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LOW GLARE ILLUMINATION SYSTEM

Contract J0113006
Advanced Systems Division
Mine Safety Appliances

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16. Abstract (Limit: 200 words)

A low-glare illuminating system using fiber optics was developed for the Bureau of Mines. Fiber bundles transmit light from sources to luminaries. Light is from tungsten halogen lamps in 2 dichroic reflectors. Six lamps are housed together with a stepdown transformer in one enclosure. Three conceptual designs were made before development of the fiber optic concept. A fluorescent concept used two F8T5 lamps in a unique W shaped reflector. The reflector gave the appearance of eight lamps. An incandescent concept used a rectangular solid plastic luminaire molded with a reflector and diffuse surface. A lamp enclosure was mounted on its end. The early fiber optic concept was changed for the final development. As finally produced, the luminaire had a lower profile and a curved underside for painting as a reflector. Top surface was abraded for diffusion. The lamp enclosure at first was for a single lamp. This was changed to six lamps in one enclosure for simplified wiring. Plastic fiber optics bundles were expensive to manufacture and economical glass fiber bundles were obtained. Nonelectrical fiber bundles make the system one of minimum electrical damage vulnerability.

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Mining research

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Tungsten halogen lamps	Luminaire
Fluorescent lamps	Lamp enclosure

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Light transmission
Diffuse surface
Low profile

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2

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Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

2.0 FOREWORD

This report was prepared by MSA-Advanced Systems Division, Evans City, Pennsylvania, under USBM Contract No. J0113006. The contract was authorized pursuant to the provisions of P.L. 91-173 (83 Stat. 799) as amended by P.L. 95-164 (91 Stat. 1320) and funded pursuant to P.L. 96-514 dated December 12, 1980. It was administered under the technical direction of the Pittsburgh Research Center with Mr. W. H. Lewis acting as Technical Project Officer. Ms. Sylvia Brown was the Contract Administrator for the Bureau of Mines. This report is a summary of the work recently completed as part of this contract during the period April 3, 1981, to October 21, 1983. This report was submitted by the author on March 23, 1984.

To the best of the contractor's knowledge and belief, no patentable features were developed during the course of this work. Therefore, no Subject Inventions have resulted from performance under this contract.

During the course of the program relationships with several other companies were a great amount of help. The following notation is meant to thank the companies for the much appreciated assistance.

Cuda Products Corporation	- Fiber Optics
Elk River Sewell Coal Company	- Cooperating Mine
Fairchild, Incorporated	- Mining Machinery
General Electric Company	- Lamp Technology
General Energy Development Corporation	- Design Work
Illuminating Engineering Society	- Psychophysical Aspects
Jeffrey Mining Machinery Division	- Mining Machinery

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued

LIST OF TABLES

3.0 EXECUTIVE SUMMARY

A low glare illuminating system using fiber optics was developed for the Pittsburgh Research Center. Fiber optic bundles transmit light from six lamps to low glare luminaires. The lamps are small Tungsten Halogen projector type lamps. Together with a voltage stepdown transformer, they are contained in one machine mounted enclosure. The diffuse plastic luminaires are located up to 20 ft. from the lamp enclosure. A fiber optic bundle of suitable length is then run from each luminaire to the housing.

Before full development of the fiber optic system was designated by the Bureau, conceptual designs were made for three types of lighting systems. A fluorescent concept used two F8T5 lamps in a unique W shaped reflector. The reflector gave the appearance of eight lamps with a uniform distribution of light. The housing would be injection molded and the lamps would be contained in polycarbonate explosion-proof tubes. It was the most expensive of the three concepts. However, it was a long life system and easily adapted to longwall and other uses.

An incandescent concept used a rectangular solid plastic luminaire. The luminaire was molded with a reflector and a diffuse surface. A small Tungsten Halogen projector type lamp in an explosion-proof enclosure was mounted on the end of the luminaire. The concept had a very uniformly lighted luminaire surface and the lowest estimated cost. Separate wiring to each fixture and many cable entrances were its chief disadvantages.

The fiber optic concept had several changes before the final development was complete. The luminaire at first was a solid molding similar to the incandescent model. As finally produced however, it had a low profile and a curved underside with paint as a reflector. Its top surface was abraded for diffusion. The lamp enclosure at first was for a single lamp. This was changed to six lamps in one enclosure for simplified wiring. Fiber optic bundles at first were going to be plastic material, but they were too expensive to manufacture. Economical glass fiber bundles were obtained instead. The non-electrical fiber bundles make the system one with minimum electrical damage vulnerability.

State-of-the-art procedures were used throughout the development. The glass fibers used are made to give the least possible light attenuation. However, bundles with more than the specified 1% broken fibers possibly contribute to a low output. Additional work will be required to meet the program's footcandle goals.

