051"	pass
		6.1.1.4.3(1)		pass
DD C-2	flexible or cushion-ed fitting, chipper's, clear plastic	6.1.3.5	0.053" 0.054" 0.053"	pass
		6.1.1.4.3(1)		pass
DD D-2	clear glass, cup type, chipper's	6.3.3.1	rt lens 0.127" lt lens 0.127"	pass
		6.1.1.4.3(1)		pass
DD E-2	clear glass, cup type, chipper's	6.3.3.1	rt lens 0.128" lt lens 0.128"	pass
		6.1.1.4.3(1)		pass
DD F-2	glass cover, shade #5 (hardened) cover-cup type, welder's	5.1.4.1.7 6.3.3.1 5.1.4.1.7 6.3.3.1	rt front 0.059" rt back 0.137" lt front 0.060" lt back 0.137"	pass
		6.1.1.4.3(3)	area = .034 in^2	fail
DD G-2	glass cover, shade #5 (hardened) cup type, welder's	5.1.4.1.7 6.3.3.1 5.1.4.1.7 6.3.3.1	rt front 0.060" rt back 0.126" lt front 0.060" lt back 0.125"	pass
		6.1.1.4.3(3)	area = .034 in^2	fail
EE L-2	flexible or cushion-ed fitting, dust and splash model, clear plastic	6.1.3.5	0.067" 0.067" 0.067"	pass
		6.1.1.4.3(2)		pass
FF B-2	flexible or cushion-ed fitting, dust and splash model, clear plastic	6.1.3.5	0.060" 0.063 0.063"	pass
		6.1.1.4.3(2)		pass
HH A-2	flexible or cushion-ed fitting, dust and splash, clear plastic	6.1.3.5	0.065" 0.065" 0.064"	pass
		6.1.1.4.3		
LL A-2	lt green, plastic chipper's	6.1.3.5	0.086" 0.081" 0.086"	pass

TABLE 8-10. DIMENSIONS - GOGGLES (Cont'd)

SwRI Code #	Description	Z87.1 #	Dimensions	Results
		6.1.1.4.3(1)	ventilation opening $\simeq$ 0.11", too large	fail
MM A-2	flexible or cushioned fitting, dust and splash, clear plastic	6.1.3.5	0.095" 0.095" 0.097"	pass
		6.1.1.4.3(2)		pass
MM C-2	flexible or cushioned fitting, dust and splash, clear plastic	6.1.3.5	0.084" 0.084" 0.084"	pass
		6.1.1.4.3(2)		
MM D-2	flexible or cushioned fitting, dust and splash, clear plastic	6.1.3.5	0.049" 0.050" 0.050"	fail
		6.1.1.4.3(2)		pass
NN A-2	clear plastic cover, shade #5 (plastic), cu type (cutters and welders)	5.1.4.1.7 6.3.3.1 5.1.4.1.7 6.3.3.1	rt front 0.049" rt back 0.136" lt front 0.69" lt back 0.136"	fail
		6.1.1.4.3(3)	ventilation OK, but doesn't prevent passage of light from side	fail
NN B-2	cover cup, chippers, clear glass	6.3.3.1	rt 0.138" lt 0.137"	pass
		6.1.1.4.3.1(1)		pass
NN D-2	cover cup, chipper and welders, plastic cover, plastic shade #5	5.1.4.1.7 6.3.3.1 6.3.3.1	rt front 0.059" rt back 0.125" lt front 0.63" lt back 0.123"	pass
		6.1.1.4.3(3)	area = .0978 in^2	fail
NN F-2	flexible or cushioned, welders, plastic shade #5	6.1.3.5	0.052" 0.054" 01056"	pass
		6.1.1.4.3(3)		pass
NN E-2	clear plastic flexible or cushioned dust and splash	6.1.3.5	.050" .050" .050"	pass
		6.1.1.4.3(2)		pass
NN C-2	clear glass, cup type (chipper's)	6.3.3.1	rt 0.138" lt 0.137"	pass
		6.1.1.4.3(1)	.096 in^2 - should be at least .305 in^2	fail

Observations:
5.1.4.1.1

Helmet Body. The helmet body shall be of such size and shape as to protect the face, forehead, ears, and neck to a vertical line back of the ears. It shall have an opening or openings in the front for filter plates or filter lenses. The helmet body shall be attached to the headgear in such a way that it will not come in contact with any part of the head and that it can be lifted up from in front of the face and hold its position in front of the head. The helmet body shall be made of vulcanized fiber, reinforced plastic, or other suitable material which shall be thermally insulating, noncombustible or slow burning; opaque to visible, ultraviolet, and infrared radiations; and capable of withstanding disinfection. The inside of the helmet body shall have a low light-reflecting finish. Rivets or other metal parts, if terminating on the inside surface, shall be adequately separated from the wearer's head.

5.1.4.1.3

Headgear. The helmet shall have a headgear or cradle that shall hold the helmet body comfortably and firmly on the wearer's head, but shall permit the helmet body to be tilted back over the head. The headgear shall be readily adjustable, for all head sizes from 6-1/2 to 7-5/8, without the use of tools. The headgear shall be made of materials which are thermally insulating, noncombustible, or slow burning, resistant to heat, and capable of withstanding disinfection. Where required, the headgear shall be fitted with a removable and replaceable sweatband covering at least the forehead portion of the headband. The sweatband shall be made of leather or other suitable material which is slow burning, and nonirritating.

5.1.4.1.5

Filter- and Cover-Plate Mounting. The front of the helmet body shall be provided with a light-tight plate-mounting frame or frames made of metal, plastic, or other suitable material, which shall be attached securely to the body of the helmet or shall be an integral part of the helmet. The frame shall provide a window through which the welding or cutting operation may be seen by the wearer; the window opening shall be not less than 3-5/8 inches wide and 1-5/8 inches high, or equivalent in area and visual field. The frame shall permit the removal and replacement of filter and cover plates without the use of tools and without damage to the plates

or frame. The mounting shall be so designed that the filter plate will be not less than 2 inches (50.8 millimeters) from the eyes of the wearer.

5.1.4.4.1 Lift Front. The lift front shall be fabricated from metal, plastic, or other suitable material. A snap hinge shall be provided so that the front part will stay up or down but will not remain in a partially opened position. The lift-front seal against the helmet shall be light tight. The lift front shall be designed to accommodate three plates: a clear impact-resisting plate in the back or fixed part, a filter plate (impact-resisting when specified), and a cover plate in the front part. The back or fixed-part plate shall be clear heat-treated glass, or plastic, not more than 3/16 inch thick and shall be capable of withstanding the impact tests specified in 5.1.4.1.6(4).

5.1.4.4.2 Chin Rest. To avoid contact of the helmet with the face of the wearer, a chin rest may be provided. In lieu of a chin rest, an adjustable position stop may be provided to perform the same function. The chin rest shall be constructed of suitable, rigid material and shall be detachable from the body of the helmet or hand shield.

Marking: 5.1.5 Helmets and shields shall bear a permanent and legible marking by which the manufacturer may be readily identified.

Weight: 5.1.4.1.2 Weight. The helmet or hand shield, exclusive of filter or cover plates, shall weigh no more than 28 ounces (793 grams).

Table 8-11 contains the result of examining some of the physical characteristics of welding helmets (observations, marking, opacity, weight, etc.).

TABLE 8-11. OBSERVATIONS, MARKING, WEIGHT - WELDING HELMETS

SwRI Code #	Description	Type of Test	Results
AA N-3	Fibre	Observation	pass
		Marking	pass
		Weight	pass (10.93 oz)
AA N-4	Fibre glass	Observation	pass
		Marking	pass
		Weight	pass (13.49 oz)
AA N-5	Fibre glass	Observation	pass
		Marking	pass
		Weight	pass (15.06)
CC A-1	Vulcanized fibre	Observation	pass
		Marking	pass
		Weight	pass (12.64 oz)
CC A-2	Vulcanized fibre	Observation	pass
		Marking	pass
		Weight	pass (17.18 oz)
CC A-3	Fiberglas	Observation	pass
		Marking	pass
		Weight	pass (17.60 oz)
CC A-4	Fiberglas	Observation	pass
		Marking	pass
		Weight	pass (14.98 oz)
CC A-5	Fiberglas	Observation	pass
		Marking	pass
		Weight	pass (18.99 oz)
CC A-6	Fiberglas	Observation	pass
		Marking	pass
		Weight	pass (20.22 oz)
CC A-7	Fiberglas	Observation	pass
		Marking	pass
		Weight	pass (16.06 oz)
CC A-8	Vulcanized fibre	Observation	pass
		Marking	pass
		Weight	pass (18.53 oz)
CC A-9	Thermoplastic	Observation	pass
		Marking	pass
		Weight	pass (13.36 oz)
CC A-10	Thermoplastic	Observation	pass
		Marking	pass
		Weight	pass (14.94 oz)
DD P-1	Fiber glass	Observation	pass
		Marking	pass
		Weight	pass (16.61 oz)

HAZE TEST (6.3.2.5, 6.3.4.4, Appendix A.1)

In addition to the problems stated earlier (Task 6), there are a few other ambiguities to be resolved in the way the haze test is worded in Appendix A.1 of the ANSI Z87.1 standard. The test specifies that the specimen be "placed in front of the aperture (A) at the photocell." Nowhere is it mentioned which side of aperture (A) is the front. Logically, the aperture should be placed between the photoelectric cell and the specimen. A simple diagram showing the relative positions of the photoelectric cell, two apertures, tungsten lamp and two different specimen positions would easily remedy the problem.

If Aperture (A) is placed between the detector and specimen, then the thickness of the material used to make aperture (A) is important. Ideally, it should be as thin as possible. Figure 8-1 will help explain the effect of an aperture made by carving a hole in a thick piece of material. In the test, it is intended that when the specimen is placed in front of aperture (A), both parallel and diffuse light strikes the detector. As the drawing indicates, however, the thicker the aperture mount, the less the amount of scattered light that will reach the detector. For this reason, we made our aperture mount out of 1/16 in. thick cold roll steel. Steel was used because of its rigidity.

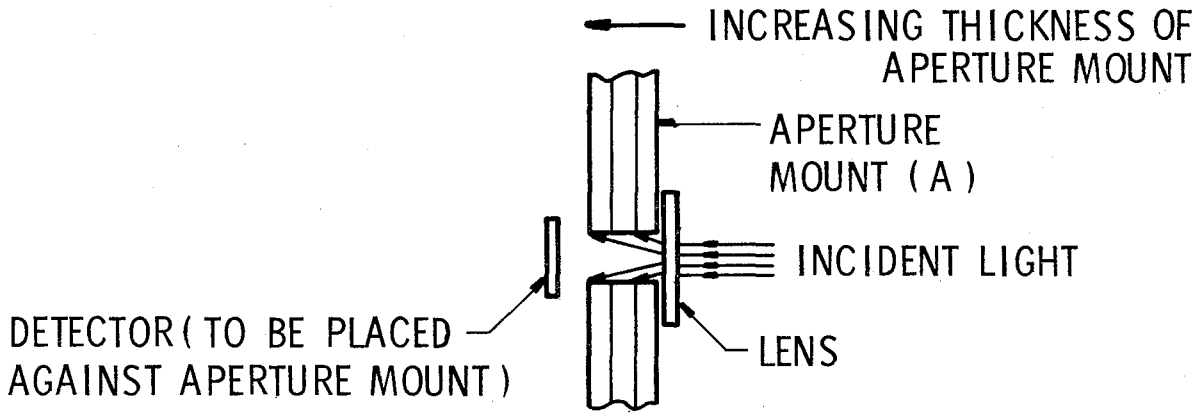
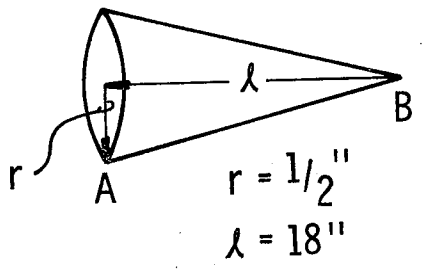


FIGURE 8-1. EFFECT OF INCREASING THICKNESS OF APERTURE MOUNT ON HAZE TEST

Another important quantity is the diameter of the detecting surface, if the surface is round, or the diameter of the largest circle that can be drawn on the detecting surface, if it is some other shape. If the diameter of aperture (A) is to have any meaning in the haze test, it must be smaller than the effective detector diameter and the detector must be placed as close to the aperture mount as possible. The aperture mount must be close to

the detector so that all of the light that goes through the aperture strikes the detector. This is also not mentioned in Appendix A. 1 of the ANSI Z87. 1 standard.

Rather than specify the aperture size and distance between apertures, the aperture size should be determined by the detector size and the distance between apertures should be determined by the solid angle subtended at the center of aperture (B) by aperture (A), both apertures being the same size. The solid angle subtended in the haze test in Appendix A. 1 is:



$$d\Omega = \frac{\hat{r} \cdot d\vec{\sigma}}{\ell^2} \qquad d\Omega = \pi/1296$$

$$d\Omega = \frac{\hat{r} \cdot \pi r^2}{\ell^2}$$

$$d\Omega = \frac{\pi(\frac{1}{2})^2}{18^2}$$

Since our photodiode had a 1/2 inch diameter circular detecting surface, we used 3/8" diameter apertures. With these dimensions, we separated the apertures 6.75 inches.

$$d\Omega_1 = d\Omega_2 \qquad \ell = 3/16\sqrt{1296}$$

$$\frac{\pi}{1296} = \frac{\pi(3/16)^2}{\ell^2} \qquad \ell = 6.75"$$

Our setup for the haze test was shown in Figure 8-2.

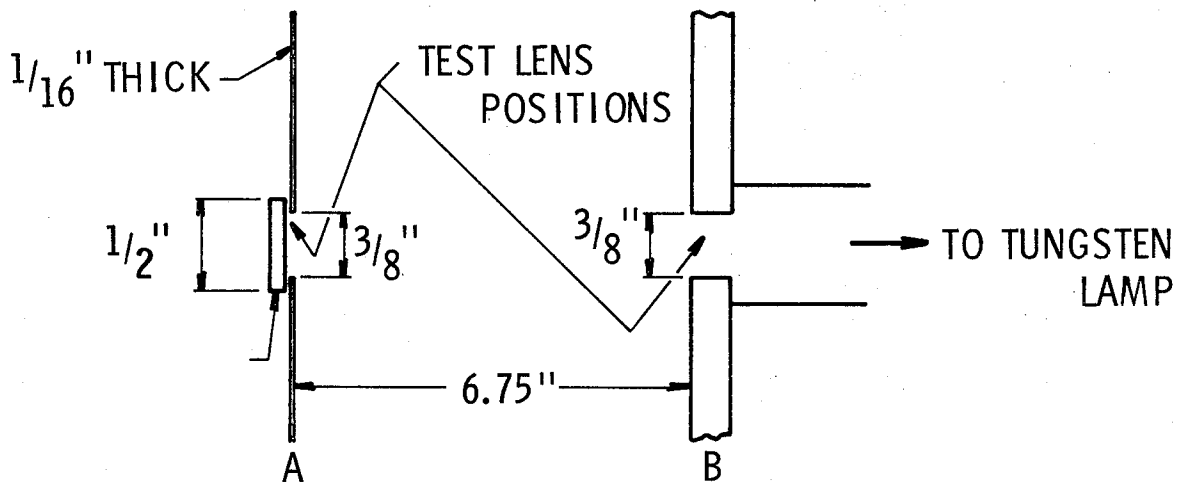


FIGURE 8-2. SETUP FOR THE HAZE TEST

When we conducted the haze test, we removed the lenses from the goggles and frames in order to place them flat against the apertures. A new

design (cf, Figure 8-3) would permit the test to be conducted while the lenses are still in their frames and thus decrease the time needed to complete the test. Care should be taken to present the same area of

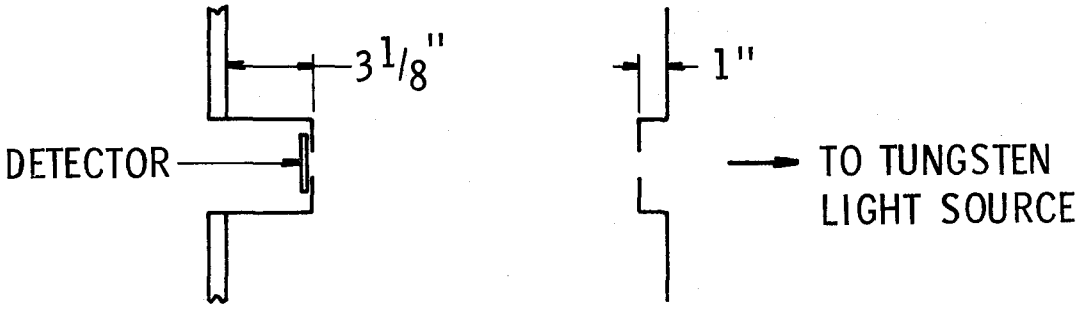


FIGURE 8-3. FUNCTIONAL DESIGN FOR HAZE TEST SETUP

the lenses to both apertures (A) and (B). In all of our measurements, we took this precaution. We also placed the lenses in such an orientation as if they are being worn and the observor is looking into the light source. I would recommend that measurements be made in the center of each lens or lens half and three measurements be made on faceshields: center-right center-center, center-left. A haze test for curved lenses should be developed if the haze test is to be kept in the new standard.

Table 8-12 shows the results of the haze test on the selected plastic face shields at the three locations suggested above. Table 8-13 shows the results of the haze test for plastic goggles. Table 8-14 shows the results of the haze test on selected plastic filter plates. Figure 8-4 and Table 8-15 show the results of the haze test performed at different locations suggested in Mil 38-169 on a selected plastic goggle. Table 8-16 shows the results of the haze test performed on the right lens of a goggle placed at different angles with respect to the apertures, zero degrees being normal to the parallel light path. Table 8-17 shows the results of the haze test on curved plastic and glass spectacle lenses for comparison. Table 8-18 shows the results of the haze test on some glass goggle lenses for comparison to plastic lenses.

It should be noted that there is some error connected with determining the value of haze of curved lenses by this method due to spreading out of the light due to the curved surfaces. Gardner Laboratories claims that their hazemeter has an error of less than 0.2% for lenses with a radius of curvature even as small as 1.5 inches. We do not have any information, however, to show this.

TABLE 8-12. HAZE TEST - FACESHIELDS

Passing Criterion: ≤ 6% average haze

Test Lens SwRI Code No.	Lens Designation	Average Haze %
AA L-1	Right	0.93
	Center	0.75
	Left	1.68
AA M-1	Right	0.73
	Center	1.82
	Left	1.45
DD N-1	Right	3.83
	Center	2.78
	Left	2.44
FF J-1	Right	1.74
	Center	1.55
	Left	1.90
JJ R-1	Right	2.26
	Center	1.90
	Left	1.92
JJ R-2	Right	1.20
	Center	1.71
	Left	0.85
JJ R-3	Right	1.20
	Center	2.06
	Left	1.54
JJ R-4 lt. green	Right	1.90
	Center	1.87
	Left	3.64
JJ R-5	Right	1.39
	Center	1.04
	Left	0.70
JJ R-6 dark green	Right	5.16
	Center	2.74
	Left	1.68

TABLE 8-13. HAZE TEST - GOGGLES

Passing Criterion: ≤ 6% average haze

Test Lens SwRI Code No.	Lens Designation	Average Haze %
AA A-1	Right	0.62
	Left	1.40
AA A-2	Right	1.55
	Left	1.85
AA A-3	Right	2.01
	Left	2.18
AA A-4	Right	1.09
	Left	1.09
AA A-5	Right	1.24
	Left	1.09
AA A-6	Right	1.71
	Left	2.16
AA A-7	Right	1.87
	Left	1.25
AA B-1	Right	1.40
	Left	1.86
AA B-2	Right	1.09
	Left	2.34
AA B-3	Right	1.71
	Left	2.02
AA B-4	Right	1.73
	Left	1.73
AA B-5	Right	1.58
	Left	1.73
AA B-6	Right	2.04
	Left	1.73
AA B-7	Right	1.57
	Left	1.56
AA C-1	plastic cover plate	1.38
AA C-2	plastic cover plate	1.38
AA C-3	plastic cover plate	0.96
AA C-4	plastic cover plate	0.96

TABLE 8-13. HAZE TEST - GOGGLES (Cont'd)

Test Lens SwRI Code No.	Lens Designation	Average Haze %
AA C-5	plastic cover plate	1.75
AA C-6	plastic cover plate	2.25
AA C-7	plastic cover plate	1.28
AA D-1	front	1.12
	back	1.44
AA D-2	front	3.22
	back	1.61
AA D-3	front	1.60
	back	1.28
AA D-4	front	1.44
	back	1.44
AA D-5	front	2.57
	back	1.60
AA D-6	front	1.61
	back	1.60
AA D-7	front	2.75
	back	0.97
DD A-1	Right	1.83
	Left	1.68
DD A-2	Right	2.34
	Left	3.00
DD A-3	Right	1.84
	Left	2.17
DD A-4	Right	2.50
	Left	2.00
DD A-5	Right	2.17
	Left	3.00
DD A-6	Right	2.01
	Left	2.86
DD A-7	Right	2.34
	Left	2.51
DD B-1 (curved)	Right	1.88
	Left	1.70

TABLE 8-13. HAZE TEST - GOGGLES (Cont'd)

Test Lens SwRI Code No.	Lens Designation	Average Haze %
DD B-2 (curved)	Right	1.88
	Left	2.56
DD B-3 (curved)	Right	2.81
	Left	1.59
DD B-4 (curved)	Right	2.31
	Left	2.13
DD B-5 (curved)	Right	2.12
	Left	2.28
DD B-6 (curved)	Right	2.48
	Left	1.59
DD B-7 (curved)	Right	2.28
	Left	0.35
DD C-1	Right	1.72
	Left	2.89
DD C-2	Right	2.92
	Left	1.54
DD C-3	Right	1.72
	Left	1.20
DD C-4	Right	1.72
	Left	1.88
DD C-5	Right	1.55
	Left	1.54
DD C-6	Right	1.89
	Left	0.85
DD C-7	Right	1.71
	Left	0.68
EE L-1	Right	3.57
	Left	2.63
EE L-2	Right	1.85
	Left	2.93
FF B-1	Right	3.50
	Left	3.82
FF B-2	Right	3.01
	Left	4.12

TABLE 8-13. HAZE TEST - GOGGLES (Cont'd)

Test Lens SwRI Code No.	Lens Designation	Average Haze %
FF B-3	Right	3.04
	Left	4.63
FF B-4	Right	3.21
	Left	3.36
FF B-5	Right	2.88
	Left	3.20
FF B-6	Right	2.26
	Left	3.06
FF B-7	Right	4.32
	Left	4.32
FF C-1 green	Right	5.98
	Left	10.3
GG M-1 (curved)	Right	3.24
HH A-1	Right	3.82
MM A-1	Right	1.30
	Left	1.47
MM B-1	Right	1.97
	Left	2.46
MM C-1 Front	Right	1.71
	Left	1.89
MM C-1 Back	Right	1.72
	Left	1.03
MM D-1	Right	2.48
	Left	2.12
MM E-1	Right	1.58
	Left	1.57
NN A-1	Right	1.81
	Left	0.83
NN A-1 Green, Back	Right	2.76
	Left	0.32
NN D-1 Front	Right	1.16
	Left	1.66

TABLE 8-13. HAZE TEST - GOGGLES (Cont'd)

Test Lens SwRI Code No.	Lens Designation	Average Haze %
NN D-1 Back	Right	2.95
	Left	1.94
NN E-1	Right	0.71
	Left	0.35
NN F-1 Dark Green	Right	0.95
	Left	4.01

Odd Type Goggles

Test Lens SwRI Code No.	Lens Designation	Average Haze %
LL A-1 (curved)	Right	1.86
	Left	0.51
LL A-2 light green (curved)	Right	2.06
	Left	0.19
LL A-3 medium green (curved)	Right	1.55
	Left	0
LL A-4 dark green (curved)	Right	2.42
	Left	3.49

TABLE 8-14. HAZE TEST - FILTER PLATES

Passing Criterion: $\leq$ 6% average haze

Test Lens SwRI Code No.	Lens Designation	Average Haze %
FF E-1	green plastic, sh #4	6.3
FF E-2	green plastic, sh #5	4.75

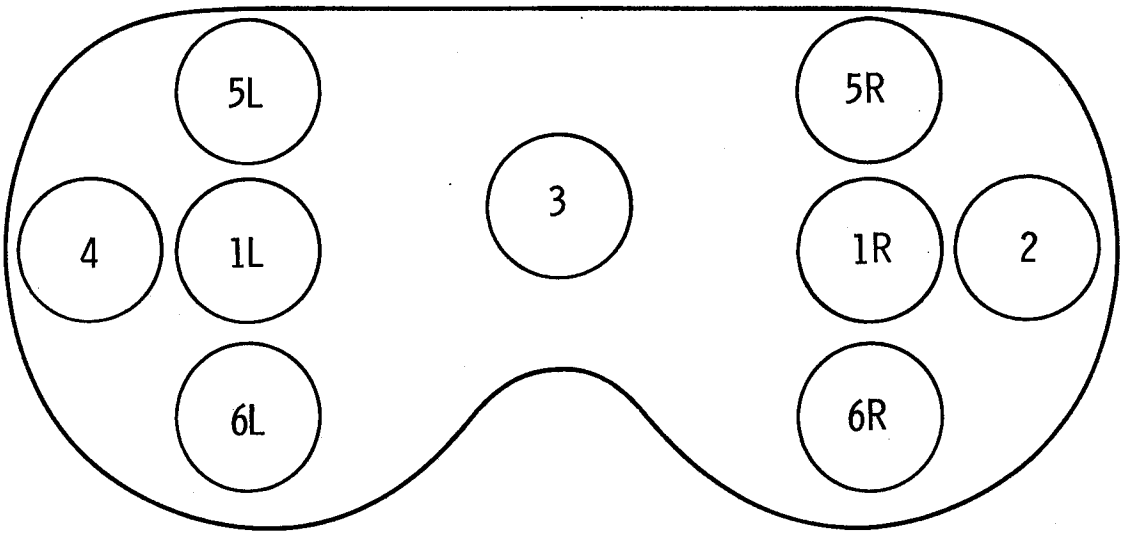


FIGURE 8-4. LOCATIONS OF HAZE MEASUREMENTS MADE ACCORDING TO MIL 38-169

TABLE 8-15. GOGGLES - MULTIPOSITION (MIL 38-169)

Passing Criterion: ≤ 6% average haze

Test Lens SwRI Code No.	Lens Designation	Average Haze %
DD A-2	1R	2.05
	1L	2.91
	2	1.71
	4	3.80
	5R	1.89
	5L	2.75
	6R	1.90
	6L	2.91
	3	2.56

TABLE 8-16. HAZE TEST - GOGGLES - MULTIANGLE

Passing Criterion: ≤ 6% average haze

Test Lens SwRI Code No.	Lens Designation	Average Haze %
DD A-2		
15°	Right	2.24
30°	Right	1.04
45°	Right	1.74

TABLE 8-17. HAZE TEST - SPECTACLE LENSES - GLASS AND PLASTIC

Test Lens SwRI Code No.	Lens Designation	Average Haze %
DD J-1	Glass	5.16
OO -1	Lexan	5.65

TABLE 8-18. HAZE TEST - GOGGLES - GLASS

Test Lens SwRI Code No.	Lens Designation	Average Haze %
AA E-1 Front	Right	0.83
Back	Right	0.50
AA F-1	Right	1.17
DD D-1	Right	1.01
DD E-1	Right	0.34
DD F-1 Front	Right	1.50
Back	Right	4.82
DD G-1 Front	Right	1.68
DD G-1	Right	0.18

To examine the validity of our values of haze, our apparatus was used to calculate the haze of a Gardner Laboratories Plastic Haze Standard with 5% haze. Twenty-one measurements were made and the haze calculated for each of the measurements. An average was then taken. Our readings averaged 4.31% for the 5% haze standard. This means that for flat specimens with 5.00% haze, our readings are 13.8% lower. One cannot, however, multiply our haze values for different lenses by 1.16 (i.e., 1.16 = 5.00/4.31) to arrive at the proper value of haze for values of true haze significantly different from 5%. A different calculation must be made as derived below:

Let $T_{A(T)}$ = true total light transmitted

$T_{B(T)}$ = true total parallel light transmitted

$T_{A(o)}$ = total light transmitted as given by our apparatus

$T_{B(o)}$ = total parallel light transmitted as given by our apparatus

If we assume that true values for $T_{A(T)}$ and $T_{B(T)}$ can be arrived at by multiplying $T_{A(o)}$ and $T_{B(o)}$ by constant values, then we can calculate true haze from our transmission values $T_{A(o)}$ and $T_{B(o)}$ as follows:

$$T_{A(T)} = x\, T_{A(o)} \qquad \text{where } x = \text{constant (assumption)} \tag{1}$$

$$T_{B(T)} = y\, T_{B(o)} \qquad \text{where } y = \text{constant (assumption)} \tag{2}$$

then True fractional haze

$$\left[\frac{T_{A(T)} - T_{B(T)}}{T_{A(T)}}\right] = \left[\frac{x\, T_{A(o)} - y\, T_{B(o)}}{x\, T_{A(o)}}\right] \tag{3}$$

Measurements from the 5% haze standard yield

$$(1.16)\left[\frac{T_{A(o)} - T_{B(o)}}{T_{A(o)}}\right] = \left[\frac{x\, T_{A(o)} - y\, T_{B(o)}}{x\, T_{A(o)}}\right] \tag{4}$$

$$(1.16) - (1.16)\left[\frac{T_{B(o)}}{T_{A(o)}}\right] = 1 - \left(\frac{y}{x}\right)\left[\frac{T_{B(o)}}{T_{A(o)}}\right] \tag{5}$$

$$\left(\frac{y}{x}\right)\left[\frac{T_{B(o)}}{T_{A(o)}}\right] = (1.16)\left[\frac{T_{B(o)}}{T_{A(o)}}\right] - (0.16) \tag{6}$$

$$\left(\frac{y}{x}\right) = (1.16) - (0.16)\left[\frac{T_{A(o)}}{T_{B(o)}}\right] \tag{7}$$

$$\left(\frac{y}{x}\right) = (1.16) - (0.16)\left[\frac{T_{A(o)}}{T_{B(o)}}\right] \tag{7}$$

$$y = \left\{(1.16) - (0.16)\left[\frac{T_{A(o)}}{T_{B(o)}}\right]\right\}(x) \tag{8}$$

For one of our actual haze values of 4.35% (~4.31% average)

$$T_{A(o)} = 59.8 \text{ mv} \tag{9}$$

$$T_{B(o)} = 57.2 \text{ mv} \tag{10}$$

therefore from (8) above

$$y \simeq \left[(1.16) - (0.16)\left(\frac{59.8}{57.2}\right)\right](x) \tag{11}$$

$$y \simeq 0.99273\, x \tag{12}$$

$$\frac{y}{x} = 0.99273 \tag{13}$$

then from (3)

$$\text{True fractional haze } \left[\frac{T_{A(T)} - T_{B(T)}}{T_{A(T)}}\right] = 1 - \left(\frac{y}{x}\right)\left[\frac{T_{B(o)}}{T_{A(o)}}\right] \tag{14}$$

$$\left[\frac{T_{A(T)} - T_{B(T)}}{T_{A(T)}}\right] \simeq 1 - (0.99273)\left[\frac{T_{B(o)}}{T_{A(o)}}\right] \tag{15}$$

Equation (15) is reliable only if assumptions (1) and (2) are valid. That is, actual transmitted energies $T_{A(T)}$ and $T_{B(T)}$ are related to our values of transmitted energies $T_{A(o)}$ and $T_{B(o)}$ by means of two constants x and y regardless of the actual value of haze. There is no guarantee that this is true, however, and as these formulations imply, more data points collected by making haze measurements of other haze standards with different values of haze should be made to examine the validity of the assumptions (1) and (2) that x and y are constant. We did not do this because haze standards are expensive and time is limited.

The description of the haze test to be performed on lenses as described in Appendix A1 of Z87.1 is inadequate in that it does not take into account plastic specimens less than 2 inches in diameter or curved specimens. The problems involved have not been adequately explained in Z87.1. The British and Australian standards for eye protectors do not have the haze test or similar tests. Perhaps it should not be included in the American standard. If it is, it should be presented in a better manner.

ULTRAVIOLET, LUMINOUS, AND INFRARED TRANSMITTANCE FOR FILTER PLATES, COVER PLATES, FACE SHIELDS, GOGGLES, AND ABSORPTIVE, FILTER, AND CLEAR LENSES. OPACITY OF WELDING HELMETS TO ULTRAVIOLET AND INFRARED TRANSMITTANCE.

Ultraviolet transmittance measurements (6.3.4.6.1) were made using an Illumination Industries Inc. 100 watt quartz mercury arc lamp #i.i.i.-107, a Bausch & Lomb monochrometer with an entrance and exit slit of 0.1 mm and with a 2700 grooves/mm diffraction grating to scan the spectral range of 180 to 400 nm, a RCA-4501/V4 ultraviolet sensitive phototube, and associated electronics including a high voltage power supply, operational amplifier, and a Hewlett-Packard #3439A digital voltmeter. Voltage readings were taken at the four mercury lines specified in Table 1 of the ANSI Z87.1 standard (313, 334, 365, and 405 nm) with and without the absorptive and filter lenses to be tested inserted between the light monochrometer source and detection system. Ultraviolet transmittance levels for various shades of absorptive lenses, filter lenses and plates are recorded in Table 8-19 which follows.

Luminous transmittance measurements (6.3.4.6.2) were made using a GE CDJ 100 watt gas filled Tungsten lamp with a color temperature near 2854°K adjusted by means of a rheostat and stabilized by means of a constant voltage transformer. The lamp was mounted in front of an adjustable front surface concave mirror and the lamp and mirror placed in a box with a 1-5/8-inch diameter 3-inch long blackened exit tube attached. The light was reflected from a white chalk flat surface placed at 45° to the lamp exit tube. The light then passed through two 1-inch apertures spaced 18 inches apart. Measurements were taken using a Gamma Scientific Model IC 2001 Telephotometer, with a photopic correction filter located in its optical path, placed approximately 6 feet from the second aperture. Test specimens were placed in front of the second aperture and the telephotometer was focused on an approximate 0.13-inch diameter spot on the specimen at the center of the aperture. Readings were taken with and without the test specimen in place and the luminous transmittance was calculated making the necessary corrections needed when auxiliary attenuation filters were used in the telephotometer. ANSI Tables 8-20 and 8-21 present luminous transmittance requirements for different eye and face protective devices. A question arises as to why the luminous transmission requirements for clear lenses varies so much, i.e., cover plates ($\geq$75%), faceshields ($\geq$85%) and other clear lenses (>89%). Why are they not all the same? Table 8-19 contains luminous transmittance of selected filter plates and absorptive lenses, and Table 8-22 contains the luminous transmittance of various other selected eye and face protective devices.

Integrated Infrared measurements (6.3.4.6.3) were made using a Tungsten lamp at a color temperature near 2854°K adjusted with a rheostat and stabilized with a constant voltage transformer. An infrared pass filter (Rolyn #65.1395) which passes wavelength of 1400 nm and above was placed over the

TABLE 8-19. TRANSMITTANCES OF VARIOUS SHADES OF ABSORPTIVE LENSES, FILTER LENSES AND PLATES

Transmittances of Various Shades of Absorptive Lenses, Filter Lenses and Plates

SwRI Code #	Description	Luminous Transmittance (%)	Integrated Infrared Transmittance (%)	Ultraviolet Transmittance (%) 313 nm	334 nm	365 nm	405 nm
AA K-1	filter plate glass-shade #4	5.12	.44	.001	.006	.000	.005
AA K-2	filter plate glass-shade #5	1.49	.70	.003	.001	.000	.004
AA K-3	filter plate glass-shade #6	0.424*	.38	.001	.001	.004	.002
AA K-4	filter plate glass-shade #8	0.0708	.41	.003	.001	.001	.002
AA K-5	filter plate glass-shade #9	0.0379	.86*	.010	.008	.003	.017
AA K-6	filter plate glass-shade #10	0.0123	.47	.002	.010	.000	.011
AA K-7	filter plate glass-shade #11	0.00476	.35	.022	.029	.006	.012
AA K-8	filter plate glass-shade #12	0.00318	.48	.003	.015	.030	.01
AA K-9	filter plate glass-shade #14	0.00114*	.33	.006	.018	.004	.113
DD L-1	filter plate glass-shade #4	4.00	.45	.003	.005	.00	.012

TABLE 8-19. TRANSMITTANCES OF VARIOUS SHADES OF ABSORPTIVE LENSES, FILTER LENSES AND PLATES (Cont'd)

SwRI Code #	Description	Luminous Transmittance (%)	Integrated Infrared Transmittance (%)	Ultraviolet Transmittance (%) 313 nm	334 nm	365 nm	405 nm
DD L-2	filter plate glass-shade #5	.188	.34	.004	.002	.002	.002
DD L-3	filter plate glass-shade #6	0.341*	.41	.005	.005	.002	.001
DD K-1a	55 mm round lenses-glass-shade #3	11.5	.92	.078	.125	.160	.100
DD K-1b	50 mm round lenses-glass-shade #3	11.2	.71	.113	.150	.171	.098
DD K-2a	50 mm round lenses-glass-shade #4	4.12†	.48	.172	.026	.039	.036
DD K-2b	50 mm round lenses-glass-shade #4	5.04†	.43	.002	.028	.011	.048
DD K-3a	50 mm round lenses-glass-shade #5	1.63	.36	.007	.034	.019	.215
DD K-3b	50 mm round lenses-glass shade #5	1.44	.37	.010	.060	.002	.189
DD K-4a	50 mm round lenses-glass-shade #6	0.484	.29	.009	.048	.009	.099
DD K-4b	50 mm round lenses-glass-shade #6	0.458‡	.39	.034	.036	.009	.088

TABLE 8-19. TRANSMITTANCES OF VARIOUS SHADES OF ABSORPTIVE LENSES, FILTER LENSES AND PLATES (Cont'd)

SwRI Code #	Description	Luminous Transmittance (%)	Integrated Infrared Transmittance (%)	Ultraviolet Transmittance (%) 313 nm	334 nm	365 nm	405 nm
DD K-5a	50 mm round lenses-glass-shade #8	0.074†	.42	.007	.038	.009	.020
DD K-5b	50 mm round lenses-glass-shade #8	0.0915†	.42	.005	.009	.031	.018
FF E-1	filter plate plastic-shade #4	4.56	2.33	.001	.002	.002	.003
FF E-2	filter plate plastic-shade #5	1.05*	1.59	.004	.019	.042	.019
FF E-3	filter plate plastic-shade #6	.373*	.62	.005	.025	.002	.012
FF E-4	filter plate plastic-shade #7	0.282	.69	.001	.020	.002	.001
FF E-5	filter plate plastic-shade #8	0.0654	.52	.004	.019	.006	.007
FF E-6	filter plate plastic-shade #9	0.0237	.55	.006	.022	.009	.003
FF E-7	filter plate plastic-shade #10	0.00882	.62	.004	.003	.006	.005
FF E-8	filter plate plastic-shade #11	0.00588	.48	.012	.011	.005	.009
FF E-9	filter plate plastic-shade #12	0.00251	.20	.013	.002	.002	.065
FF E-10	filter plate plastic-shade #13	.00292*	.16	.012	.013	.009	.009

TABLE 8-19. TRANSMITTANCES OF VARIOUS SHADES OF ABSORPTIVE LENSES, FILTER LENSES AND PLATES (Cont'd)

SwRI Code #	Description	Luminous Transmittance (%)	Integrated Infrared Transmittance (%)	Ultraviolet Transmittance (%) 313 nm	334 nm	365 nm	405 nm
FF E-11	filter plate plastic-shade #14	.00189*	.25	.005	.038	.003	.035
FF F-1a	50 mm round lenses-plastic-shade #4	2.40**	1.41	.005	.010	.005	.002
FF F-1b	50 mm round lenses-plastic-shade #4	2.66**	1.66	.006	.082	.007	.006
FF F-2a	50 mm round lenses-plastic-shade #5	1.47	.47	.006	.007	.002	.006
FF F-2b	50 mm round lenses-plastic-shade #5	1.53	.57	.013	.092	.002	.005
FF F-3a	50 mm round lenses-plastic-shade #6	0.773	1.06	.021	.020	.023	.029
FF F-3b	50 mm round lenses-plastic - shade #6	0.823	1.18	.007	.055	.008	.037

*Indicates failure.
† Each lens not within 20% of each other.
‡Warped.
**Equivalent to shade #5.