4.0 INTRODUCTION

The purpose of this report is to describe in detail all work accomplished under Contract J0113006. The report summarizes the results of the work and includes reasons and trade-offs used to select and design equipment assembled into the fiber optic Low Glare Illumination System. Key work steps were as follows:

- Review present regulations, mining conditions, and attempts to minimize glare.
- Conceptually design three alternate feasible illumination systems.
- Report the conceptual work so that one system could be designated by the Bureau of Mines for complete development.
- Develop and construct a prototype and four final systems with all devices required for machine operation.

The Low Glare Illumination System uses optical fibers to transmit light from six sources to six luminaires. Luminaires are molded plastic. Light is furnished by small Tungsten Halogen lamps in 2" dichroic reflectors. Six lamps are housed together with a stepdown transformer in one enclosure. From the machine mounted enclosure to luminaires placed for maximum lighting of the work place, light is transmitted with the shortest fiber bundle possible. A laboratory view of the prototype system is shown in Figure 4-1. Design concepts are detailed in the sections that follow.

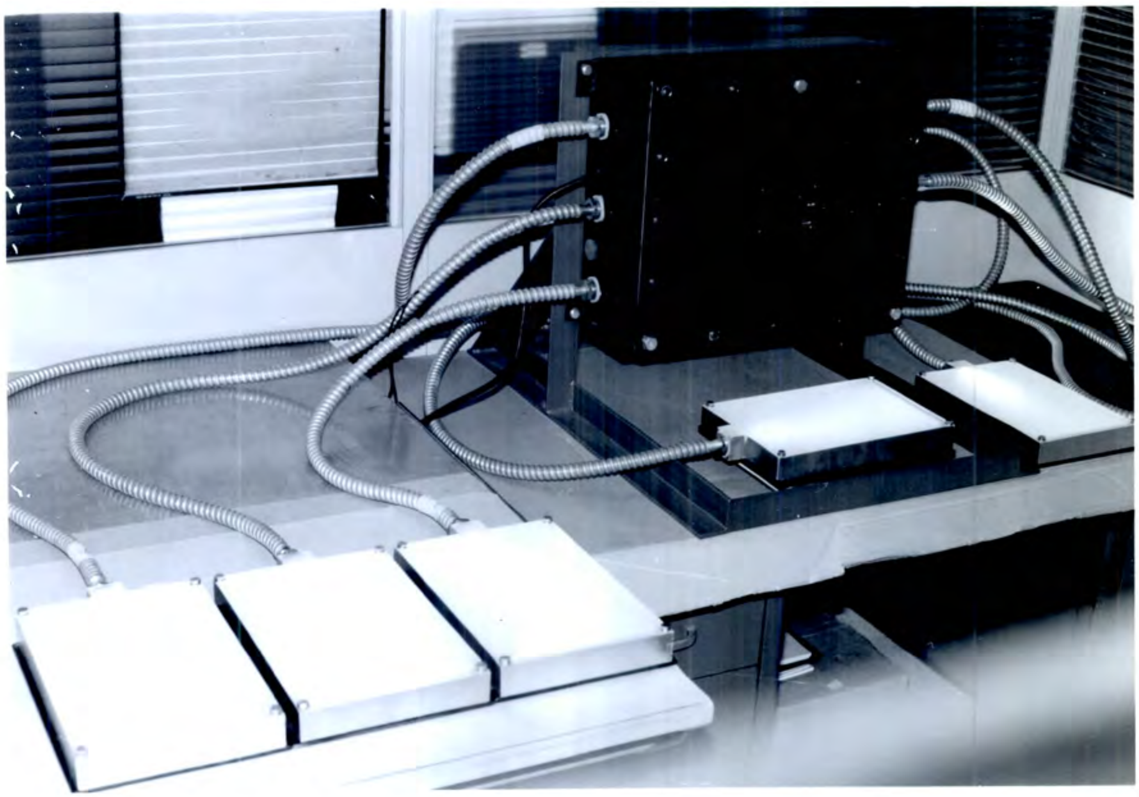


FIGURE 4-1 FIBER OPTIC LOW GLARE LIGHTING SYSTEM PROTOTYPE

5.0 BACKGROUND

Lighting has generally found acceptance in higher seam coal. In lower seam coal there still exists a need for improved lighting systems that minimize disability and discomfort glare. The beginning tasks for this program investigated the unique constraining factors that would be involved to provide such a system. Low coal mining, typical mining machines, present lighting applications, and glare were investigated. The results are described in these sections.