TABLE 8-20. TRANSMITTANCES AND TOLERANCES IN TRANSMITTANCE OF VARIOUS SHADES OF ABSORPTIVE LENSES, FILTER LENSES, AND PLATES

Shade Number	Optical Density			Luminous Transmittance			Maximum Infrared Transmittance	Maximum Spectral Transmittance in the Ultraviolet and Violet for Four Wavelengths (millimicrons) (or nanometers)*			
	Maximum	Standard	Minimum	Maximum	Standard	Minimum		313 mu	334 mu	365 mu	405 mu
				Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1.5	0.26	0.214	0.17	67	61.5	55	25	0.2	0.8	25	65
1.7	0.36	0.300	0.26	55	50.1	43	20	0.2	0.7	20	50
2.0	0.54	0.429	0.36	43	37.3	29	15	0.2	0.5	14	35
2.5	0.75	0.643	0.54	29	22.8	18.0	12	0.2	0.3	5	15
3.0	1.07	0.857	0.75	18.0	13.9	8.50	9.0	0.2	0.2	0.5	6
4.0	1.50	1.286	1.07	8.50	5.18	3.16	5.0	0.2	0.2	0.5	1.0
5.0	1.93	1.714	1.50	3.16	1.93	1.18	2.5	0.2	0.2	0.2	0.5
6.0	2.36	2.143	1.93	1.18	0.72	0.44	1.5	0.1	0.1	0.1	0.5
7.0	2.79	2.571	2.36	0.44	0.27	0.164	1.3	0.1	0.1	0.1	0.5
8.0	3.21	3.000	2.79	0.164	0.100	0.061	1.0	0.1	0.1	0.1	0.5
9.0	3.64	3.429	3.21	0.061	0.037	0.023	0.8	0.1	0.1	0.1	0.5
10.0	4.07	3.857	3.64	0.023	0.0139	0.0085	0.6	0.1	0.1	0.1	0.5
11.0	4.50	4.286	4.07	0.0085	0.0052	0.0032	0.5	0.05	0.05	0.05	0.1
12.0	4.93	4.714	4.50	0.0032	0.0019	0.0012	0.5	0.05	0.05	0.05	0.1
13.0	5.36	5.143	4.93	0.0012	0.00072	0.00044	0.4	0.05	0.05	0.05	0.1
14.0	5.79	5.571	5.36	0.00044	0.00027	0.00016	0.3	0.05	0.05	0.05	0.1

*1 mu = 1 nm.

TABLE 8-21. LUMINOUS TRANSMITTANCES REQUIREMENTS

Item	Shade	% Transmittance	ANSI Z87.1#
Filter Plates	cf ANSI Table 1	cf ANSI Table 1	5.1.4.1.6(3) 6.3.3.3.1 6.3.3.3.2
Cover Plates	clear	≥ 75	5.1.4.1.7
Face Shields	clear	≥ 85	5.2.8.3
	light	50 ± 7	
	medium	23 ± 6	
	dark	14 ± 6	
Other Lenses	clear	$\geq 89\%$	6.3.3.3

TABLE 8-22. LUMINOUS TRANSMITTANCE - OTHER LENSES (NOT ABSORPTIVE OR FILTER)

SwRI Code #	Description	Luminous Transmittance (%)
AA K-12	clear plastic-cover plate	91.7
AA J-1a	glass-shade # 7, 4, 8	91.7
AA J-1b	glass-shade # 7, 4, 8	91.3
AA L-3	clear plastic-faceshield	86.5
AA B-3	clear flex goggle	89.4
CC G-3	clear plastic-faceshield	89.8
CC F-3	dark green plastic-faceshield	15.7
DD L-4	clear glass-cover plate	91.1
DD J-3a	glass—shade # 7, 4, 8	90.7
DD J-3b	glass-shade # 7, 4, 8	90.3
DD N-3	clear plastic-faceshield	89.2
DD C-3	clear flex goggle	88.6*
EE L-2	clear flex goggle	89.7
FF E-12	clear glass-cover plate	91.5
FF B-3	clear flex goggle	85.2*
GG M-3	odd clear plastic spectacles	83.4*
HH A-3	clear flex goggle	84.4*
JJ R-2	clear plastic-faceshield	89.8
JJ R-4	medium green plastic-faceshield	17.2
JJ R-6	dark green plastic-faceshield	1.54†

TABLE 8-22. LUMINOUS TRANSMITTANCE - OTHER LENSES (NOT ABSORPTIVE OR FILTER) (Cont'd)

SwRI Code #	Description	Luminous Transmittance (%)
LL A-1	clear goggles	97.6
MM D-3	clear flex goggle	84.2*
NN E-3	clear flex goggle	81.5*

*Indicates failure.
† Equivalent to shade #5.

exit aperture of the light source which was aligned on the entrance slit of an Eppley Thermopile #2942. The output of the thermopile was read on the Hewlett-Packard digital voltmeter mentioned above. Measurements were taken with and without filter lenses and plates between the light source and thermopile and the integrated infrared transmittance was calculated and recorded in Table 8-

Opacity measurements of welding helmets to ultraviolet radiation were made using a 100-watt quartz mercury arc lamp and a phototube sensitive to ultraviolet radiation. Opacity measurements of welding helmets to infrared radiation were made using a 100-watt gas filled tungsten lamp and a thermopile.

Table 8-23 contains the results of the opacity of welding helmets to ultraviolet and infrared radiation. The helmets were tested for opacity to visible and infrared radiations by placing a section of the helmet between a standard Tungsten light source and a thermopile, noting the reading and comparing it to a reading taken when the light is blocked with a piece of metal. The whole apparatus was in a darkened room to diminish the effects of stray scattered light. A welding helmet was considered opaque when it had a transmittance less than that of the lower bound of a shade #14 filter plate.

All lenses were carefully cleaned with soap and water, rinsed in distilled water, and dried before tests were begun. All transmittance measurements were taken in a darkened room.

TABLE 8-23. OPACITY TO ULTRAVIOLET AND INFRARED RADIATION - WELDING HELMETS (5.1.4.1.1)

Passing Criteria: UV transmittance <0.05%
IR transmittance <0.3%

SwRI Code #	Description	UV Transmittance (%)*	IR Transmittance (%)†
SM N-3	fibre	0.00	0.0
FM A-2	vulcanized fibre	0.00	0.0
FM A-6	fiberglas	0.00	0.0
FM A-9	thermoplastic	0.00	0.0

*UV transmittance measurements were made using a Mercury arc lamp and UV sensitive phototube detector.
†IR transmittance measurements were made with a tungsten lamp and thermopile detector.

PRISMATIC POWER, REFRACTIVE POWER AND DEFINITION TESTS

The prismatic power (6. 3. 4. 1. 1), refractive power (6. 3. 4. 1. 2) and definition (6. 3. 4. 1. 3) tests were performed on various eye and face protective devices using the telescope with micrometer calibration and NBS resolving - power chart pattern 20 mentioned in Task 7 of this document and the test setup specified in ANSI Z87. 1 - 1968. Filter plates have to have less than 1/8 prism diopter [5. 1. 4. 1. 6(2)] and all other lenses less than 1/16 prism diopter (6. 3. 2. 2, 6. 3. 4. 1. 1) in order to pass the prismatic power test. We found that the prismatic power, refractive power, and definition tests could not be performed satisfactorily for shades #4 and above due to inadequate illumination (we used overhead flourescent lighting). For the higher shade numbers, direct projected lighting and/or shorter working distances will have to be used. This is a problem associated with the present standard and should be corrected. All of these tests state that the test lens be held in front of the objective lens of the telescope, and no mention is made as to the relative position of the test lens and the telescope objective lens. We noted that any angular movement of the lens with respect to the optical axis of the telescope had a tremendous effect on results of the prismatic power test. This must be clarified. In tune with the intent of the test, we positioned all flat lenses (cover plates, goggles, face shields, etc.) such that the normal to the largest surfaces of the lenses were parallel to the telescope optical axis. This was accomplished by placing a 1" thick piece of aluminum with smooth parallel faces and a 0. 75" diameter hole drilled through it in such a manner that the parallel faces were perpendicular to and the aperture was in line with the optical axis of the telescope. The inside of the aperture and the surface of the block facing the telescope were painted black to minimize reflections. The viewing surface of the test lens was then placed against this block and centered in front of the aperture. Another problem arises when plano lenses with curvature are tested since the geometric and optical center axes need not coincide. Lenses should be ground so that the optical center of the lens when worn will coincide with the line of vision of the wearer as he looks directly in front of him. Ideally the test should be performed with the lens mounted in their frames and placed on a suitable headform with the objective lens of the telescope replacing the eye of the headform. This setup would better simulate actual conditions. Since the standard does not mention how to position curved plano lenses, such as spectacle lenses, in front of the telescope, we centered the lenses on the aperture in the block with the protruding curved portion facing the block and partially cradled in the aperture. In this manner irregularities in the edges of the lenses could be overcome. It is recognized that this is not the best possible way to test these lenses and a more suitable method should be developed. Section 6. 3. 2. 2 in talking about lenses, filter plates being excluded, states that "the refractive power, in any meridian, of any noncorrective lens shall not exceed plus or minus 1/16 diopter. The difference in refractive power of any two meridians shall not exceed 1/16 diopter." To examine the difference in refractive power

of any two meridians, we placed the lens horizontal in the normal wearing position and perpendicular to this direction. The prismatic power and definition tests were performed with the lenses in the horizontal position.

Table 8-24 contains the results of the tests mentioned above performed on cover plates; Table 8-25, on face shields; Table 8-26, on goggles; and Table 8-27, on spectacle lenses.

TABLE 8-24. COVER PLATES (TELESCOPE TESTS)

Passing Criteria:
Prismatic Power: $\leq$ 1/16 diopter
Definition: NBS pattern #20 clearly resolvable
Refractive Power: -1/16 diopter $\leq$ Ref. Power $\leq$ + 1/16 diopter

SwRI Code #	Description	Prismatic Power (diopter)	Definition	Refractive Power (diopter)
AA K-12	clear plastic	< 1/16	good	within ± 1/16
DD L-4	clear glass	< 1/16	good	within ± 1/16
FF E-12	clear glass	< 1/16	good	within ± 1/16

TABLE 8-25. FACE SHIELDS (TELESCOPE TESTS)

Passing Criteria:
Prismatic Power: $\leq$ 1/16 diopter
Definition: NBS pattern #20 clearly resolvable
Refractive Power: -1/16 diopter $\leq$ Ref. Power $\leq$ + 1/16 diopter

SwRI Code #	Description	Prismatic Power (diopter)	Definition	Refractive Power (diopter)
AA L-3	clear plastic	< 1/16	good	within ± 1/16
AA M-3	clear plastic	< 1/16	good	within ± 1/16
CC F-3	green plastic	< 1/16	bad	not within ± 1/16
CC G-3	clear plastic	< 1/16	good	within ± 1/16
CC E-3	clear plastic	< 1/16	good	within ± 1/16
CC D-3	clear plastic	< 1/16	good	within ± 1/16
CC C-3	clear plastic	< 1/16	good	within ± 1/16
DD N-3	clear plastic	< 1/16	good	within ± 1/16
FF J-3	clear plastic	< 1/16	good	within ± 1/16
JJ R-3	clear plastic	< 1/16	good	within ± 1/16
JJ R-5	clear plastic	< 1/16	good	within ± 1/16

*Failure.

TABLE 8-26. GOGGLES (TELESCOPE TESTS)

Passing Criteria:
Prismatic Power: $\leq$ 1/16 diopter
Definition: NBS pattern #20 clearly resolvable
Refractive Power: -1/16 diopter $\leq$ Ref. Power $\leq$ + 1/16 diopter

SwRI Code #	Description	Prismatic Power (diopter)	Definition	Refractive Power (diopter)
AA A-3	flexible or cushioned fitting clear plastic	< 1/16	good	within ± 1/16
AA B-3	flexible or cushioned fitting clear plastic	< 1/16	good	within ± 1/16
AA C-3	flexible or cushioned fitting welder's, cutter's clear plastic cover plate	< 1/16	good	within ± 1/16
AA D-3	flexible or cushioned fitting chipper's, clear plastic, cover and back	< 1/16	good	within ± 1/16
AA E-3	welder's cover cup, clear glass cover circle	< 1/16	good	within ± 1/16
AA F-3	flexible chipper's clear glass, 50 mm round lens	< 1/16	good	within ± 1/16
DD A-3	flexible or cushioned fitting dust & splash clear plastic	< 1/16	good	within ± 1/16
DD B-3	flexible or cushioned fitting dust & splash clear plastic	< 1/16	good	within ± 1/16
DD C-3	flexible or cushioned fitting dust & splash clear plastic	< 1/16	good	within ±1/16
DD D-3	cup, chipper's clear glass	< 1/16	good	within ± 1/16
DD E-3	cup, chipper's clear glass	< 1/16	good	within ± 1/16

TABLE 8-26. GOGGLES (TELESCOPE TESTS) (Cont'd)

SwRI Code #	Description	Prismatic Power (diopter)	Definition	Refractive Power (diopter)
EE L-2	flexible or cushioned fitting dust & splash clear plastic	> 1/16*	bad*	not within ± 1/16
FF B-3	flexible or cushioned fitting dust & splash clear plastic	> 1/16*	bad*	within ± 1/16
HH A-3	flexible or cushioned fitting dust & splash clear plastic	> 1/16*	good	within ± 1/16
LL A-1	flexible or cushioned fitting clear plastic	< 1/16	bad*	within ± 1/16
MM A-3	flexible or cushioned fitting dust & splash clear plastic	< 1/16	good	not within ± 1/16*
MM C-3	flexible or cushioned fitting dust & splash clear plastic	< 1/16	good	within ± 1/16
MM D-3	flexible or cushioned fitting dust & splash clear plastic	< 1/16	good	within ± 1/16
NN A-3	cup, cutter's & welder's, clear plastic cover circle	< 1/16	good	within ± 1/16
NN B-3	cover cup, chipper's, clear glass, 50 mm round lens	< 1/16	good	within ± 1/16
NN C-3	cup, chipper's, clear glass, 50 mm round lens	< 1/16	good	within ±1/16
NN D-3	cover cup, welder's & cutter's clear plastic cover circle	< 1/16	good	within ± 1/16
NN E-3	flexible or cushioned fitting dust & splash clear plastic	> 1/16*	bad*	within ± 1/16

* Failure.

TABLE 8-27. SPECTACLE LENSES (TELESCOPE TESTS)

Passing Criteria:
Prismatic Power: $\leq$ 1/16 diopter
Definition: NBS pattern #20 clearly resolvable
Refractive Power: -1/16 diopter $\leq$ Ref. Power $\leq$ + 1/16 diopter

SwRI Code #	Description	Prismatic Power (diopter)	Definition	Refractive Power (diopter)
AA G-3	clear glass	< 1/16	good	within ± 1/16
AA H-3	clear glass	< 1/16	good	within ± 1/16
AA J-2a 2b	clear glass	< 1/16	good	within ± 1/16
AA P-3	clear glass	< 1/16	good	within ± 1/16
DD H-3	clear glass	< 1/16	good	within ± 1/16
DD J-1a, 1b	clear glass	< 1/16	good	within ± 1/16
EE L-5	clear glass	< 1/16	good	within ± 1/16
FF D-3	clear glass	< 1/16	good	within ± 1/16
FF G-1a, 1b	clear glass	< 1/16	good	within ± 1/16
GG M-3	clear plastic	> 1/16*	good	not within ± 1/16*
GG P-3	clear plastic	> 1/16*	bad*	not within ± 1/16*
HH D-1a	clear glass	< 1/16	good	within ± 1/16
HH E-1a	clear glass	> 1/16*	good	within ± 1/16
MM F-3	clear glass	< 1/16	good	within ± 1/16
MM H-3	clear glass	< 1/16	good	within ± 1/16
NN G-3	clear glass	< 1/16	good	within ± 1/16
NN H-3	clear glass	< 1/16	good	within ± 1/16

* Failure.

WATER ABSORPTION - PLASTIC PARTS (6.2.4)

Plastic lenses and frames were tested for water absorption using the procedure specified in Number 7031 of the Federal Test Methods Standard 406. It should be noted that the eye and face protective equipment tested were not within the size tolerances required in the test. Test method 7031 was designed for plastics and not for eye and face protective equipment. This ambiguity needs to be resolved in a new standard for this protective equipment.

For this test we used the following apparatus:

1. Desiccator
2. Balance accurate to milligrams
3. Micrometer accurate to 0.001"
4. Buckets large enough to accommodate the test specimens so that they could be stood on end.
5. Distilled water
6. Circulating air oven which can maintain 50°C ± 3°C (122°F ± 5.4°F) and 105°C - 110°C (221°F - 230°F)
7. Grounded Conductor
8. Thermometer

Since no specific duration of the test was mentioned in ANSI Z87.1, we used Procedure A which specified immersion in water for 24 hours. Procedure A was recommended in Method 7031 when absorption values of different plastics are to be compared. Method 7031 also specified that when data is to be used for comparison with other plastics, that one dry the specimens in an oven for 24 hours at 50°C ± 3°C.

Our procedure was as follows:

1. The specimens were washed in soap and water and rinsed in water. We then washed them in soap and distilled water and rinsed them in distilled water.
2. The specimens were then dried in a circulating air oven for 24 hours at 50°C ± 3°C, cooled in a desiccator, and lightly rubbed with a grounded conductor to remove any static charge.
3. The specimens were then weighed to the nearest milligram and measured to the nearest 0.001" in predetermined locations.
4. The specimens were placed on edge and entirely immersed in a container of distilled water at 23°C ± 1.1°C for 24 hours.
5. The specimens were removed from the water, dried with a dry, lint-free cloth, reweighed and measured.

6. The specimens were reconditioned in the oven, dried in the desiccator, rubbed with a grounded conductor, reweighed, and remeasured.
7. Observations as to warping, cracking, or change in appearance were made whenever the specimens were handled.
8. Calculations are as follows:

$$\% \text{ increase in weight} = \frac{(\text{wet weight}) - (\text{conditioned weight})}{(\text{conditioned weight})} \times 100$$

$$\% \text{ change in dimensions} = \frac{(\text{dim. after immersion}) - (\text{conditioned dim.})}{(\text{conditioned dimensions})} \times 100$$

$$\% \text{ soluble matter lost} - \frac{(\text{conditioned weight}) - (\text{reconditioned weight})}{(\text{conditioned weight})} \times 100$$

= 0.00% if the reconditioned weight is greater than the conditioned weight

% water absorbed = (% increase in weight) + (% solution matter lost)

Another quantity comparing the conditioned dimensions with the reconditioned dimensions, i.e., % change in dimensions =

$$\frac{(\text{reconditioned dimensions} - \text{conditioned dimensions})}{(\text{conditioned dimensions})} \times 100$$ was added for convenience. This quantity was calculated and recorded in the appropriate tables which follow.

Table 8-28a and Table 8-28b contain the results of the water absorption test on the lenses of selected flexible or cushioned fitting goggles. Table 8-29a and Table 8-29b contain the results of the water absorption test on the frames of selected flexible or cushioned fitting goggles. The water absorption test was conducted with the lenses separated from the frames. To pass the ANSI Z87.1-1968 standard, the amount of water absorbed shall not exceed 5 percent.

A further comment needs to be made about the water absorption test for clarity. We determined the water absorption of individual components (i.e., lenses and frames) of eye protectors because we recognized that different materials could be used in the lenses than in the frames, and we felt that the intent of the Z87.1 standard was that no component of the protective device should absorb more than 5% (by weight) water. There may be a tendency by some to determine the percent by weight of water absorbed in the whole goggle. It should be noted that total percent of water absorbed in an eye protector is not the sum of the percents of water absorbed in each component, but rather is proportional to the ratio of the total weight of water absorbed to the total initial weight of the eye protector, taking into account the effect of differences in conditioned weight versus reconditioned weight. Therefore, 4% water absorbed in one lens, 3% water absorbed in the other lens, and 5% water absorbed in the frame does not yield 12% total water absorbed in the eye protector but rather some value less than 5%. A brief proof will demonstrate this:

TABLE 28a. WATER ABSORPTION - EFFECT ON WEIGHT (LENSES)

Conditioning: 24 hours at 50°C + 3° C
Immersion: 24 hours in distilled water at 23°C ± 1.1°C
Lenses of Flexible or Cushioned Fitting Goggles

Passing Criterion: ≤ 5% (by weight) water absorbed

SwRI Code #	Cond. Wt (gm)	Wet Wt (gm)	Recond. Wt (gm)	% increase in weight	% soluble matter	% water absorbed
AA A-5 clear plastic	15.521	16.182	15.441	0.07	0.07	0.14
AA B-5 clear plastic	15.449	16.098	15.514	4.20	none	0.45
DD A-5 clear plastic	13.025	13.083	13.039	0.45	none	0.45
DD B-5 clear plastic	21.869	22.819	21.895	4.34	none	4.34
DD C-5 clear plastic	18.075	18.169	18.129	0.52	none	0.52
EE L-1 clear plastic	17.791	18.189	17.723	2.24	0.38	2.62
FF B-5 clear plastic	14.745	14.755	14.735	0.07	0.07	0.14
HH A-4 clear plastic	17.085	18.082	17.959	0.54	0.15	0.69
LL A-4 green plastic	31.741	31.897	31.659	0.49	0.26	0.75

TABLE 28a. WATER ABSORPTION - EFFECT ON WEIGHT (LENSES) (Cont'd)

SwRI Code #	Cond. Wt (gm)	Wet Wt (gm)	Recond. Wt (gm)	% increase in weight	% soluble matter	% water absorbed
MM A-5 clear plastic	18.183	18.375	18.059	1.06	0.68	1.74
MM C-5a clear plastic	12.819	13.423	12.845	4.71	none	4.71
MM C-5b clear plastic	12.693	13.273	12.689	4.57	0.03	4.60
MM D-5 clear plastic	15.911	16.613	15.909	4.41	0.01	4.42
NN E-5 clear plastic	*	24.991	24.541	---	---	---
NN F-5 green plastic	13.826	14.301	14.099	3.44	none	3.44

*No reading taken.

TABLE 28b. WATER ABSORPTION - EFFECT ON DIMENSIONS (LENSES)

Conditioning: 24 hours at 50°C ± 3°C
Immersion: 24 hours in distilled water at 23°C ± 1.1°C
Lenses of Flexible or Cushioned Fitting Goggles
(Note: Measurements were taken on the center of the right lens, center bridge, and left lens of each goggle)

SwRI Code #	Cond. Dim (in)	Wet Dim (in)	Recond. Dim (in)	% change in dim. cond to wet	% change in dim. cond to recond
AA A-5	.060	.061	.059	1.7	-1.7
clear	.060	.060	.060	0.0	0.0
plastic	.061	.060	.061	-1.6	0.0
AA B-5	.059	.060	.059	1.7	0.0
clear	.060	.060	.061	0.0	1.7
plastic	.059	.060	.061	1.7	3.4
DD A-5	.056	.056	.053	0.0	-5.4
clear	.053	.054	.056	0.0	5.7
plastic	.053	.053	.053	0.0	0.0
DD B-5	.052	.052	.059	0.0	13.5
clear	.052	.053	.052	1.9	0.0
plastic	.052	.052	.052	0.0	0.0
DD C-5	.053	.052	.054	-1.9	1.9
clear	.054	.054	.055	0.0	1.9
plastic	.053	.053	.053	0.0	0.0
EE L-1	.067	.068	.066	1.5	-1.5
clear	.068	.069	.068	1.5	0.0
plastic	.069	.068	.068	-1.5	-1.5
FF B-5	.060	.060	.060	0.0	0.0
clear	.060	.062	.061	3.3	1.7
plastic	.063	.061	.063	-3.2	0.0
HH A-4	.063	.064	.063	1.6	0.0
clear	.064	.061	.064	-4.7	0.0
plastic	.061	.064	.062	4.9	1.6
LL A-4	.078	.083	---*	6.4	----
green	.077	.083	---	7.8	----
plastic	.074	.083	---	12.2	----

TABLE 28b. WATER ABSORPTION - EFFECT ON DIMENSIONS (LENSES) (Cont'd)

SwRI Code #	Cond. Dim(in)	Wet Dim (in)	Recond. Dim (in)	% change in dim. cond to wet	% change in dim. cond to recond
MM A-5	.095	.094	.095	-1.1	0.0
clear	.097	.096	.096	-1.0	-1.0
plastic	.096	.098	.094	2.1	-2.1
MM C-5a	.041	.041	.041	0.0†	0.0
clear	.041	.040	.041	-2.4	0.0
plastic	.041	.041	.041	0.0	0.0
MM C-5b	.041	.041	.040	0.0	-2.4
clear	.042	.041	.040	-2.4	-4.8
plastic	.040	.041	.041	2.5	2.5
MM D-5	.050	.051	.050	2.0	0.0
clear	.051	.050	.051	-2.0	0.0
plastic	.050	.050	.050	0.0	0.0
NN E-5	.261	.238	.232	-8.8	-11.1
clear	.227	.237	.223	4.4	-1.8
plastic	.223	.232	.230	4.0	3.1
NN F-5	.058	.058	.058	0.0	0.0
green	.057	.059	.056	3.5	1-.8
plastic	.057	.058	.057	1.8	0.0

*Erroneous readings.
† Lens warped during reconditioning.

TABLE 29a. WATER ABSORPTION - EFFECT ON WEIGHT (FRAMES)

Conditioning: 24 hours at 50°C ±3°C
Immersion: 24 hours in distilled water at 23°C ± 1.1°C
Frames of Flexible or Cushioned Fitting

Passing Criterion: ≤ 5% (by weight) water absorbed

SwRI Code #	Cond. Wt (gm)	Wet Wt (gm)	Recond. Wt (gm)	% increase in weight	% soluble matter	% water absorbed
AA A-5 clear plastic	60.531	61.749	60.379	2.01	0.25	2.26
AA B-5 clear plastic	60.929	61.656	60.619	1.19	0.51	1.70
DD A-5 clear plastic	54.619	55.259	54.532	1.17	0.16	1.33
DD B-5 clear plastic	72.711	73.476	72.699	1.05	0.02	1.07
DD C-5 clear plastic	43.421	43.709	43.419	0.66	0.01	0.67
EE L-1 clear plastic	56.204	57.425	56.213	2.17	none	2.17
FF B-5 clear plastic	47.126	48.175	47.088	2.23	0.08	2.31
HH A-4 clear plastic	47.645	49.958	47.569	4.85	0.16	5.01
LL A-4 green plastic	12.161	12.121	12.129	0.33	0.26	0.59

TABLE 29a. WATER ABSORPTION - EFFECT ON WEIGHT (FRAMES) (Cont'd)

SwRI Code #	Cond. Wt (gm)	Wet Wt (gm)	Recond. Wt (gm)	% increase in weight	% soluble matter	% water absorbed
MM A-5 clear plastic	59.744	60.173	59.599	0.72	0.24	0.96
MM C-5 clear plastic	61.521	61.875	61.049	0.58	0.77	1.35
MM D-5 clear plastic	61.769	62.298	61.579	0.86	0.31	1.17
NN F-5 green plastic	51.388	52.295	51.339	1.77	0.10	1.87
NN E-5 clear plastic	47.671	48.485	47.749	1.71	none	1.71

TABLE 29b. WATER ABSORPTION - EFFECT ON DIMENSIONS (FRAMES)

Conditioning: 24 hours at 50°C ± 3°C
Immersion: 24 hours in distilled water at 23°C ± 1.1°C
Frames of Flexible or Cushioned Fitting Goggles
(Note: Measurements were taken on the top right, top center, and top left portions of each frame)

SwRI Code #	Cond. Dim (in)	Wet Dim (in)	Recond. Dim (in)	% change in dim. cond to wet	% change in dim. cond to recond
AA A-5	.065	.085	.080	30.8	23.1
clear	.065	.080	.090	23.1	38.5
plastic	.073	.083	.091	13.7	24.7
AA B-5	.082	.077	.059	-6.1	-28.0
clear	.080	.075	.055	-6.3	-31.3
plastic	.081	.077	.058	-4.9	-28.4
DD A-5	.057	.045	.070	-21.1	22.8
clear	.059	.043	.061	-27.1	3.4
plastic	0.61	.046	.062	-24.6	1.6
DD B-5	1.031	1.018	1.029	-1.3	-0.2
clear	1.031	1.015	1.024	-1.6	-0.7
plastic	1.025	1.019	1.025	-0.6	0.0
DD C-5	.066	.067	.065	1.5	-1.5
clear	.066	.063	.066	-4.5	0.0
plastic	.066	.065	.065	-1.5	-1.5
EE L-1	.079	.095	.081	20.3	2.5
clear	.079	.094	.084	19.0	6.3
plastic	.077	.096	.083	24.7	7.8
FF B-5	.062	.060	.054	-3.2	-12.9
clear	.063	.059	.068	-6.4	7.9
plastic	.062	.059	.081	20.3	-19.4
HH A-4	.062	---*	.064	---	3.2
clear	.063	---	.063	---	0.0
plastic	.066	---	.067	---	1.5
LL A-4	.034	.045	.043	32.4	26.5
green	.037	.043	.039	16.2	5.4
plastic	.034	.048	.040	41.2	17.6

TABLE 29b. WATER ABSORPTION - EFFECT ON DIMENSIONS (FRAMES) (Cont'd)

SwRI Code #	Cond. Dim (in)	Wet Dim (in)	Recond. Dim (in)	% change in dim. cond to wet	% change in dim. cond to recond
MM A-5	.067	.065	.071	-3.0	6.0
clear	.064	.064	.065	0.0	1.6
plastic	.071	.060	.062	-15.5	-12.7
MM C-5	.068	.097	.072	42.6	5.9
clear	.067	.098	.066	46.3	-1.5
plastic	.064	.095	.063	48.4	-1.6
MM D-5	.089	.065	.070	-27.0	-21.3
clear	.090	.064	.065	-28.9	-27.8
plastic	.095	.067	.067	-29.5	-29.5
NN E-5	.062	.058	.055	-6.5	-11.3
clear	.069	.059	.059	-14.5	-14.5
plastic	.056	.058	.058	3.6	3.6
NN F-5	.062	.058	.055	-6.5	-11.3
green	.059	.063	.059	6.8	0.0
plastic	.051	.060	.054	17.6	5.9

*Erroneous readings.

$$\% \text{ increase in weight} = \frac{\text{(wet weight) - (conditioned weight)}}{\text{(conditioned weight)}} \times 100$$

Let W_1, W_2, W_3 = weight of water absorbed in each of the three components in a goggle (2 lenses and frame)

M_{c_1}, M_{c_2}, M_{c_3} = conditioned weight of each component

Then the % increase in weight, (Q) due to water absorbed in each component and in the entire goggle is as follows:

$$Q_1 = \frac{W_1}{M_{c_1}} \times 100 \tag{1}$$

$$Q_2 = \frac{W_2}{M_{c_2}} \times 100 \tag{2}$$

$$Q_3 = \frac{W_3}{M_{c_3}} \times 100 \tag{3}$$

$$Q_T = \frac{W_T}{M_{c_T}} \times 100 \tag{4}$$

where W_T = total water absorbed in the goggle (2 lenses + frame)
M_{c_T} = total conditioned weight of the goggle (2 lenses + frame)

Rewriting Equation (4) in terms used in Equations (1), (2), and (3):

$$Q_T = \frac{W_1 + W_2 + W_3}{M_{c_1} + M_{c_2} + M_{c_3}} \times 100 \tag{5}$$

$$\text{N. B. } Q_T \neq Q_1 + Q_2 + Q_3 = \frac{W_1}{M_{c_1}} \times 100 + \frac{W_2}{M_{c_2}} \times 100 + \frac{W_3}{M_{c_3}} \times 100 \tag{6}$$

Equations (5) and (6) show that the total percent water absorbed in a goggle is not the sum of the percents of water absorbed in each component. Using an example (MM C-5a, MM C-5b, and MM C-5) from Tables 8-28a and 8-29a, the total percent increase in weight of the goggle (conditioned weight to wet weight) is:

$$\% \text{ increase in weight} = \frac{\text{(wet weight) - (conditioned weight)}}{\text{(conditioned weight)}} \times 100$$

$$= \frac{(13.423\text{g} - 12.819\text{g}) + (13.273\text{g} - 12.693\text{g}) + (61.875\text{g} - 61.521\text{g})}{(12.819\text{g} + 12.693\text{g} + 61.521\text{g})} \times 100$$

$$= \frac{(6.04g) + (.580g) + (.354g)}{(87.033g)} \times 100$$

$$= \frac{1.538g}{87.033g} \times 100$$

$$= 1.77\%$$

The total % soluble matter lost in the goggle (conditioned weight to reconditioned weight) is:

$$\% \text{ soluble matter lost} = \frac{(\text{conditioned weight}) - (\text{reconditioned weight})}{(\text{conditioned weight})} \times 100$$

= 0.00% if the reconditioned weight is greater than the conditioned weight.

$$= \frac{(0.00g) + (0.004g) + (.472g)}{(12.819g) + (12.693g + 61.521g)} \times 100$$

$$= \frac{(.476g)}{(87.033g)} \times 100$$

$$= 0.55\%$$

Total % water absorbed = (Total % increase in weight) + (Total % soluble matter lost)

$$= 1.77\% + 0.55\%$$

$$= 2.32\%$$

This value of 2.32% water absorbed for the goggle MM C-5 is substantially different from the 10.66% arrived at by adding the percents of water absorbed by each component.

FLAMMABILITY TEST

The flammability test was conducted on welding helmets (5.1.4.6), face shields (5.2.8.4), and goggle frames and lenses (6.1.1.4.1, 6.1.3.5, 6.1.4.4, 6.2.5.1, 6.3.4.5).

As specified in ANSI Z87.1 - 1968 sections 5" × 1/2" were cut out of the thinnest section of welding helmets and sections 5" × 1/2" were cut out of plastic window face shields. These sections were carefully and slowly cut with a band saw to eliminate unnecessary heating deformation. The flammability test for these two types of items was the same and our procedure was as follows. A blue-flame Bunsen burner and ringstand were placed in a draft-free location. The strip to be tested was rigidly attached to the ringstand in such a manner that it was inclined 45 degrees with its 5" longitudinal axis horizontal. The burner flame was adjusted to a height of 1/2" and the edge of the specimen was placed above the center of the flame at the top of the central bright blue-green cone, the hottest portion of the flame. After 10 seconds, the burner was removed and measurement of the burning rate was begun using a ruler and stop watch.

Goggle frames and lenses were tested using sections at least one inch long. Where possible, sections 1" × 1" were cut out of the samples and tested. The Bunsen burner flame was adjusted to 3/4" and the specimen was ignited by holding the edge of the specimen horizontally at the top of the hottest portion of the flame. After ignition the specimen was removed and the rate of propagation of the flame was measured with a stop watch.

It should be noted that the rate of propagation for helmets and face shields is measured in inches/minute and for other plastic items in seconds/inch. A consistent use of a length/time interval would be more appropriate. Also, the size and shape of specimens other than welding helmets and face shields should be better defined where possible.

Table 8-30 contains the results of the flammability test for welding helmets, Table 8-31 for plastic window face shields, Table 8-32 for goggle lenses, and Table 8-33 for goggle frames.

TABLE 8-30. FLAMMABILITY - WELDING HELMETS (5.1.4.6)

Passing Criterion: Rate of propagation shall be less than 3 inches per minute.

SwRI Code #	Description	Propagation Rate (in/min)	Results
AA N-3	Fibre	0.6	pass
AA N-4	Fibre Glass	0.5	pass
CC A-1	Vulcanized Fibre	0.6	pass
CC A-3	Fiberglass	0.2	pass
CC A-9	Thermoplastic	0.7	pass
DD P-1	Fiber Glass	0.1	pass

TABLE 8-31. FLAMMABILITY - PLASTIC WINDOW FACE SHIELDS (5.2.8.4)

Passing Criterion: Rate of propagation shall be less than 3 inches per minute.

SwRI Code #	Description	Propagation Rate (in/min)	Results
AA L-1	clear plastic	*	pass
AA M-1	clear plastic	*	pass
CC C-1	clear plastic	4.0	fail
CC D-1	clear plastic	1.5	pass
CC E-1	clear plastic	4.0	fail
CC G-1	clear plastic	*	pass
DD N-1	clear plastic	2.0	pass
FF J-1	clear plastic	*	pass
JJ R-1	clear plastic	*	pass
JJ L-6	green plastic	*	pass

*Would not continue to burn when flame was removed.

TABLE 8-32. FLAMMABILITY - LENSES OF FLEXIBLE FITTING GOGGLES (6. 3. 4. 5)

Passing Criterion: Rate of propagation shall be 24 seconds per inch or less. (2. 5 inches/minute).

SwRI Code #	Description	Propagation Rate (in/min)	Results
AA A-4	clear plastic	5. 0	fail
AA B-4	clear plastic	< 2. 5	pass
DD A-4	clear plastic, lens #2	*	pass
DD B-4	clear plastic	3. 0	fail
DD C-4	clear plastic	< 2. 5	pass
EE L-1	clear plastic	3. 2	fail
FF B-4	clear plastic	< 2. 5	pass
HH A-2	clear plastic, lens #2	*	pass
LL A-3	lt green plastic	< 2. 5	pass
MM A-4	clear plastic	< 2. 5	pass
MM C-4	clear plastic, lens #1	3. 5	fail
MM C-4	clear plastic, lens #2	3. 2	fail
MM D-4	clear plastic	3. 0	fail
NN E-4	clear plastic	< 2. 5	pass
NN F-4	green plastic	4. 0	fail

*Would not continue to burn when flame was removed.

TABLE 8-33. FLAMMABILITY - FRAMES OF FLEXIBLE FITTING GOGGLES (6.2.5.1)

Passing Criterion: Rate of propagation shall be 24 seconds per inch or less. (2.5 inches/minute)

SwRI Code #	Description	Propagation Rate (in/min)	Results
AA A-4	flexible fitting	0.5	pass
AA B-4	flexible fitting	0.9	pass
DD A-4	flexible fitting	0.9	pass
DD B-4	flexible fitting	0.6	pass
DD C-4	flexible fitting	0.9	pass
EE L-1	flexible fitting	*	pass
FF B-4	flexible fitting	0.6	pass
HH A-2	flexible fitting	0.9	pass
LL A-3	flexible fitting	0.5	pass
MM A-4	flexible fitting	0.5	pass
MM C-4	flexible fitting	0.8	pass
MM D-4	flexible fitting	0.6	pass
NN E-4	flexible fitting	0.9	pass
NN F-4	flexible fitting	*	pass

*Would not continue to burn when flame was removed.

IMPACT AND PENETRATION RESISTANCE TESTS

FACE SHIELDS

5.2.8.1 Impact Resistance, Plastic-Window Face Shield. The face shield shall be mounted on a holder consisting of a standard wooden hat block, size 7, mounted vertically on a wooden support fastened securely to a base. The face shield shall be so mounted that the headband fits snugly around the periphery of the base of the block and the crown strap is in contact with the crown portion of the block. An additional supporting block, approximately 1 inch wide and curved to conform to the shape of the plastic window, shall be provided as a support for the window at its lower end or, if the face shield is provided with a chin rest, as a support under the chin rest. The face shield will then rest in a position such that the axis of the cylindrical window is horizontal and the outer surface of the window is uppermost. The impact test shall be made at room temperature (65°F to 85°F) under normal humidity conditions. A 7/8-inch diameter steel ball, weighing approximately 1.56 ounces, shall be freely dropped from a height of 50 inches onto the apex of the window at a point approximately 3 inches below the point of attachment. The window shall not be fractured nor separated nor removed from any of its points of fastening to the headgear by the impact of the steel ball. See Table 8-34.

5.2.8.2 Penetration Resistance, Plastic-Window Face Shield. The face shield shall be mounted in a manner described in 5.2.8.1 and shall be tested under similar conditions. A pointed projectile of suitable size, consisting of a new Singer number 25, size 135 × 17 needle fastened into a holder, weighing approximately 1.56 ounces, shall be freely dropped, needle point downward, from a height of 50 inches onto the apex of the window at a point approximately 3 inches below the point of attachment. The projectile may be guided, but not restricted, in its fall by dropping it through a tube extending to within approximately 4 inches of the face-shield window. The window shall not be fractured, pierced through, nor separated or removed from any of its points of fastening on the headgear by the impact of the projectile. See Table 8-34.

From our interpretation of the description of the support for face shields (5.2.8.1), the face shield was placed in its raised position and was supported by its headgear on the top end and an approximate 1" wide wooden block on the bottom end during the tests. This support is adequate for testing the strength of the window material but is not particularly good for testing the strength of the headgear fastening mechanism since the bottom of the face shield is restricted

TABLE 8-34. IMPACT AND PENETRATION TEST PARAMETERS

Steel Ball Dia. (in)	Drop Height (in)	Drop Height (ft)	Weight (ozs)	Weight (lbs)	Mass (slugs)	Velocity (ft/sec)	Momentum (slug-ft sec)	Kinetic Energy (ft-lbs)
5/8	39	3.25	.565	0.035	0.0011	14.47	0.016	0.115
7/8	50	4.17	1.56	0.098	0.0030	16.38	0.049	0.403
1	50	4.17	2.4	0.150	0.0047	16.38	0.077	0.631
1-1/8	50	4.17	3.36	0.210	0.0065	16.38	0.107	0.872
1-1/4	50	4.17	4.62	0.289	0.0090	16.38	0.147	1.207
1-1/2	50	4.17	7.94	0.496	0.0154	16.38	0.252	2.066
1-3/4	50	4.17	12.61	0.788	0.0245	16.38	0.401	3.287
2	50	4.17	18.85	1.178	0.0366	16.38	0.600	4.910
2-1/2	50	4.17	36.83	2.302	0.0715	16.38	1.171	9.592
3-1/2	50	4.17	101.18	6.324	0.1964	16.38	3.217	26.347
3-1/2	84-1/4	7.02	101.18	6.324	0.1964	21.26	4.176	44.385
spear	50	4.17	1.56	0.098	0.0030	16.38	0.049	0.403

*$Vy^2 = V_{yo}^2 + 2ay\ (y - y_o)$

where a_y = gravitational acceleration (32.2 ft/sec^2)

y = drop height in inches (variable)

y_o = final position of object dropped in inches (0)

Vy_o = initial velocity in in/sec (0)

Velocity $Vy = 2a_y y$

Momentum $P = M\ V = \frac{\text{slug - ft}}{\text{sec}}$

Kinetic Energy $T = 1/2\ mv^2 = \frac{\text{slug-ft}^2}{\text{sec}^2} = \text{ft-lb}$

British System: $F = ma$

$lbs = (slugs)(32.2\ ft/sec^2)$

$oz = (lb)(16\ oz/lb)$

$oz = slugs \times (32.2\ ft/sec^2)(16\ oz/lb)$

$m = slugs = \frac{oz}{(32.2\ ft/sec^2)(16\ oz/lb)}$

*Calculations of Velocity, Momentum and Kinetic Energy of Projectiles.

from moving by the wooden support. To test the reliability of the fastening mechanism, a test similar to this should be performed with the face shield supported only by its headgear and placed on a headform in the horizontal position with the facial portion facing upward. This configuration would allow the face shield to undergo its normal flexural motion after impact.

The comments made above apply to the penetration tests performed on plastic window face shields as well as to the drop ball test. The length of the projectile used in the penetration tests should be mentioned. Complying with the weight specification and the type of projectile head, we used a 37-3/4" long, 1/4" diameter phenolic shaft which gave our spear a total length of approximately 38-3/4". Using a 39-1/4" long, 3/8" outside diameter, 5/16" inside diameter stainless steel guide tube, we felt that this long spear would have much more directional control than a shorter projectile. It should be noted that the spear was caught after impact to avoid additional damage to the specimen.

After examining these tests some questions immediately came to mind. Are the tests adequate or should they be made more severe to account for advances in technology? What are the relationships between the test parameters and actual user conditions? What is the effect of temperature? Some of these questions may be answered after more extensive testing and evaluation.

Table 8-35 contains the results of the impact and penetration resistance tests performed on face shields. Due to the small number of face shields on hand, we conducted the impact test on the face shields first and then the penetration test on the same face shield. This should not adversely affect the results of the penetration test unless the face shield fails the impact test.

TABLE 8-35. IMPACT AND PENETRATION RESISTANCE - FACE SHIELDS

SwRI Code #	Description	Impact (5.2.8.1)	Penetration (5.2.8.2)
AA L-1	clear plastic	pass	pass
AA M-1	clear plastic	pass	pass
CC C-1	clear plastic	pass	pass
CC D-1	clear plastic	pass	pass
CC E-1	clear plastic	pass	pass
CC G-1	clear plastic	pass	pass
DD N-1	clear plastic	pass	pass
FF J-1	clear plastic	pass	pass
JJ R-1	clear plastic	pass	pass
JJ R-6	green plastic	pass	pass

FLEXIBLE AND CUSHIONED FITTING GOGGLES

6.1.3.4 The methods of attachment to frame shall be such that the lens will not be inwardly dislodged from its seat when it is subjected to the impact resistance or penetration tests specified in 6.3.4.2, 6.3.4.3, or 6.1.1.4.6(4), whichever is applicable.

6.1.4.6(4) This section number does not exist in ANSI Z87.1 - 1968.

6.3.4.2 A 1.00-inch diameter steel ball, weighing approximately 2.4 ounces, shall be dropped in free fall from a height of 50 inches onto the horizontal upper surface of the lens, impinging the lens within a circular area of 5/8-inch diameter centered at the lens mechanical center. The lens edge shall not be chipped and the lens shall not be displaced from the frame eye in this test. (Lens in Frame -- Glass and Plastic).

6.3.4.3 Penetration Resistance -- Plastic Only. The frame and lens shall be supported on a wooden block of such size and shape as to fit the frame securely. (The performance of the test is the same as that mentioned in 5.2.8.2.)

The type of support to be used for testing impact resistance and penetration resistance of flexible and cushioned fitting goggles is unclear. Since the mounting arrangement for these goggles is not clearly stated in the ANSI Z87.1 - 1968 Standard, we securely mounted the goggles to the size 7 hat block used in the penetration resistance for face shields and supported the hat block such that the goggle lens was parallel to the floor. The impact tests were performed on the right lenses by dropping a 1.00 inch diameter steel ball 50" onto the surface of the lens, and the penetration tests were performed on the left lenses by dropping the spear mentioned previously 50" onto the surface of the lens. The passing criteria used for face shields (5.2.8.1, 5.2.8.2) was used for the flexible and cushioned fitting goggles since those sections are more complete and relevant to these goggles.

Table 8-36 contains the results of the impact and penetration tests performed on these goggles.

EYECUP GOGGLES

6.1.1.4.6(1) Chipper's Models and Dust and Splash Models. Clear and absorptive lenses for shades 1.7 through 3.0 shall be subjected to the impact test specified in 6.3.4.2.

TABLE 8-36. IMPACT AND PENETRATION RESISTANCE - FLEXIBLE AND CUSHIONED FITTING GOGGLES

SwRI Code #	Description	Impact (6.3.4.2.1)	Penetration (6.3.4.3)
AA A-4	clear plastic	pass	pass
AA B-4	clear plastic	fail *	pass
DD A-4	clear plastic	fail †	pass
EE L-1	clear plastic	pass	pass
FF B-4	clear plastic	pass	pass
HH A-2	clear plastic	pass	pass
LL A-3	lt. green plastic	pass	pass
MM A-4	clear plastic	pass	pass
MM C-4	clear plastic	pass	pass
MM D-4	clear plastic	pass	pass
NN E-4	clear plastic	pass	pass
NN F-4	clear plastic	pass	pass

*Detachment of lens from bottom lens support.
†Detachment of lens from bottom nose support.

6.1.1.4.6(2) Welder's and Cutter's Models. Filter lenses shall be subjected to the following impact test: the lens shall be removed from the eyecup and shall be placed flat on the end of a wooden tube having an internal diameter of 1.77 inches (45 millimeters) and a rim to fit the lens. A washer of neoprene rubber packing of a 40 plus or minus 5 durometer reading not more than 1/8 inch thick, and of the same internal diameter as the tube, shall be placed between the lens and the tube. A 7/8 inch steel ball shall be freely dropped from a height of 50 inches (1.27 meter) onto the horizontal outer surface of the lens. The lens shall not fracture from the impact of the steel ball.

Glass cover lenses (circles) shall not be heat treated for impact resistance.

The impact and penetration resistance tests for eyecup goggles with clear and absorptive lenses are full of ambiguities. The reference (6.3.4.2) made in 6.1.1.4.6(1) specifies a mounting arrangement which is totally inadequate. To remedy this problem we fastened the goggles by its headband to the size 7 hat block mentioned earlier and supported the hat block so that

the outer surface of the lens (the surface farthest from the wearer) faced upward. A 1.00 inch diameter steel ball was then dropped 50 inches onto the center of the left lens in accordance with section 6.3.4.2.1. The right lens was removed and placed on the support stand mentioned in 6.1.4.6(2). A 1.00 inch diameter steel ball was dropped 50 inches onto the center of this lens in accordance with section 6.3.4.2.2. If the right lens did not break upon impact and if it was made of glass, the steel ball size and/or drop height was varied until breakage occurred. The breakage pattern was then observed in accordance with section 6.3.4.2.3.

Filter lenses were tested by dropping a 7/8 inch diameter steel ball 50 inches onto the lens supported by the wooden test block specified in section 6.1.1.4.6(2).

Any plastic lenses should be tested according to the penetration test outlined in section 6.3.4.3.

Table 8-37 contains the results of the impact on Chipper's type eyecup goggles. Table 8-38 contains the results of the impact test on filter lenses of welder's and cutter's type eyecup goggles.

FILTER PLATES AND CLEAR WELDING IMPACT RESISTING PLATES

5.1.4.1.6(4) Impact Resistance. When specified, filter plates shall be impact resistant and withstand the following impact test:

> The filter plate shall be supported on a suitable rigid frame having internal dimensions of 1.77 inches (4.5 centimeters) by 4.02 inches (10.2 centimeters). A washer of neoprene rubber packing of 40 ± 5 durometer reading, not more than 1/8 inch thick and of the same internal dimensions as the support, shall be placed between the plate and the support. A 5/8 inch (15.9 millimeter) steel ball, approximately 0.565 ounce (16 grains), shall be freely dropped from a height of 39 inches (1 meter) onto the center of the horizontal outer surface of the plate. The plate shall not fracture from the impact of the steel ball.

Heat treated filter plates and the backmost clear plate in the welding helmet lift front were impact tested according to 5.1.4.1.6(4) (5/8 diameter steel ball dropped 39 inches). After impact testing, plastic filter plates underwent the penetration test in section 6.3.4.3 mentioned earlier (50 inches drop height).

Table 8-39 contains the results of these tests.

TABLE 8-37. IMPACT RESISTANCE - CHIPPER'S EYECUP GOGGLES (6.3.4.2.1, 6.3.4.2.2, 6.3.4.2.3)

SwRI Code #	Description	Lens (right/left)	Test	Results
DD D-2	clear glass, flat	left	lens in frame	pass
		right	lens on block	pass
		right	breakage pattern	pass *2
DD E-4	clear glass, flat	left	lens in frame	pass
		right	lens on block	pass
		right	breakage pattern	pass *2
KK A-5	clear glass, flat	left	lens in frame	pass
		right	lens on block	pass
		right	breakage pattern	pass *2
KK C-5	clear glass, flat	left	lens in frame	pass
		right	lens on block	pass
		right	breakage pattern	pass *1
NN B-5	clear glass, curve	left	lens in frame	pass
		right	lens on block	pass
		right	breakage pattern	pass *3
NN C-5	clear glass, curve	left	lens in frame	pass
		right	lens on block	pass
		right	breakage pattern	pass *1

Note: Numbers were used in calling out footnotes instead of * and † for convenience.

The order of ball size and drop height used in the test for a breakage pattern are:

*1 7/8" @ 50", 1" @ 50", 1-1/8" @ 50", 1-1/4" @ 50", 1-1/2" @ 50", 1-1/3" @ 50"
*2 *1 plus 2" @ 50"
*3 *2 plus 2-1/2" @ 50", 3-1/2" @ 50", 3-1/2" @ 84-1/4"

TABLE 8-38. IMPACT RESISTANCE - WELDER'S EYECUP GOGGLES [6.1.1.4.6(2) - lens on block] (Note: tested right lens only)

SwRI Code #	Description	Results
DD F-5	glass shade #5	pass
DD G-5	glass shade #5	pass
KK B-5	glass shade #5	pass
KK D-5	glass shade #5	pass
NN A-5	plastic shade #5	pass
NN D-5	plastic shade #5	pass

TABLE 8-39. IMPACT AND PENETRATION RESISTANCE - FILTER PLATES AND CLEAR WELDING IMPACT RESISTING PLATES

SwRI Code #	Description	Impact (5.1.4.1.7(4))	Penetration (6.3.4.3)
AA K-1	glass shade #4	pass	pass
AA K-3	glass shade #6	pass	pass
AA K-8	glass shade #12	pass	pass
AA N-5	plastic, welding back plate	pass	pass
CC A-2	plastic, welding back plate	pass	pass
CC A-6	plastic, welding back plate	pass	pass
CC A-8	plastic, welding back plate	pass	pass
DD L-1	glass shade #4	pass	pass
DD L-3	glass shade #6	fail *	pass
FF E-1	plastic shade #4	pass	pass
FF F-3	plastic shade #6	pass	pass
FF E-9	plastic shade #12	pass	pass

* Good breakage pattern.

MECHANICAL TESTS ON SPECTACLE FRAMES AND LENSES

6.1.2.4.3	Metal Frames (1) Strength of Joints (2) Flat Transverse Test - apply a downward force of 8 ounces with a spring balance attached to the outermost portion of the frame of the left lens while supporting frame by the right lens container. (3) Edge Transverse Test - apply force with lower edge of left lens container to balance 3 pounds on the other arm of the balance.
6.1.2.4.4	Plastic Frames (1) Flat Transverse Test - attach 16 ounces of weights to the outermost portion of the frame of one of the lenses. (2) Edge Transverse - apply force with lower edge of left lens container to balance 5 pounds on the other arm of the balance.
6.1.2.4.5	Combination Metal - Plastic Frames (1) Strength of Joints (2) Flat Transverse Test - apply a downward force of 8 ounces with a spring balance attached to the outermost portion of the frame of the left lens while supporting frame by the right lens container. (3) Edge Transverse Test - apply force with lower edge of left lens container to balance 3 pounds on the other arm of the balance.
6.3.4.2.1	Lens in Frame Impact Test - 1.00 inch diameter ball dropped 50"
6.3.4.2.2	Lens on Block Impact Test - 1.00 inch diameter ball dropped 50"
6.3.4.2.3	Breakage Pattern - Glass Only
6.3.4.3	Penetration Resistance - Plastic Only (drop height is 50")

The order of testing spectacle frames was as follows: flat transverse, edge transverse, and strength of joints (where applicable). There are a few inconsistencies in the spectacle frame tests. The ANSI Z87.1 - 1968 standard specifies that the right lens container be the supporting member for metal frames and metal-plastic frames whereas the supporting member for plastic frames is not specified. Also the amount of force supplied to the end of plastic frames (16 oz) and the method of applying the force (wts) are different

for plastic frames than for metal and metal-plastic frames (8 ounces applied with a spring balance). The weight used in the counterbalance for the edge transverse test is larger for plastic frames (5 pounds) than for metal and metal-plastic frames (3 pounds).

The method of impact testing spectacle lenses in the frame needs some improvement. When we conducted this test we found that we had to cut the frame into right and left halves so that the lens could be properly balanced on the anvil. Part of the nose pad was removed by filing and the temple hinge was removed to provide better positioning of the frame on the anvil. A better designed frame support would eliminate these possible harmful alterations of the frame.

Caution should be taken when obtaining 40 ± 5 durometer neoprene rubber gasket material for the lens on the block test. Several distributers sent us 50 and 60 durometer neoprene rubber gasket material when we asked for 40 durometer gasket material. We measured all of our rubber gasket material for hardness with a Shore Durometer Hardness meter Type "A-2" which was calibrated at 60 durometer and 100 durometer and found that the rubber gasket material received from American Packing and Gasket Company in Houston, Texas was the proper hardness.

The test performed on glass lenses for breakage pattern was conducted by increasing the ball size and/or drop height.

The type of wooden block needed and the manner of attaching a spectacle lens frame with plastic lenses to the wooden block are unclear for the penetration test performed on plastic lenses. We used the size 7 hat block and mounted the frame to the block by means of an elastic spectacle strap which is commercially available and which attaches to the end of the temples near the ears and fits around the wearer's head. The hat block was then positioned in such a manner that the front surface of the lens faced upward towards the oncoming spear.

The strength of the frame tests were conducted first and then the impact tests. Of the frames that had no deformation around the lens containers, the right lens and its container were tested in the frame. The left lens was tested without the frame with a 1 inch ball dropped 50 inches and for breakage using larger balls and/or longer drop heights.

Table 8-40 contains the results of the mechanical tests performed on spectacle frames and lenses.

TABLE 8-40. MECHANICAL TESTS - SPECTACLES

SwRI Code #	Description	Test	Results
AA H-3	plastic frame clear glass S7-48 lenses	flat transverse edge transverse lens in frame lens out of frame breakage pattern	pass pass pass pass pass *6
AA P-3	metal frame clear glass S7-48 lenses	flat transverse edge transverse strength of joints lens in frame lens out of frame breakage pattern	pass pass pass fail *2 pass pass *7
AA G-3	plastic frame clear glass S7-48 lenses	flat transverse edge transverse lens in frame lens out of frame breakage pattern	pass pass pass pass pass *8
DD H-3	plastic frame clear glass S7-48 lenses	flat transverse edge transverse lens in frame lens out of frame breakage pattern	pass pass pass pass pass *8
EE L-3	plastic frame clear glass S7-48 lenses	flat transverse edge transverse lens in frame lens out of frame breakage pattern	pass pass fail *1 pass pass *6
FF D-3	plastic frame clear glass S7-48 lenses	flat transverse edge transverse lens in frame lens out of frame breakage pattern	pass pass pass pass pass *7
GG N-3	plastic frame green plastic lense, odd size	flat transverse edge transverse lens in frame lens out of frame breakage pattern	pass pass pass pass pass *8

TABLE 8-40. MECHANICAL TESTS - SPECTACLES (Cont'd)

SwRI Code #	Description	Test	Results
GG Q-3	plastic frame	flat transverse	pass
	green plastic	edge transverse	pass
	lense, odd size	lens in frame	
		lens out of frame	
		breakage pattern	pass *8
HH B-1a	plastic frame	flat transverse	pass
	clear glass	edge transverse	pass
	S7-4622 lenses	lens in frame	fail *3
		lens out of frame	
		breakage pattern	pass *7
HH D-1a	plastic frame	flat transverse	pass
	clear glass	edge transverse	pass
	S7-44 lenses	lens in frame	fail *4
		lens out of frame	pass
		breakage pattern	pass *5
KK E-3	plastic frame	flat transverse	pass
	clear glass	edge transverse	pass
	S7-48 lenses	lens in frame	fail *3
		lens out of frame	pass
		breakage pattern	pass *8
KK F-3	plastic frame	flat transverse	pass
	clear glass	edge transverse	pass
	S7-48 lenses	lens in frame	pass
		lens out of frame	pass
		breakagae pattern	pass *6
KK G-3	metal frame	flat transverse	pass
	green glass	edge transverse	pass
	S7-4822 lenses	strength of joints	pass
		lens in frame	pass
		lens out of frame	pass
		breakage pattern	pass *8
KK H-3	metal frame	flat transverse	pass
	green glass	edge transverse	pass
	S7-48 lenses	strength of joints	pass
		lens in frame	pass
		lens out of frame	pass
		breakage pattern	pass *8

TABLE 8-40. MECHANICAL TESTS - SPECTACLES (Cont'd)

SwRI Code	Description	Test	Results
MM F-3	plastic frame	flat transverse	pass
	clear glass	edge transverse	pass
	S7-48 lenses	lens in frame	pass
		lens out of frame	pass *8
		breakage pattern	pass
MM H-3	plastic frame	flat transverse	pass
	clear glass	edge transverse	pass
	S7-46 lenses	lens in frame	pass
		lens out of frame	pass *8
		breakage pattern	pass
MM N-1	plastic frame	flat transverse	pass
	clear glass	edge transverse	pass
	S7-48 lenses	lens in frame	pass
		lens out of frame	pass *8
		breakage pattern	pass
NN G-3	plastic frame	flat transverse	pass
	clear glass	edge transverse	pass
	S7-4822 lenses	lens in frame	pass
		lens out of frame	pass *8
		breakage pattern	pass
NN H-3	metal frame	flat transverse	pass
	clear glass	edge transverse	pass
	S7-48 lenses	strength of joints	pass
		lens in frame	fail *2
		lens out of frame	pass *6
		breakage pattern	pass

Note: Numbers were used in calling out footnotes instead of * and † for convenience.

*1 Low lens.
*2 Lens chipped.
*3 Top lens.
*4 Lens and frame broke.

The order of ball size and drop height used in the test for a breakage pattern are:

*5 1" @ 50", 1-1/4" @ 50"
*6 1" @ 50", 1-1/4" @ 50", 1-1/2" @ 50"
*7 *5 plus 1-3/4" @ 50"
*8 *6 plus 1-7/8" @ 50"

DISINFECTION TEST

6.2.2 Disinfection. All materials shall be such as to withstand, without deterioration or discoloration, the cleansing and disinfection procedure specified in 6.4.3.

6.4.3.2 Procedure. Thoroughly clean all surfaces with soap or suitable detergent, and warm water. Carefully rinse all traces of soap or detergent. Completely immerse the protector for 10 minutes in a solution of modified phenol, hypochlorite, or quaternary ammonium compounds, in a strength specified by the manufacturer, at a room temperature of 68°F . . . .

To test the effect of disinfection on eye and face protective equipment, various types of eyewear were tested in three types of disinfecting solutions. Only small pieces of welding helmets and face shields (5" x 1/2") were used and all other protectors were dissassembled to the extent possible without tools prior to the washing and disinfection procedure.

The hypochlorite solution we used was a Clorox solution (sodium hypochlorite 5.25%; inert ingredients 94.75%) at a strength recommended by its manufacturer for disinfection (3/4 cup Clorox/gallon water). The phenol solution we used was a Lysol solution (active ingredients: soap 16.5%, o - lhenylphenol 2.8%, o - benzyl - p - chlorophenol 2.7%, alcohol 1.8%, xylenols 1.5%, isopropyl alcohol 0.9%, tetrasodium ethylenediamine tetra-acetate 0.9%; inert ingredients: 72.9%) at its manufacturer's recommended strength of 2 1/2 tablespoons/gallon water. Finally, the quaternary ammonium compound we used consisted of a Hyamine 3500 Germicide Concentrate (50%) solution (active ingredient: n - alkyl (50% C_{14}, 40% C_{12}, 10% C_{16}) dimethyl benyl ammonium chloride 50%; inert ingredients: water and ethanol (50%) with a minimum phenol coefficient of 250 and at the strongest recommended aqueous solution concentration of 1 part in 1000 parts water (or 1 part in 500 parts water in this case). Distilled water was used in making the above solutions and slightly more than a gallon was made of each one of them. The phenol and hypochlorite solutions are weak acids and the quaternary ammonium compound solution is a weak alkali. None of these solutions at the concentrations and temperatures used should adversely affect the protectors.

Each protector tested for disinfection was cleaned in soap and water, rinsed in water, dried with a lint-free towel, immersed in the hypochlorite solution for 10 minutes, removed and examined. This same item then underwent the same procedure using the phenol solution and then the quaternary ammonium compound solution. When more than one item was placed in the same container for disinfection, care was taken to keep the items separated. The solutions were all kept at approximately 68°F, room temperature.

All of the items tested withstood the disinfection procedure without deterioration or discoloration. Table 8-41 contains a list of the protectors tested.

TABLE 8-41. LIST OF ITEMS WHICH WITHSTOOD THREE DIFFERENT DISINFECTION PROCEDURES

SwRI Code #	Description	SwRI Code #	Description
AA M-1	Face Shield	AA C-6	Welding Goggle Frame
AA L-1	Welding Helmet	AA C-6	Filter Shade #5
AA N-4	Welding Helmet	AA C-6	Cover Plate Clear
AA N-3	Welding Helmet	AA D-6	Welding Goggles Clear Frame
AA P-6	Spectacles	AA D-6	Clear Lens Plastic
AA G-6	Spectacles	AA D-6	Clear Cover Plate Plastic
AA K-2	Glass Filter Plate Shade #5	AA F-6	Welding Goggles Clear Frame
AA K-12	Plastic Cover Plate	AA F-6	Clear Lens, Rt. Lens
AA B-6	Flex. Goggle Frame	AA F-6	Clear Lens, Lt. Lens
AA B-6	Lens Clear	CC C-1	Face Shield
AA E-6	Welding Goggle Frame	CC D-1	Face Shield
AA E-6	Rt. Lens Shade #5	CC E-1	Face Shield
AA E-6	Lt. Lens Shade #5	CC G-1	Face Shield
AA E-6	Cover Plate, Lt. Lens	CC A-1	Welding Helmet
AA E-6	Cover Plate, Rt. Lens	DD N-1	Face Shield
AA A-7	Flex. Goggle Frame	DD P-1	Welding Helmet
AA A-7	Clear Lens		

TABLE 8-41. LIST OF ITEMS WHICH WITHSTOOD THREE DIFFERENT DISINFECTION PROCEDURES (Cont'd)

SwRI Code #	Description
DD H-7	Spectacles
DD L-1	Glass Filter Plate Shade #4
DD L-4	Glass Cover Plate
DD K-1a	Round Glass Filter Circle, Shade #3
DD E-3	Cup Type Goggles Frame
DD E-3	Clear Lens, Rt. Lens
DD E-3	Clear Lens, Lt. Lens
DD B-7	Flex. Goggles Black Frame
DD B-7	Clear Lens
DD D-3	Cup Type Goggles Black Frame
DD D-3	Clear Glass Lens Rt. Lens
DD D-3	Clear Lens Glass Lt. Lens
DD G-7	Cup Type Goggles Black Frame
DD G-7	Filter Plate Shade #5 Rt. Lens
DD G-7	Filter Plate Shade #5 Lt. Lens
DD G-7	Cover Plate Glass
DD G-7	Cover Plate Glass
DD C-6	Flex. Goggles Clear Frame
DD C-6	Clear Lens Plastic
DD F-7	Cover Cup Goggles Black Frame
DD F-7	Filter Plate Shade #5 Rt. Lens
DD F-7	Filter Plate Shade #5 Lt. Lens
DD F-7	Glass Cover Plate
DD F-7	Glass Cover Plate
DD A-7	Flex. Goggles Clear Frame
DD A-7	Clear Lens
EE L-4	Spectacles
FF D-2	Spectacles
FF E-1	Plastic Filter Plate Shade #4
FF E-12	Glass Cover Plate
FF F-1a	Round Plastic Filter Circle, Shade #4
FF B-1	Flex. Goggles Clear Frame
FF B-1	Clear Lens Plastic
GG M-5	Spectacles
GG P-5	Spectacles
HH B-1b	Spectacles
HH A-1	Flex. Goggles Clear Frame
HH A-1	Clear Lens, Plastic
JJ R-6	Face Shield
JJ R-1	Face Shield

TABLE 8-41. LIST OF ITEMS WHICH WITHSTOOD THREE DIFFERENT DISINFECTION PROCEDURES (Cont'd)

SwRI Code #	Description
LL A-2	Flex. Goggles Green Plastic Frame
LL A-2	Lt. Green Lens Plastic
MM F-7	Spectacles
MM H-7	Spectacles
MM A-7	Flex. Goggles Clear Frame
MM A-7	Clear Plastic Lens
MM C-7	Flex. Goggles Clear Frame
MM C-7	Clear Lens Plastic
MM D-7	Flex. Goggles Clear Frame
MM D-7	Clear Lens Plastic
NN G-5	Spectacles
NN H-6	Spectacles
NN E-6	Flex. Goggle Frame
NN E-6	Clear Lens Plastic
NN D-6	Welding Goggles Frame
NN D-6	Filter Lens Shade #5 Rt. Lens
NN D-6	Filter Lens Shade #5 Lt. Lens
NN D-6	Cover Plate, Rt. Lens
NN D-6	Cover Plate, Lt. Lens
NN A-6	Welding Goggles Cup Type Frame
NN A-6	Filter Lens Shade #5 Rt. Lens
NN A-6	Filter Goggles Shade #5 Lt. Lens
NN A-6	Cover Plate, Rt. Lens
NN A-6	Cover Plate, Lt. Lens
NN B-7	Chipper's Goggles Cover Cup Type Frame
NN B-7	Clear Lens, Rt. Lens
NN B-7	Clear Lens, Rt. Lens
NN C-7	Chipper's Goggle Cup Type Frame
NN C-7	Clear Lens, Rt. Lens
NN C-7	Clear Lens, Lt. Lens
NN F-6	Flex. Goggle Frame Green
NN F-6	Lens Plastic Shade #5

HEAT DEFORMATION TEST - CHIPPER'S WELDER'S, AND CUTTER's EYECUP GOGGLES (6. 1. 1. 5, FIG. 1 AND 2)

The heat deformation test was conducted in accordance with Section 6. 1. 1. 5 using the mounting procedure shown in Figure 1 and Figure 2 in the ANSI Z87. 1 - 1968 standard.

Attaching the eyecup to the support stand by means of a wire through the existing hole in the eyecup proved to be quite cumbersome but could be accomplished with perserverance. Due to the shape of the goggles and the type of support stand specified, it was at times difficult to position the lenses so that they were horizontal. This proved to be tedious but not insurmountable. The time for removal of the weight, either immediately after removing the goggle from the oven, a fixed time after removing the goggle from the oven, or after the goggle has cooled, is not mentioned.

It is felt that the "intent" of the standard is to allow the goggle to cool before removing the weight. Therefore the goggle was allowed to cool before the weight was removed. One goggle is recorded in Table 1 which had the weight removed immediately after it was taken from the oven for comparison with the other half of the goggle which had the weight removed after it cooled. The differences in the values obtained does not appear to be too significant.

Table 8-42 contains the results of the heat deformation test.

TABLE 8-42. RESULTS OF HEAT DEFORMATION TEST FOR CHIPPER'S, WELDER'S AND CUTTER'S MODELS EYECUP GOGGLES

Passing Criteria:
Dimension A : ≤ 1/2%
Dimension B : ≤ 1/2%
Dimension C : ≤ 5%

SwRI Code #	Description	Temperature	Position of Measurement	Before Deform. (in)	After Deform. (in)	% Change
DD D-1	Chipper's	150°F	A	1.795	1.791	-0.2
	Cup Type		B	1.804	1.800	-0.2
	Lt. Lens		D	2.164	2.156	-0.4
DD E-2	Chipper's	150°F	A	1.793	1.791	-0.1
	Cup Type		B	1.795	1.796	+0.1
	Rt. Lens		D	2.721	2.623	+0.1
DD F-6	Welder's	180°F	A	1.793	1.795	+0.1
	Cup Type		B	1.804	1.745	-3.3*
	Lt. Lens,†		D	2.614	2.975	+13.8*
DD G-6	Welder's Cover	180°F	A	1.834	1.841	+0.4
	Cup Type		B	1.804	1.745	-3.3*
	Lt. Lens		D	2.198	2.463	+12.1*
KK A-4	Chipper's	150°F	A	1.727	1.752	+1.4*
	Cup Type		B	1.737	1.732	-0.3
	Lt. Lens		D	2.165	2.167	+0.1
KK C-4	Chipper Cover	150°F	A	1.719	1.720	+0.1
	Cup Type		B	1.723	1.723	0.0
	Lt. Lens		D	2.642	2.648	+0.2
KK B-4	Welder's	180°F	A	1.730	1.890	+9.2*
	Cup Type		B	1.735	1.700	-2.0*
	Lt. Lens		D	2.238	2.254	+0.7

TABLE 8-42. RESULTS OF HEAT DEFORMATION TEST FOR CHIPPER'S, WELDER'S AND CUTTER'S MODELS EYECUP GOGGLES (Cont'd)

SwRI Code #	Description	Temperature	Position of Measurement	Before Deform. (in)	After Deform. (in)	% Change
KK D-4	Welder's Cover	180°F	A	1.727	1.757	+1.7*
	Cup Type		B	1.734	1.705	-1.7*
	Lt. Lens,†		D	2.757	2.734	-0.8
NN B-4	Chipper's Cover	150°F	A	1.723	1.736	+0.8*
	Cup Type		B	1.724	1.722	-0.1
	Lt. Lens		D	2.635	2.694	+2.2
NN C-4	Chipper's	150°F	A	1.732	1.726	-0.3
	Cup Type		B	1.731	1.720	-0.6*
	Lt. Lens		D	2.138	2.195	+2.7
NN A-4	Welder's	180°F	A	1.738	1.768	+1.7*
	Cup Type		B	1.751	1.732	-1.1*
	Lt. Lens		D	2.225	2.388	+7.3*
NN D-4	Welder's Cover	180°F	A	1.716	1.756	+2.3*
	Cup Type		B	1.715	1.606	-0.5
	Lt. Lens		D	2.766	3.000	+8.5*
NN A-4	Welder's	180°F	A	1.737	1.730	-0.4
	Cup Type		B	1.724	1.784	+3.5*
	Rt. Lens,‡		D	2.217	2.359	+6.4*

*Indicates failure because of excessive percent change in dimension.
† Indicates failure because of tight retaining ring after test.
‡The weight was removed immediately after the goggle was taken out of the oven. All the other goggles above were allowed to cool before the weight was removed.

CORROSION RESISTANCE TEST

The corrosion resistance test was performed according to USA Standard Method of Salt Spray (Fog) Testing, Z118.1 - 1966 (called out in ANSI Z87.1, Section 6.2.3). An exposure period of 48 hours was used as specified in MIL-STD-810B, 15 June 1967, Method 509.

The Salt Fog Chamber used was one designed specifically for fog testing. It was a Model SS-3-4 made by Associated Testing Laboratories, Inc., in Wayne, New Jersey with an effective test chamber volume of 18" x 18" x 18". A 5% by weight salt solution consisting of 95 parts de-ionized water and 5 parts Baker Analyzed Reagent Sodium Chloride (#3624) was made. The resultant solution, having a pH of 6.8 and a specific gravity of 1.0290 at 95°F, was poured into the salt solution reservoir and the test chamber apparatus was turned on and allowed to stabilize before the test items were installed. When testing, the specimens were suspended from plastic bars or placed on wooden blocks such that the lenses were between 15 degrees and 30 degrees from the vertical (normal edge uppermost and back side of lenses downward to avoid collection of water) and parallel to the principal direction of horizontal flow of fog through the chamber.

Two groups of specimens were tested for 48 hours each. During these tests the chamber temperature varied from 95°F to 96°F (95°F + 2°F - 3°F required), the pH from 6.6 to 6.7 (6.5 to 7.2 required), the specific gravity from 1.0300 to 1.0310, and the collection rate from 1.1 ml/hr - 80 cm^2 to 1.5 ml/hr - 80 cm^2 (1.0 ml/hr - 80 cm^2 to 2.0 ml/hr - 80 cm^2 required). After the test, the specimens were removed and gently washed in running water not warmer than 100°F, allowed to dry and inspected.

Table 8-43 contains the results of the corrosion resistance test. The corrosion test did not appear to affect any lenses, plastic parts, or headbands of the specimens. Some of the metal components were slightly corroded, but taking into account the severity of the test, their corrosion resistance was good. All specimens were reusable after the test.

(3) Development of New Tests

Development of new tests has occurred throughout this report. To present all the new tests in this section would be needlessly repetitious. Task 9, in addition to containing the standards, contains a list of comments denoting the origin of sections of the standards.

TABLE 8-43. CORROSION RESISTANCE

Conditioning: 48 hour exposure to salt fog (5% NaCl (by weight), 95% distilled water). Chamber temperature: 95°F + 2°F - 3°F. pH: 6.5 to 7.2
Passing Criterion: Reusable for intended purpose.
Comment: All of the following passed the above criteria.

SwRI Code #	Description	Test Group	Observations
JC A -1	dust & splash goggle	#1	Slight degree of corrosion on headband buckles, attachment screws, ventillator screens and parts.
AO A-6	flexible goggle dust & splash	#1	No noticeable corrosion.
AO C-7	flexible goggle dust & splash	#1	No noticeable corrosion.
AO F-1	cover cup goggle welders & cutters	#1	Slight degree of corrosion on staple in headband.
AO G-1	cup goggles welders & cutters	#1	Slight degree of corrosion on staple in headband.
BL B-3	chippers goggle	#1	Slight degree of corrosion on headband buckle, cup attachment buckle, and staple in headband.
BL C-3	chippers goggle	#1	Slight degree of corrosion on headband buckle, staple in headband, and cup attachment slotted support.
BL D-3	welders and cutters cover cup goggle	#1	Slight degree of corrosion on headband buckle, cup attachment buckle, and staple in headband.
BL E-2	flexible goggle dust & splash	#1	No noticeable corrosion.

TABLE 8-43. CORROSION RESISTANCE (Cont'd)

SwRI Code #	Description	Test Group	Observations
AO E-1	chippers cup goggles	#2	Slight degree of corrosion on staple in headband.
BL F-2	welders & cutters flexible goggle	#2	No noticeable corrosion.
GO B-2	chippers flexible goggle	#2	No noticeable corrosion.
MS A-1	chippers flexible goggle	#2	No noticeable corrosion.
WO A-6	chippers flexible goggle	#2	No noticeable corrosion.
SM B-2	chippers flexible goggle	#2	No noticeable corrosion.
SM C-1	welders flexible goggle	#2	Slight degree of corrosion on headband buckle and moderate corrosion of filter plate attachment.
SM D-2	chippers flexible goggle	#2	Slight degree of corrosion on headband buckle and staple in flexible goggle headband and moderate corrosion of plate attachment.
SM E-3	welders & cutters cover cup goggles	#2	Slight degree of corrosion on headband buckle and staple in headband.

TASK 9 - DEVELOPMENT OF A RECOMMENDED STANDARD FOR OCCUPATIONAL AND EDUCATIONAL EYE AND FACE PROTECTION

In accordance with the Scope of Work and the SwRI Technical Proposal for this project, a recommended Standard for occupational and educational eye and face protection was developed which contained the following three main sections:

(1) Performance section - a part of the Standard which describes the performance requirements expected from the various types and/or classes of eye and face protective devices.

(2) Test section - a part of the Standard which describes in detail and in proper sequence, the test conditions, methods, equipment, and procedures for testing each of the attributes of the eye and face protective devices for determining whether or not the devices meet the requirements set forth in the performance section of the Standard.

(3) User section - a part of the Standard which describes the procedures for selection of suitable eye and face protective devices which will afford the user protection against work hazards while permitting him to perform his work duties. The user section of the Standard also describes the methods and practice for the proper usage, cleaning, maintenance, and storage of the protective devices.

The recommended Standard which was developed is contained in a separate volume. In order to clarify the origins of different parts of the proposed Standard, Table 9-1 was developed and included in this task. This table contains a list of references from which various parts of the recommended Standard were developed.

TABLE 9-1. DEVELOPMENT OF A RECOMMENDED STANDARD FOR OCCUPATIONAL AND EDUCATIONAL EYE AND FACE PROTECTION

Section in Recommended Standard		References
1.1		Ref. 9-1*, Section 1.1†
3.1		
	Absorptive Lens	Ref. 9-1, Section 3.2
	Bevel	NIOSH Recommendation
	Cover Lens	Ref. 9-1, Section 3.2
	Cover Plate	Ref. 9-1, Section 3.2
	Cup Goggle	Ref. 9-2, Section 1.2.3
	Diopter	Ref. 9-1, Sections 6.3.4.1.1 & 6.3.4.1.2
	Disinfection	Ref. 9-1, Section 3.2
	Face Shield	Ref. 9-1, Section 3.2
	Filter Lens	Ref. 9-1, Section 3.2
	Glabella	Ref. 9-3
	Goggle	Ref. 9-1, Section 3.2; Ref. 9-2, Section 1.2.2
	Haze	Ref. 9-1, Section A1.5.1
	Headband	Ref. 9-1, Section 3.2
	Infrared Radiation	Ref. 9-4, Task 4‡
	Lens	NIOSH Recommendation
	Luminous Transmittance	Ref. 9-1, Section 6.3.4.6.2
	Plano Lens	Ref. 9-1, Section 3.2
	Prismatic Power	Ref. 9-1, Section 6.3.4.1.1; Ref. 9-4, Task 7
	Refractive Power	Ref. 9-4, Task 7
	Safety Spectacle	Ref. 9-1, Section 3.2
	Striae	NIOSH Recommendation
	Ultraviolet Radiation	Ref. 9-4, Task 4
	Visible Light	Ref. 9-4, Task 4
4.1 to 4.1.2.22		Ref. 9-4, Task 8
5.0 to 5.6		Ref. 9-4, Task 2
6.3.1.1.3		Ref. 9-1; Ref. 9-4, Task 8
6.3.1.1.4		Ref. 9-1; Ref. 9-4, Task 8
6.3.1.2		Ref. 9-1; Ref. 9-4, Tasks 5 & 8

TABLE 9-1. DEVELOPMENT OF A RECOMMENDED STANDARD FOR OCCUPATIONAL AND EDUCATIONAL EYE AND FACE PROTECTION (Cont'd)

Section in Recommended Standard	References
6.3.2	Ref. 9-1; Ref. 9-4, Task 8
Table 6.3.2.5-I	Ref. 9-1; Ref. 9-4, Task 4
Table 6.3.2.5-II	Ref. 9-1
6.3.3	Ref. 9-1; Ref. 9-4, Tasks 5 & 8; Ref. 9-5; Ref. 9-6
Table 6.3.3.5-I	Ref. 9-1; Ref. 9-4, Tasks 5 & 8
6.3.4	Ref. 9-1; Ref. 9-4, Tasks 5 & 8
Table 7.1-I	Ref. 9-4, Task 2
7.4.1.1.3	Ref. 9-1; Ref. 9-4, Task 8
7.4.1.1.4	Ref. 9-1; Ref. 9-4, Task 8
7.4.1.2	Ref. 9-1; Ref. 9-4, Tasks 5 & 8
7.4.2	Ref. 9-1; Ref. 9-4, Task 8
7.4.3	Ref. 9-1; Ref. 9-4, Tasks 5 & 8; Ref. 9-5; Ref. 9-6
7.4.4	Ref. 9-1; Ref. 9-4, Tasks 5 & 8

TABLE 9-1. DEVELOPMENT OF A RECOMMENDED STANDARD FOR OCCUPATIONAL AND EDUCATIONAL EYE AND FACE PROTECTION (Cont'd)

Section in Recommended Standard	References
Table 8.2.1-I	Ref. 9-4, Task 2
Table 8.2.2-I	Ref. 9-4, Task 4; Ref. 9-7; Ref. 9-8
8.4	Ref. 9-1; Ref. 9-4, Task 8
8.5	Ref. 9-4, Task 3

Note: Reasons for changes in wavelength limits for the ultraviolet, visible, and infrared radiation regions can be found in the following:

Ref. 9-4, Task 4
Ref. 9-9
Ref. 9-10
Ref. 9-11
Ref. 9-12

*Refers to references at the end of this task.
†Refers to a particular section of a reference at the end of this task.
‡Refers to another task in this document (i.e., Ref. 9-4).

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APPENDIX A

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APPENDIX B

LOS ANGELES COUNTY ACCIDENT DATA

File 72-0-4175 - Employers First Report of Injury

21 Laboratory Assistant
22 Less than 6 months
23 Employee was chipping zenker crystals
24 As employee was chipping crystals, a particle flew into her eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 To be more cautious
30 Foreign body, right eye.