5.1 Low Coal Mining

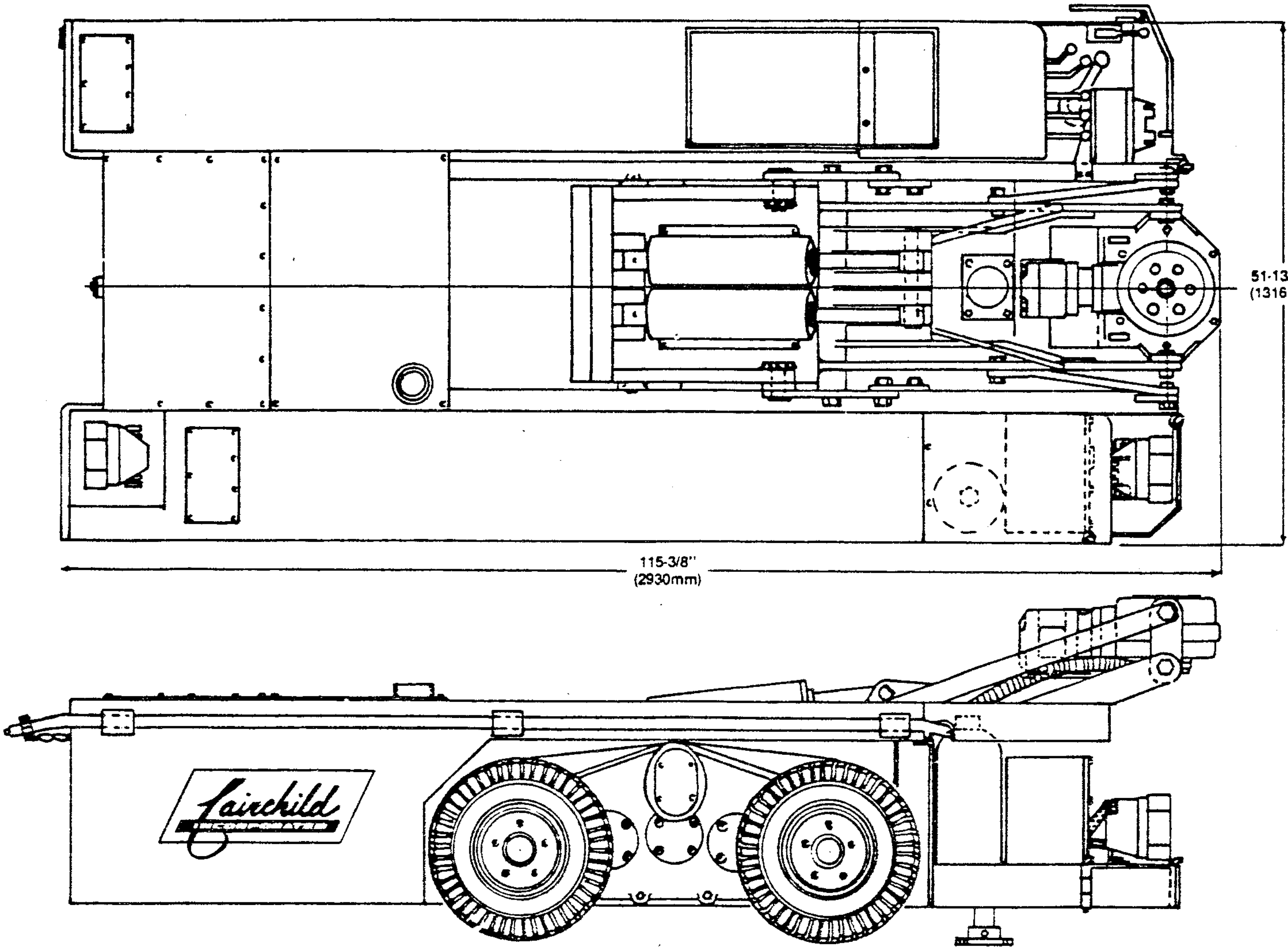
Complete cooperation from Elk River Sewell Coal Company allowed close examination of the mining process. Their 40" coal seam is being mined with lighted continuous mining equipment and their personnel indicate the glare problem is being tolerated. The reason for the toleration is that the positive effects of the light are a vast improvement over previous conditions using only cap lamps. However, Mr. Post, president of the company, stressed his intention to improve the lighting to enhance safety conditions as well as production.

The face was reached by crawling about 100 yards. In the face area 10 men worked very close to each other, to the moving parts of the mining machine and to the light fixtures. The machine rubbed against the ribs several times. Manual work included cutting and setting temporary posts and shoveling loose coal for the scoop. All work was done from a kneeling or sitting position. The miners seemed enthusiastic about their work even though the machine luminaires were never out of their direct line of vision.

The installed machine lighting in addition to headlamps was incandescent lamp luminaires. Nylon tape reduced the point source glare from some viewing angles. However, it was not a comfortable situation. Especially noticeable was the high apparent intensity of the illumination and reflectances due to the close spacial confinement.

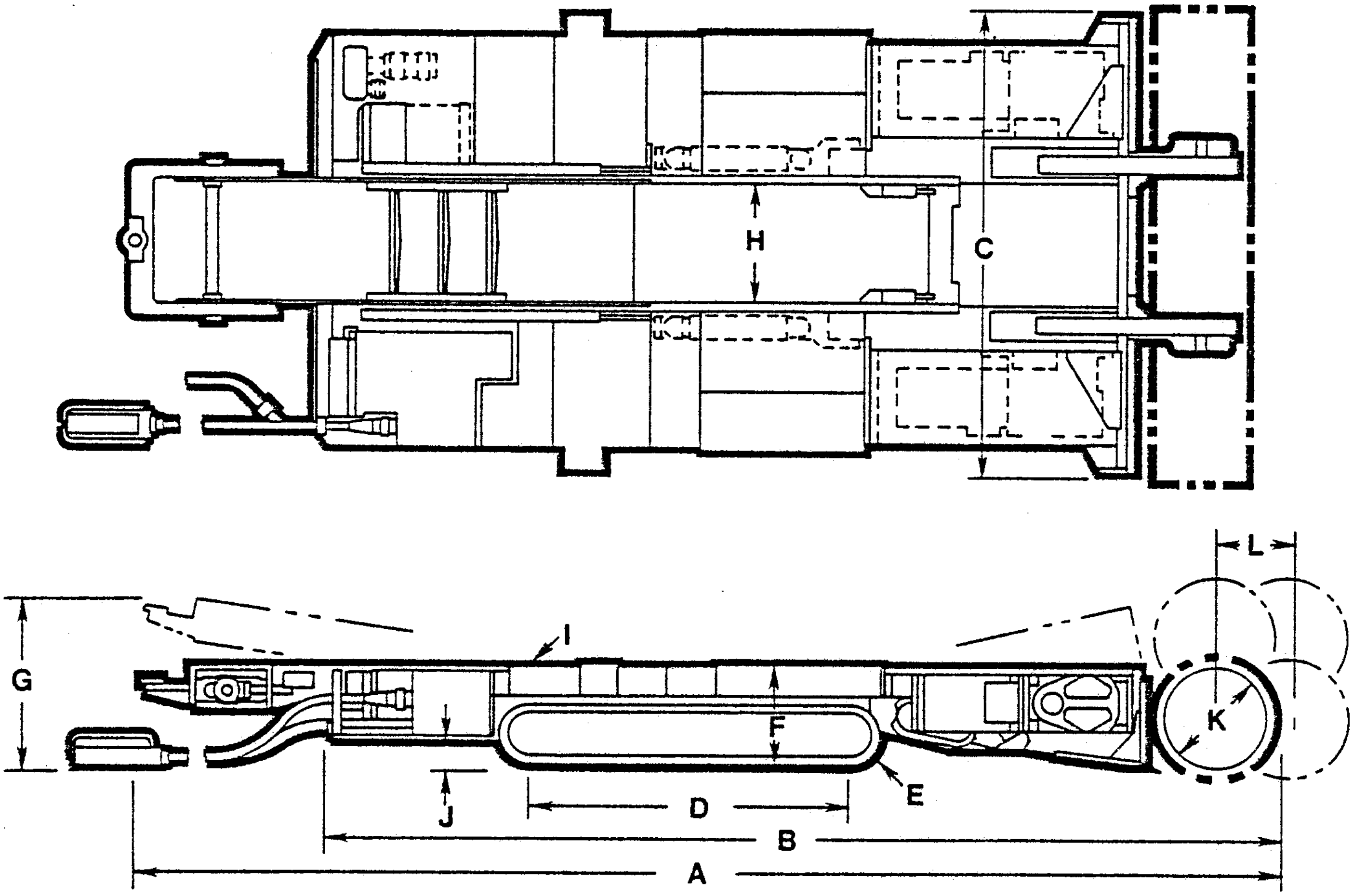
5.2 Mining Machinery

The equipment selected for study and application is the WRD Roof Bolter and the 101MC Continuous Miner. This typical machinery is used by the cooperating coal company and present the problems generally applicable to all manufacturers. Figure 5-1 shows dimensions and views of the roof bolter. Figure 5-2 similarly presents the continuous miner.



DESCRIPTION	DIMENSION
1. Tram Height	24"
2. Ground Clearance	4"
3. Length	115-3/8"
4. Width	51-13/16"
5. Drill Head Thickness	8"
6. Maximum Lift Height	44"

FIGURE 5-1 MODEL J-4 WILCOX WRD ROOF BOLTER



DESCRIPTION		DIMENSION
Length		
Overall	A	23' 5"
Bumper to face	B	19' 5"
Width		
Chassis	C	9' 6"
Crawler CL to CL (sprockets)	D	6' 8"
Crawler pad	E	12"
Height		
Basic	F	24"
Over rear conveyor	G	3' 4-3/8"
Conveyor		
Width	H	30"
Depth	I	4-1/2"
Ground clearance	J	5-3/4"
Cutter diameter	K	26" or 30"

FIGURE 5-2 JEFFREY 101MC HELIMATIC CONTINUOUS MINER

Visits were made to the manufacturers of the above equipment. Discussion with manufacturer's lighting engineers brought similar information. The companies have obtained STE's and the machines are often furnished with factory installed lighting. A common problem is frequently having fixtures rubbing on the ribs. Protected places on the machines for lighting installation does not exist. There is no room for additional switches or power supplies in the electrical boxes installed on either machine. Little work has been done to design built-in lighting because the machines are too compact and the lighting equipment is too large. Both companies are very interested in this project and agreed to help in any way they can.