No Doctor's First Report of Work Injury

File 72-0-5028 - Employers First Report of Injury

Report missing from file

Doctor's First Report of Work Injury

11 Patient states that "While in the kitchen at Rancho on Friday, March 10, 1972, sometime before none, she thinks she got detergent in her left eye. It became red but she did not get any treatment for this. On March 14, 1972, her eye was hurting and she saw doctor at Rancho who referred her here for treatment."
12 OS shows moderate hyperemia of bulbar conjunctiva, especially over nasal half of globe and there is subconjunctiva hemorrage in the semi-lunar fold. Slit/lamp shows no staining OS cornea, no AC ray or cells, and no corneal or conjunctival foreign body, including upper tarsal conjunctiva. Diagnosis OS acute conjunctivitis and subconjunctival hemorrage, probably traumatic.

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File 72-0-5047 - Employers first Report of Injury

21 Millwright
22 Less than 6 months
23 Working in machine shop
24 Supervisor noticed employees eye was bloodshot and irritated. Employee stated he thought he had something in it from unknown source.
25 None
26 Blank
27 Yes
28 Yes
29 Blank
30 Right eye was irritated.

Doctor's First Report of Work Injury

11 Patient stated that while working something flew into left eye.
12 Foreign body at 1:30 o'clock, 1-1/2 millimeters inside limbus.

File 72-0-5066 - Employers First Report of Injury

21 Custodian
22 Less than 6 months
23 Straightening up after bending over to pick up towel.
24 Employee struck mop handle as he straightened up.
25 Mop handle
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee was struck in left eye by mop handle

Doctor's First Report of Work Injury

11 "I leaned over to pick up a rag and raised up and and hit end of mop handle with left eye."
12 Has injectio of medial inferior sclera of left eye. Eye's PERLA, EOM normal period. Fundus looks normal.

File 72-0-5364 - Employers First Report of Injury

21 Carpenter Working Foreman
22 Over 2 years
23 Loading Truck
24 Foreign material got into right eye from gust of wind
25 None
26 Blank
27 Yes
28 Yes
29 No improvement recommended.
30 Right eye.

Doctor's First Report of Injury

11 "I was working on a saw and something flew into my right eye. I still feel something."
12 There is mild conjunctival erythema and edema of the right eye. There is no F. B. visualization at this time.

File 72-0-5695 - Employers First Report of Injury

No report in the file.

Doctor's First Report of Injury

11 "I was leaning over a waste basket pushing paper down into the basket and dust flew up into my right eye."
12 Has injection of left conjunctiva and sclera. No foreign bodies seen.

File 72-0-5749 - Employers First Report of Injury

No report in the file.

Doctor's First Report of Injury

11 "I was running metered mail, a piece of metal flew off the machine and struck my right eye."
12 Piece of metal (?) versus right eye from machine patient was working with. No foreign body found. Does have small superficial abrasion right lateral cornea (seen per fluoroscan staining).

File 72-0-5755 - Employers First Report of Injury

21 Transcriber Typist
22 6 Months to 2 years
23 Holding a container that was being filled with duplicating fluid. Tub slipped out of the container and fluid splashed in her eyes.
24 Blank
25 Blank
26 Blank
27 Blank
28 Blank
29 Use funnel for that type of pouring
30 Eyes stung from fluid.

Doctor's First Report of Injury

11 Patient was putting solution for copy machine in container and solution splashed into left eye
12 Slight injection of conjunctiva, cornea clear, chemical conjunctivitis.

File 72-0-5775 - Employers First Report of Injury

21 Apprentice Electrician
22 Over 2 years
23 Drilling a hole in the wall.
24 A piece of plaster flew in his eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Left eye injury

Doctor's First Report of Injury

11 Patient was drilling hole in plaster and feels piece of plaster is in left eye.
12 Marked sclerol conjunctivitis left eye, dust-like foreign body conjuncivitis left eye, dust-like foreign body.

File 72-0-5783 - Employers First Report of Injury

21 Clerk, heavy lifting
22 Less than 6 months
23 Operating mailing machine
24 Plate covering, date dye in mailing maching postage machine suddenly hurled from the machine striking employee in right eye.
25 Postage meter
26 Plate cover on date dye
27 Yes
28 No
29 Blank
30 Bruised right eye.

Doctor's First Report of Injury

No Doctor's report in file

File 72-0-6135 - Employers First Report of Injury

21 Deputy Sheriff - Reserved
22 Over 2 years
23 Involved in shooting at location
24 Gun powder or paraffin from revolver caused severe eye irritation
25 Hand gun
26 Blank
27 Blank
28 Blank
29 Blank
30 Severe eye irritation.

Doctor's First Report of Injury

11 Patient claims irritation of left eye -- draining.
12 Conjunctivitis left eye.

File 72-0-6184 - Employers First Report of Injury

21 Inspector's Aid, Weights and Measures
22 Less than 6 months
23 Delivering perchlorethylene into 50-gallon measure while on cat-walk in meter pit.
24 Small amount of product splashed into left eye.
25 None
26 None
27 Yes
28 Yes
29 Require a stronger physical grip while holding the nozzle
30 Burning sensation in left eye.

Doctor's First Report of Injury

11 "This morning while working with perchlorethylene spray, some of the solution sprayed into my left eye. I washed it out with water."
12 Left eye slightly infected. Cornea appears normal.

File 72-0-6217 - Employers First Report of Injury

21 Medical Technician Trainee (PEP)
22 Less than 6 months
23 Employee states he was called to check a kidney machine flow meter.
24 Employee states while checking the machine flow meter as it would not fill, the patient was standing beside me beginning to clear the lines. When she depressed the plunger, the contents of the syringe squirted into right eye of employee.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye. Sent to employee clinic and referred out.

Doctor's First Report of Injury

11 Patient using dialysis machine, squirted bleach into patient's right eye. He washed it out with water but severe pain is present.
12 Superficial keratitis and conjunctivitis, right eye, of chemical origin.

File 72-0-6561 - Employers First Report of Injury

21 Teacher
22 Over 2 years
23 Participating in basketball game
24 Hit on right eye by elbow
25 None
26 Blank
27 Blank
28 Blank
29 Blank
30 Cut on right eyebrow

Doctor's First Report of Injury

11 "While working, I was playing basketball with children and a boy clipped me above my right eye, cutting me."
12 LCM laceration of right upper lid. No involvement of globe. Pupil regular and reacts to light; extra ocular movement intact. Diagnosis: laceration, right upper lid.

File 72-0-6659 - Employers First Report of Injury

21 Registered Nurse
22 Blank
23 Standing at Ward Desk
24 Accidentally stuck medicine room key in right eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Being more observant; placing the medicine room key in proper place when not in use.
30 Foreign body, right eye.

Doctor's First Report of Injury

11 Employee states that while standing at ward deck, she accidentally stuck medicine room key in her right eye.
12 Corneal abrasion, right eye.

File 72-0-6700 - Employers First Report of Injury

21 Deputy Sheriff I
22 Less than 6 months
23 Wrestling during physical training
24 Employee's eye was hit by the elbow of his wrestling partner.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Injury to left orbiyal area.

Doctor's First Report of Injury

11 Patient was in training at the academy. While wrestling, his eye was hit by the elbow of his partner.
12 Contusion, left orbiyal area and laceration.

File 72-0-6958 - Employers First Report of Injury

21 Laborer
22 Less than 6 months
23 Cleaning Swimming pool
24 Accidentally splashed acid into right eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Irrigation of right eye

Doctor's First Report of Injury

11 Patient states while at work cleaning swimming pool, accidentally splashed acid into right eye. Eye is burning and irritated.
12 Chemical juncitivitis with roughening of cornea, normal visual acuity.

File 72-0-7081 - Employers First Report of Injury

Report missing from file

Doctor's First Report of Injury

11 I was dusting for roaches, and something flew into my left eye.
12 Abrasion with conjunctivitis, cornea right eye.

File 72-0-7120 - Employers First Report of Injury

21 Food Service Worker
22 Blank
23 Unknown. Reported to Supervisor at Martin Luther King Hospital on 3/13/72, that salute splashed in her eye,
24 Employee states that salute splashed in her eye in 700 kitchen on Saturday, 3/11/72.
25 Salute, a dishwashing compound
26 Blank
27 Yes
28 Unknown
29 Blank
30 Eye red and swollen.

Doctor's First Report of Injury

Report missing from file

File 72-0-4025 - Employers First Report of Injury

21 Fireman, 56 Hours.
22 Over 2 years
23 Driving utility truck
24 While driving utility truck on San Diego Freeway, something blew in window and lodged in his eye.
25 Utility truck
26 Driver's compartment
27 Yes
28 Yes
29 Driving with windows closed
30 Foreign object in left eye.

Doctor's First Report of Injury

Report not in file (narative report)

File 72-0-4307 - Employers First Report of Injury

21 Fireman, 56 hours
22 Over 2 years
23 Looking up at pipes, etc. in basement of administration building at Leroy Boys Home -- familiarization tour
24 Particles of dust, dirt, and rusty steel fell in my eye while looking up.
25 Rusty pipes
26 Blank
27 Blank
28 Blank
29 Wear goggles
30 Particles of dust, dirt and rusty steel fell in left eye

Doctor's First Report of Injury

11 Patient states left eye injury, inspecting a basement and reached up to touch a pipe and something fell into eye.
12 Imbedded corneal FB left eye.

File 72-0-5333 - Employers First Report of Injury

21 Public Health Nurse
22 Over 2 years
23 Blank
24 Mantoux conversion -- 2/69 negative. 10/70 negative. 12/71, 20 millimeter enduration
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Blank

Doctor's First Report of Injury

Report missing from file.

File 72-0-5812 - Employers First Report of Injury

21 Fireman, 56 hours
22 6 months to 2 years
23 Cleaning fire engine
24 Metal chip fell while cleaning underside of engine of dirt and grease.
25 Fire engine 11
26 Rear axle
27 Yes
28 No
29 Wear Safety goggles
30 Foreign body in left eye (metal chip)

Doctor's First Report of Injury

11 Was working under truck and something fell into left eye.
12 Imbedded steel foreign body, cornea, left eye.

File 72-0-4450 - Employers First Report of Injury

21 Fireman Specialist, 56 hours
22 6 months to 2 years
23 Cleaning shelves
24 Foreign body swept off shelf imbedded in eyeball
25 Foxtail broom
26 None
27 No
28 No
29 No practical means of avoiding this accident.
30 Left eye

Doctor's First Report of Injury

11 Cleaning off a shelf, something fell in my left eye.
12 Foreign body, center of left cornea.

File 72-0-6406 - Employers First Report of Injury

21 Fireman Specialist
22 Over 2 years
23 Walking
24 As he passed a grinding machine, a spark flew into his eye.
25 Grinding machine
26 Blank
27 Blank
28 Blank
29 Blank
30 Spark in left eye.

Doctor's First Report of Injury

11 Walking near a grinding machine and apparently a spark went in my left eye.
12 Imbedded foreign body, cornea, left eye.

File 72-0-5546 - Employers First Report of Injury

21 Fire Captain
22 6 months to 2 years
23 Fire patrol
24 While on fire patrol, a foreign body blew in through open window of the patrol vehicle and lodged in my left eye.
25 Does not apply
26 Blank
27 Blank
28 Blank
29 Nonpreventable occupational hazard
30 Left eye.

Doctor's First Report of Injury

11 3-4 weeks ago, he thinks he got something in his left eye, and irritation persists.
12 Pingueculitis, inner canthus, left eye.

File 72-0-4424 - Employers First Report of Injury

21 Hazard Abatement Laborer
22 Over 2 years
23 Cutting brush
24 Got object in his eye
25 None
26 Blank
27 Blank
28 Blank
29 Be more careful
30 Object in his right eye.

Doctor's First Report of Injury

Report missing from file.

File 72-0-6990 - Employers First Report of Injury

21 Assistant Arboretum Gardener
22 Over 2 years
23 Watering plants
24 Wind blew dirt or wood chip into eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye redened and inflamed, lid puffy, great deal of soreness and irritation.

Doctor's First Report of Injury

11 "I was watering and something hit me in the right eye. I think it was a piece of wood."
12 Corneal abrasion, right eye.

File 72-0-6677 - Employers First Report of Injury

21 Arboretum Gardener
22 Over 2 years
23 Connecting quick-couplers, for watering
24 Water, under pressure, shot up around quill and hit him in the eye.
25 Quick-coupler quill with impact-head sprinkler.
26 Blank
27 Blank
28 Blank
29 Blank
30 Irritated right eye, as if scratched or foreign material were present.

Doctor's First Report of Injury

11 Patient stated has foreign body in right eye; happened at arboretum yesterday.
12 61-year-old man who states he has foreign body in right eye. Examination reveals a foreign boty in the right cornea. This was removed under pontocaine, local, without difficulty. Neosporin ointment and eye patch applied. Advice on care given.

File 72-0-4283 - Employers First Report of Injury

21 Grounds Maintenance Man
22 Over 2 years
23 Shoveling sawdust into spreader
24 Employee was shoveling sawdust into spreader and sawdust blew into his left eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Foreign body in left eye

Doctor's First Report of Injury

11 Sawdust flew into right eye
12 Small foreign body on O. D. (oculus dexter); slight conjunctiva irritation.

File 72-0-6102 - Employers First Report of Injury

21 Grounds Maintenance Man
22 6 months to 2 years
23 Unloading trash from truck
24 While unloading trash from truck, something entered his eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Eye has something in it.

Doctor's First Report of Injury

11 Patient stated, while working with grasses, right eye became swollen and painful.
12 Conjunctivitis, right eye.

File 72-0-6973 - Employers First Report of Injury

21 General Maintenance Man
22 Over 2 years
23 Inserting nozzle into cell door track
24 Co-worker pulled the pin on the handle of the CO_2 tank and faulty valve allowed tank to empty contents with great force.
25 3-foot nozzle and CO_2 tank
26 Valve on CO_2 tank
27 Yes
28 Yes
29 Have valve checked at time of refills
30 Foreign bodies in left eye.

Doctor's First Report of Injury

11 Patient stated "Safety valve blew off air tank; dirt blew into left and right eye."
12 Foreign bodies in left eye.

File 72-0-4362 - Employers First Report of Injury

21 Tree Trimmer
22 Over 2 years
23 Loading brush on truck
24 A piece of the brush he was loading pushed his glasses off and hit him in the eye.
25 Brush (sycamore)
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye injury.

Doctor's First Report of Injury

11 Patient states he was struck in the right eye with a tree branch while trimming a tree.
12 Conjunctival abrasion over right eye, laterally, moderate conjunctivitis.

File 72-0-5196 - Employers First Report of Injury

21 Tree Trimmer, WFmn
22 Over 2 years
23 Placing chain around stump
24 Leaf poked him in eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Eye injury

Doctor's First Report of Injury

11 The patient states that while working, he was hit in the right eye with the edge of a sharp blade.
12 Examination reveals generalized infection, lacrimation and photophobia of the right eye. Fluorescein stain is retained on the cornea in linear fashion from 12 to 6 o'clock. Visual acuity, OD (oculus dexter): 20/50; OS (oculus sinister): 20/25.

File 72-0-4512 - Employers First Report of Injury

No report in file.

Doctor's First Report of Injury

11 "I was walking outside of Hall of Administration, on Hill Street side, and dust from palm tree trimmings got into my left eye"
12 No foreign bodies seen.

File 72-0-6546 - Employers First Report of Injury

21 Clerk
22 Over 2 years
23 Cleaning 3-M reader/printer
24 Employee got photo chemical in eye by rubbing eye while he had chemicals on hands
25 3-M reader/printer
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye has discharge and affected vision

Doctor's First Report of Injury

11 "I was cleaning the 3-M machine and I think I got chemical in my right eye from my hands."
12 Has a tender swelling medial aspect, right eye over duct area, with discharge. First noticed last Friday. This does not appear to be an industrial injury. It appears to be an infection or dacryocystitis.

File 72-0-4004 - Employers First Report of Injury

No report in file.

Doctor's First Report of Injury

11 "I was working on a report when I became distracted and lifted my pencil up and struck my left eye with the pencil."
12 Has a cold with tearing of left eye. No hemorrage ecchymosis or abrasions seen in or around left eye. No soreness or tenderness.

File 72-0-6735 - Employers First Report of Injury

No report in file.

Doctor's First Report of Injury

11. "I was reading proof sheets and there were small particles of paper which I believe somehow got into my left eye."
12 No foreign bodies seen. Has apparent infection of conjunctiva of both eyes. Left eye feels better now.

File 72-0-6094 - Employers First Report of Injury

21 Appraiser I
22 Over 2 years
23 Unknown -- received eye injury scratch
24 Blank
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Received eye injury scratch

Doctor's First Report of Injury

11 "Yesterday, I don't remember really what I was doing, but felt something in my left eye. I washed eye out last night, but this morning I could feel irritation like something was in my eye again."
12 No foreign bodies seen. Has very sensitive eyes all of the time, and it is difficult to examine.

File 72-0-4808 - Employers First Report of Injury

No report in file.

Doctor's First Report of Injury

11 "I was walking from parking lot when I noticed something in my left eye."
12 No foreign bodies seen.

File 72-0-7010 - Employers First Report of Injury

21 Typist Clerk
22 Over 2 years
23 Answering the telephone
24 Scratched her right eye with fingernail as she was answering the phone.
25 Telephone
26 Blank
27 Blank
28 Blank
29 Blank
30 Subconjunctival hemorrage along medial canthus, right eye. No carneal lesions.

Doctor's First Report of Injury

11 Patient stated that about 20 minutes ago, she poked her right eye with her fingernail while she was reaching to answer the telephone.
12 Subconjunctival hemorrage along medial canthus, right eye. No corneal lesions.

File 72-0-5124 - Employers First Report of Injury

21 Deputy Sheriff
22 Over 2 years
23 Employee was traveling eastbound on Firestone, responding to a call
24 Unknown foreign object flew into vehicle and into employee's eye via the open right window.
25 Flying debris
26 Blank
27 Blank
28 Blank
29 Blank
30 Foreign object in eye.

Doctor's First Report of Injury

11 Driving car and felt particle blow into right eye.
12 Foreign Body, OD.

File 72-0-5137 - Employers First Report of Injury

21 Deputy Sheriff
22 Over 2 years
23 Completing paper work in the attorney room.
24 Employee felt something in right eye.
25 Unknown
26 Blank
27 Blank
28 Blank
29 Blank
30 Unknown foreign matter in right eye.

Doctor's First Report of Injury

11 Unknown; possibly flying particle from pistol range.
12 Healing conjunctival erosion, temporarily OD.
3 filaments in corneal epithelium OD.

File 72-0-5715 - Employers First Report of Injury

21 Deputy Sheriff I
22 Over 2 years
23 Escorting inmate to module
24 Inmate turned and swung, hitting employee in the eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Small cut on left eye and swelling of the eye.

Doctor's First Report of Injury

11 Patient states that a prisoner struck him in the left eye.
12 Contusion, left face.

File 72-0-7027 - Employers First Report of Injury

21 Deputy Sheriff
22 6 months to 2 years
23 Attempting to restrain a vicious dog
24 Another deputy accidentally sprayed Federal Streamer on my right arm and right face area.
25 Federal Streamer
26 Blank
27 Blank
28 Blank
29 Blank
30 Irritation to right arm.

Doctor's First Report of Injury

11 Officer stated that about 8:20 PM, while trying to apprehend a suspect, the suspect's vicious German Shepherd dog started to attack him. Another officer sprayed dog with streamer spray, accidentally spraying CN spray into patient's right eye and on patient's right arm.
12 Conjunctivitis, minor, right eye, chemical.

File 72-0-6341 - Employers First Report of Injury

21 Deputy Sheriff III
22 Over 2 years
23 Assisting another Deputy in restraining an inmate.
24 The inmate struck employee on right eye with his right clinched fist.
25 Inmate's fist
26 Blank
27 Blank
28 Blank
29 Blank
30 Bruise over left eye.

Doctor's First Report of Injury

11 Altercation today; complains of pain, right thumb, MP joint.
12 Diagnosis: bruise, left temple, sprained right thumb, MP joint. Examination: thumb swollen, ruled range of motion, no pain. Bruised temple, forehead, left. Not knocked out.

File 72-0-4149 - Employers First Report of Injury

21 Deputy Sheriff
22 Over 2 years
23 Participating as a mock demonstrator during a training session with deputy personnel
24 While participating in a mock demonstration, employee suffered the described injury.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Scratched right eye.

Doctor's First Report of Injury

11 Patient's team mate stuck his finger in patient's eye.
12 Abrasion of cornea.

File 72-0-5627 - Employers First Report of Injury

21 Deputy Sheriff, Sergeant
22 Over 2 years
23 Filing training files
24 Employee pulled folder, corner of file hitting left eye.
25 Folder
26 Blank
27 Blank
28 Blank
29 Blank
30 Swelling and infection of left eye.

Doctor's First Report of Injury

11 "I pulled a file folder out and accidentally hit my left eye."
12 Conjunctivitis, left eye.

File 72-0-6383 - Employers First Report of Injury

21 Senior Air Pollution Engineer
22 Over 2 years
23 Employee was measuring the size of a lead melting furnace.
24 As employee was standing near the back of the furnace, the operator charged a piece of lead into the front of the furnace, causing some molten lead to splatter.
25 Lead melting furnace.
26 Blank
27 Blank
28 Blank
29 Blank
30 Lead splattered out of an opening into employee's eye.

Doctor's First Report of Injury

11 "We were inspecting a lead melting furnace and taking some measurements when the lead was thrown into the pot and some of it flew into my left eye."
12 Has infection, left eye, with burn area on sclera, mainly at 4/5 o'clock.

File 72-0-5603 - Employers First Report of Injury

21 Civil Engineering Assistant
22 6 months to 2 years
23 Sitting outside during coffee break.
24 While employee was sitting outside during coffee break, the wind blew a foreign object in his eye.
25 Foreign object.
26 Blank
27 Blank
28 Blank
29 Blank
30 Swelling and puffing of left eye.

Doctor's First Report of Injury

11 Patient states there is a possible foreign body in left eye.
12 Conjunctiva inflammed and edematous. Cornea clear. No foreign body present.

File 72-0-4843 - Employers First Report of Injury

21 Air Pollution Technician
22 Over 2 years
23 Employee was calibrating an instrument that uses a reagent.
24 As employee was calibrating the instrument, the reagent splashed in his right eye.
25 Liquid Reagent
26 Blank
27 Yes
28 Yes
29 Face Shield should be replaced with safety glasses.
30 Slight burning sensation in right eye.

Doctor's First Report of Injury

11 "I was making a disconnect on a Saltzman reagent pump when a few drops splattered into my right eye. I irrigated it with water."
12 Right eye looks normal without injection and feels alright now.

File 72-0-6688 - Employers First Report of Injury

21 Head Construction Inspector
22 Over 2 years
23 Checking excavation for storm drainage installation
24 Excessive rock dust in right eye; contractor depositing rock in trench excavation.
25 Dust particles from crushed rock
26 N/A
27 N/A
28 N/A
29 Blank
30 Constant watering and irritation of eye

Doctor's First Report of Injury

11 "While working, some rock dust entered my right eye."
12 Visual acuity with glasses; right eye, 20/20; left eye, 20/30. Right eye: no evidence of foreign body or corneal abrasion.

File 72-0-6051 - Employers First Report of Injury

21 Medical Laboratory Technician
22 Over 2 years
23 Performing laboratory tests as per requisitions.
24 In adding acid mixture to tube of patient's serum, tube blew up and splashed acid on employee's face and eyes.
25 Acid mixture
26 Blank
27 Blank
28 Blank
29 Blank
30 Inflammation of both eyes due to acid and blurry vision

Doctor's First Report of Injury

11 "I was doing a laboratory procedure when a mixture of concentrated acids backfired into my face, hitting my eyes.
12 Complaints of blurring of right eye with difficulty in reading pipettes. Both eyes look normal.

File 72-0-6415 - Employers First Report of Injury

21 Senior Attendant
22 Over 2 years
23 Walking to work area
24 Employee stated that around 4:00 PM, her eye became red and irritated.
25 Unknown foreign body
26 Blank
27 Yes
28 Yes
29 Maintain well-lighted work area; try to avoid small flying objects; Keep eyes at a distance to foreign particles, such as urine. dust, and patients' articles; avoid rubbing eyes.
30 Left eye red and irritated.

Doctor's First Report of Injury

No report in file.

File 72-0-3998 - Employers First Report of Injury

21 Licensed Vocational Nurse
22 6 months to 2 years
23 Employee was coming to work, walking in front of out-patient building. Construction workers were sand-blasting.
24 The out-patient building; some of the debris flew into eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Unavoidable accident
30 Foreign body, eight eye.

Doctor's First Report of Injury

No report in file.

File 72-0-3999 - Employers First Report of Injury

21 Licensed Vocational Nurse
22 Over 2 years
23 Walking through the basement of General Hospital
24 Another employee was dumping trash. Some of the particles of trash flew into employee's left eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Foreign body, left eye.

Doctor's First Report of Injury

No report in file.

File 72-0-4747 - Employers First Report of Injury

21 Public Health Nurse
22 6 months to 2 years
23 Performing a Mantoux test
24 Performing a Mantoux test, needle and syringe separated. A small amount of 5 tu (PPD) went into her right eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye

Doctor's First Report of Work Injury

Report not in file

File 72-0-4915 - Employers First Report of Injury

21 Public Health Clinic Nurse
22 Over 2 years
23 Giving a Mantoux skin test
24 Giving a Mantoux skin test, needle and syringe separated, spraying eyes with solution
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Eyes

Doctor's First Report of Injury

11 Accidentally got PPD solution in both eyes. Eyes now redened.
12 Alergic conjunctivitis

File 72-0-6186 - Employers First Report of Injury

21 Public Health Nurse
22 Over 2 years
23 Giving Mantoux test
24 Patient struck out at employee. Employee removed needle from patient's skin and at the same time compressed alcohol sponge. A fine spray sprayed employee's right eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye.

Doctor's First Report of Injury

Report missing from file.

File 72-0-6372 - Employers First Report of Injury

21 Public Health Nurse
22 Over 2 years
23 Making home visit.
24 Sitting on couch when teenage brother brought in small metal tear gas pen. Sister accidentally discharged the pen, and tear gas filled the room.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Both eyes became red, swollen, tearing, severely painful.

Doctor's First Report of Injury

11 "While working for patient in home, children had tear gas pen, and it went off, and now my eyes are burning."
12 Visual acuity: left eye 20/50; right eye 20/40; both eyes 20/30. Vision apparently is poor because she just removed contact lenses. Pupils equal and regular, react to light and accommodation; extra ocular movements intact. Eyes actually appear entirely normal.

File 72-0-6553 - Employers First Report of Injury

21 Public Health Nurse
22 6 months to 2 years
23 Breaking top off swabs
24 Swabs splintered and splashed gonococcus contaminated culture medium out of container backward into employee's eyes.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Eyes

Doctor's First Report of Injury

11 Patient states had taken a gonorrhea culture and snapping tops of cotton swabs off the bottom which were inserted in the medium. The sticks split and splashed contaminated medium into her eyes.
12 Eyes appear uninjected and normal to examination. Diagnosis: history of possible contamination of both eyes with infectious process.

File 72-0-6468 - Employers First Report of Injury

21 Senior Sanitarian
22 Blank
23 Reaching over to unlock the car door.
24 Car was parked by a tree. As he reached over to unlock the door, the tree branch scratched him.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Eye lid and corner of eye.

Doctor's First Report of Injury

Report missing from file.

File 72-0-4022 - Employers First Report of Injury

21 Flood Control Laborer
22 Over 2 years
23 Trimming hedge
24 Employee states that while trimming a hedge, a twig struck him in the right eye.
25 Twig
26 Blank
27 Yes
28 No
29 Wear goggles
30 Irritation and swelling in right eye.

Doctor's First Report of Injury

11 Patient was trimming leaves at work. Branch went into his right eye, causing pain.
12 Conjunctivitis, right eye.

File 72-0-5787 - Employers First Report of Injury

21 Flood Control Laborer
22 6 months to 2 years
23 Working in manhole shaft.
24 Employee states that while working in manhole shaft, a gust of wind blew sand in his eye.
25 Sand
26 Blank
27 Blank
28 Blank
29 Blank
30 Sand in left eye.

Doctor's First Report of Injury

11 "While working, I was in a manhole shaft cleaning a pipe, and got something in my left eye."
12 Visual acuity: right eye 20/20; left eye 20/20. Left eye, there is a corneal abrasion at 3 o'clock adjacent to the limbus. Demonstrable diagnosis: traumatic corneal abrasion, left eye.

File 72-0-4617 - Employers First Report of Injury

21 Flood Control Maintenance Man
22 6 months to 2 years
23 Loading debris onto truck
24 Employee states that while loading debris onto truck, a particle of dust entered his eye.
25 Particle of dust
26 Blank
27 Yes
28 No
29 Wear goggles
30 Particle of dust in right eye.

Doctor's First Report of Injury

11 Loading truck with pitchfork and something flew into right eye.
12 Visual acuity: OD 20/50 without correction; OS 20/50. OD/small foreign body central cornea. Anterior chamber clear. Foreign body OD.

File 72-0-4395 - Employers First Report of Injury

21 Road laborer
22 6 months to 2 years
23 Employee states he was helping another employee cut foundation bolts with a torch.
24 Employee states a hot piece of metal went behind safety glasses and stuck to his eyeball.
25 Foreign object
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee states he has a foreign object in his left eye.

Doctor's First Report of Injury

11 Welding, something flew into right eye.
12 Corneal abrasion, right eye over medial iris.

File 72-0-5598 - Employers First Report of Injury

21 Road Laborer
22 Over 2 years
23 Employee states he was sweeping sand.
24 Employee states that the sand blew in his left eye.
25 Sand or foreign object.
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee states he has sand or foreign object in his left eye.

Doctor's First Report of Injury

Report missing from file.

File 72-0-6319 - Employers First Report of Injury

21 Road Laborer
22 6 months to 2 years
23 Employee states he was standing beside truck.
24 Employee states the driver of the truck dumped bucket into bed of truck and a foreign object blew into his left eye.
25 Foreign object.
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee complains of foreign object in his left eye.

Doctor's First Report of Injury

11 "While at work, another employee was loading, and something flew into my left eye."
12 Some conjunctivitis of left eye. Some irritation. Cannot see a foreign object. Fluorescein stain - negative.

File 72-0-4766 - Employers First Report of Injury

21 Road Maintenance Man
22 6 months to 2 years
23 Employee states he was changing a tire.
24 Employee states he was removing lug bolts with an impact wrench. A foreign object blew into his right eye and lodged there.
25 Foreign object
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee states he has a foreign object in his right eye.

Doctor's First Report of Injury

11 Foreign body, right eye.
12 Foreign body, right eye.

File 72-0-6537 - Employers First Report of Injury

21 Sign Poster
22 Over 2 years
23 Running jack hammer
24 Foreign object flew into eye
25 Jack hammer
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee states he has irritation of the left eye.

Doctor's First Report of Injury

11 "While working with a jack hammer, something got in my left eye.
12 20/20, 20/40. Corneal foreign body, left eye, approximately 4 o'clock.

File 72-0-7159 - Employers First Report of Injury

21 Sewer Maintenance Man I
22 Less than 6 months
23 Dusting for roaches
24 Something blew into left eye.
25 Truck and blower
26 Blank
27 Yes
28 Yes
29 Blank
30 Something in left eye.

Doctor's First Report of Injury

Report missing from file.

File 72-0-5855 - Employers First Report of Injury

Report missing from file.

Doctor's First Report of Injury

11 "As I was walking through the tunnel, a man was drilling a hole in the ceiling. I waited until he quit and the dust settled before I walked through, but the wind blew and dust got in my eye."
12 Metal shavings blew into eyes while passing man who had been drilling. After irrigation, no foreign bodies appreciated. Corneal stain, negative. Fundoscopic, negative.

File 72-0-4714 - Employers First Report of Injury

21 Airport Service Man
22 Over 2 years
23 Was working on removal of instrument panel of vehicle
24 Debris fell into eyes
25 Debris from under dash
26 N/A
27 N/A
28 Blank
29 Wearing eye protection and using compressed air to blow dust.
30 Foreign matter in eyes.

Doctor's First Report of Injury

11 Working under instrument panel of tractor, something fell into right eye.
12 Slit-lamp revealed foreign body under right upper lid.

File 72-0-5669 - Employers First Report of Injury

21 Airport Service Man
22 Over 2 years
23 Drilling mounting holes in flagpole base prior to installation.
24 Drilling chips flew into corner of eye.
25 Drill press
26 Blank
27 Yes
28 Unknown
29 Goggles that don't prevent use of prescription glasses.
30 Pain in eye. Doctor removed a particle.

Doctor's First Report of Injury

11 Patient states he has foreign body in right eye.
12 Foreign body in right eye.

File 72-0-5951 - Employers First Report of Injury

21 Airport Service Man
22 Over 2 years
23 Driving a tractor
24 Rock or foreign material flew off tire and into eye.
25 Tractor (rubber tired), skip-loader
26 Tractor
27 Yes
28 No
29 Wearing of safety glasses
30 Penetrating corneal laceration.

Doctor's First Report of Injury

11 Driving a skip-loader to put unit away at the end of work period. A stone, or unknown material, flew off tire and into my right eye while in motion.
12 Circumferential injection of vessels in conjunctiva, none around nimbus. No corneal or other demonstrable injury to central eye structure. Impression: contusion, conjunctiva, right eye.

File 72-0-4721 - Employers First Report of Injury

21 Welder
22 Over 2 years
23 Walking
24 Piece of dirt lodged in his eye
25 Dirt
26 Blank
27 N/A
28 Blank
29 None
30 Piece of dirt in eye.

Doctor's First Report of Injury

11 "I was working in a cell in the Hall of Justice with a blower operating to vacuum the fumes, and I believe a particle of paint or asbestos flew into my right eye.
12 No foreign body seen, but has some injection of right sclera and conjunctiva. Also has pterygium both eyes.

File 72-0-6618 - Employers First Report of Injury

21 Plasterer
22 Over 2 years
23 Using an electric screw gun screwing into metal stud.
24 The vibration caused plaster to fall from above the door opening. It bounced on floor, then hit him in eye.
25 Electric screw gun
26 N/A
27 N/A
28 Blank
29 Blank
30 Soreness in left eye.

Doctor's First Report of Injury

11 (Writing in report illegible)
12 Corneal abrasion.

File 72-0-4851 - Employers First Report of Injury

21 Apprentice Carpenter
22 Over 2 years
23 Using router, routing out drawer front.
24 While using router, shaving was blown into eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Foreign object in right eye.

Doctor's First Report of Injury

11 Patient states while using hand router, something flew into right eye.
12 Conjunctivitis, right eye.

File 72-0-4499 - Employers First Report of Injury

Report missing from file

Doctor's First Report of Injury

11 "I was taking down a bookcase and got comething in my left eye."
12 No foreign body seen. Patient has an eyelash lateral aspect, upper left lid which appears to rub on the sclera. The sclera is injected.

File 72-0-6441 - Employers First Report of Injury

21 Carpenter
22 Over 2 years
23 Cutting a 4 x 4 R. D. W.
24 Wind blew sawdust into eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Left eye.

Doctor's First Report of Injury

11 Patient states he was cutting a post, and sawdust blew into his left eye.
12 Conjunctivitis. No corneal abrasions seen with magnifier. No foreign body noted.

File 72-0-5958 - Employers First Report of Injury

21 Electrician Helper
22 Over 2 years
23 Walking
24 Formica sheet fell down on floor -- raised dust and particle of dirt entered right eye.
25 DNA
26 Blank
27 Blank
28 Blank
29 Blank
30 Dirt in right eye.

Doctor's First Report of Injury

11 Walking -- something in eye.
12 Metallic foreign body, right eye.

File 72-0-6638 - Employers First Report of Injury

21 Electrician Helper
22 6 months to 2 years
23 Putting battery down onto platter.
24 When battery was set down, water came up fill cap breather holes.
25 Battery
26 N/A
27 No
28 No
29 Design breather caps so water cannot come out.
30 Water from battery got on hands and in left eye.

Doctor's First Report of Injury

11 "I dropped a battery and the battery acid came out of the fill hole and splattered my face and left eye. I irrigated it with water from a fire hose and also distilled water."
12 Injection of sclera, left eye.

File 72-0-4369 - Employers First Report of Injury

21 Helper, Masonry
22 Over 2 years
23 He was dumping concrete out of a wheelbarrow
24 Some concrete splashed up and got in his eye.
25 Concrete
26 Blank
27 N/A
28 Blank
29 Blank
30 Cement in right eye.

Doctor's First Report of Injury

11 While mixing concrete, concrete got in right eye.
12 No corneal foreign body or abrasive cement. Conjunctiva markedly injected.

File 72-0-7152 - Employers First Report of Injury

21 Helper, Metal Working
22 Over 2 years
23 Employee states he was soldering a gas tank.
24 Employee states he applied hot soldering iron to the acid and it exploded. (This is the method used for cleaning debris from soldering iron.)
25 Soldering iron and acid.
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee states he has pain in his right eye.

Doctor's First Report of Injury

11 "While working soldering, liquid acid exploded entering my right eye."
12 Visual acuity: right eye 20/40; left eye 20/20. Right eye, marked conjunctival reaction and scleral injection. Marked blepharospasm. Diagnosis: chemical conjunctivitis, right eye.

File 72-0-5801 - Employers First Report of Injury

21 Food Service Worker
22 Less than 6 months
23 Putting soap in sinks
24 Employee was putting soap in sinks, turned on water to fill sinks, and soap splattered into his eyes.
25 Soap
26 Blank
27 Blank
28 Blank
29 Put some water in sink first.
30 Eyes burn - soap in both eyes.

Doctor's First Report of Injury

Report missing from file.

File 72-0-4159 - Employers First Report of Injury

21 Institutional Food Service Worker
22 6 months to 2 years
23 Employee was opening hot food cart door because there was a smell of smoke in pantry. When he opened the door to food cart, smoke caused vision in left eye to be temporarily impaired.
25 Hot food cart
26 Blank
27 Blank
28 Blank
29 Staff should leave food carts disconnected and cleared of food.
30 Left eye was red, watery, and swollen. He could hardly see.

Doctor's First Report of Injury

11 Opening doors on a hot foot cart and was overcome by smoke into eyes.
12 Mild conjunctivitis, left eye.

File 72-0-5599 - Employers First Report of Injury

21 Electrician
22 Less than 6 months
23 Pulling wire
24 Pulling wire; came loose and struck employee in left eye.
25 No. 14 strand wire
26 Blank
27 No
28 Blank
29 Wear safety glasses (Note: employee has requested same but has not received).
30 Scratched left eyeball.

Doctor's First Report of Injury

11 Patient states he has left eye injury. Piece of wire flopped on eye.
12 Abrasion of left cornea.

File 72-0-5425 - Employers First Report of Injury

21 Electrician
22 6 months to 2 years
23 Knocking a hole in ceiling to install a ventilation fan.
24 Felt a foreign object strike him in left eye.
25 Hammer and plaster
26 Blank
27 Yes
28 Yes
29 Blank
30 Very irritated, sore left eye.

Doctor's First Report of Injury

11 "I was knocking a hole in a ceiling and got something in my left eye."
12 Diagnosis: Mild conjunctivitis, OS: No apparent foreign body.

File 72-0-6436 - Employers First Report of Injury

21 Electrician, Temporary
22 Less than 6 months
23 Employee was knocking hole through plaster ceiling to install fixture.
24 Falling plaster fell into left eye.
25 Hand-held hammer
26 Blank
27 Blank
28 Blank
29 Goggles and hard-hat will be issued.
30 Injury to left eye.

Doctor's First Report of Injury

11 Patient states he was knocking hole in a plaster wall at work at 2:00 PM this date. Got something in left eye. Complains of pain and redness in left eye.
12 Foreign body, left cornea.

File 72-0-5335 - Employers First Report of Injury

Report missing from file.

Doctor's First Report of Injury

11 "I was cleaning a floor and got wood slivers in my fingers."
12 Evaluation of possible foreign body in left eye. None found.

File 72-0-6760 - Employers First Report of Injury

21 C & R Laborer
22 Over 2 years
23 Taking out window screen
24 Dust or grass got into eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Eye irritation

Doctor's First Report of Injury

11 "I was taking off a screen from a window and something got into my right eye."
12 Diagnosis: Corneal abrasion, right eye.

File 72-0-4901 - Employers First Report of Injury

21 Construction and Repair Labor Foreman
22 Over 2 years
23 Employee states he was making group replacements on street light lamps.
24 Employee states he was looking up while laborer was moving extension ladder into trees for changing lamps, when a foreign object entered his left eye.
25 Foreign object
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee states he has a foreign object in his left eye.

Doctor's First Report of Injury

11 While working, doing street light replacement, something entered my left eye. No other complaints.
12 Foreign body in left eye under upper lid.

File 72-0-6560 - Employers First Report of Injury

21 Equipment Maintenance Man
22 Over 2 years
23 Servicing a material handler electric cart
24 Foreign matter in right eye.
25 Material handler electric cart
26 Blank
27 N/A
28 Blank
29 Blank
30 Irritation and imflammed right eye.

Doctor's First Report of Injury

11 Patient states was working on piece of equipment and something flew into right eye.
12 Conjunctiva inflammed, cornea clear. No foreign body present.

File 72-0-6788 - Employers First Report of Injury

21 Equipment Maintenance Man
22 Over 2 years
23 Working under a sweeper
24 Foreign object entered eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Eye red and swollen

Doctor's First Report of Injury

11 Patient states he has something (dirt) in right eye. Happened 6/2/72 PM
12 Small foreign body, right eye, at 7 o'clock position. Pupil normal. Tension normal. Eye lids normal. Diagnosis: foreign body in cornea.