5.3 Present Low Glare Low Coal Lighting

Shields and diffusing materials on luminaires are used to minimize glare. Attempts are made to position shields to take into account different viewing positions of personnel around the machine. Lamp manufacturers provide different diffusers to combat the glare problem. Table 5-1 lists major manufacturers' data describing their diffusing system. However, retrofitting light fixtures and completely protecting workers from the effects of disability and discomfort glare has not been generally successful.

Government regulations have been reduced in several areas to combat the glare problem. Where mine height is less than 42" the areas where light is measured is reduced to 5' from the machine. Lighting is not required at all near operators of remote control mining machines or roof bolters. Lighting is not required in work places where rope-propelled auger-type continuous mining or bottom cutting machines are operated if workers are inby the operator. In these areas even a small amount of glare can be hazardous when cap lamps are used for communication.

5.4 Glare

Problems in low coal mining come from both disability glare and discomfort glare. The differences in these phenomena are described in the following paragraphs. The information is taken from a report by Mr. Cash Crouch and the Illumination Engineering Research Institute entitled, "Psychophysical Aspects of Three Alternate Conceptual Designs for Illumination Systems to Apply to Different Low Coal Mining Machines."

- Disability Glare

  Disability glare results in a decrease in visibility of the details to be seen. It is caused by scatter of rays of light from bright light sources as they enter the eye from the periphery of the field of view. This scatter is caused by particles in the cornea (the bulge in the front of the eye), the lens, and the vitreous humor (the jelly-like substance filling the eyeball). The result is a dispersion of

TABLE 5-1

GLARE SUPPRESSION

FIXTURE	DIFFUSER
Bacharach	
VHO Fluorescent	Max - One layer of 0.005-inch thick polycarbonate and one layer of 0.006-inch thick mylar.
Crouse-Hinds	
Sodium & Mercury 100W Globe	Min - Globe is painted yellow inside utilizing a frosted bulb inside.
	Max - Globe is painted yellow inside with three bands (6 inches wide) of two-layer gray tape (3M Polyimide Film No. 5413) placed on the globe.
150W Sodium & 100W Mercury Globe	Min - Globe is painted white with a frosted lamp.
	Max - Globe is painted white with one band (5-inch wide strip) of two layers of yellow tape (3M Polyimide Film No. 5413) with a 150W HPS coated lamp.
VHO Fluorescent	Min - Sand-blasted polycarbonate tube.
	Max - Sand-blasted polycarbonate tube with a one-inch wide yellow paint stripe.
VHO Fluorescent	Max - Sand-blasted polycarbonate tube with a strip of two-inch wide gray tape (3.5 mil. thick 3M No. 5490).
Joy	
VHO Fluorescent	Min - Coarse-grained polycarbonate (both sides) running the full length inside the luminaire lens with a 1.5-inch overlay.
	Max - Coarse-grained polycarbonate (both sides) running the full length inside the luminaire lens with a 1.5-inch overlay plus a 5/8-inch strip of tinted polycarbonate running the full length of the tube. Tinted strip to be adjusted for viewing comfort.
McJunkin	
#400 Tri-Plane 150W Sodium	Min - One layer of TFE teflon tape plus one layer of Kapton tape.
	Max - Two layers of TFE teflon tape plus one layer of Kapton tape and additional back and side shielding when in operator's line of sight.
VHO Fluorescent	Min - One layer of the polycarbonate film material installed with the frosted side facing out.
	Max - One layer of the polycarbonate film material plus the rotation of the reflector such that the reflector is between the center of the lamp and the operator's normal line of sight.
	Max - One layer of film material plus 1/2-inch keybar steel added to the cage of the luminaire such that the keybar steel is between the center of the lamp and the operator's normal line of sight.
#400 Tri-Plane 150W Incandescent	Min - With or without one layer of .002-inch thick Kapton tape.
#400 Tri-Plane 175W Mercury	Min - One layer of TFE teflon tape.
	Max - Two layers of TFE teflon tape.
MSA	
VHO Fluorescent	Min - One layer of external snap-on nylon material.
	Max - Two layers of external snap-on nylon material.
NMS	
VHO Fluorescent	Min - Coarse-grained polycarbonate (both sides) running the full length inside the luminaire lens with a 1.5-inch overlay.
	Max - Corase-grained polycarbonate (both sides) running the full length inside the luminaire lens with a 1.5-inch overlay plus a 5/8-inch strip of tinted polycarbonate running the full length of the tube. Overlay can be adjusted for operator's maximum comfort.
Sodium Globe	Min - Pigmented and frosted-coated polycarbonate globe with side "half-moon" shield and back shield when placed in the operator's viewing field.
Ocenco	
15/3 Fluorescent 30 Fluorescent	Max - One layer of 0.004- to 0.015-inch thick mylar diffuser (frosted on both sides) with a minimum of 3/4-inch overlay of mylar placed along the longitudinal axis of the fixture.

light such as occurs in a fog which causes a veiling brightness to overlay the image of the object in the back of the eye where the seeing is being done. The amount of loss of visibility may be large if there is a lot of peripheral brightness from lighting units.