File 72-0-6353 - Employers First Report of Injury

21 Senior General Maintenance Man
22 Over 2 years
23 Working with grinder -- had goggles on. Somehow a piece of metal flew in his right eye.
24 Blank
25 Blank
26 Blank
27 Blank
28 Blank
29 Nonpreventable
30 Right eye inflammed. Metal imbedded in right eye.

Doctor's First Report of Injury

11 Patient states that he got unknown object in eye yesterday while on the job. Eye red, not bothered as much as before.
12 F.B. cornea.

File 72-0-4314 - Employers First Report of Injury

21 Custodian
22 6 months to 2 years
23 Picking up trash
24 Putting trash into bag. Dust flew up and went into eyes.
25 N/A
26 N/A
27 Blank
28 Blank
29 Blank
30 Foreign matter in eyes.

Doctor's First Report of Injury

11 Was picking up bags of trash and something got in left eye.
12 Slit-lamp revealed no stain -- no foreign body, left upper lid eversion. Some redness in cornea.

File 72-0-4960 - Employers First Report of Injury

21 Custodian
22 Over 2 years
23 Pushing dolly with broom on it
24 Employee struck his eye with broom handle
25 Broom handle
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee injured his eye

Doctor's First Report of Injury

11 Broom handle hit the patient in right eye.
12 Fluorescein does not reveal any damage to the eye, the seeing part that is, but there is some edema of the orbit which is slight.

File 72-0-5486 - Employers First Report of Injury

21 Custodian (Perm)
22 Less than 6 months
23 Operating buffer on gym floor
24 Struck in left eye by basketball
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Bruised left eye

Doctor's First Report of Injury

Report missing from file

File 72-0-5854 - Employers First Report of Injury

21 Custodian
22 Over 2 years
23 Trying to straighten a light shade in corridor with a broom
24 Pulled down shade and in the process, got dust particles in eyes
25 Dust particles
26 Blank
27 Blank
28 Blank
29 Blank
30 Sensation of foreign body under eye lid

Doctor's First Report of Injury

11 I knocked a light fixture with a broom and something fell into my left eye.
12 Sensation of foreign body under upper eye lid. Cornea clear. No conjunctivitis. No exudate. Tarsal glands negative. Imp. -- residuals of foreign body, left eye.

File 72-0-5927 - Employers First Report of Injury

21 Custodian
22 Over 2 years
23 Washing face bowl
24 Part of solution containing ammonia, splashed into employee's eye while cleaning
25 Ammonia solution
26 Blank
27 Blank
28 Blank
29 Blank
30 Solution in left eye.

Doctor's First Report of Injury

Report missing from file

File 72-0-6296 - Employers First Report of Injury

21 Custodian
22 Over 2 years
23 Opening a 1-gallon jug of Staphene
24 Aften opening jug, employee set it down too hard, causing some to splash into eye.
25 Staphene
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye was inflammed and running.

Doctor's First Report of Injury

11 Pain in right eye, spilled Staphene (cleaning solvent) in eye at work
12 Chemical conjunctivitis O. D.

File 72-0-7109 - Employers First Report of Injury

21 Custodian (PEP)
22 Less than 6 months
23 Sweeping
24 The wind blew something in his eye
25 Wind
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee's right eye was injured.

Doctor's First Report of Injury

11 "I got something in my right eye while working at the loading dock. I think it is out now."
12 Right eye feels alright now. No foreign bodies seen.

File 72-0-7236 - Employers First Report of Injury

21 Custodian
22 Over 2 years
23 Employee was pouring ammonia into water.
24 As employee was pouring ammonia into water, it splashed in his eyes.
25 Ammonia
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee complained that his eye was burning and it had turned dark red.

Doctor's First Report of Injury

Report missing from file

File 72-0-5070 - Employers First Report of Injury

21 Painter
22 Over 2 years
23 Sanding and applying putty to woodwork
24 Foreign object flew into eye
25 Sand paper and putty knife
26 Blank
27 No
28 Blank
29 Blank
30 Foreign object in eye.

Doctor's First Report of Injury

11 "On Friday, 3/10/72, at approximately 2:00 PM, I was at work scraping some material from a pedestal when I got a piece into my left eye which has been irritating since."
12 No foreign body seen in left eye, and no real irritation seen now.

File 72-0-5495 - Employers First Report of Injury

21 Microfilm Technician
22 Over 2 years
23 Cleaning out a developer tank
24 Tray cleaner splashed into left eye
25 Developer tank
26 Blank
27 Yes
28 No
29 Wear safety glasses
30 Smarting and burning sensation of left eye.

Doctor's First Report of Injury

11 "I was pouring tray cleaner into the developer tank and some splashed into my left eye."
12 Patient washed out left eye with water for 10 minutes. Eye looks alright and feels alright now.

File 72-0-7108 - Employers First Report of Injury

21 Stationary Engineering Appraiser, 1st year
22 6 months to 2 years
23 Employee states he was loading chemical tanks
24 Employee states chemicals splashed into eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Injured left eye

Doctor's First Report of Injury

Report missing from file

File 72-0-4683 - Employers First Report of Injury

21 Plumber (Temp)
22 6 months to 2 years
23 Sil-braying copper pipe
24 Eye started hurting; could not see good
25 Torch
26 Blank
27 Blank
28 Blank
29 Blank
30 Eye burns, can hardly see, very red.

Doctor's First Report of Injury

11 Patient at work, exposed to flash burns from torch
12 Flash burns of eyes.

File 72-0-4953 - Employers First Report of Injury

21 Plumber
22 Over 3 years
23 He was adjusting heating ducts
24 Dust got in eyes
25 Dust
26 Blank
27 No
28 Blank
29 Blank
30 Eyes were watering and burning

Doctor's First Report of Injury

11 Patient was adjusting a ventilating duct, wat hit in the face with a spray of dust -- thought he had washed it all out of his eyes -- Patient now complains of irritation of left eye.
12 Diagnosis: traumatic conjunctivitis, left eye.

File 72-0-5712 - Employers First Report of Injury

21 Plumber
22 Over 2 years
23 Employee was silver-soldering copper pipe. This entailed the use of the oxy-acetylene torch and protective glasses.
24 The flame from the oxy-acetylene welding torch was too bright and employee didn't use the eye protection provided.
25 Blank
26 Blank
27 Blank
28 Blank
29 Employees are being instructed to use all protective devices as needed.
30 Flash burns to both eyes.

Doctor's First Report of Injury

11 Patient states that while at work and using wending torch all day, the flash from the torch caused pain to both eyes.
12 Examination reveals bilateral conjunctival infection; no foreign body; no abrasion. Imp. Actinic conjunctivitis.

File 72-0-4341 - Employers First Report of Injury

21 Light Tractor Operator
22 Over 2 years
23 Mowing lawn
24 Object flew in air and hit him in eye
25 76-inch mower
26 Blank
27 Blank
28 Blank
29 Blank
30 Left eye injury

Doctor's First Report of Injury

11 "While I was operating the tractor, something flew in my left eye."
12 Eye examination: Right eye 20/30; left eye 20/25. Right J5; left J7. Topic anesthesia. Very small black foreign body found and removed from under left upper lid.

File 72-0-4978 - Employers First Report of Injury

21 Power Equipment Operator
22 Over 2 years
23 Employee states he was operating equipment.
24 Employee states the wind was blowing and a foreign object entered left eye.
25 Foreign object
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee states that foreign object entered left eye.

Doctor's First Report of Injury

11 Somethind in left eye.
12 Conjunctivitis, left eye.

File 72-0-5344 - Employers First Report of Injury

21 Power Equipment Operator
22 Over 2 years
23 Employee states he was operating a paving machine.
24 Employee states a foreign object entered his left eye.
25 Foreign object
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee states he has foreign object in his left eye.

Doctor's First Report of Injury

11 "While at work operating a street paver, something flew into my left eye."
12 Patient claims co-worker allegedly removed a bug from his left eye shortly after the injury. At present injection and lacrimation of left eye. Visual acuity, without glasses: left 10/20; right 20/40. With glasses: left 20/40; right 20/70. Examination: Eye's PERLA, right, cloudy cover of mild degree, bilaterally. Diagnosis: (1) Nebunitis/conjunctivitis with allergic reaction, left eye, (2) Corneal optification, bilaterally.

File 72-0-6518 - Employers First Report of Injury

21 Power Equipment Repairman
22 Over 2 years
23 Working under dashboard of vehicle
24 Dirt got in eye
25 None
26 N/A
27 Yes
28 Yes
29 Blank
30 Right eye sore and red.

Doctor's First Report of Injury

11 "I walked from the lunch area back to my tools and picked up some tools starting toward an automobile, and something got in my right eye."
12 No foreign bodies siin in right eye.

File 72-0-5858 - Employers First Report of Injury

21 Body and Fender Apprentice
22 Over 2 years
23 Walking behind another employee who was grinding vehicle
24 Metal particles flew into left eye.
25 Grinder
26 Blank
27 Yes
28 No
29 Wear safety glasses at all times.
30 Metal in left eye.

Doctor's First Report of Injury

11 "I was grinding metal and something got in my left eye."
12 Diagnosis: Two deeply imbedded corneal foreign bodies with severe conjunctivitis.

File 72-0-6588 - Employers First Report of Injury

21 Sheet Metal Body Builder
22 Over 2 years
23 Was looking for a tool in toolbox
24 Something fell in box and bounced back, hitting in right eye, the right side of my safety glasses shattering
25 Toolbox
26 N/A
27 Yes
28 Yes
29 Blank
30 Traumatic conjunctivitis.

Doctor's First Report of Injury

11 "While working, I was looking for a tool in my toolbox. Something fell in box and bounced back, hitting the right side of my safety glasses, shattering them (was wearing safety glasses at time)."
12 The safety glass lens of the right eye was shattered but there are no particles of glass missing from the lens. The conjunctiva is red. Patient knows that he has had granulated eyeballs for years. Diagnosis: traumatic conjunctivitis.

File 72-0-7069 - Employers First Report of Injury

21 Fire Equipment Repairman
22 Over 2 years
23 Underneath vehicle installing a drive line
24 Piece of metal fell into eye.
25 Drive line
26 Blank
27 Yes
28 Yes
29 He had glasses on, but the metal fell under them.
30 Metal in right eye.

Doctor's First Report of Injury

11 "While working, I was underneath a truck taking a drive shaft out, when some dirt fell in my right eye."
12 Imbedded foreign body 5 o' clock, cornea of right eye, resulting in slight bulbar conjunctivitis with slight photophobia and lacrimation of same.

File 72-0-4926 - Employers First Report of Injury

21 Refrigeration Mechanic
22 Over 2 years
23 Using oil and graphite on air conditioner.
24 A drop hit right eye and was very painful.
25 Oil and graphite
26 Blank
27 Unknown
28 Blank
29 Blank
30 Right eye had burning sensation.

Doctor's First Report of Injury

11 "I climbed a ladder and took the oil squirt gun and worked the trigger to squirt oil on the linkage on a static clamper motor. On the second squirt on the trigger, a drop of penetrating oil and graphite bounced off the linkage and entered my right eye."
12 Drop of "acid" splashed into right eye. Examination reveals minimal injection of conjunctive inner canthus, right eye. Cornea looks normal. PERLA.

File 72-0-5799 - Employers First Report of Injury

21 Water Service Man
22 Over 2 years
23 Removing a hatch cover
24 A foreign particle became lodged in his right eye as he removed hatch cover at reservoir.
25 Wooden hatch cover
26 N/A
27 N/A
28 Blank
29 Blank
30 Particle in right eye.

Doctor's First Report of Injury

11 "I was shaking chlorine into the water tank and something blew into my eye."
12 No foreign body noted. No corneal laceration. Diagnosis" chemical conjunctivitis, right eye.

File 72-0-4127 - Employers First Report of Injury

21 Community Worker I
22 Blank
23 Standing -- turned around and chair leg hit me in the eye.
24 Court ward was carrying a chair over his head. When the employee turned around, the chair leg hit him in the right eye.
25 Chair
26 Blank
27 Blank
28 Blank
29 Staff to instruct ward to use caution and safety manners when carrying furniture.
30 Soreness around eye and pupil of eye smarted; swelling around eye area; felt tender.

Doctor's First Report of Injury

11 Was turning around while someone was carrying a chair. Leg of chair struck right eye. Now eye sensitive to bright light.
12 Red, watering eye. No foreign body seen in right eye. No injury to ocular structure.

File 72-0-5471 - Employers First Report of Injury

21 Deputy Probation Officer I
22 Over 2 years
23 Cleaning out desk drawer in examination room with dust rag and whisk broom.
24 Foreign body flew in his right eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Unavoidable.
30 Right eye swollen, red and sore.

Doctor's First Report of Injury

11 "I was cleaning out a drawer and some dust flew in my right eye."
12 R/O possible foreign body; conjunctivitis.

File 72-0-4032 - Employers First Report of Injury

21 Deputy Probation Officer II
22 Over 2 years
23 Leaving elevator, stopped to open brief case to get out paper when bumped from behind.
24 When bumped from behind, the paper he had in his hand hit him in the right eye.
25 Paper
26 Blank
27 Blank
28 Blank
29 Do not read papers while standing in hall or walkway
30 Stuck paper in eye.

Doctor's First Report of Injury

Report missing from file

File 72-0-4349 - Employers First Report of Injury

21 Deputy Probation Officer
22 6 months to 2 years
23 Restraining a ward
24 After restraining a ward, employee released him to see to a further altercation. Ward then struck employee with his fist, knocking him to his left knee.
25 None
26 Blank
27 Blank
28 Blank
29 Unavoidable
30 Right eye bruised.

Doctor's First Report of Injury

11 "While working, was in riot and knocked unconscious and hit on head."
12 There is stated tenderness and pain on right side of face, chiefly over malar ridge. There is no tenderness of scalp. No open areas on skin. No abnormal eye reflex signs. Blood pressure, 130/76. Diagnosis: facial contusion and concussion syndrome.

File 72-0-5765 - Employers First Report of Injury

21 Deputy Probation Officer II
22 Over 2 years
23 Working in the building
24 Building was being painted. Fresh paint gave off fumes the past four days in question.
25 The atmosphere inside the building
26 Blank
27 Blank
28 Blank
29 Discussing the acquisition of a blower with Mechanical Department
30 Headaches, blurred vision.

Doctor's First Report of Injury

11 "While working, I inhaled paint fumes and noticed double vision on April 5th, 10th, 11th, and 12th."
12 Visual acuity: left eye 20/40; right eye 20/30, with glasses. Complains of double vision in left eye, relates it to painting at work. No double vision in right eye. Diagnosis: No traumas seen.

File 72-0-6368 - Employers First Report of Injury

21 Deputy Probation Officer II
22 Over 2 years
23 Supervising basketvall game. Ward accidentally stuck his right middle finger in employee's right eye.
24 Blank
25 Blank
26 Blank
27 Blank
28 Blank
29 Nonpreventable
30 Right eye swollen and hazy vision.

Doctor's First Report of Injury

11 Got a finger shoved into his eye while playing basketball last evening at work. Pain with movement of eye.
12 Moderate conjunctival injection. Cornea clear. No foreign body found. Diagnosis: Conjunctivitis.

File 72-0-4776 - Employers First Report of Injury

21 Homemaker II
22 Over 2 years
23 At client's home supervising children and doing light house work.
24 Employee was bending over to pick up dirty clothes scattered over floor. The client's three children threw an object which struck employee under the lower eyelid.
25 Unknown
26 N/A
27 N/A
28 N/A
29 Blank
30 Lower right eyelid was blue and black. A tiny scratch noticed in this area. Employee suffers from headaches.

Doctor's First Report of Injury

11 Patient stated a boy threw spool of thread or screwdriver, hitting right eye.
12 Puncture wound on lower part of right eyelid, was swelling, and ecchymosis of the lower eyelid.

File 72-0-4887 - Employers First Report of Injury

21 Deputy Sheriff - Reserve
22 Blank
23 Assisting in injury accident; put down flare pattern.
24 Flare exploded.
25 Flare
26 Blank
27 Blank
28 Blank
29 Blank
30 Pupil of left eye.

Doctor's First Report of Injury

11 While working at traffic accident, a flare blew up, burning patient's left side of face and eye. Patient received treatment at Harvard General Hospital. Patient states eye has remained painful and has difficulty seeing.
12 Examination of left eye shows small whitish corneal scar at 8o'clock position, near pupillary area. Orthometer examination: Visual acuity for distance - right 20/18; left 20/33, both 20/18.

File 72-0-5647 - Employers First Report of Injury

21 Deputy Clerk II
22 6 months to 2 years
23 Lighting cigarette with match
24 Substance from match entered left eye, causing irritation, soreness
25 Match
26 Blank
27 Blank
28 Blank
29 Be more cautious
30 Irritated, painful left eye.

Doctor's First Report of Injury

11 "I was lighting a cigarette and closed the matchbook when a particle from the match tip flew up and struck left eye."
12 Has burn of left eyelid and possible cornea with injection of conjunctiva and sclera.

File 72-0-6177 - Employers First Report of Injury

21 Deputy Marshall
22 Over 2 years
23 Attempting to pick up clipboard dropped on floor by defendent signing court appearance form.
24 In bending down, struck bar section in court room.
25 Edge of court bar.
26 Edge
27 No
28 Blank
29 More foresight
30 Left eye - outer area.

Doctor's First Report of Injury

11 Patient stated that while working in court, he bent over and hit his head on a counter. He was not knocked out.
12 The patient has no swelling, eccymois or tenderness over the left orbit at the outer canthus of the left eye. There is 1+ injection of the conjunctiva upper lid on the left lateral aspect. Pupils equal, round, react to light accommodations; extra ocular motion intact. Diagnosis: minimal conjunctivitis and mild bruise, lateral orbit.

File 72-0-5132 - Employers First Report of Injury

21 Deputy Marshall
22 Over 2 years
23 Removing burned out tail light bulb from County Vehicle No. 41057.
24 Light bulb shattered -- particles of glass or dirt flew into both eyes.
25 Tail light bulb
26 Dirt or glass from bulb
27 No
28 Blank
29 No way to foresee this type of situation.
30 Debris in both eyes.

Doctor's First Report of Injury

11 Removing a tail light bulb, it shattered, getting something in both eyes.
12 History of something entering both eyes when tail light bulb shattered. No foreign bodies seen.

File 73-0-0188 - Employers First Report of Injury

Report missing from file.

Doctor's First Report of Injury

11 "I was going through some files, and as I pull one up, it went under my glasses and struck my left eye."
12 Complains of pain in left eye. No foreign bodies seen.

File 73-0-0308 - Employers First Report of Injury

Report missing from file.

Doctor's First Report of Injury

11 "I was opening a newspaper and I pulled a corner of the paper across my right eye."
12 Has a linear abrasion across right cornea.

File 73-0-0330 - Employers First Report of Injury

21 Carpenter Helper
22 Over 2 years
23 Cutting aluminum
24 A piece flew in his right eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye, corneal abrasion.

Doctor's First Report of Injury

11 "I had been cutting aluminum and a piece flew in my right eye."
12 Corneal abrasion, right eye.

File 73-0-0936 - Employers First Report of Injury

21 Electronics Communications Technician
22 Over 2 years
23 Employee states that he was prying off a headliner in a truck
24 Employee states that the screw driver slipped and struck him over the left eyebrow.
25 Screw driver (Philips)
26 N/A
27 No
28 Blank
29 Blank
30 Injury resulted in conjunctival hemorrage in left eye and slight laceration over left eyebrow.

Doctor's First Report of Injury

11 Patient stabbed himself in the right eye with a screw driver 2 hours prior to my examination.
12 Physical examination: Visual acuity - 20/25 + 2 in each eye with correction. Pupils equal and react to light. Extra ocular muscles - full. Lids: superficial laceration margin right upper lid, medially. Conjunctiva laceration, right eye, superiorly approximately 18 millimeters in length, running from 11 o'clock to medial canthus and gaping. Cornea clear in each eye. Interior chamber--right eye 1+ flare; left eye clear. Applanation tension--14 in each eye. Fundus examination reveals normal disc vessels and macula in each eye.

File 73-0-1099 - Employers First Report of Injury

21 Construction and Repair Laborer
22 Over 2 years
23 Working on metal window
24 Piece of metal flew into eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye injured.

Doctor's First Report of Injury

11 Patient states, "I was drilling holes in a metal frame and got something in my left eye."
12 Chalazion left lower eyelid. Doubts industrial etiology.

File 73-0-1113 - Employers First Report of Injury

21 Blank
22 Less than 6 months
23 Unloading equipment off truck
24 Pulled counterboard off a truck; it slid sideways and struck victim in left eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Left Eye.

Doctor's First Report of Injury

11 Patient states he was unloading some boards for booze at a festival, and a steel hook on the board him him in the corner of left eye.
12 Abrasion and superficial laceration, nasal corner of left eye. No conjunctiva irritation. Cornea clear. Vision 20/20. Normal visual acuity.

File 73-0-1199 - Employers First Report of Injury

21 Inter. Supv. Typist Clerk
22 Blank
23 Sitting eating her lunch on the patio area around building.
24 Gardener was raking, and dirt flew into her eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye.

Doctor's First Report of Injury

11 "I was sitting out in front of Health Building eating lunch when the gardener was raking dirt, and something flew into my right eye."
12 Has a black foreign body at 9 o'clock on right cornea, present since yesterday.

File 73-0-0874 - Employers First Report of Injury

21 Fire Control Laborer
22 6 months to 2 years
23 Removing paint
24 Paint chip flew in left eye while removing paint.
25 Wire brush
26 Blank
27 Yes
28 No
29 Use of goggles
30 Paint chip, left eye.

Doctor's First Report of Injury

11 "Sand or rust blew into my left eye."
12 Small foreign body, left eye; was scarring cornea.

File 73-0-0994 - Employers First Report of Injury

21 Fire Control Laborer
22 6 months to 2 years
23 Cutting brush with chain saw
24 A twig got into eye
25 None
26 Blank
27 Yes
28 Yes
29 Blank
30 Scratch on inside of eyelid, left eye.

Doctor's First Report of Injury

11 Patient was cutting with a chain saw when twig or branch flew into patient's left eye.
12 Small abrasion on inside of lower left eyelid.

File 73-0-1278 - Employers First Report of Injury

21 Fire Control Laborer
22 6 months to 2 years
23 Picking seed
24 Material lodged in eye
25 N/A
26 N/A
27 N/A
28 N/A
29 Wear safety goggles
30 Particles in eye.

Doctor's First Report of Injury

11 Something in right eye, irritative, possible grass seed.
12 No foreign body seen now. Probably removed by patient. No corneal abrasion.

File 73-0-0263 - Employers First Report of Injury

21 Fireman, 56 hours
22 Over 2 years
23 Descending cliff by means of operation.
24 While descending cliff, rocks and dirt scratched victim's eyeball.
25 Rope
26 None
27 No
28 No
29 Wearing goggles
30 Scratched right eyeball.

Doctor's First Report of Injury

11 Going down cliff, making rescue, dirt flew into right eye.
12 Possible foreign body O.B.

File 73-0-1180 - Employers First Report of Injury

21 Fireman, 56 hours
22 Over 2 years
23 Extinguishing rubbish fire
24 Force of water from fire hose splashed foreign material into eye.
25 Fire hose
26 None
27 Yes
28 No
29 Use greater care in directing fire stream away from operator.
30 Irritation of right eye by foreign material.

Doctor's First Report of Injury

11 At rubbish fire, 8/14/72, something got on lower lid.
12 External hordeolum OD lower lid.

File 73-0-0344 - Employers First Report of Injury

21 Camp Foreman (FM Spec.)
22 Over 2 years
23 Fighting a brush fire in mountain terrain
24 Contacted foreign object in right eye.
25 Blank
26 Blank
27 Yes
28 Yes
29 Occupational hazard
30 Irritation in right eye.

Doctor's First Report of Injury

11 Injured right eye while fighting fire one week ago.
12 Patient referred to Dr. Giordano. Conjunctivitis, right eye.

File 73-0-1195 - Employers First Report of Injury

21 Fireman Specialist, 56 hours
22 Over 2 years
23 Holding large section of response map against blackboard to estimate trimming.
24 Upper edge of paper curled and scraped left eyeball.
25 Paper response map
26 None
27 None
28 None
29 No comment -- unusual accident
30 Slight cut or scratch on left eyeball.

Doctor's First Report of Injury

11 Patient states: "Sharp edge of a piece of paper cut my eye lid.
12 Corneal abrasion.

File 73-0-0348 - Employers First Report of Injury

21 Fireman Specialist, 56 hours
22 Over 2 years
23 Changing fluorescent lamp above apparatus, feet slipped, broke lamps, spraying glass in eye.
24 Fluorescent lamp was lying on top of hose on the fire apparatus. Patient was climbing onto apparatus, his foot slipped, cropping a lamp.
25 Fluorescent lamp
26 None
27 Blank
28 Blank
29 Keep material out of climbing area
30 Blass in left eye.

Doctor's First Report of Injury

11 Patient states he thinks he has glass in left eye.
12 Conjunctivitis due to chemical irritation.

File 73-0-0287 - Employers First Report of Injury

21 Grounds Maintenance Man, AN
22 6 months to 2 years
23 Cleaning beach and restrooms
24 Inadvertently rubbed a virus (?) into eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Conjunctivitis.

Doctor's First Report of Injury

11 Dust blew in eye, 90+ injection.
12 Gilaterel (?) conjunctivitis (very bad writing)

File 73-0-1010 - Employers First Report of Injury

21 GMM
22 Over 2 years
23 Filing hole
24 Piece of steel flew into eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Steel in left eye.

Doctor's First Report of Injury

11 I was filing metal and got a piece of metal in my left eye.
12 Red, irritated OS. Diagnosis: Foreign body with secondary conjunctivitis.

File 73-0-1222 - Employers First Report of Injury

21 Ground Maintenance Man
22 Over 2 years
23 Hand weeding
24 Wind blew dirt particles into eye.
25 None
26 Blank
27 Blank
28 Blank
29 Blank
30 Foreign body in eye (left).

Doctor's First Report of Injury

11 "It was windy and the wind blew something into my left eye"
12 Mild conjunctival infection, left eye. Examination fails to reveal foreign body or excoriation of the cornea.

File 73-0-0908 - Employers First Report of Injury

21 Intermediate Clerk
22 Over 2 years
23 Employee was filing charts
24 Employee stated that something flew into her right eye. Eye now reddened, swollen, and painful.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Possible foreign body in right eye.

Doctor's First Report of Injury

11 While filing, something fell into right eye.
12 Imbedded conjunctival foreign body, right upper lid. Vision: right eye 20/25; left eye 20/20.

File 73-0-0917 - Employers First Report of Injury

21 Supervising Transcribing Typist
22 Over 2 years
23 Unloading supply of paper, picked up a pad of stationery and same flipped into her face.
24 Pointed edge of pad struck her in eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 None
30 Eye

Doctor's First Report of Injury

11 Pointed end of paper slipped and hit her right eye.
12 Diagnosis: Conjunctivitis, right eye.

File 73-0-0881 - Employers First Report of Injury

21 Medical Stenographer
22 Less than 6 months
23 Employee states that while working at her desk, some debris that was flying around, irritated her eye.
24 Employee states that the electrician was working over her desk and that debris from his work was flying around the room and it irritated her eye.
25 DNA
26 Blank
27 Blank
28 Blank
29 Blank
30 Debris irritated the right eye, and employee complained of vision loss of right eye.

Doctor's First Report of Injury

Report missing from file.

File 73-0-0022 - Employers First Report of Injury

21 Store Helper
22 Less than 6 months
23 Water boiler scale splashed up from fountain basin into employee's eyes while drinking water.
24 Same as above
25 Water fountain
26 Blank
27 Blank
28 Blank
29 The drinking fountain should have been covered or a sign should have been posted stating, "Danger, do not use." The drinking fountain had been chemically treated to unplug basin of draining problem with a solution of water scale cleaner. His eyes were washed out and given an eye wash solution for continued self treatment--no restrictions were imposed. He was to return to doctor if his eyes continued to bother him.
30 Employee complained that his eyes are burning.

Doctor's First Report of Injury

11 Patient stated: Cleaning acid in drain of fountain splashed into right eye while patient was attempting to drink water.
12 Conjunctivitis, right eye, due to liquid.

File 73-0-0524 - Employers First Report of Injury

21 Storekeeper I
22 6 months to 2 years
23 Closing storeroom
24 Wind blew foreign object into left eye.
25 N/A
26 N/A
27 N/A
28 N/A
29 Blank
30 Movement of eyelid causes irritation in left eye.

Doctor's First Report of Injury

11 Patient states he was closing up at work and something flew into left eye.
12 Traumatic conjunctivitis of left eye.

File 73-0-0802 - Employers First Report of Injury

21 Deputy Sheriff
22 Over 2 years
23 Attempting to make an arrest
24 While making an arrest, employee suffered the described injury.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Eye injury, right eye.

Doctor's First Report of Injury

11 Patient states he was struck in the right eye by a fist today while on duty.
12 25-year-old mail who was struck in right eye by fist. X-rays reveal no bony injury to the orbit. No indication of bony injury on X-ray. Vision intact. Pupils of equal size. No blood in anterior chamber. Advice on care given. Diagnosis: contusion of R. T. orbit R/O fx.

File 73-0-0808 - Employers First Report of Injury

21 Deputy Sheriff
22 Over 2 years
23 Patrolling in a marked black and white radio car
24 Foreign object flew into eye
25 Unknown
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye bothered as if some object had flown into it.

Doctor's First Report of Injury

11 F/B in right eye -- while on patrol.
12 Possible F/B right eye - 7:00 PM. Still feeling of something under lid. Sclera injected. No F/B found.

File 73-0-0542 - Employers First Report of Injury

21 Deputy Sheriff II
22 Over 2 years
23 Attempting to restrain an inmate
24 Apparently struck the keys of assisting Deputy.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Contusion and abrasion of left eye.

Doctor's First Report of Injury

Report missing from file. However, Doctor's notes are in file.

File 73-0-0182 - Employers First Report of Injury

21 Deputy Sheriff - Sergeant
22 Over 2 years
23 Driving N/B on Miramonte Blvd. in County vehicle.
24 A bug flew in the left driver's window striking employee in the left eye.
25 Bug
26 Blank
27 Blank
28 Blank
29 Blank
30 Pain in eye. Profuse watering of, and slight swelling of left eye.

Doctor's First Report of Injury

11 Patient states driving along and a bug flew into right eye at 8:00 PM.
12 Right eye, allergic reaction. Etiology unknown.

File 73-0-0759 - Employers First Report of Injury

21 Life Guard, recurrent
22 Over 2 years
23 Working out, paddling.
24 Returning to beach and struck by board of another surfer
25 Surfboard
26 Blank
27 Blank
28 Blank
29 Blank
30 1/2-inch cut over left eyebrow.

Doctor's First Report of Injury

11 During paddling workout, struck by surfboard. Not knocked out.
12 Approximately 1-inch laceration of left eyebrow. Eye PERLA eonmition (?) - (very poor writing).

File 73-0-0183 - Employers First Report of Injury

Report missing from file

Doctor's First Report of Injury

11 "I work around a lot of soap, and all of a sudden, my right eye became swollen, and I think I got some soap in my eye."
12 Patient said right eye was swollen, but isn't now. "It feels alright." No foreign body seen in the eye.

File 73-0-0605 - Employers First Report of Injury

21 Animal Control Officer I
22 Over 2 years
23 Chasing stray dog at large in area.
24 Chasing stray dog in vacant lot, was struck in right eye by hanging tree branch and limbs.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye inflammed, red, bloodshot.

Doctor's First Report of Injury

11 "While working, I was chasing a dog and a tree branch struck me in the right eye."
12 Visual acuity: left eye 20/30; right eye 20/30; both eyes 20/30. Superficial conjunctival laceration over left iris. No foreign bodies seen, even with fluorescein exam. Diagnosis: Conjunctival laceration, right eye.

File 73-0-0144 - Employers First Report of Injury

21 Animal Control Officer II
22 Over 2 years
23 Walking behind a kennel run
24 Something blew into right eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Eye infected; could not see out of right eye.

Doctor's First Report of Injury

11 Something blew in patient's right eye while walking outside along kennel building.
12 Right sclera red; conjunctiva red.

File 73-0-0064 - Employers First Report of Injury

21 Electronics Audio Technician
22 Over 2 years
23 Employee states accident occurred while driving to Long Beach or climbing into attic at location.
24 Employee states that something entered left eye while driving to location or climbing into attic.
25 None
26 Blank
27 Blank
28 Blank
29 Blank
30 Irritation of left eye from foreign particle.

Doctor's First Report of Injury

Report missing from file.

File 73-0-0240 - Employers First Report of Injury

21 Public Health Microbiologist
22 Over 2 years
23 Looking through microscope
24 Chemical on eyepiece of microscope got into employee's eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Left eye.

Doctor's First Report of Injury

11 "I went to use the microscope and apparently there was something on the left eyepiece, and my left eye started to burn instantly. I rinsed my left eye with tap water and felt better for 2-3 hours, but then it started to itch and burn."
12 Left eye looks normal. No foreign bodies seen. No irritation of left lower lid. Skin appears normal.

File 73-0-0277 - Employers First Report of Injury

21 Ambulance Attendant
22 6 months to 2 years
23 Employee was covering an auto vs. auto accident and was putting out road flares.
24 Employee states road flare blew up in his face, sending hot wax, etc. into his right eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Blurred vision in right eye.

Doctor's First Report of Injury

11 "There was an accident at Third and Western, so we stopped. I was putting out road flares and one blew up in my face. It hurts and burns, especially on the right side of my face."
12 Erythema right bulbar conjunctiva -- fluorescein stain negative.

File 73-0-0708 - Employers First Report of Injury

21 Attendant
22 6 months to 2 years
23 Employee states he was suctioning patient.
24 Employee states while performing duty, patient coughed and sputum was projected into his eye.
25 Suction catheter and secretions
26 Blank
27 Blank
28 Blank
29 Blank
30 Injured left eye.

Doctor's First Report of Injury

Report missing from file.

File 73-0-1207 - Employers First Report of Injury

21 Senior Attendant
22 Over 2 years
23 Employee washing his hands with Phisohex.
24 Employee pressed a water pedal with right foot into hands holding the Phisohex, and splashed the Phisohex into her face.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Splashed Phisohex into eye.

Doctor's First Report of Injury

11 Patient states she was in nursery scrubbing hands with Phisohex, when it splashed into her right eye.
12 Abrasion secondary to chemical conjunctivitis and pruritus, right sclera.

File 73-0-1303 - Employers First Report of Injury

21 Senior Nursing Attendant
22 Over 2 years
23 Employee stated that she was making a patient's bed
24 The sheet hit her in the corner of the right eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye irritation.

Doctor's First Report of Injury

Report missing from file.

File 73-0-0644 - Employers First Report of Injury

21 Supervising Nurse
22 Over 2 years
23 Checking sick rooms and turning off lights to keep rooms cool.
24 Had a pen in her hand and accidentally stuck it in her left eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Keep pens out of hands while working.
30 Small irritation, left eye.

Doctor's First Report of Injury

11 Patient states injured left eye at work today. Stuck writing pen in it.
12 Rule out injury to left eye.

File 73-0-0915 - Employers First Report of Injury

21 Flood Control Laborer
22 6 months to 2 years
23 Removing bit with hammer
24 Employee states that while removing bit with hammer, a piece of steel broke off and hit and lodged in his eye.
25 Piece of steel
26 Blank
27 Yes
28 No
29 Blank
30 Piece of steel in right eye.

Doctor's First Report of Injury

11 Steel fragment flew into right eye while drilling in concrete.
12 Triangular piece of steel imbedded in right upper eyelid.

File 73-0-0990 - Employers First Report of Injury

21 Flood Control Laborer
22 6 months to 2 years
23 Connecting 4-inch suction hose to mud pump.
24 While employee was straightening hose to make connection, one end of the hose came up and struck him above the left eyebrow.
25 4-inch suction hose.
26 Blank
27 Blank
28 Blank
29 Blank
30 Cut above left eyebrow.

Doctor's First Report of Injury

11 "I was attaching a suction hose to a pump and the end of it flipped off and hit me above my left eye."
12 1/4-inch laceration, left eyebrow.

File 73-0-0850 - Employers First Report of Injury

21 Carpenter
22 Over 2 years
23 Repairing ceiling tile
24 A particle of dust entered my left eye.
25 A piece of acoustical tile
26 N/A
27 Yes
28 Yes
29 Instruct employes to use goggles.
30 Left eye.

Doctor's First Report of Injury

11 "I was drilling overhead and some sawdust got into my left eye.
12 No foreign bodies seen in left eye, but it has a small "pimple" under left upper lid medial aspect.

File 73-0-0970 - Employers First Report of Injury

21 Carpenter
22 6 months to 2 years
23 Employee states he was bolting down typewriters and installing locks.
24 Employee states that while doing his job, some dust got in his left eye.
25 Sawdust
26 Blank
27 Yes
28 Yes
29 Advised to wear eye shields.
30 A piece of sawdust in left eye.

Doctor's First Report of Injury

Report missing from file.

File 73-0-0413 - Employers First Report of Injury

21 Helper, Metal Working
22 Over 2 years
23 Working on food dispenser.
24 Got a flash burn or foreign particle in eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Eye gland infection.

Doctor's First Report of Injury

11 Possible arc flash or foreign object in left eye.
12 Visual acuity: OD 20/25; OS 20/30. OS: dilated vessels with pigment deposits, lids. Diagnosis: Int. hordeolum left lower lid.

File 73-0-0773 - Employers First Report of Injury

21 Intermediate Food Service Worker
22 Over 2 years
23 Emptying the food carts
24 Employee stated that some particles of food flew into his right eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Red and irritated right eye, off and on since D. O. I.

Doctor's First Report of Injury

Report missing from file. However, there is a long doctor's report in the file. Diagnosis: Probable conjunctivitis or irititis of the right eye.

File 73-0-0658 - Employers First Report of Injury

21 Senior General Maintenance Man
22 Over 2 years
23 Installing chain and post
24 Car kicked up sand, hitting employee in eye.
25 None
26 Blank
27 Yes
28 No
29 Can't use glasses all the time.
30 Eyes

Doctor's First Report of Injury

11 Blank
12 Corneal hemorrage and abrasion. (Unable to read the rest; very poor writing)

File 73-0-0961 - Employers First Report of Injury

21 Flood Control Laborer
22 6 months to 2 years
23 Helping on drilling rig.
24 While employee was helping on drilling rig, the wind blew a foreign object in his eye.
25 Wind
26 Blank
27 Yes
28 Yes
29 Blank
30 Foreign object in left eye.

Doctor's First Report of Injury

11 While working, foreign body vs. left eye.
12 Foreign body in left eye. Removed. No evidence of corneal or scleral laceration. Diagnosis: Foreign body of left eye.

File 73-0-0977 - Employers First Report of Injury

21 Custodian
22 Over 2 years
23 Emptying trash into large trash can.
24 While emptying trash in the bins, something flew into his eyes.
25 Trash bins.
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye.

Doctor's First Report of Injury

Report missing from file.

File 73-0-0241 - Employers First Report of Injury

21 Custodian
22 Over 2 years
23 Employee was wringing out mop.
24 Some water from the mop splashed into employee's eyes.
25 Mop water
26 Blank
27 Blank
28 Blank
29 Blank
30 Mop water splashed in employee's eyes.

Doctor's First Report of Injury

Report missing from file.

File 73-0-0255 - Employers First Report of Injury

21 Custodian
22 Less than 6 months
23 Filling the incinerator to burn
24 Ashes got into his eye.
25 Ashes
26 Blank
27 Blank
28 Blank
29 Blank
30 Ashes in his eye.

Doctor's First Report of Injury

11 Foreign body in left eye while putting trash in the incinerator.
12 No foreign body or corneal defect noted after fluorescein installation. Bulbar and palpebral conjunctiva, left eye injected.

File 73-0-0390 - Employers First Report of Injury

21 Custodian
22 Less than 6 months
23 Routine work when light bulb fell that was standing in corner, and broke
24 Light bulb fell and broke.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee stated that when he turned his eye a certain way, his eye hurt.

Doctor's First Report of Injury

11 While working, pushing cart into room, cart hit box against wall causing fluorescent light to fall. The gas from light fixture went into left side of face and both eyes.
12 Moderately marked conjunctivitis of both eyes. No foreign bodies seen. No corneal damage noted. Visual acuity: right 20/20; left 20/26.

File 73-0-0685 - Employers First Report of Injury

21 Custodian
22 6 months to 2 years
23 Washing baseboards
24 While washing baseboards in the restrooms, some of the washing solution splashed into his eyes.
25 Washing solution
26 Blank
27 Blank
28 Blank
29 Blank
30 Eyes

Doctor's First Report of Injury

11 Patient states that he got some chemicals in his right eye while at work.
12 P. E. redness of the lower aspect of the bulbar; conjunctiva of the right eye. Cornea appears normal. Diagnosis: Irritation to the right eye, conjunctivitis.

File 73-0-1071 - Employers First Report of Injury

21 Custodian
22 6 months to 2 years
23 Cleaning chair.
24 Spraying ammonia water out of bottle when some of the mixture got into employee's eye when top came off bottle.
25 Ammonia water
26 Blank
27 Blank
28 Blank
29 Blank
30 Left eye was affected by ammonia water.

Doctor's First Report of Injury

Report missing from file.

File 73-0-1235 - Employers First Report of Injury

21 Custodian
22 Over 2 years
23 Employee was washing windows.
24 Employee raised his head and bumped his right eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Right eye cut.

Doctor's First Report of Injury

11 Employee stated that he was washing windows and raised his and bumped his right eye.
12 Diagnosis: 2 centimeter laceration, right eyebrow.

File 73-0-1259 - Employers First Report of Injury

21 Custodian
22 Over 2 years
23 Employee was dumping trash
24 Employee stated that something flew into his left eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Possible foreign body in left eye.

Doctor's First Report of Injury

11 "While at work, I was dumping trash, something got in my left eye. I rubbed it and thought I got it out, but still have pain in corner of left eye."
12 Left eye reveals circum-corneal infection with small particles imbedded in medial aspect of left eye. Eyelid sulcus at right pterygium. Diagnosis: Traumatic conjunctivitis of left eye.

File 73-0-0316 - Employers First Report of Injury

21 Assistant Dam Operator
22 Over 2 years
23 Cutting brush
24 Employee states that while cutting brush, foreign matter entered his eye.
25 Blank
26 Blank
27 Yes
28 No
29 Wear goggles
30 Foreign matter in left eye.

Doctor's First Report of Injury

11 "I was cutting brush and sweat rolled into both eyes. I wiped my face and since then both eyes have been hurting, especially my left one."
12 Complained of eyes hurting. Eyes were swollen. Examined eyes and unable to find foreign matter. Probable allergic reaction.

File 73-0-1027 - Employers First Report of Injury

21 Park Patrolman
22 Less than 6 months
23 Blank
24 Shrapnel in left eye.
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Left eye.

Doctor's First Report of Injury

11 Patient states he got shrapnel in left eye during training drill.
12 Mild contusion and minimal scleral irritation OD.

File 73-0-1046 - Employers First Report of Injury

21 Stationary Engineer, APP. I
22 6 months to 2 years
23 Cleaning fire-side of boiler, sweeping and dusting tubes and bricks.
24 A small object went through hole in side of eye guard and went in his right eye.
25 Corn broom
26 Blank
27 Yes
28 Yes
29 Goggles with no vent holes
30 Foreign matter under right eye lid.

Doctor's First Report of Injury

Report missing from file.

File 73-0-0228 - Employers First Report of Injury

21 Custodian WKG Foreman
22 Over 2 years
23 Cleaning drinking fountain
24 As employee was cleaning drinking fountain, the cleaning solution got in his eyes.
25 Cleaning solution
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee's left eye was injured.

Doctor's First Report of Injury

11 Patient states that cleaning fluid was splashed into his left eye.
12 Mild infection of sclera. No corneal damage seen. F/M. Fundia is normal.

File 73-0-0676 - Employers First Report of Injury

21 Water Service Man
22 Over 2 years
23 Operating backhoe
24 A hydraulic hose burst
25 Hydraulic hose, jot oil
26 Hydraulic system
27 No
28 No
29 Blank
30 Hot hose burst, spraying hot oil in eyes, causing inflammation.

Doctor's First Report of Injury

11 "I was grading a yard and my hydraulic hose burst, causing oil to splash in both of my eyes."
12 Under a micro exam, severe conjunctivitis bilaterally due to oil retardant. No F.B. noted or found. Diagnosis: Severe bilateral conjunctivitis.

File 73-0-1186 - Employers First Report of Injury

21 Utility Tractor Operator
22 Over 2 years
23 Operating a skip-loader
24 Employee states that while operating skip-loaded, the bucket caught on a tree limb, bounced back, and struck his eyeball.
25 Skip-loader bucket
26 Blank
27 Blank
28 Blank
29 Blank
30 Small contusion on left eyebrow.

Doctor's First Report of Injury

11 Patient's statement: "I was driving in the channel with the bucket up, and it hit some overhanging branches - and something flew into my left eye - and hit me in the eye."
12 Contusion of the left eye (sclera). Ecchymosis of left eye at 3 o'clock.

File 73-0-1083 - Employers First Report of Injury

21 Power Equipment Repair Man
22 Over 2 years
23 Working under vehicle, putting weights on wheel.
24 Rust fell into eye
25 Hammer used in pounding balance weights on wheel
26 Left front wheel of vehicle
27 Yes
28 No
29 Blank
30 Foreign particle lodged in right eye.

Doctor's First Report of Injury

11 Patient states that on 8/17/72, at about 3:30 PM, while working on car, something fell into his right eye. 8/18/72, eye is red and swollen.
12 F. B. right eye, surface only.

File 73-0-0076 - Employers First Report of Injury

21 Lineman working for Util.
22 6 months to 2 years
23 Employee states that he was blowing water out of a distributor on his pickup with air hose.
24 Employee states a small object struck his right eye.
25 Air hose
26 Blank
27 Yes
28 Yes
29 To wear safety glasses.
30 Pain and discomfort caused by small object in right eye.

Doctor's First Report of Injury

11 "While blowing water from a distributor with air hose, object struck right eye."
12 Foreign body cornea OD (removed).

File 73-0-0710 - Employers First Report of Injury

21 Res. Hosp. Admin. 8060
22 Less than 6 months
23 Employee states she was driving vehicle to a meeting in community.
24 Employee states sharp foreign particle flew in through window into eye.
25 Foreign particle
26 Blank
27 Blank
28 Blank
29 Blank
30 Minor laceration to cornea.

Doctor's First Report of Injury

Report missing from file.

File 73-0-0157 - Employers First Report of Injury

21 Community Worker II
22 Over 2 years
23 While driving on Freeway, on County business (delivery of documents to Hall of Records), a foreign body flew into left eye.
24 Blank
25 Blank
26 Blank
27 Blank
28 Blank
29 Unavoidable
30 Foreign body flew into left eye while driving on Harbor Freeway North.

Doctor's First Report of Injury

11 "I was driving down the street and something flew into my right eye."
12 Corneal laceration, superior pole, right eye.

File 73-0-0123 - Employers First Report of Injury

21 Locker Attendant
22 Blank
23 Trying to prevent fight
24 Poked in eye
25 Blank
26 Blank
27 Blank
28 Blank
29 Blank
30 Left eye injury

Doctor's First Report of Injury

11 Patient stated he was struck by a finger in the eye while trying to stop a fight while engaged in his normal work duties, 7/3/72, at place of employment.
12 Mild conjunctivitis, left eye.

File 73-0-0707 - Employers First Report of Injury

21 Road Maintenance Man
22 Over 2 years
23 Employee states that he was loading weeds onto a truck
24 Employee states that while loading the weeds, the wind blew trash into his face and eyes.
25 Pitch fork
26 Blank
27 Blank
28 Blank
29 Blank
30 Employee complains of great eye irritation.

Doctor's First Report of Injury

11 While working, cleaning off County lot, as I picked up some trash, something blew into my left eye.
12 Multiple foreign bodies, conjunctiva of left eye. Imbedded foreign body, cornea of left eye at 6 o'clock with small corneal abrasion.

File 72-C-2308 - Employers First Report of Injury

21 Custodian
22 Less than 6 months
23 Employee states she was cleaning wall receptacle in bathroom.
24 Employee states she was pouring ammonia into water and some splashed into her left eye.
25 Ammonia
26 DNA
27 Blank
28 Blank
29 Blank
30 Injured left eye.

Doctor's First Report of Injury

11 Patient states got ammonia in left eye while at work today after 10:00 AM.
12 Ammonia in left eye.

File 72-C-2522 - Employers First Report of Injury

21 Dictating Equipment Technician
22 Less than 6 months
23 Employee states he was walking from car to client's office
24 Employee states something flew into the right eye from a gust of wind.
25 Blank
26 Blank
27 Unknown
28 Unknown
29 Blank
30 Employee complains of itching and tearing of lower portion of right eye. Employee observed lower portion of right eye appears to be inflammed and swollen.

Doctor's First Report of Injury

11 "I was crossing the street to deliver dictating machines to John Wesley Hospital when something flew into my right eye. It has been bothering me and I have some tearing from the irritation."
12 No F.B. seen in right eye. Has edema and medial aspect, right lower lid with wrinkling of the skin.

File 72-C-2975 - Employers First Report of Injury

21 F. C. Construction Foreman
22 Over 2 years
23 Operating Gunite machine
24 While employee was operating nozzle on Gunite machine, the air line broke at nozzle, causing sand to blow into employee's eyes.
25 Gunite machine
26 Nozzle
27 Yes
28 No
29 Wear goggles
30 Sand imbedded in eyes. Cornea on both eyes were sand-blasted.

Doctor's First Report of Injury

11 While operating machine, the rubber tip exploded, filling both eyes with sand and raw cement.
12 Traumatic and chemical iridoconjunctivitis.

File 72-C-2503 - Employers First Report of Injury

21 Comb. Truck Driver
22 Over 2 years
23 Unloading supplies off truck
24 Dust and/or foreign matters got into left eye.
25 Truck bed, pallets, cartons, and hand hydraulic dolly.
26 None
27 None
28 None
29 Possibly - keep from rubbing eyes with hands while working - wash hands first - use goggles.
30 Left eye watery, inflammed and sensitive to sudden excessive light.

Doctor's First Report of Injury

11 Foreign body entered OS yesterday while patient was at work.
12 Corneal ulcer and irititus OS.

File 72-C-2343 - Employers First Report of Injury

21 Senior Cook
22 Less than 6 months
23 Walking from kitchen to the Officers' dining room.
24 Employee slipped on wet, waxed floor, striking his right forehead on the tile floor
25 Floor
26 Blank
27 Blank
28 Blank
29 Blank
30 Laceration on the right eyebrow.

Doctor's First Report of Injury

11 "I slipped on a freshly waxed floor in the hallway and I either hit the baseboard or the floor and hurt my right eye."
12 Has 3 sutures and laceration lateral to right eye placed there on 4/11/72 at orthopedic hospital. Complains of "ringing in ears as if I was at 10,000 feet, and headaches." Feels unsure of his steps while walking. Has tenderness around right orbit. Eye's PERLA, EOM normal period. Right fundus not visualized well.

File 72-C-2689 - Employers First Report of Injury

21 Electrician
22 Over 2 years
23 Drilling concrete
24 Particles of cement dust got into eye.
25 Electric hammer drill
26 N/A
27 Yes
28 No
29 Blank
30 Right eye, particle of cement.

Doctor's First Report of Injury

11 "I was drilling a hole in the ceiling. Concrete and a large amount of plaster got in my right eye."
12 No foreign body seen, but has conjunctivitis and Episcleritis of right eye with edema of upper lid.

File 72-C-2679 - Employers First Report of Injury

21 P. E. R.
22 Over 2 years
23 Repairing license plate light
24 A piece of dirt entered left eye.
25 License plate light
26 Blank
27 Yes
28 Yes
29 Blank
30 Soreness and pain in left eye, turned red and looked irritated.

Doctor's First Report of Injury

11 "I was changing a license plate on a car and got something in my left eye."
12 Eye irrigated - no foreign body seen. Fluorescein test negative for corneal injury.

File 72-C-2273 - Employers First Report of Injury

21 Power Equipment Repair man
22 Over 2 years
23 Welding spring bracket
24 An old chip of paint fell into his eye.
25 Paint
26 Rear spring
27 Yes
28 Yes
29 Blank
30 Chip of paint in left eye.

Doctor's First Report of Injury

11 "I was welding overhead while lying under a fuel truck. When I finished I raised up welding hood and a paint chip got in my left eye."
12 Has red foreign body at 9 o'clock, left eye.

File 72-C-2363 - Employers First Report of Injury

21 Sheet Metal Worker
22 Over 2 years
23 Drilling hole in metal door
24 Small particle of steel flew into eye
25 Drill motor
26 Blank
27 Yes
28 Yes
29 Hazard of trade
30 Right eye.

Doctor's First Report of Injury

11 "I was drilling a hole in door for a locking device when a piece of dust or chip flew into my right eye."
12 Has foreign body, right eye, about 9 o'clock in cornea.

File 72-0-4006 - Employers First Report of Injury

21 Fireman, 56 hours.
22 Over 2 years
23 Firefighting on lumberyard fire
24 Smoke inhalation while firefighting in lumberyard on the leeward side
25 Hose lines
26 None
27 No
28 No
29 Possible use of air mask on exterior fires
30 Smoke inhalation to lungs and eyes

Doctor's First Report of Work Injury

11 Patient states his eyes are burning and scratching
12 Flash burn, both eyes

File 72-0-7170 - Employers First Report of Injury

21 Deputy Sheriff
22 6 months to 2 years
23 Participating in physical training.
24 During physical training employee was struck in right eye.
25 Ball
26 Blank
27 Blank
28 Blank
29 Blank
30 Abrasion of right cornea

Doctor's First Report of Work Injury

11 Patient states while in physical training playing Volley Ball, struck in right eye
12 Abrasion, right cornea

APPENDIX C

"EYE PROTECTION FROM CONTACT LENSES, "*

Roy H. Rengstorff, O. D., Ph. D.,
Chester J. Black, M. D.

*This article was obtained from the Journal of the American Optometric Association, Volume 45, Number 3, March 1974, pp. 270-276.

Eye protection from contact lenses**

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ROY H. RENGSTORFF, O.D., Ph.D., CHESTER J. BLACK, M.D.

ABSTRACT—The eyes of many individuals who wear contact lenses have been exposed to physical trauma and chemical irritation. A review of 128 documented incidents reveals that contact lenses minimized or completely protected the eyes from more serious injuries.

ABOUT OUR AUTHOR—Dr. Rengstorff received his O.D. from Northern Illinois College of Optometry, M.S. degree from Pacific University, and Ph.D. in physiological optics from The Ohio State University. His experimental work has been in contact lenses, corneal and lens physiology and visually evoked responses. Presently, he is a research optometrist, Experimental Medicine Branch, Biomedical Laboratory, Edgewood Arsenal, Maryland.

Dr. Black is an ophthalmologist presently with the Elmhurst Clinic, Elmhurst, Illinois.

Dr. Black is a clinical investigator for Bausch & Lomb, Dow Corning and Abbott Laboratories. His special interest is contact lenses.

Do contact lenses cause a greater risk of ocular damage in the event of an accident involving the eyes? In 1972 this question was discussed by members of the Z-80 Subcommittee on Contact Lenses, American National Standards Institute (ANSI)*. We agreed to study the question further and report our results which are described here.

This information was obtained from two sources: 1) published case histories provided by many ANSI members, as well as our own search of the literature, and 2) a survey of contact lens practitioners conducted with a questionnaire which we prepared. The questionnaire asked for descriptions of individual instances in which contact lens wearers experienced eye *protection* or *damage* following exposure to chemicals, fumes or foreign bodies. About 300 practitioners, optometrists and ophthalmologists, received the questionnaire. Most of the optometrists were diplomates of the Contact Lens Section, American Academy of Optometry. The ophthalmologists were selected and surveyed through the cooperation of Burton, Parsons & Company, Inc., a pharmaceutical and contact lens solution manufacturer. About 65% of the questionnaires were returned.

Results

Table 1 summarizes the number of instances in which contact lenses protected the eyes in categories of accidents, similar to the categories used in an earlier review by Pearson.[1]

The following pages contain brief descriptions of individual cases in each of the categories in Table 1. Unless indicated otherwise, the corneal abrasions that were reported were minor and healed completely. The identification column includes the state (abbreviated) or foreign country where the incident occurred and, when available, the age, sex and initials of each patient. When a patient's initials were not provided, we used the doctor's initials.

Additional details about each case can be

*ANSI is a federation of trade, technical, labor and consumer organizations, companies, and government agencies (1430 Broadway, New York, N Y 10018).

**Read before the Section on Public Health and Occupational Optometry, American Academy of Optometry, New York City, New York, December 17, 1972.

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found in the referenced article (previously reported cases), or in the comments following each category (new cases).

TABLE 1
Documented Cases of Contact Lenses Protecting Eyes from Serious Injuries

Type of Accident	Previously reported cases (before 1972)*	New cases**	Total
Sports	16	9	25
Automobile	8	8	16
Workshop	19	11	30
Miscellaneous	15	17	32
Chemical	6	19	25
Total	64	64	128

*References 1-19
**Results from questionnaires

Comments

Patient (17) was a football player who was kicked in the face hard enough to produce a concussion. He had contusions about his left eye and a deep gouge was apparent on the corneal section of the lens.

Patient (18) was playing Rugby football, and was kicked in the eye, causing only a slightly scratched lens.

Patient (19) was wrestling in a high school match when he was hit in the eye with the fingernail of his opponent. The lens broke into three pieces.

Patient (20) ran into a tree and received a severe blow to the head and concussion. His lens broke into several pieces.

Patient (21) was playing basketball when an opponent's fingernail scratched his face, eyelids, and conjunctiva. The lens flipped out onto the floor.

Patient (22) playing in a professional football game, was struck in the eye by someone's fingernail. The team physician said the lens saved his eye.

Patient (23) was hit directly on the eye by a high speed squash ball with such force that he saw a bright flash of light and was knocked to the floor.

Comments

Patients (9 and 10) had multiple facial lacerations, caused by impact with European unlaminated automobile windshields.

Patient (11) sustained serious injuries and both lenses were broken on the eyes.

Patient (12) had windshield glass removed from his conjunctival sac. Both lenses had several scratches on them.

SPORTS

PATIENT No.	HAZARD	CIRCUMSTANCES	CONTACT LENS	CORNEA	OTHER	STATE OR COUNTRY	AGE YR	SEX	INIT.	REF.
1.	fist	professional water polo player	cracked (scleral)	none	hematoma, unconscious	Hungary	32	M	LD	2
2.	fist	water polo player	none (scleral)	none	hematoma	Hungary	25	M	PP	2
3.	fist	playing basketball	broken	abrasion		IL	24	M	MU	3
4.	steel pellet	direct from B-B gun	cracked	none		IL	16	M	CB	3
5.	religious medal (star)	playing basketball	cracked	none		NJ	18	M	LF	4
6.	hockey stick	playing hockey	broken and knocked out	abrasion	ecchymosis	England	16	F	SR	5
7.	glass	billiard ball broke drinking glass	cracked	none		OR		M	AF	6
8.	ski pole	fell while skiing	broken	none	eyelid perforated	NJ		M	IV	6
9.	thumb	playing basketball	broken	abrasion		WA		M	BN	6
10.	steel pellet	ricochet from B-B gun	cracked	none		TX	14	M	SB	6
11.	metal buckle	on baseball glove	broken	none		CT		F	SD	6
12.	thorn	while hunting	cracked	none		MI		M	PN	6
13.	steel-tipped dart	thrown in anger	broken	none		MO		M	OP	6
14.	football shoe	college football	scratched	none	eyelids lacerated	MO		M	SL	6
15.	baton tip	twirling	broken	none	nose broken	NC	17	F	WS	6
16.	tip of fishing pole	slipped from grasp	broken	abrasion		CA	22	M	HP	7
17.	football shoe	college football	scratched (scleral)	none	contusions, concussion	IN		M	EG	
18.	Rugby shoe	playing Rugby	scratched (scleral)	none	facial abrasions	England		M	RF	
19.	fingernail	wrestling match	broken	abrasion		OH	17	M	DB	
20.	tree	ran into tree	broken	none	concussion	MA		M	LG	
21.	fingernail	playing basketball	knocked out	none	lacerations	CA		M	EG	
22.	fingernail	professional football	none	none		IL	24	M	RB	
23.	squash ball	returned off wall directly on eye	none	none	contusion	MD	36	M	RR	
24.	shell casing	ejected from rifle	broken	abrasion		FL		M	GM	
25.	lacrosse stick	playing lacrosse	cracked	none		NY	21	M	DR	

AUTOMOBILE

PATIENT No.	HAZARD	CIRCUMSTANCES	CONTACT LENS	CORNEA	OTHER	STATE OR COUNTRY	AGE YR	SEX	INIT.	REF.
1.	windshield glass	auto accident	none	none	head injuries	CO		M	RM	6
2.	windshield glass	auto accident	none	none	eyelid lacerated	OR		M	FL	6
3.	windshield glass	auto accident	cracked	none		CA		F	RE	6
4.	windshield glass	auto accident	none	none		OR	33	M	DB	6
5.	windshield glass	auto accident	none	none	concussion, unconscious	England	24	F	JL	8
6.	windshield glass	auto accident	broken	abrasion		England	19	F	DG	9
7.	sun visor	auto accident	bent	none	ecchymosis	MN		F	JD	10
8.	truck wheel	driven over upper trunk and face	none	none	ecchymosis, skull fractures	MO	19	M	MS	11
9.	windshield glass	auto accident	scratched	none	lacerations	France		F	FK	
10.	windshield glass	auto accident	none	abrasion	lacerations	France		M	FK	
11.	windshield glass	auto accident	broken	none		CA		F	HP	
12.	windshield glass	auto accident	scratched	none		CA		M	EG	
13.	windshield glass	auto accident	scratched	none	eyelids lacerated	PA		F	MN	
14.	windshield glass	auto accident	none	none	contusions	IL	27	M	TJ	
15.	windshield glass	auto accident	none	none		IL	29	F	JF	
16.	rear view mirror	auto accident	scratched	none	eyelids lacerated	MN		F	JK	

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WORKSHOP

PATIENT No.	HAZARD	CIRCUMSTANCES	CONTACT LENS	CORNEA	OTHER	STATE OR COUNTRY	AGE YR	SEX	INIT.	REF.
1.	metal chip	ricochet from hammer	embedded in lens	abrasion		Hungary	48	M	JA	2
2.	metal splinter	industrial accident	embedded in lens	slight scar		IL		M	CB	3
3.	nail	hammering	broken	abrasion		IL	62	M	MG	3
4.	metal	operating a lathe	chipped	none		Germany		M	PA	6
5.	metal	operating a lathe	cracked, knocked out	none	contusion	WA		M	DL	6
6.	rivet	opening a crate of lettuce	broken	abrasion		CO		M	KP	6
7.	nail	on roofing job	broken	none		NC		M	BL	6
8.	screwdriver	hit on eye after fall on engine fan	broken	none		MA		M	RR	6
9.	plastic	cutting on band saw	cracked	none		IL	19	M	WH	6
10.	stone	chipping cement	cracked	none		WA		M	RM	6
11.	rope	backlash starting a generator	none	abrasion		IL		M	HG	6
12.	scissors	expelled opening drawer	cracked	none		CA		F	CS	6
13.	electric plug	pulled from socket	broken	none		PA		F	AB	6
14.	molten slag	welding	embedded in lens	ulcer at limbus		OR		M	DH	6
15.	nail	hammering into brick wall	broken	none	conjunctival hemorrhage	England		M	FD	12
16.	metal splinter	split wood using wedge and sledge hammer	broken	none		WA	18	M	FB	13
17.	staple	opening cardboard carton	scratched, knocked out	none		MA	31	M	ES	13
18.	cardboard box	fell onto eye	none	none	macular hemorrhage	Japan		M	SS	14
19.	screw	hammering with chisel	cracked	abrasion		TX		M	HC	15
20.	metal splinter	chiseling a rusted nut	cracked	none		OH	28	M	DA	
21.	nail	hammering	broken	abrasion		OH	17	M	IB	
22.	hot metal	welding slag	burned hole in lens	slight scar		KA	25	M	WS	
23.	needle	broken from sewing machine	broken	none		MI	39	F	BG	
24.	iron	from grinding wheel	embedded in lens	none		IL	28	M	JP	
25.	staple	from industrial stapler	broken	none		MO	24	F	PL	
26.	metal shaving	industrial machine	none	abrasion		MI		M	MB	
27.	metal piece	machine part	broken	abrasion		FL		M	GM	
28.	metal sliver	automobile repair	broken	none		PA		M	HL	
29.	end mill	industrial tool	broken and knocked out	abrasion		MO	23	M	JP	
30.	glass	projectile at work	scratched	none		CA	40	M	SW	

Patient (13) struck her head against the windshield. Her face was cut severely, and the attending physician said her sight was saved by the lenses.

Patient (14 and 15) broke the windshields with their heads and received only contusions.

Patient (16) struck the edge of the rear view mirror and severed her upper lid. The lenses were deeply scratched.

Comments

Patient (20) attempted to chisel a nut rusted onto the bolt of an appliance. The impact from a steel splinter cracked the lens in half.

Patient (21) hammered a nail indirectly and it struck his left eye, breaking the lens in half. Physicians said he would have been blinded had he not been wearing the lens.

Patient (22) was welding with no eye protection. Welding slag burned a hole in the lens and caused a 2 mm slight corneal scar.

Patient (23) was operating a sewing machine when the needle broke and struck her contact lens, breaking the lens.

Patient (24) was using a grinding wheel when a piece of metal struck and embedded into his lens.

Comments

Patient (16) was walking along a sidewalk and was hit directly on her right contact lens by a stone from a passing automobile. She removed the lens and saw it was severely cracked.

Patient (17) was chopping a branch of a tree with a machete when a fast flying chip of wood hit him in the eye, breaking his lens. A large piece of lens fell off his eye and he removed the other piece himself.

Patient (18) was assembling a toy rocket for a Christmas present when it ejected, struck his lens and knocked it off his eye.

Patient (19) was adjusting his motorcycle when his haptic lens was hit by an elastic strap with a metal end.

Patient (20) was testing a stapler when a

MISCELLANEOUS

PATIENT No.	HAZARD	CIRCUMSTANCES	CONTACT LENS	CORNEA	OTHER	STATE OR COUNTRY	AGE YR	SEX	INIT.	REF.
1.	thorn	walking in forest	scratched	none		Hungary	30	F	KL	2
2.	fist with ring	altercation	broken	abrasion	conjuntiva lacerated	IL	21	M	DB	3
3.	fist	altercation	broken	abrasion	eyelid lacerated					
4.	flame	gas cigarette lighter	crazed	none	eyelids blistered	England		F	MB	5
5.	bullwhip	actor rehearsing	none	none	conjunctival hemorrhage	CA		M	JB	6
6.	fingernail	playing with child	none	limbus lacerated		CA		M	AL	6
7.	pea	blown from pea-shooter	broken	none		CA		M	JM	6
8.	pencil point	thrown by classmate	broken	abrasion		CA	16	F	MM	6
9.	pencil point	poked into eye	broken	none		OR		M	DD	6
10.	popgun	toy directed at eye	broken	abrasion		TX	16	M	PP	6
11.	stairs	fell down stairs	scratched	none	ecchymosis	PA		M	CA	6
12.	stone	from passing truck	embedded, knocked out	none	contusions	WA		M	AD	6
13.	kitchen knife	playing with friend	hole in lens	abrasion		Germany	9	M	AK	16
14.	glass	dropped laboratory beaker	embedded in lens	none	sclera lacerated	MD		M	AS	17
15.	broomstick	poked by point	cracked	abrasion		MD		M	AS	17
16.	stone	from passing auto	cracked	none		MA		F	MF	
17.	wood	chopping a tree	broken, knocked out	none		OR		M	DH	
18.	toy rocket	assembling present	knocked out	none		FL		F	GH	
19.	metal clip	end of elastic strap	scratched (scleral)	none		England	21	M	RF	
20.	staple	accident	scratched	none		IL	14	F	KY	
21.	fists	mugged	none	none	ecchymosis, unconscious	IL	30	M	LG	
22.	foreign body	unknown	none	abrasion		PA	16	F	CC	
23.	foreign body	unknown	broken	none		MN		M	JK	
24.	foreign body	unknown	cracked	none		CA		F	HM	
25.	plastic comb	thrown by classmate	broken	abrasion		AL	14	M	HP	
26.	tree limb	walked into tree	knocked out	abrasion		FL		M	DW	
27.	umbrella rib	opening umbrella	knocked out	abrasion		MO	34	M	LG	
28.	stick	thrown	scratched	none		MA		M	WD	
29.	bullwhip	unknown	broken	none		MN		M	JK	
30.	thumb	unknown	broken	none		IL	18	M	MT	
31.	rattail comb	unknown	scratched	none		IL	24	M	RP	
32.	orange	thrown at party	broken	none	ecchymosis	OH	20	F	SS	

staple ejected and hit directly against his lens.

Patient (21) was mugged, beaten into unconsciousness, but his lenses were never dislodged or damaged.

Comments

Patients (7 and 8) wore contact lenses in environments containing high concentrations of tear gas. Immediate and subsequent biomicroscopic examination, including fluorescein staining, revealed no corneal epithelial effects.

The author (R.R.) was patient (9) and was exposed repeatedly to numerous tear gas environments.

Patient (10) dumped flour into a vat and had not noticed that flour accumulated under his lenses over a long period of time.

Patient (11) wore haptic lenses to prevent eye damage from ring rosin on boxing gloves. The same optometrist has fitted a number of other boxers for similar purposes and none incurred eye injuries.

Patient (12) was a laboratory technician who poured acid into a beaker and some acid splashed into his eye. The flexible lens was lost following eye lavage.

Patient (13) somehow got a type of wood finish on his eye which "soft lens absorbed."

Patients (14 and 15) were spraying paint which blew onto their faces and eyes. The lenses were cleaned with acetone.

Patient (16) was a painter exposed to lead fumes for over 12 years with no adverse ocular effects.

Patient (17) worked in a paint plant office. Fumes caused subjective eye irritation. No ocular damage was present, but patient was advised to discontinue wearing lenses.

Patient (18) splashed Chlorox onto his left eye. He wore a lens on that eye because he had keratoconus. He had a prosthesis for his right eye.

Patient (19) had caustic oven cleaner splashed on his eyes abrading the limbal area and irritating the bulbar conjunctiva.

Patient (20) had sulfur particles strike

CHEMICAL

PATIENT No.	HAZARD	CIRCUMSTANCES	CONTACT LENS	CORNEA	OTHER	STATE OR COUNTRY	AGE YR	SEX	INIT.	REF.
1.	sulfuric acid	splashed from dropped battery	etched	none		PA		M	RK	6
2.	acid	on job as carpenter	none	none		NJ		M	HA	6
3.	caustic soda	school chemistry laboratory	none	none		LA		F	SG	6
4.	hair spray	styling hair	coated	none		NY		F	MS	6
5.	acid	school chemistry laboratory	etched	none		England		F	FD	7
6.	grease	from frying pan	coated	none	facial, eyelid burns			F	NW	18
7.	tear gas (CS)	military research	none	none		MD	21	M	JC	19
8.	tear gas (CS)	military research	none	none		MD	24	M	SR	19
9.	tear gas (CS)	military research	none	none		MD	36	M	RR	
10.	flour	bakery employee repeated exposure	none (scleral)	abrasion		IN	28	M	DE	
11.	rosin	boxing	none (scleral)	none		IN		M	DE	
12.	hydrochloric acid	splashed from beaker	none (soft lens)	none		OH	25	M	RP	
13.	varnish	unknown	absorbed (soft lens)	none		OR	18	M	MW	
14.	paint	spraying	painted	none		IL	36	M	AM	
15.	paint	spraying	painted	none		OH	21	M	RW	
16.	fumes, paint	daily exposure	none	none		NY	30	M	JB	
17.	fumes, paint solvents	paint factory	none	none		CA	28	F	SW	
18.	Chlorox	unknown	none	none		OH	52	M	RP	
19.	oven cleaner	splashed onto eye	none	stippling where not covered		IL	37	F	BF	
20.	sulfur vapors	school chemistry laboratory explosion	none	stippling where not covered		NJ	15	F	LC	
21.	varnish remover	splashed in face	none	stippling where not covered		IL	34	F	GP	
22.	cleaning fluid	splashed onto eye	none	edema where not covered		NY	21	F	JE	
23.	radiator contents	auto radiator blew up in face	none	none	face scalded	MA	28	M	IO	
24.	acid fumes	from solder	none	none		IL	38	M	AL	
25.	acetone	chemistry experiment	none	none		PA	22	M	DE	

her face and eyes causing a conjunctivitis and partial limbal involvement.

Patient (21) was removing varnish with a solvent that splashed onto her eye. Cornea was affected only in periphery.

Patient (22) was cleaning rollers on a printing device when the cleaning fluid splashed onto her left eye. The cornea was edematous only where not protected by the lens.

Added: "We have had several cases of caustic fluids or fumes to the eye where after first aid flushing the cornea was clear under the contact lens area, but showed chemical irritation beyond. Frequently seen with hair spray or deodorant spray."

Discussion

Most of those who replied to the questionnaire stated that they had not seen any patients who had ocular accidents involving contact lenses, e.g.:

"I cannot recall one case."

"No loss of vision or eye damage due to trauma in connection with the wearing of contact lenses."

"Sorry, no documented cases to report."

"In 22 years of contact lens practice . . . no knowledge of an injury . . . associated with contact lenses."

"I have not had a single case of ocular damage due to wearing contact lenses in an industrial environment."

". . . fitting over 3,000 patients . . . have not seen any permanent chemical or foreign body injuries."

". . . case records at least 100,000 . . . never seen an industrial accident where the contact lens was really involved."

"No cases of permanent ocular damage due to above circumstances."

"Never had a case to my knowledge."

". . . don't have any cases that I can document where a contact lens wearer received protection or damage . . ."

"I have not seen any cases of damage from contact lenses in the case of chemicals, fumes or foreign body."

"I have not had any such case."

"Estimate fitting . . . 750 to 1,000, but no cases within the parameter of this report."

Among the 128 patients described in this report, the doctors often wrote their opinion that contact lenses gave added protection and minimized or completely protected the eyes from more serious injuries. "One of the most common misconceptions we hear patients express is that if a patient is injured while wearing contact lenses, the lens will contribute to the extent of the injury. Actually, when one examines the situation, it becomes evident that contact lenses in many cases are far safer than spectacles."[20]

The protection from contact lenses is obvious in cases of physical trauma, in comparison to a survey of spectacles lens injuries[21], as well as the large amount of literature on the subject of ocular injuries in general.[22] In addition animal experiments[18] and the patients reported here show contact lenses provided protection in chemical accidents. From this evidence it is difficult to accept generalizations that contact lenses are unsafe in chemical environments.

Most of the lenses described in this report were conventional corneal lenses made from polymethylmethacrylate (PMMA), but similar protection occurred with a smaller number of individuals wearing scleral (7) and soft (2) lenses.

There may be circumstances where an individual cannot wear contact lenses and such cases are best evaluated by contact lens specialists. In the event of an industrial accident, one doctor wrote, "The fact that industrial nurses and physicians are unfamiliar with contact lens removal procedures is not an indictment of contact lenses but rather of the need for training in this area."

The wearing of eye protection in environments that contain eye hazards is not an issue in this report. Such a requirement is a sine qua non[23], and certainly all individuals working in eye hazardous environments should wear protective devices which meet or exceed the requirements of ANSI Z-87 Standard*. **AOA**

Acknowledgment

We thank all those doctors who contributed to this report by replying to the questionnaire.

*Occupational and Educational Eye and Face Protection.

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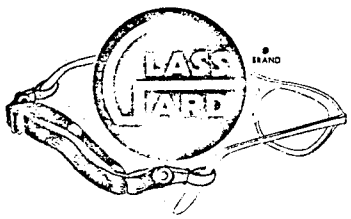

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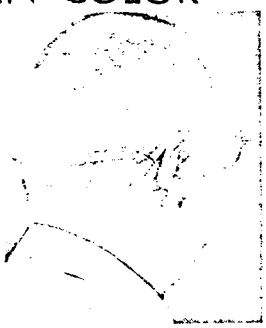

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APPENDIX D

WELDING ARC SPECTRAL IRRADIANCE DATA

WELDING ARC SPECTRA DATA

The following are plots of Spectral Irradiance [milliwatts/(centimeter)^2-nanometer] vs Wavelength (nanometers), subdivided into the ultraviolet, visible, and infrared regions of each welding arc condition. To determine the spectral irradiance of a particular welding condition at a specific wavelength from these plots it is merely necessary to locate the wavelength on the abscissa, traverse vertically from this position until the curve is intersected, and then traverse horizontally from this position to the corresponding value in milliwatts/(centimeter)^2 on the ordinate.

In general, the matching between the three regions (ultraviolet-to-visible and visible-to-infrared) is good. When examining the transition from the ultraviolet to the visible regions of the spectrum, it is best to chose points near 400 nm. Values between 350 to 400 nm have limited accuracy due to the small amount of energy emitted in this region from the standard Tungsten lamp which was used for calibration. Discrepancies in the matching of the different regions of the spectrum can be due to a number of causes. Since extreme care was taken in the alignment of the detecting apparatus with respect to the welding arc, and careful computer analysis of the raw data was made, inconsistencies are most likely due to the inherent welding arc fluctuations and monochrometer resolution. Care was taken by allowing the voltage to stabilize before recording data, but amperage fluctuations could not be eliminated since this is normal to the welding process. The wavelengths were scanned slowly to decrease the effect of these fluctuations but because of the irreproducability of the welding process due to all of the parameters involved, they could not be entirely eliminated. Another factor to be taken into account when matching portions of the spectrum for a given welding process is the resolution. The resolution was 0.32 nanometers in the ultraviolet region, 6.4 nanometers in the visible region, and 25.6 nanometers in the infrared region. These differences are due to the combination of the reciprocal linear dispersion factors of the monochrometer diffraction gratings and the slit width. Even with these inherent problems and problems related to the calibration of the apparatus, it is felt that the matching between portions of the spectrum for a given welding arc condition is quite good.

Caution should be taken when examining the welding arc data. Any values below 200 nanometers are fictitious and were intentionally fabricated by the computer program since our calibration did not extend below this wavelength. It should be noted that the scale divisions on the graphs vary frequently and should be examined independently in this regard. The computer program was written to optimize data presentation by taking into account the spread in the output values.