- Discomfort Glare

  If one looks up from his work and momentarily encounters a bright light source there is a feeling of discomfort which has been called discomfort glare. It has been found that discomfort glare has little relationship to disability glare. It is believed that the feeling of discomfort comes physiologically from the sphincter muscle closing down the pupillary opening. Discomfort glare has been studied since 1919. As a result, limitations have been made of the luminance of luminaires in office, schools, industry, etc.

5.5 Design Constraints

The preceding sections can be summarized by the following apparent design constraints.

- Most mine machine lighting is a retrofit application and easy installation is important. Familiar cable entry procedures should be used.

- The system should be as low in cost as practical, however it does not have to be lowest in cost to be user acceptable.

- In design, choice of materials, electrical connections, and locations of components, personnel safety is a first priority consideration.

- Environment will have a maximum of humidity, corrosion, dust, shock and vibration.

- High reliability and easy maintenance are required. Replaceable parts must be easy to change.

6.0 THREE CONCEPTUAL DESIGNS

Information on the conceptual designs has been divided for this report as follows:

- A description of the design
- Projected Manufacturing costs
- Relative merits and problems

Similar information was delivered earlier to the Bureau along with a separately printed opinion on further development. The opinion, submitted as "Addendum to the Phase I Report" is included in the Appendix. The information and opinion were important factors in the Bureau's decision designating the fiber optics system for complete development

6.1 Fiber Optics Conceptual Design

This concept used low cost fiber optic bundles to transmit light to plastic luminaires. One Tungsten Halogen lamp would provide light for each luminaire and each lamp would be housed in a single lamp enclosure.

6.1.1 Luminaire

The luminaire for this concept is shown in Figure 6-1. It was solidly molded from plastic. Included in the molding was a reflector and a diffuse outside surface. Threads molded with the unit furnished mounting for the optical fibers. Four mounting bolts were provided. The luminaire would be 2" high and weigh approximately nine pounds.

6.1.2 Luminance and Illumination

Figure 6-2 is a mock-up used to determine experimentally the luminance and illumination characteristics that were expected with the luminaire. A 15 ft. long fiber bundle and a 150 watt lamp were used. Average photometric brightness of the lighted surface was approximately 200 footlamberts. Table 6-1 and Figure 6-3 show data and isointensity diagrams for footcandle measurements in a simulated coal mine. The fiber supplier reported lower light loss material could be available and results calculated for it are shown in Figure 6-3.