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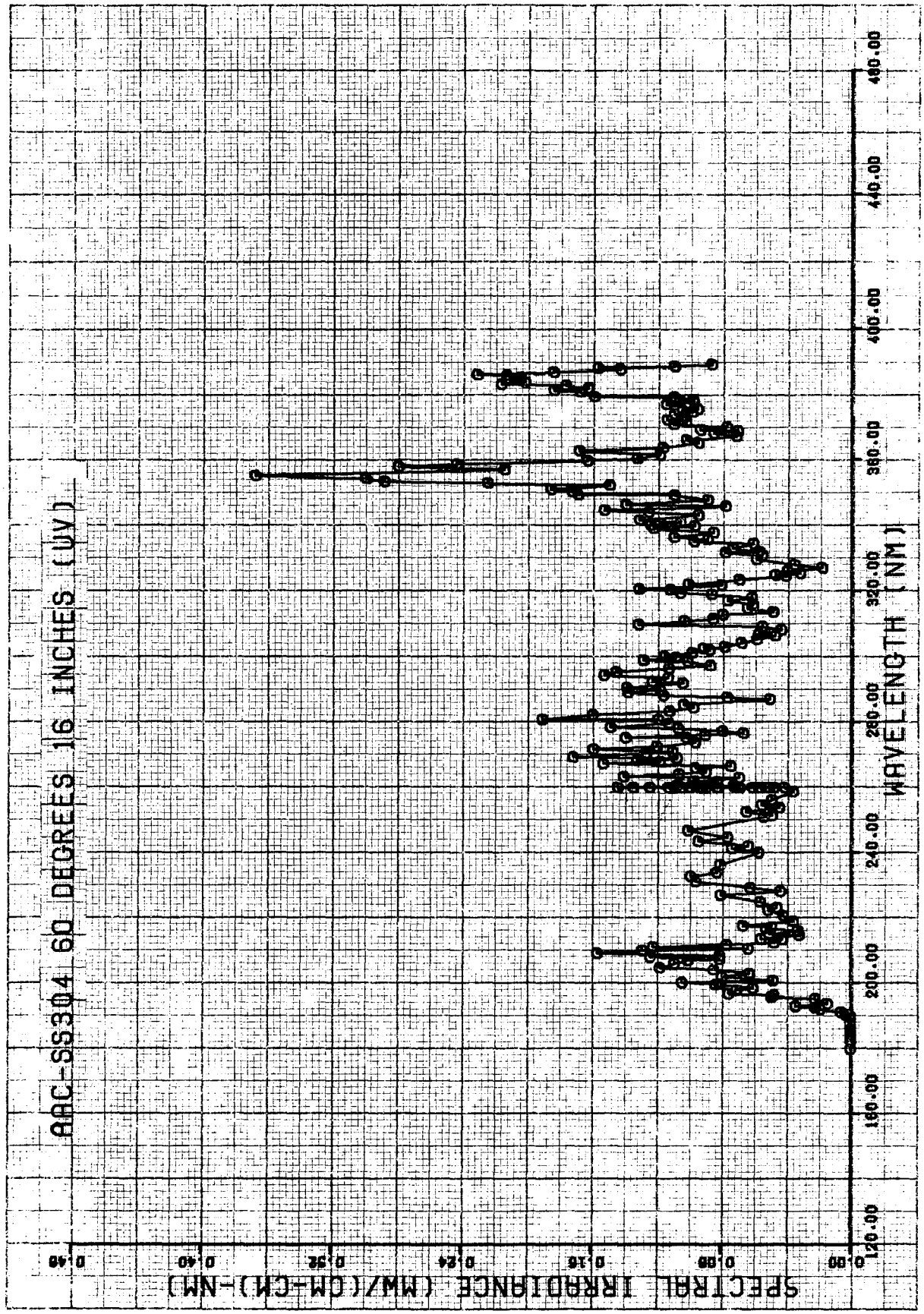
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WAVELENGTH (NM)
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280.00
320.00
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400.00
440.00
480.00

SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
0.00
0.04
0.08
0.12
0.16
0.20
0.24
350.00
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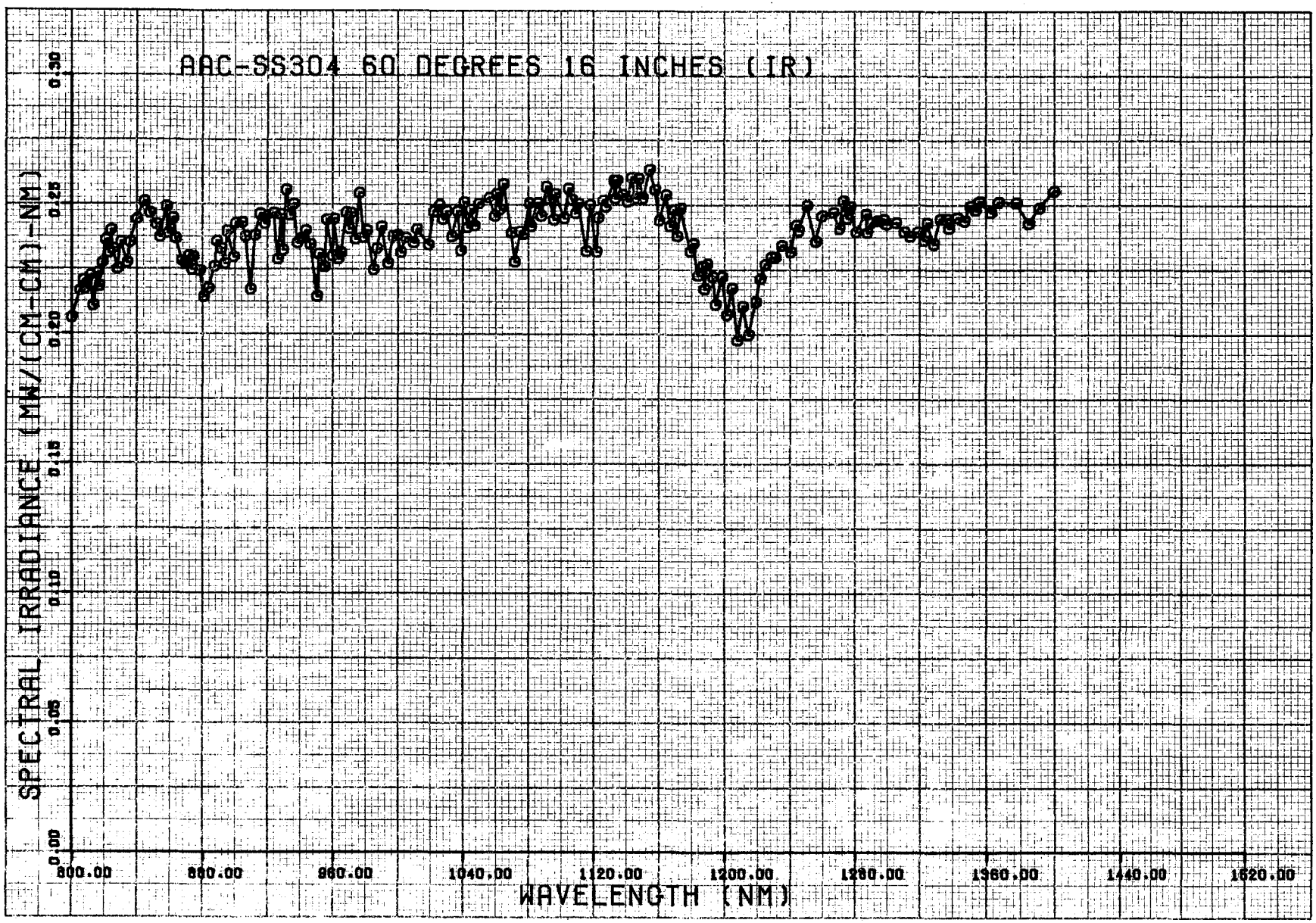
AAC-SS304 60 DEGREES 16 INCHES (IR)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
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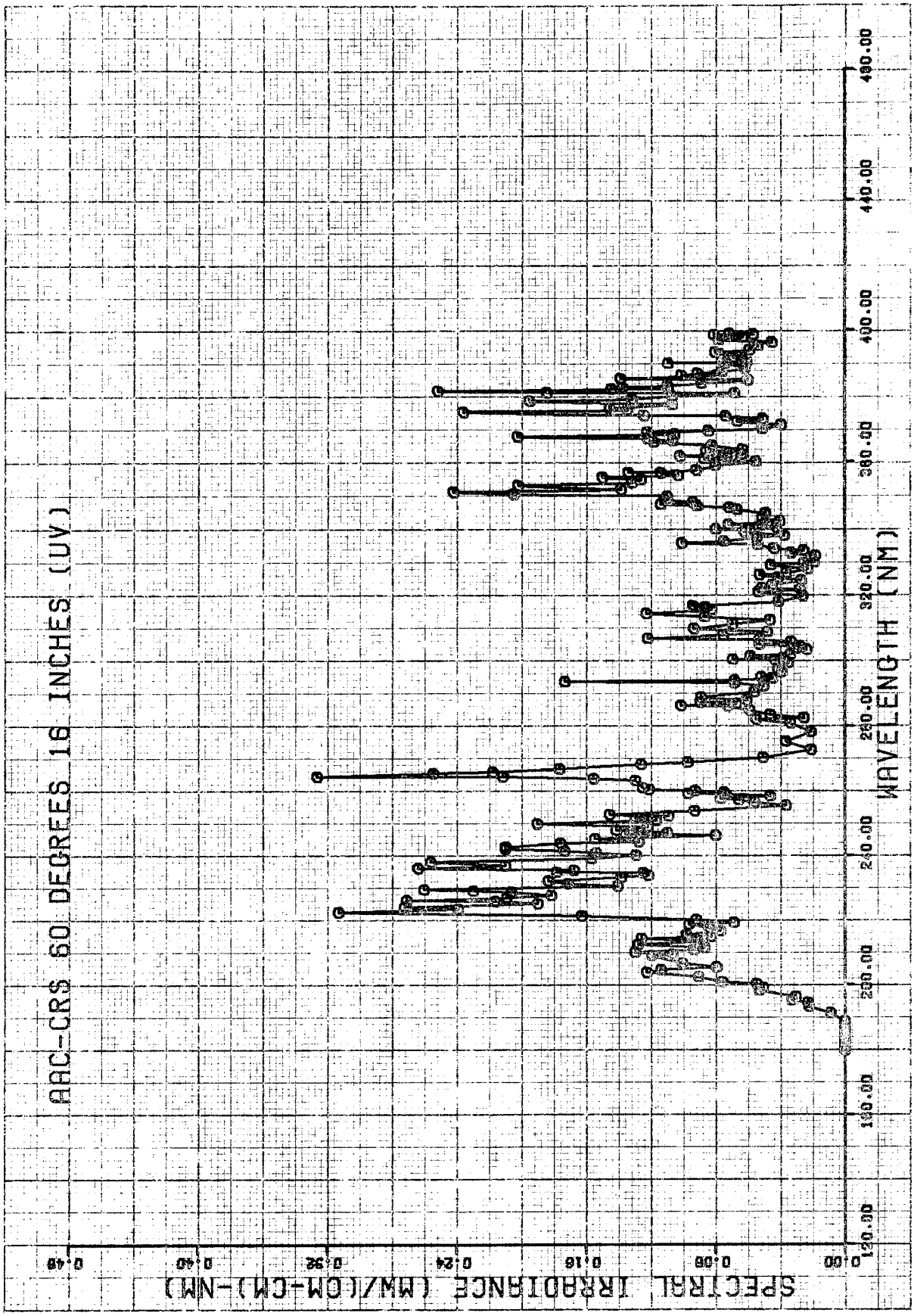
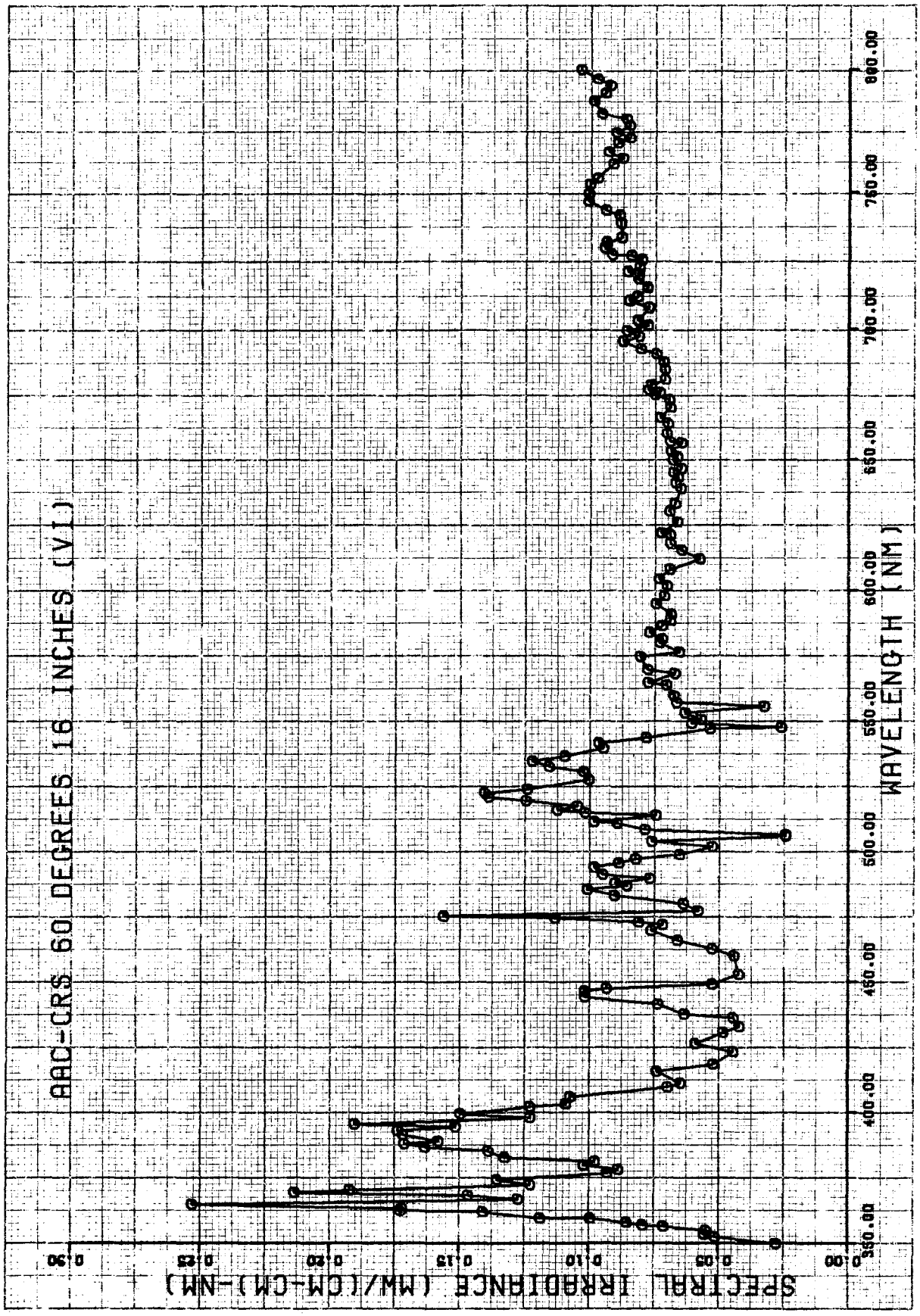
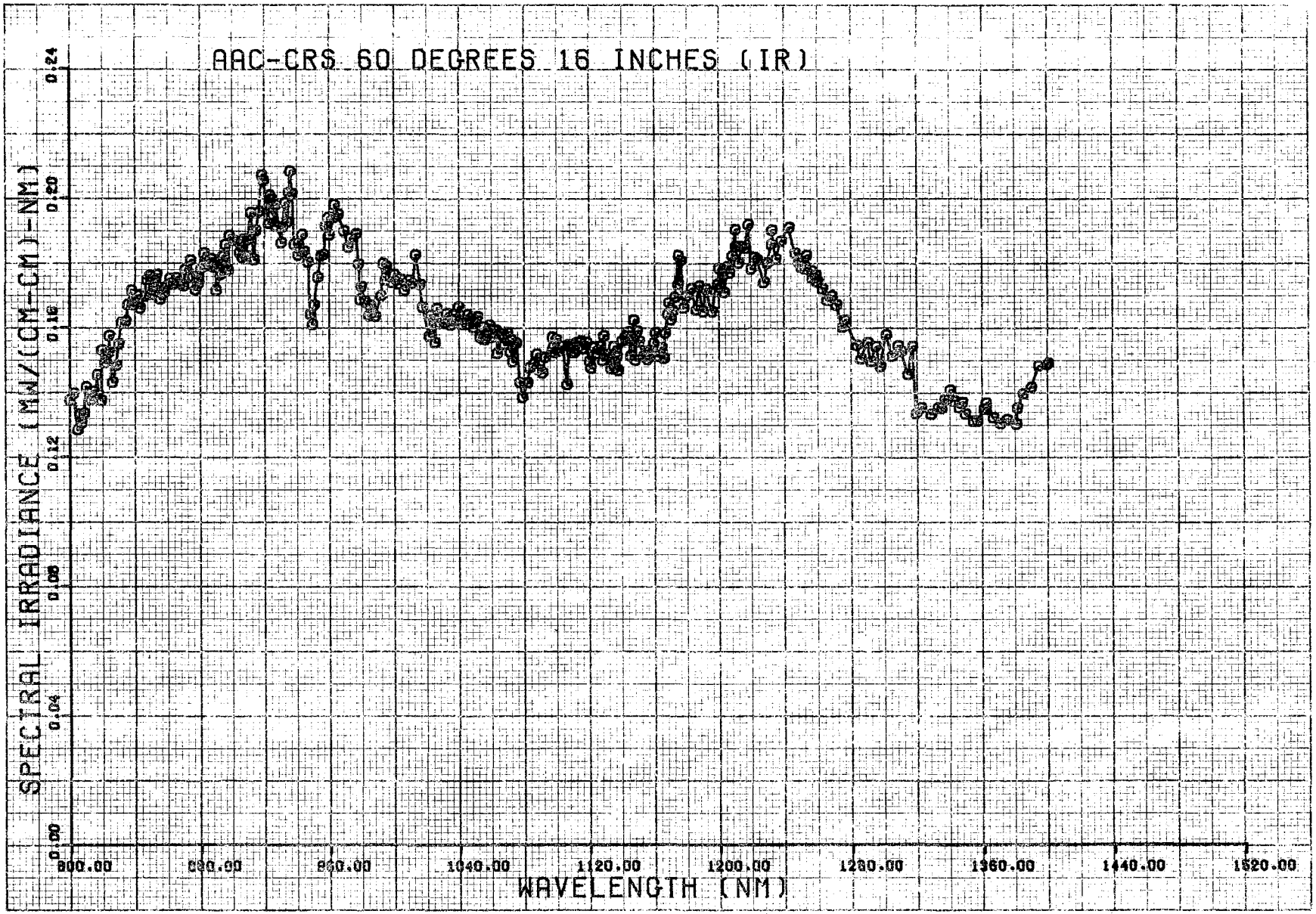
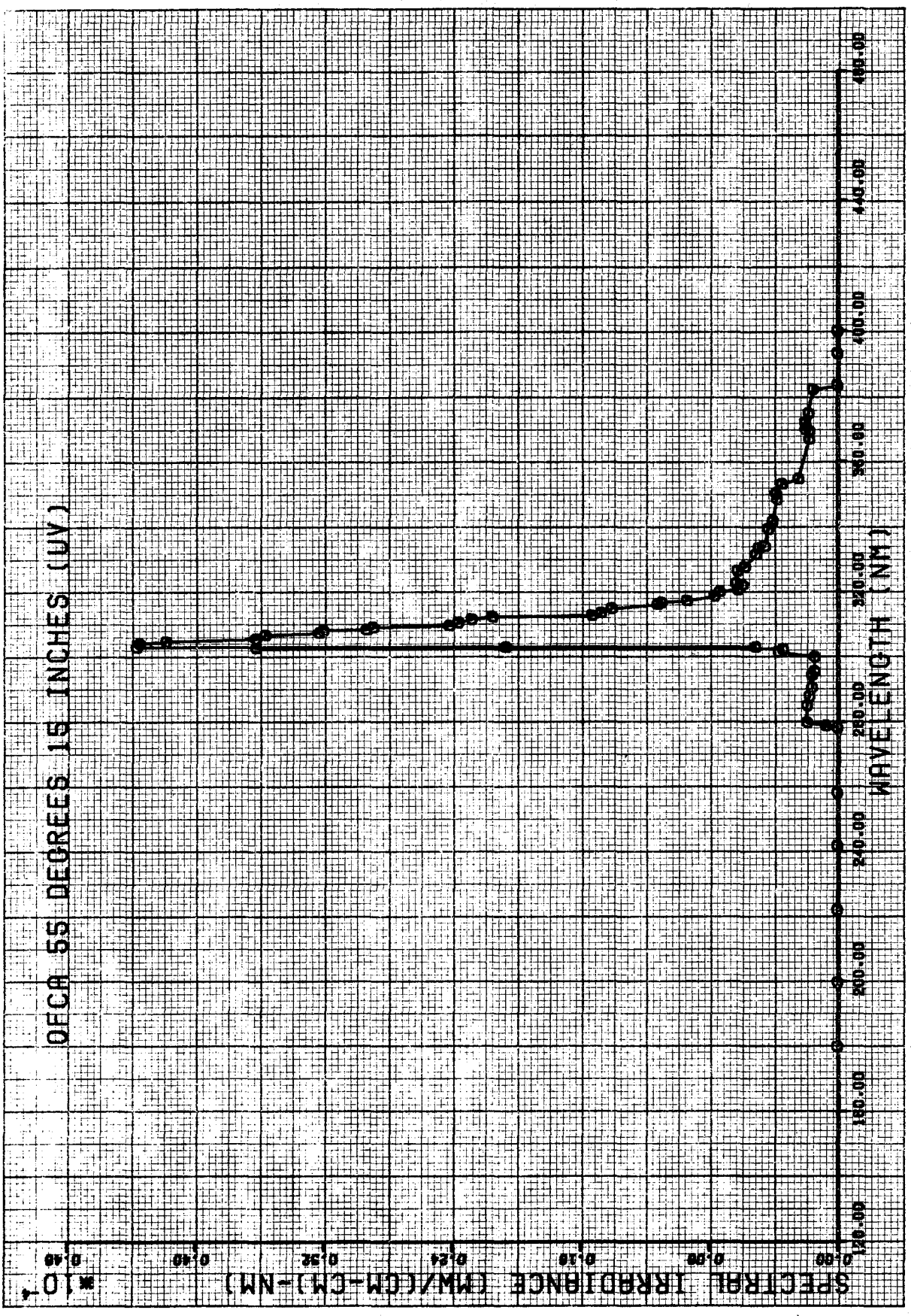
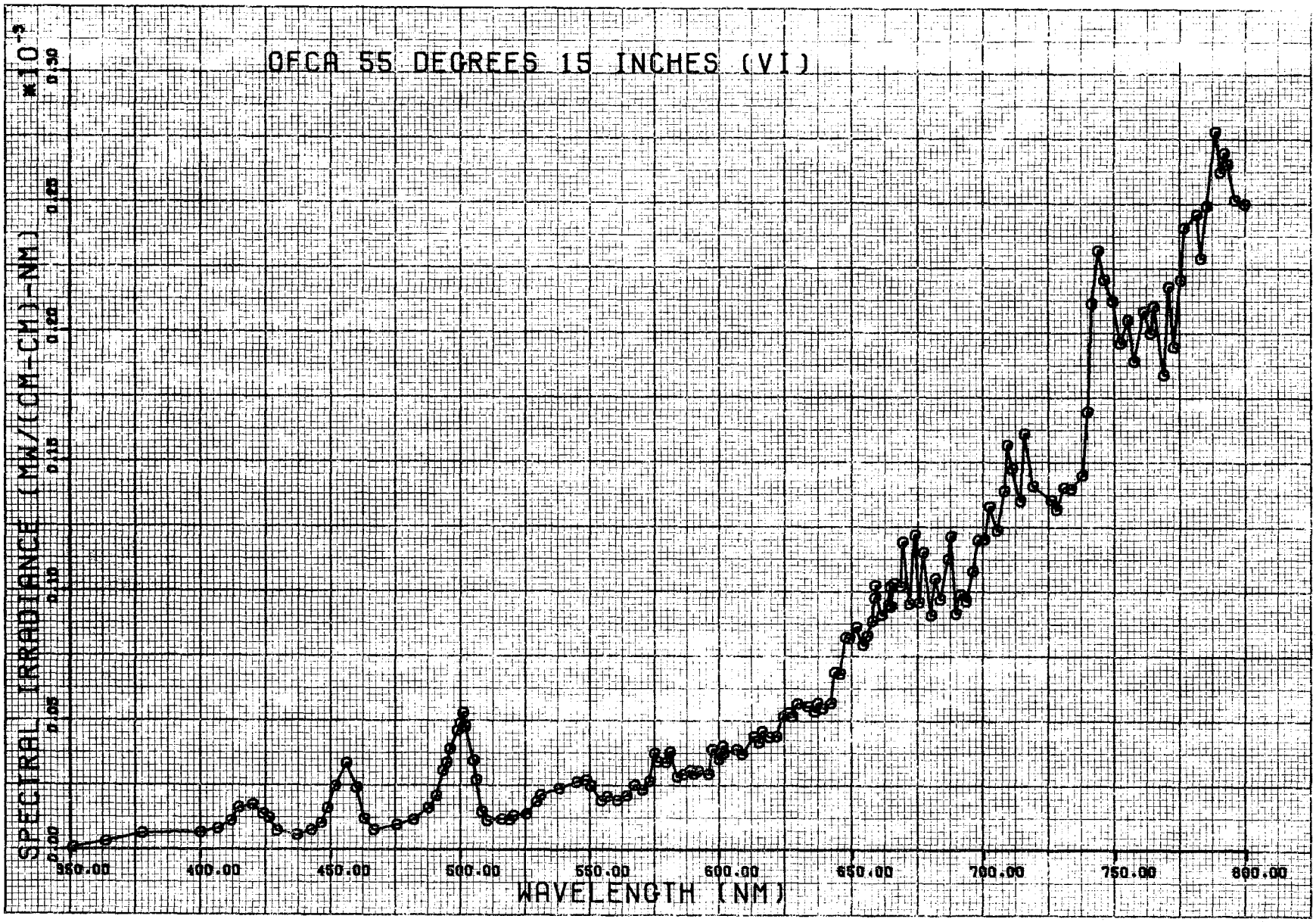
1040.00
1120.00
1200.00
1280.00
1360.00
1440.00
1520.00
WAVELENGTH (NM)

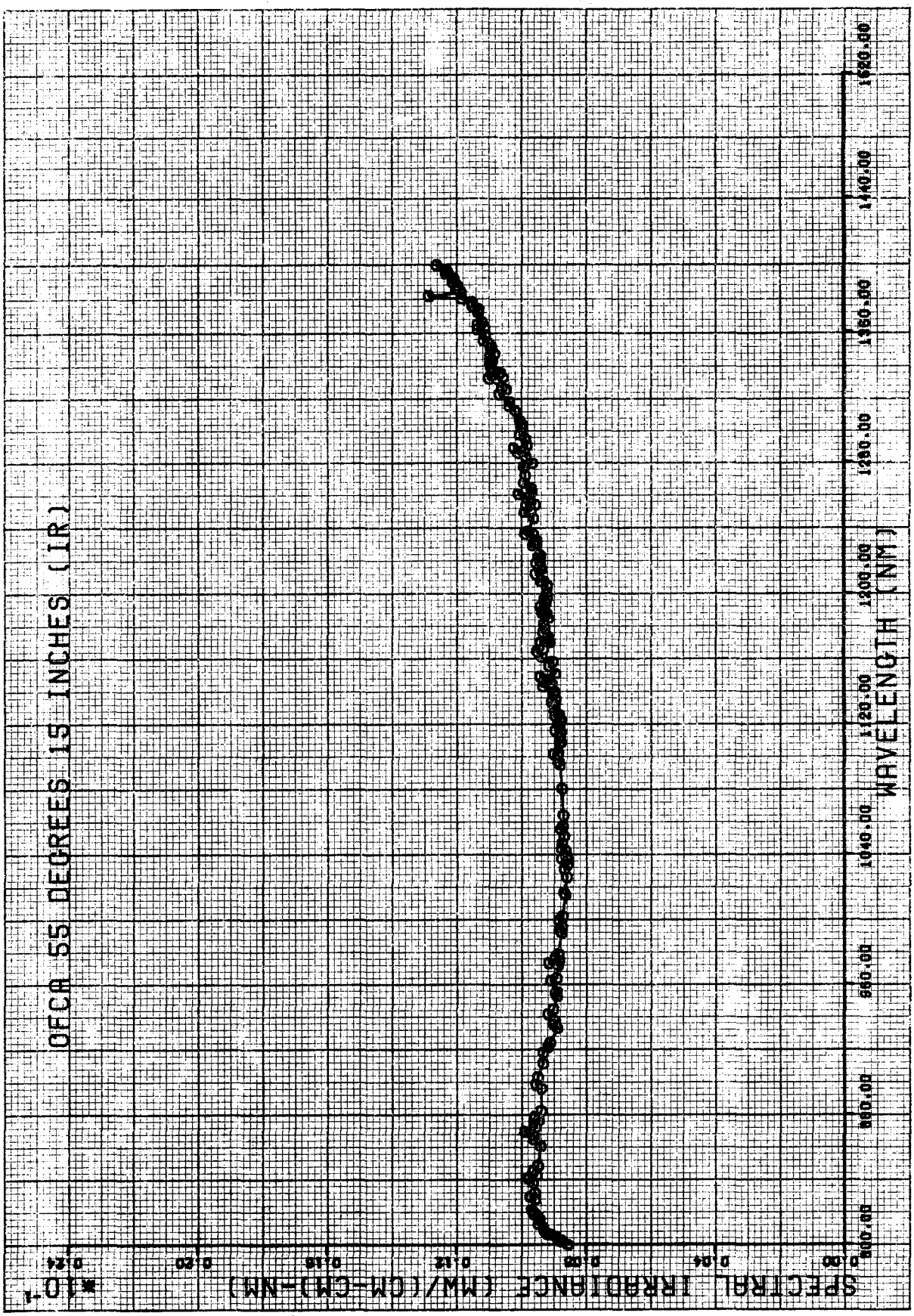

ARC-CRS 60 DEGREES 16 INCHES (UV)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
0.00
0.08
0.16
0.24
0.32
0.40
0.48
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
480.00

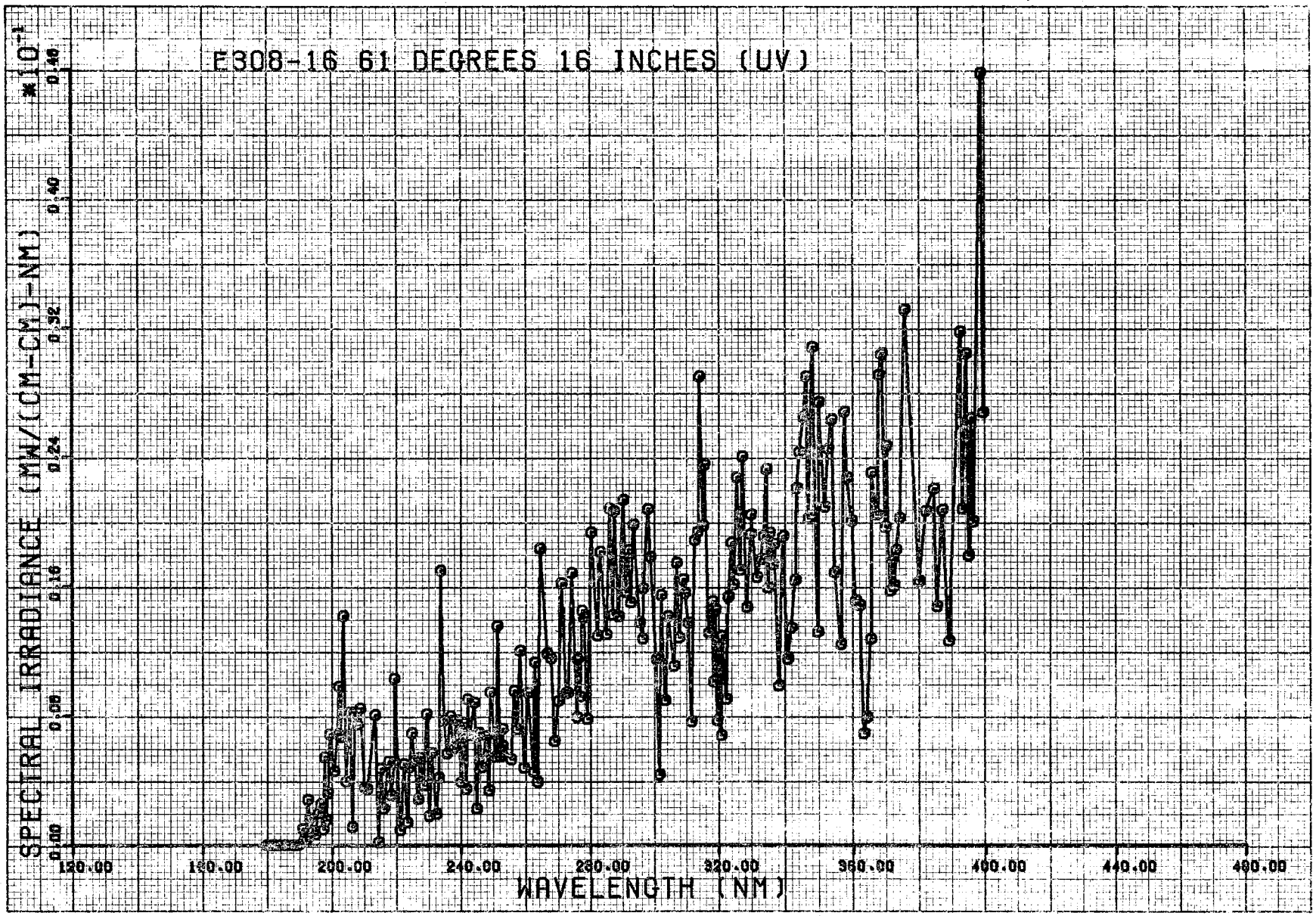

AAC-CRS 60 DEGREES 16 INCHES (V.)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
350.00
400.00
450.00
500.00
550.00
600.00
650.00
700.00
750.00
800.00

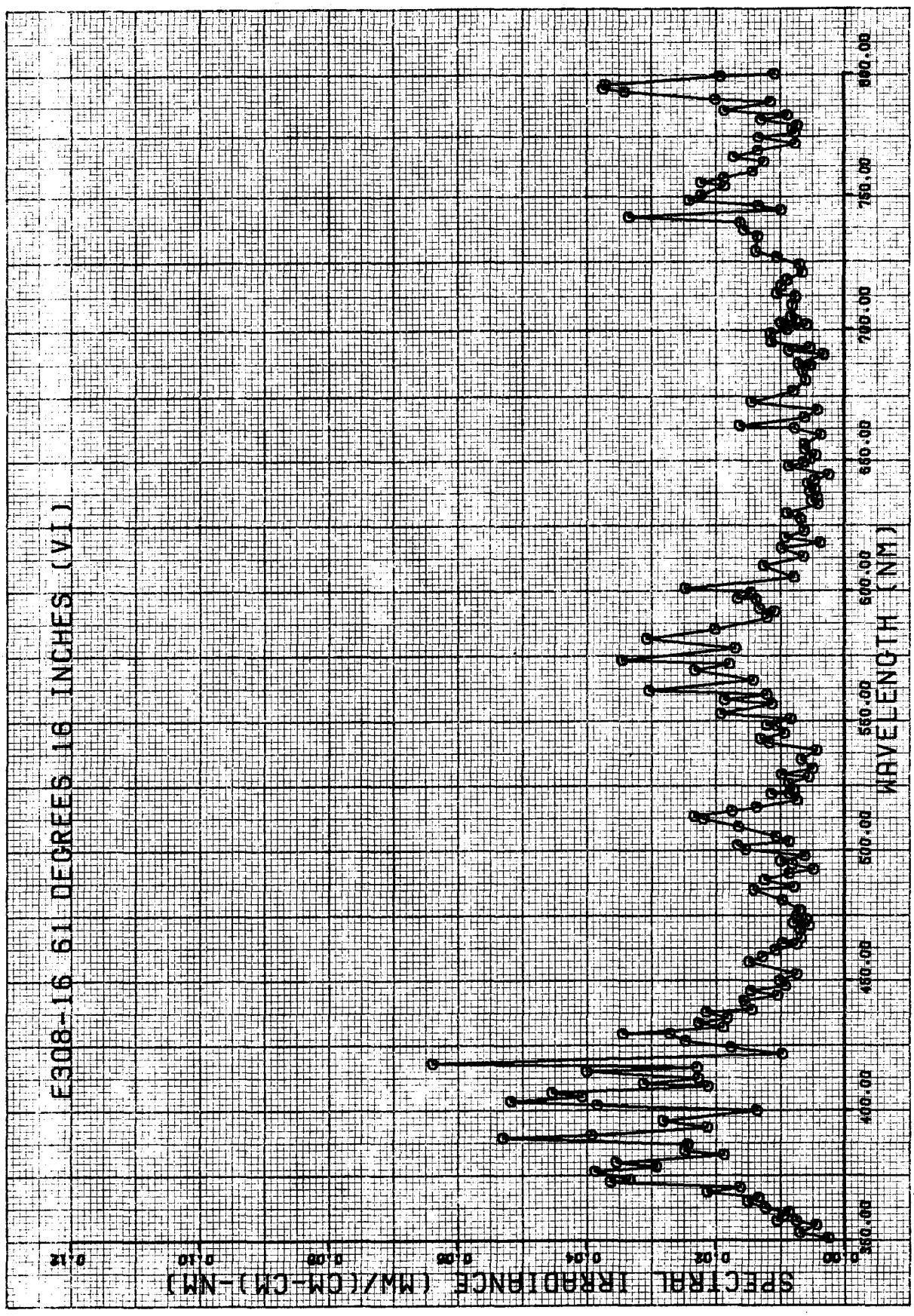

AAC-CRS 60 DEGREES 16 INCHES (IR)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
0.24
0.20
0.16
0.12
0.08
0.04
0.00
800.00
880.00
960.00
1040.00
1120.00
1200.00
1280.00
1360.00
1440.00
1520.00
WAVELENGTH (NM)

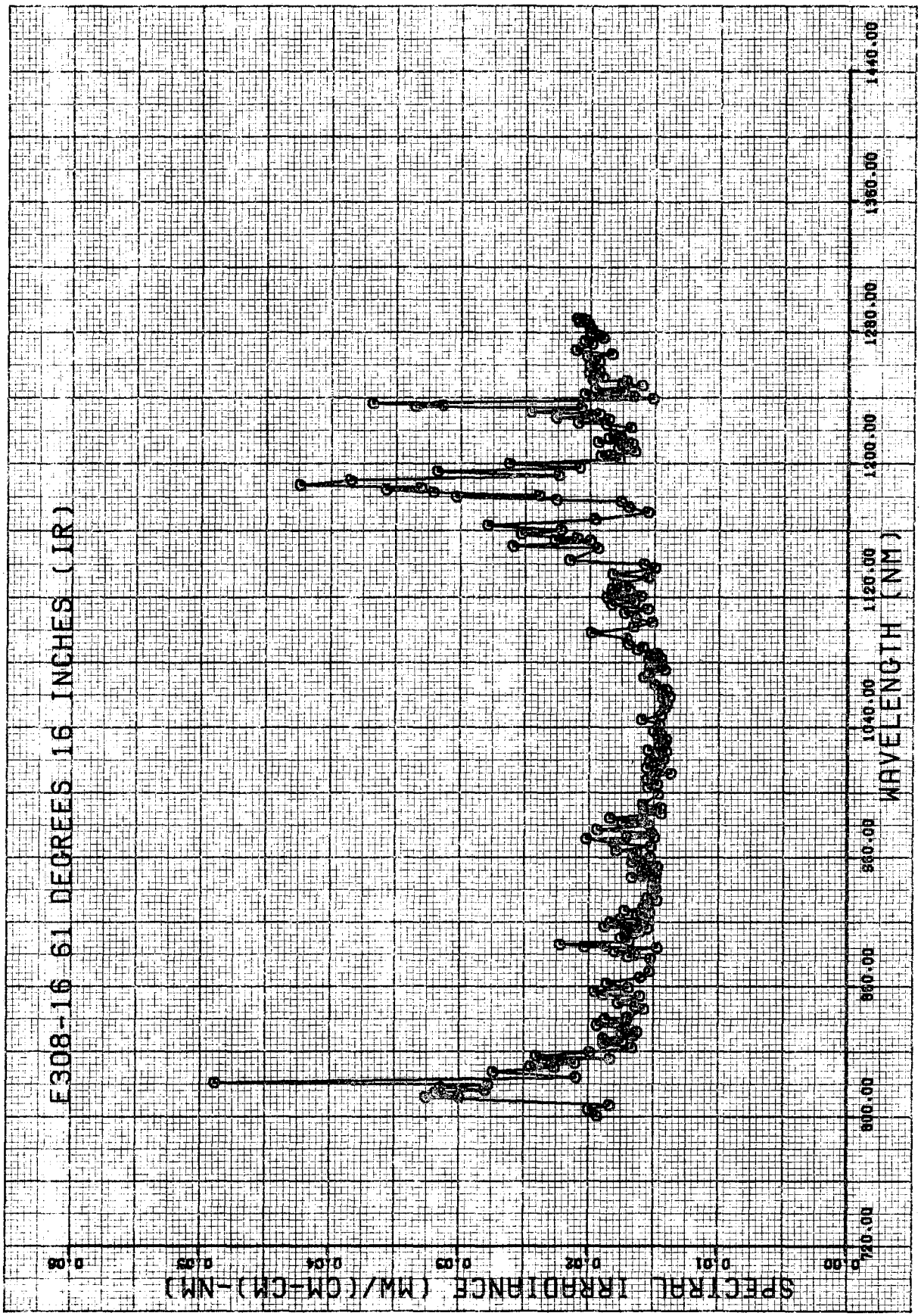

OFCA 55 DEGREES 15 INCHES (UV)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
*10⁻⁴
0.00
0.08
0.16
0.24
0.32
0.40
0.48
WAVELENGTH (NM)
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
480.00

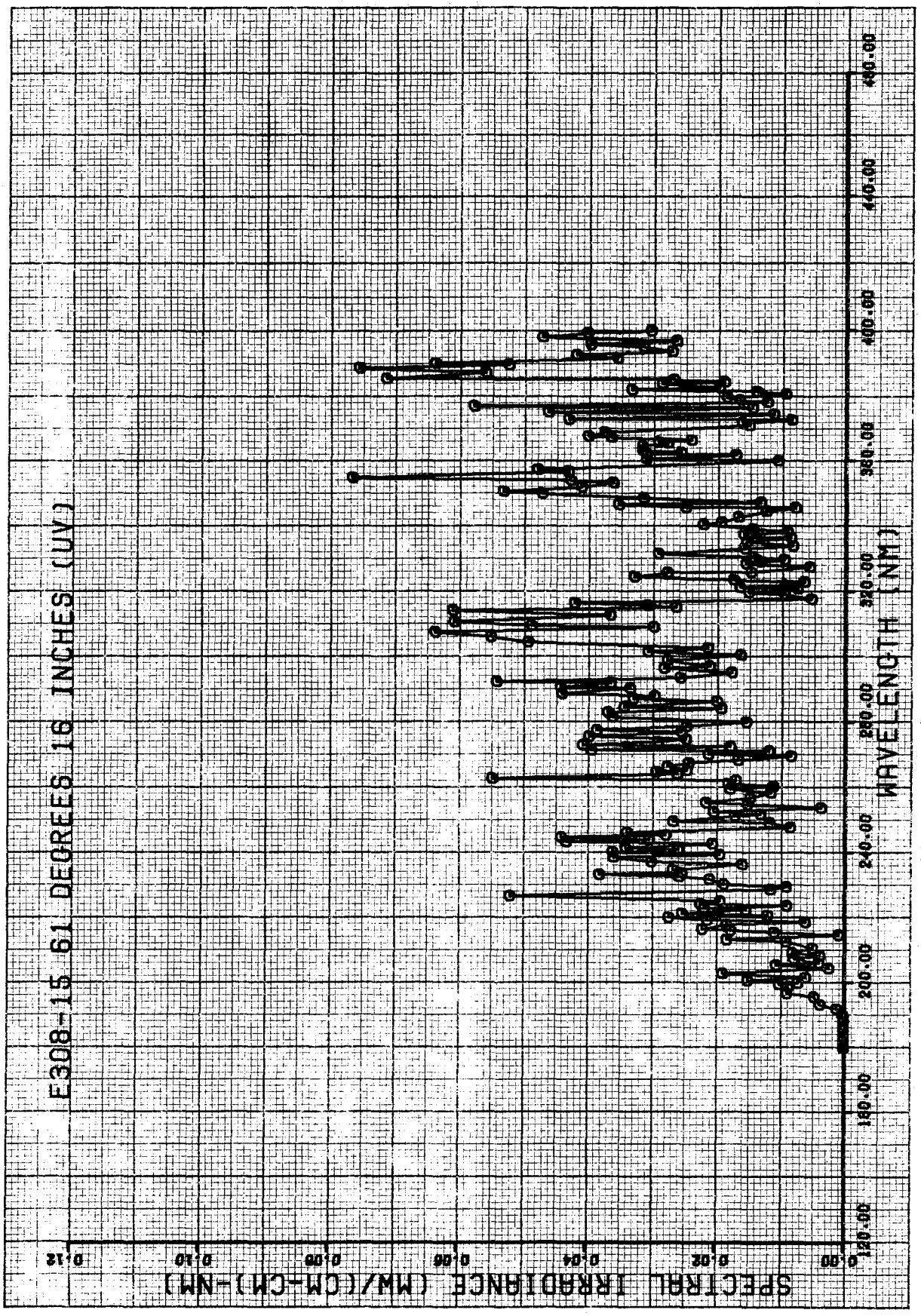

OFCA 55 DEGREES 15 INCHES (VI)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM) *10**-3
0.00
0.05
0.10
0.15
0.20
0.25
0.30
350.00
400.00
450.00
500.00
550.00
600.00
650.00
700.00
750.00
800.00
WAVELENGTH (NM)