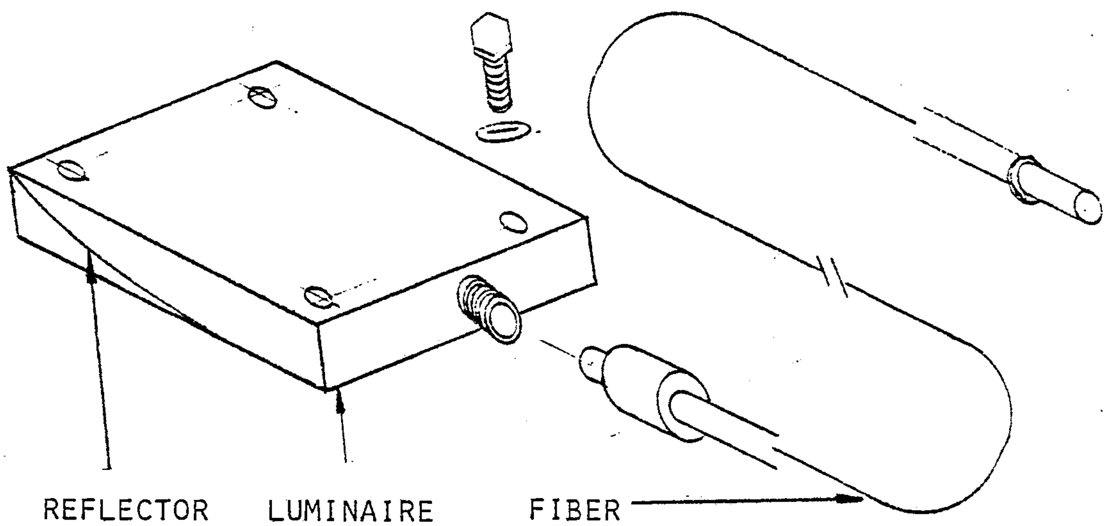


FIGURE 6-1 LUMINAIRE WITH FIBER OPTICS BUNDLE

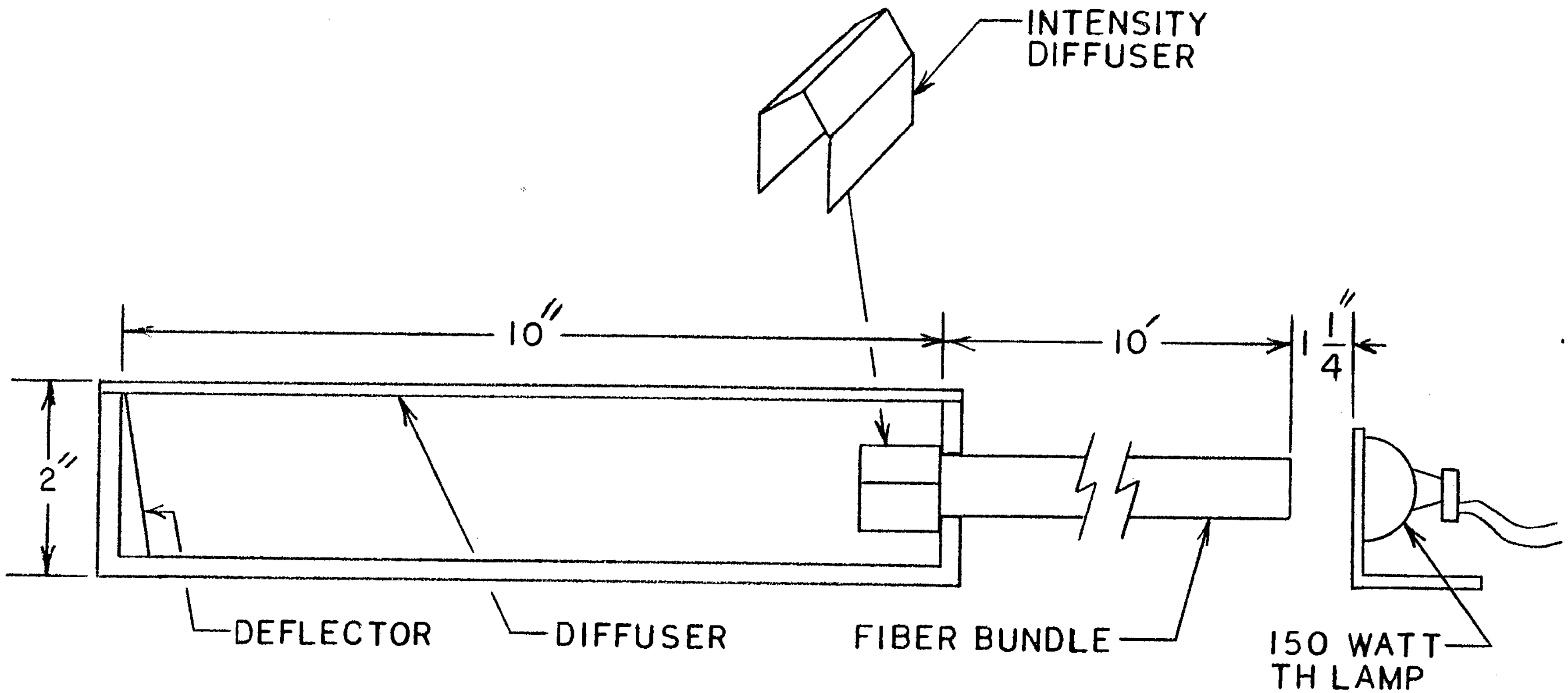


FIGURE 6-2 FIBER OPTICS MOCKUP

TABLE 6-1 FIBER OPTIC CONCEPT FOOTCANDLE MEASUREMENTS

FACE

12' (width) × 4' (height)

0.4	0.6	0.8	0.9	0.8	0.6	0.4
0.5	0.7	1.0	1.1	1.0	0.7	0.5
0.4	0.6	0.8	0.9	0.8	0.6	0.4
6'	4'	2'	0'	2'	4'	6'

FLOOR

6' (depth)

0.4	0.6	0.8	0.9	0.8	0.6	0.4
0.5	0.8	1.4	1.9	1.4	0.8	0.5
0.2	0.5	1.5	3.0	1.5	0.5	0.2
6'	4'	2'	0'	2'	4'	6'