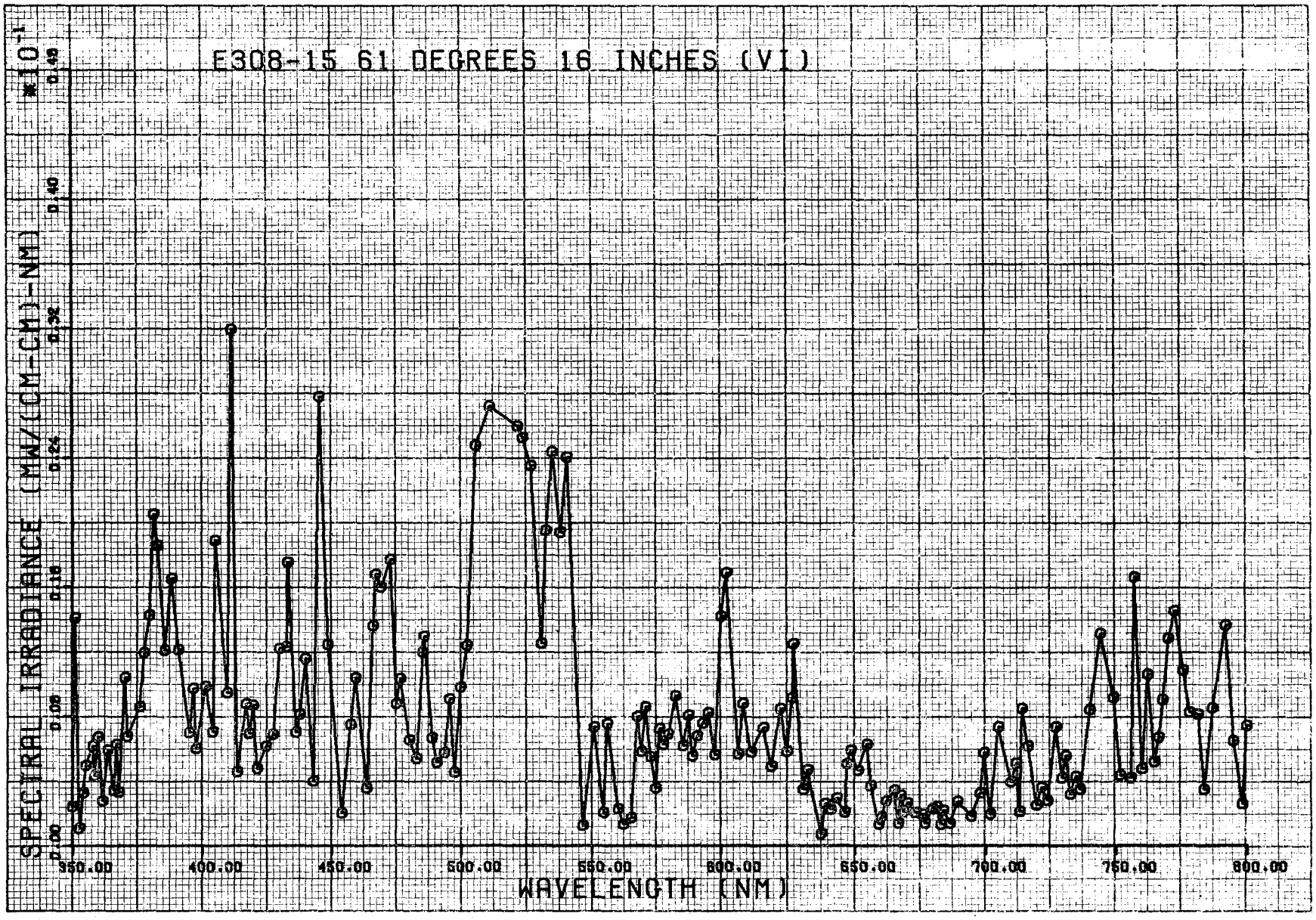

OFCA 55 DEGREES 15 INCHES (IR)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)

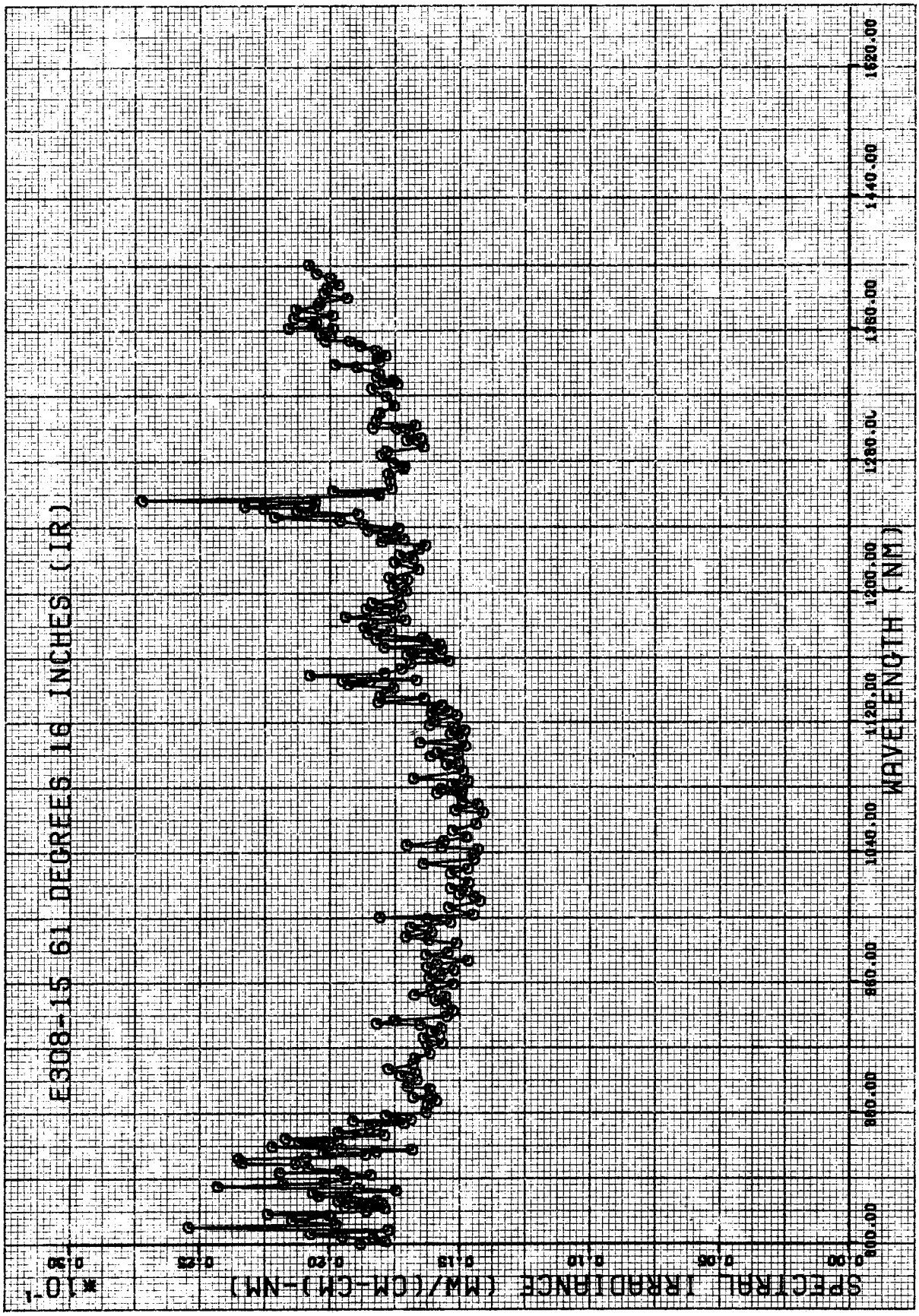

E308-16 61 DEGREES 16 INCHES (UV)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM) *10-1
0.00
0.08
0.16
0.24
0.32
0.40
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
480.00
WAVELENGTH (NM)

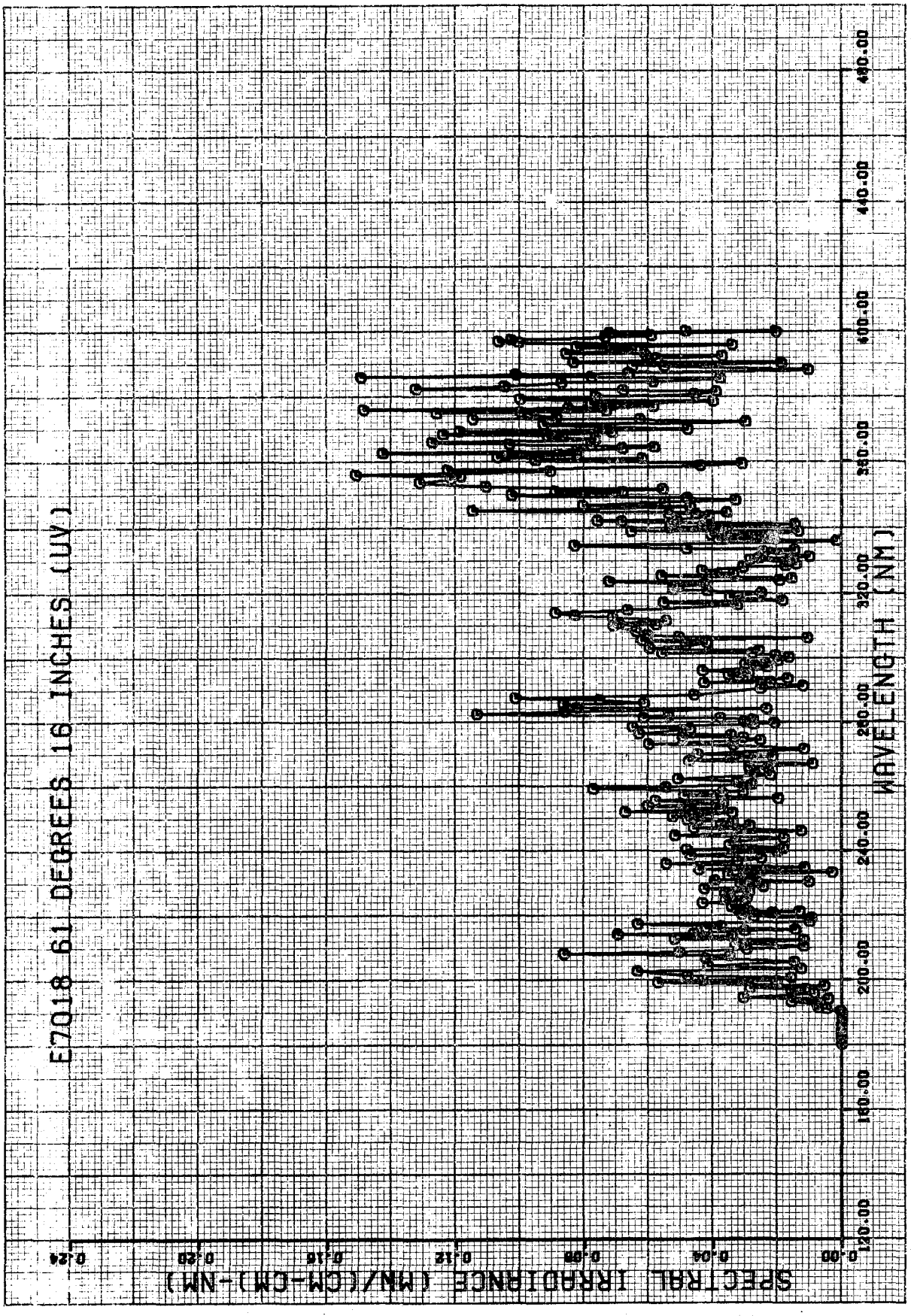

E308-16 61 DEGREES 16 INCHES (V1)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
350.00
400.00
450.00
500.00
550.00
600.00
650.00
700.00
750.00
800.00

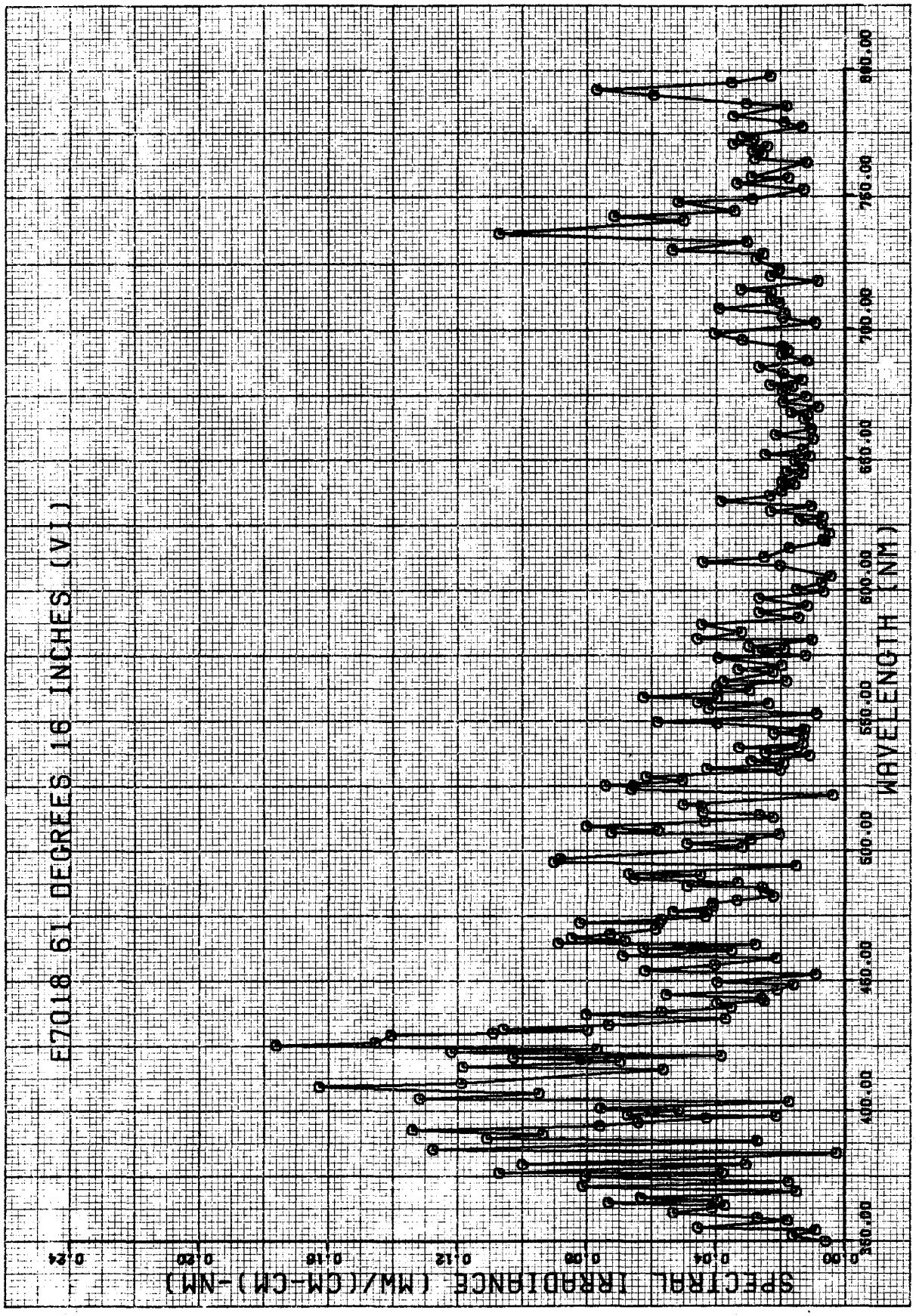

E308-16 61 DEGREES 16 INCHES (IR)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
720.00
800.00
880.00
960.00
1040.00
1120.00
1200.00
1280.00
1360.00
1440.00


E308-15 61 DEGREES 16 INCHES (UV)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00

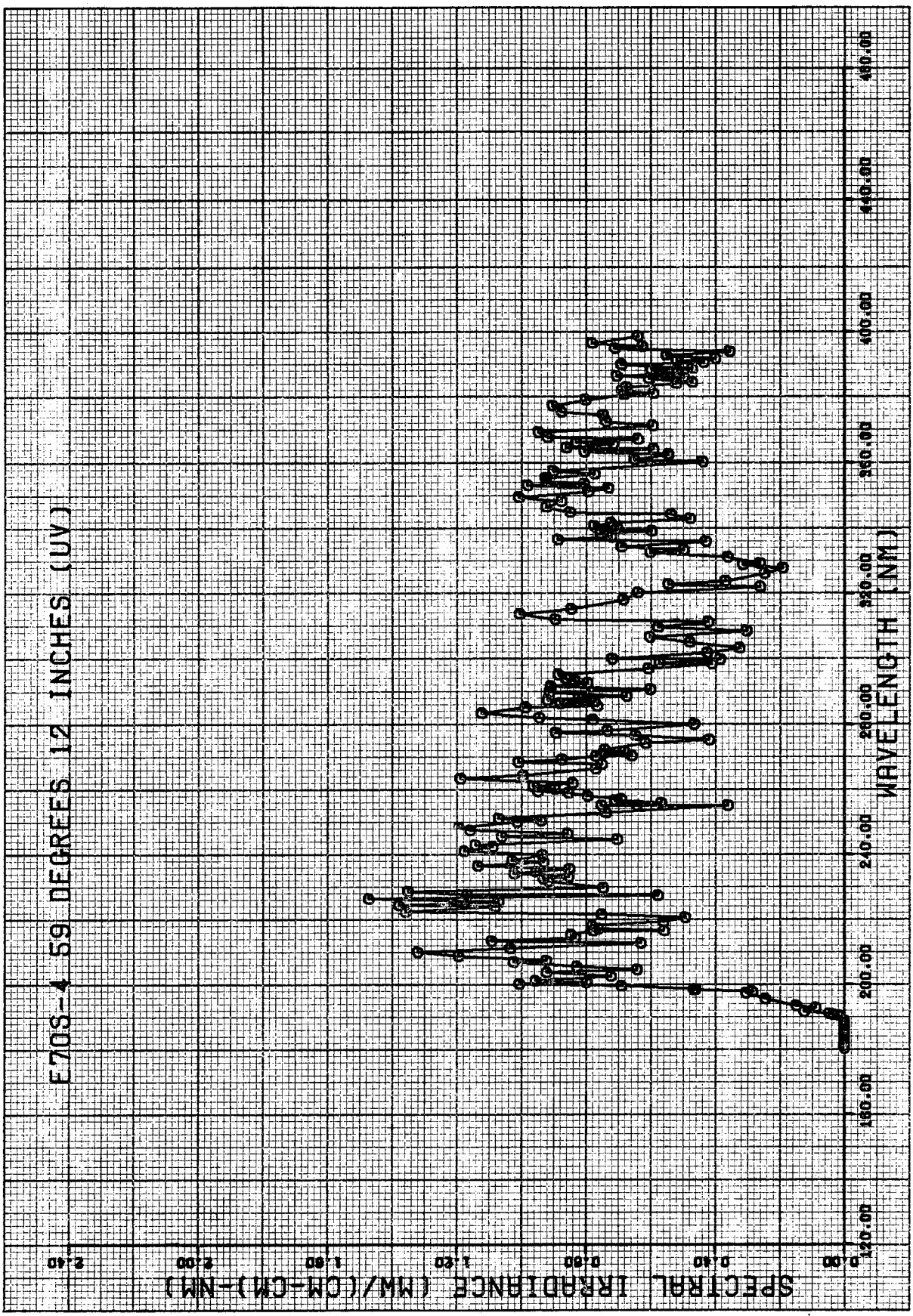

E308-15 61 DEGREES 16 INCHES (VI)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM) *10^-1
0.00
0.08
0.16
0.24
0.32
0.40
0.48
350.00
400.00
450.00
500.00
550.00
600.00
650.00
700.00
750.00
800.00
WAVELENGTH (NM)

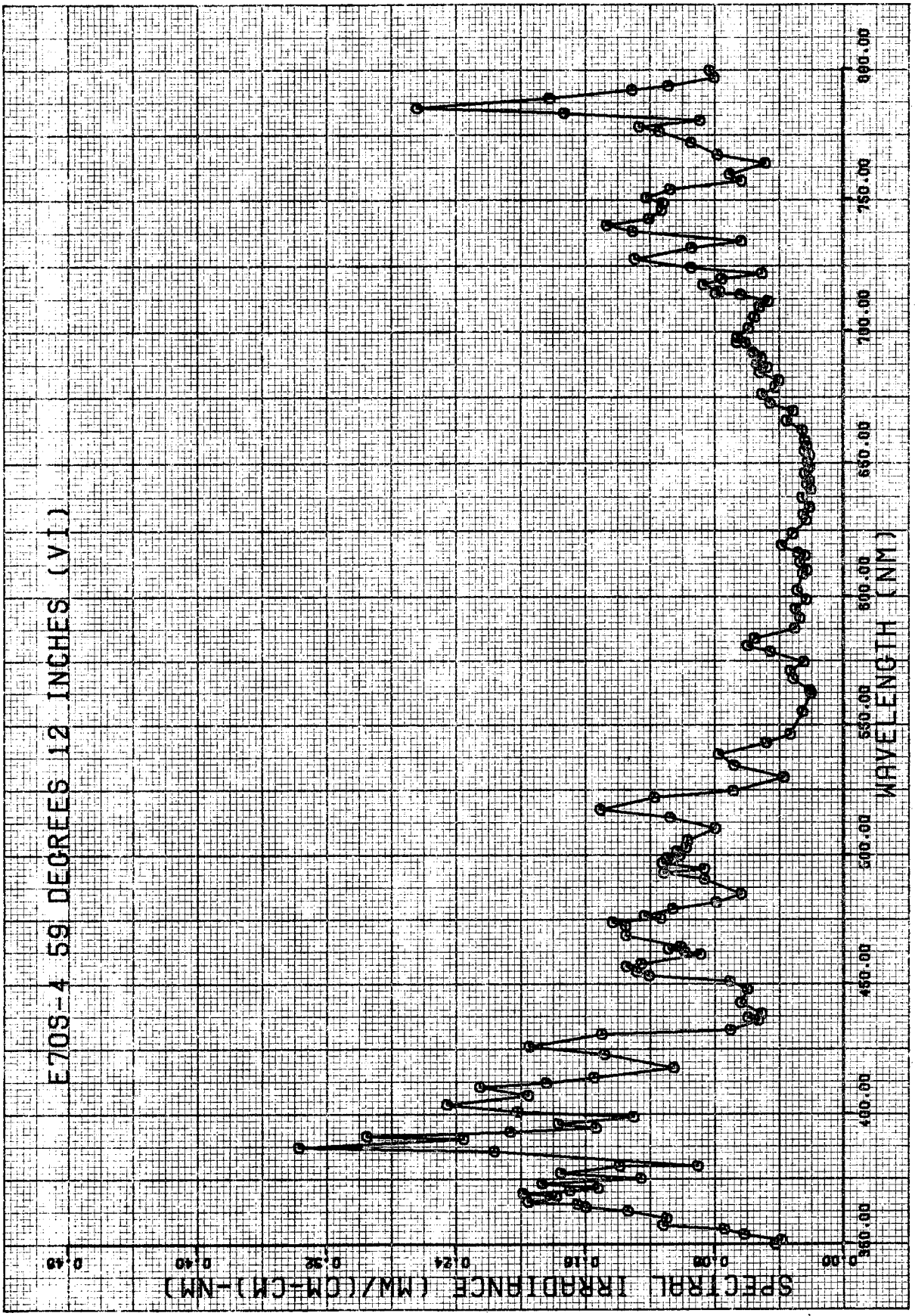

E308-15 61 DEGREES 16 INCHES (IR)
SPECTRAL IRRADIANCE (MW/(CM-(CM)-NM)
WAVELENGTH (NM)
800.00
960.00
1040.00
1120.00
1200.00
1280.00
1360.00
1440.00
1520.00
0.00
0.05
0.10
0.15
0.20
0.25

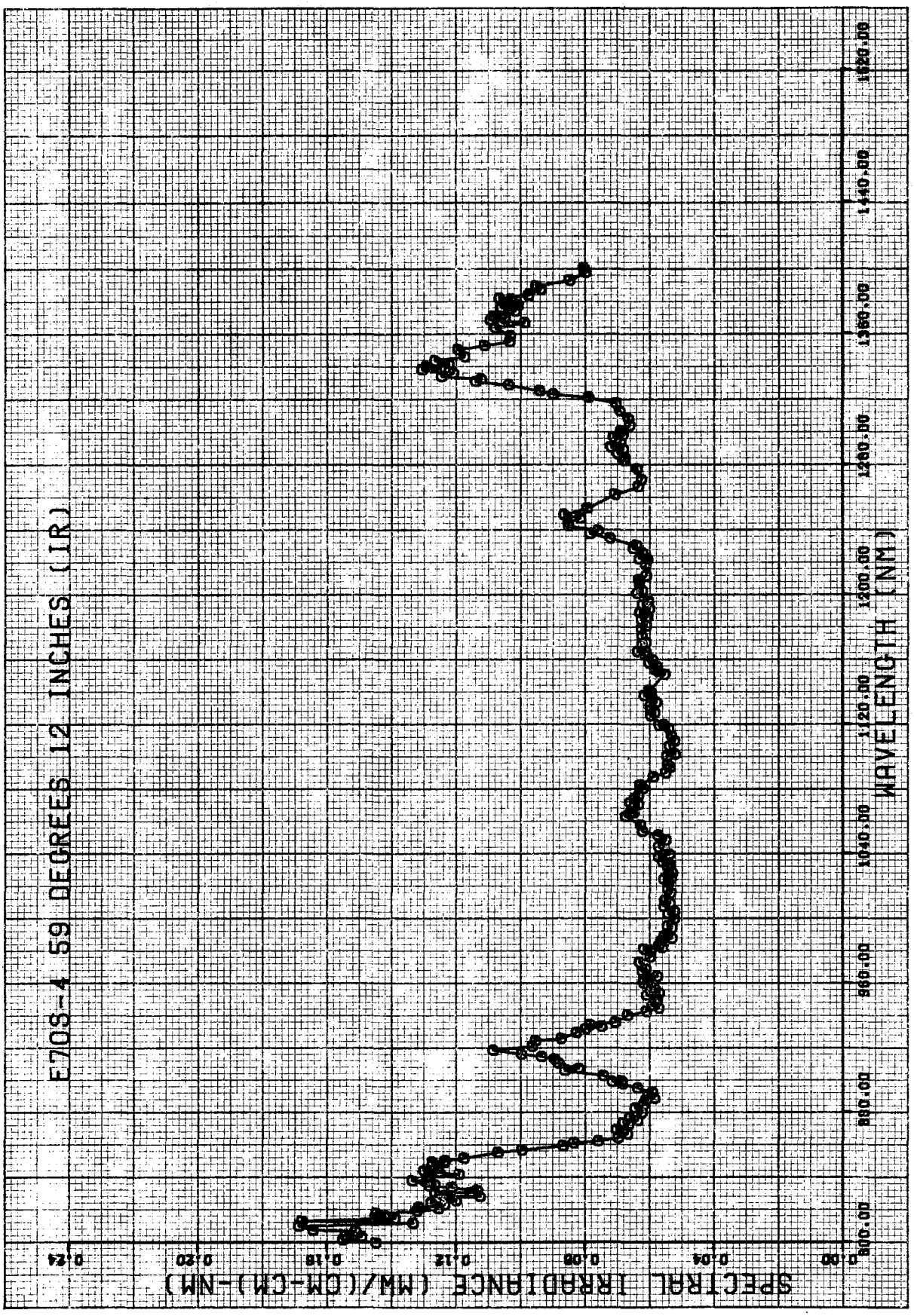

E7018 61 DEGREES 16 INCHES (UV)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
0.00
0.04
0.08
0.12
0.16
0.20
0.24
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
480.00

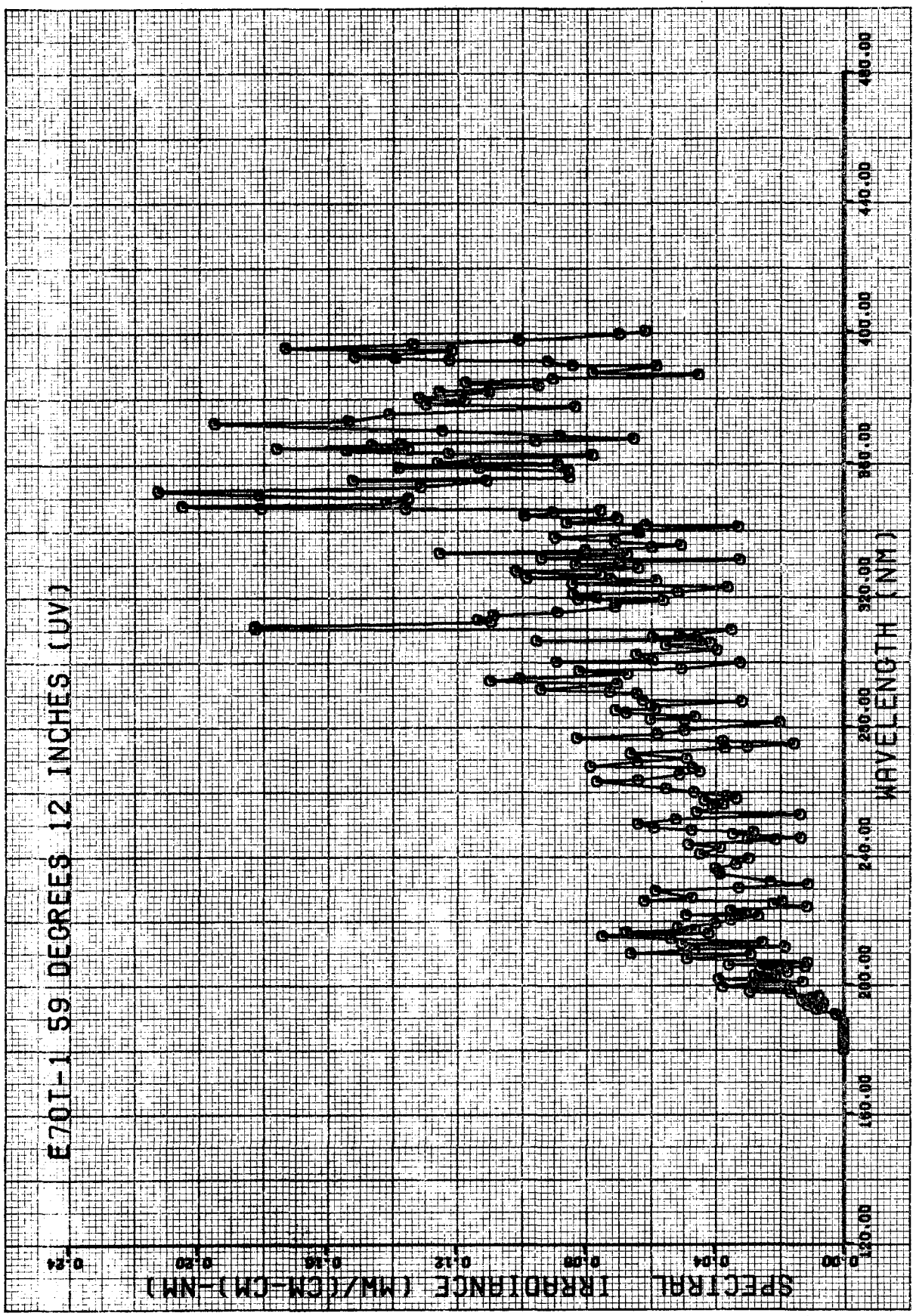

E7018 61 DEGREES 16 INCHES (VL)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
0.00
0.04
0.08
0.12
0.16
0.20
0.24
360.00
400.00
460.00
500.00
550.00
600.00
650.00
700.00
750.00
800.00

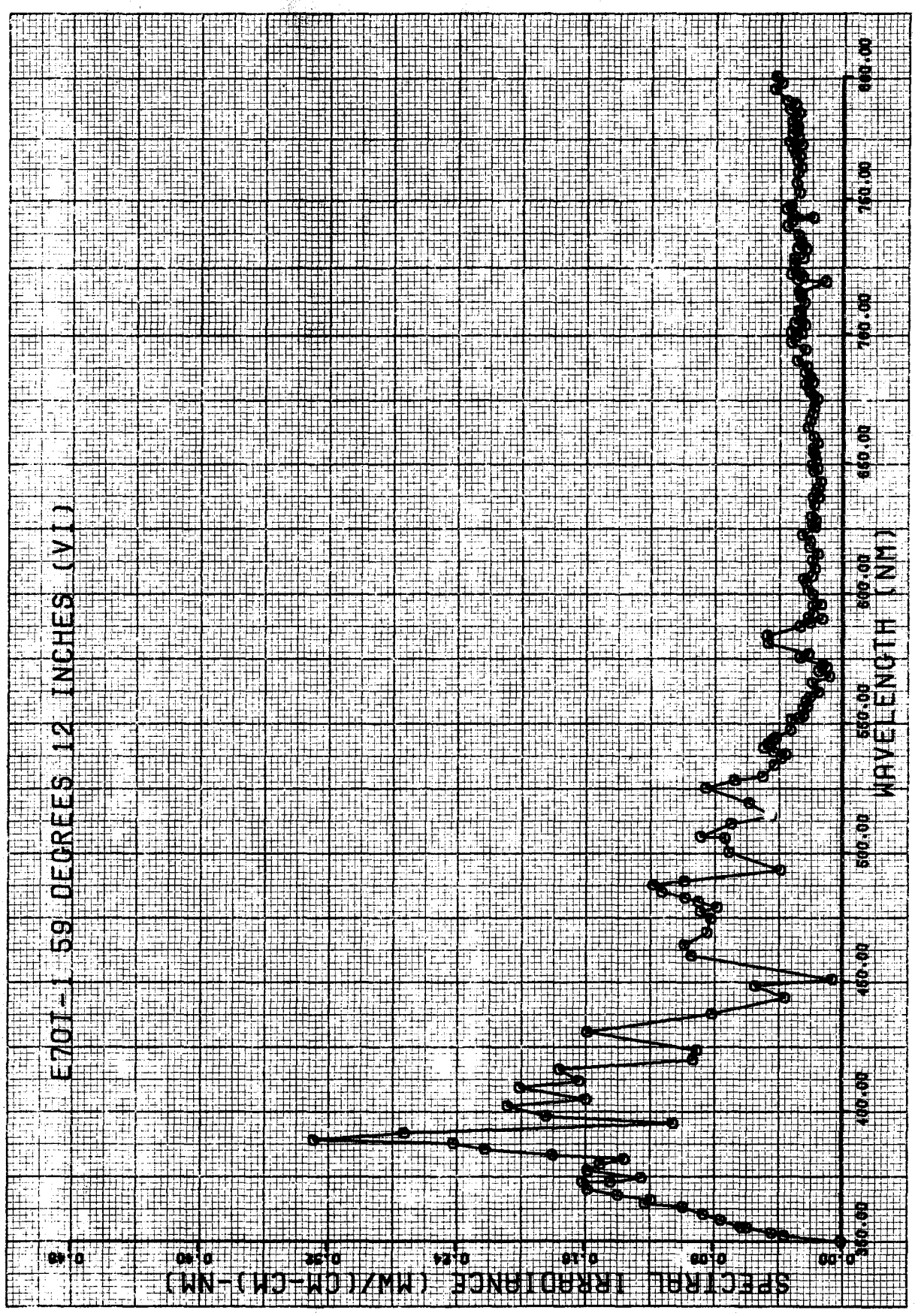
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
E7018 61 DEGREES 16 INCHES (IR)
800.00
880.00
960.00
1040.00
1120.00
1200.00
1280.00
1360.00
1440.00
1520.00
WAVELENGTH (NM)

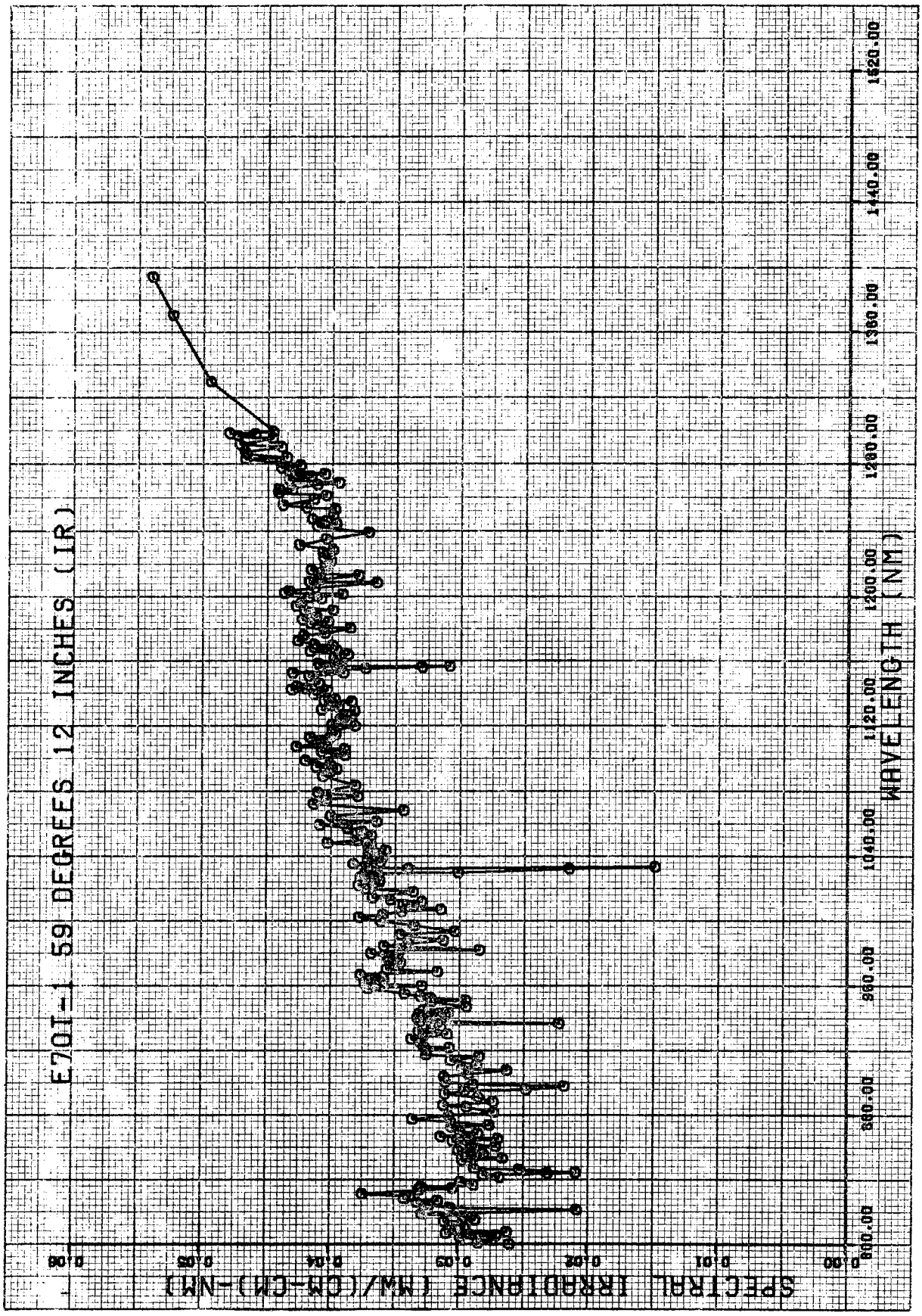

E7OS-4 59 DEGREES 12 INCHES (UV)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
480.00
0.00
0.40
0.80
1.20
1.60
2.00
2.40


E70S-4 59 DEGREES 12 INCHES (V.I.)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
0.08
0.16
0.24
0.32
0.40
0.48
360.00
400.00
450.00
500.00
550.00
600.00
650.00
700.00
750.00
800.00


E70S-4 59 DEGREES 12 INCHES (IR)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
800.00
960.00
1040.00
1120.00
1200.00
1280.00
1360.00
1440.00
1520.00
0.00
0.04
0.08
0.12
0.16
0.20
0.24


E70I-1 59 DEGREES 12 INCHES (UV)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
480.00
0.00
0.04
0.08
0.12
0.16
0.20
0.24


E70I-1 59 DEGREES 12 INCHES (V1)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
360.00
400.00
450.00
500.00
550.00
600.00
650.00
700.00
750.00
800.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48


E70T-1 59 DEGREES 12 INCHES (IR)
SPECTRAL IRRADIANCE (MW/(CM-CM)-NM)
WAVELENGTH (NM)
800.00
960.00
1040.00
1120.00
1200.00
1360.00
1440.00
1620.00
0.00
0.01
0.02
0.03
0.04
0.05