SOURCE

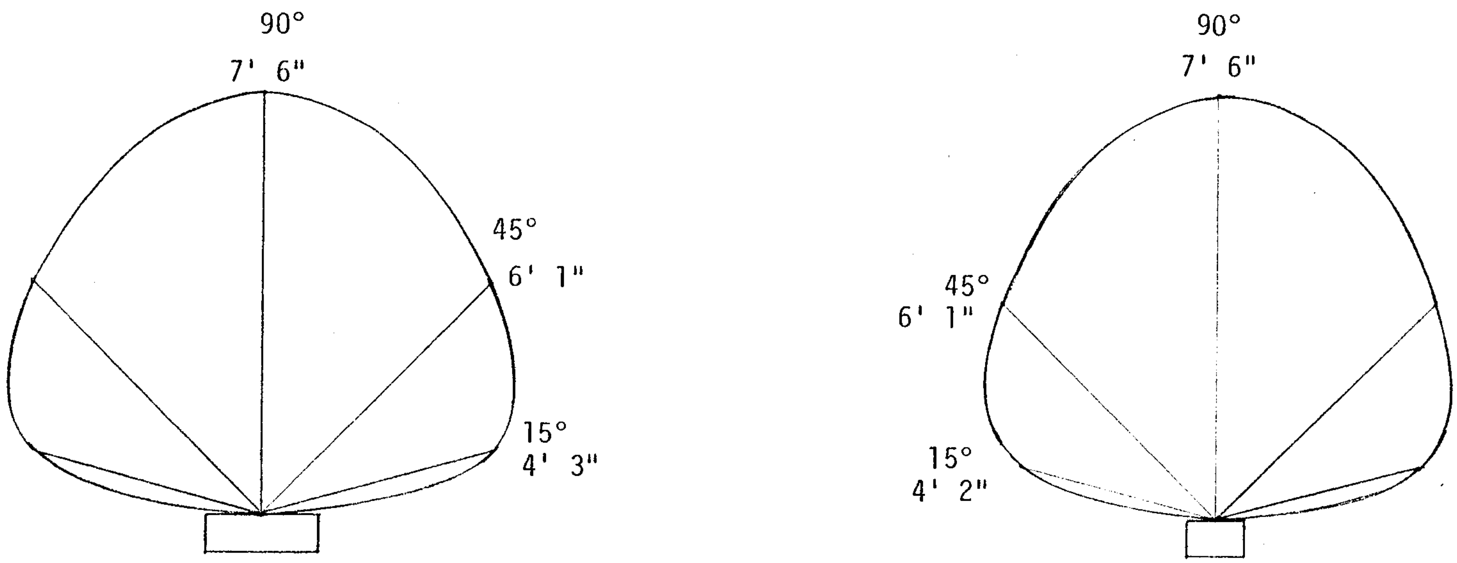
ROOF

6' (depth)

0.4	0.6	0.8	0.9	0.8	0.6	0.4
0.5	0.8	1.4	1.9	1.4	0.8	0.5
0.2	0.5	1.5	3.0	1.5	0.5	0.2
6'	4'	2'	0'	2'	4'	6'

SOURCE

VALUES CALCULATED FOR LOW LOSS FIBERS
FROM MEASUREMENTS MADE WITH HIGH LOSS FIBERS



LUMINAIRE LONG AXIS PARALLEL TO FLOOR

LUMINAIRE SHORT AXIS PARALLEL TO FLOOR

FIGURE 6-3 FIBER OPTIC ISOINTENSITY DIAGRAM FOR 2 FOOTCANDLES

6.1.3 Light Source

Tungsten Halogen projector type lamps were investigated as the light source for the fiber optics system. It was determined that they are usually easy to obtain for replacement, are rugged, and have good lumen to watt characteristics. The lamps have dichroic coated glass reflectors which allow much of the heat to pass through for dissipation at the rear.

For mock-up testing a 150 watt, 20 v lamp was used. It was operated at 17 v to extend the life and minimize heat. Power was about 120 watts and the output was calculated to be 2400 lumens. This would provide 15 percent more light than needed, if the transmission of the fiber optic cables was nominally 40-45 percent. A further reduction in operating voltage would be made later if needed.

6.1.4 Lamp Enclosure

Mining standards require this type of lamp to be in an explosion-proof enclosure. Small enclosures for one lamp as well as large enclosures for several lamps were investigated. Designs for each type are shown in Figure 6-4 and Figure 6-5. Emphasis was placed on heat transfer and determining that components would be within manufacturer's temperature specification. The tests of Table 6-2 concluded that both single-lamp and multiple-lamp designs would be feasible. Spaces for the small single-lamp type were more readily available and more easily protected. Therefore, an enclosure similar to Figure 6-4 was recommended for further development. It will be noted from Section 7 that this design was later changed to a large enclosure for six lamps for more practical electrical wiring.

6.1.5 Fiber Optics

Information from 14 major manufacturers of fiber optics was obtained to search out availability and properties of the material. Two companies offered plastic material. Twelve companies manufactured glass fiber optic bundles. Differing transmittance values were reported ranging between 20% and 49% of the source light to be transmitted. Costs for a 10 ft. bundle varied between $135 and $1200. Plastic fiber optic bundles would cost $222 and transmit approximately 35% of the light. Economical plastic fiber was also available in bulk quantities from DuPont and one foot and ten foot bundles were laboratory manufactured. From these samples, estimates were made for manufacturing suitable bundles for approximately $35. Based on this information it was planned

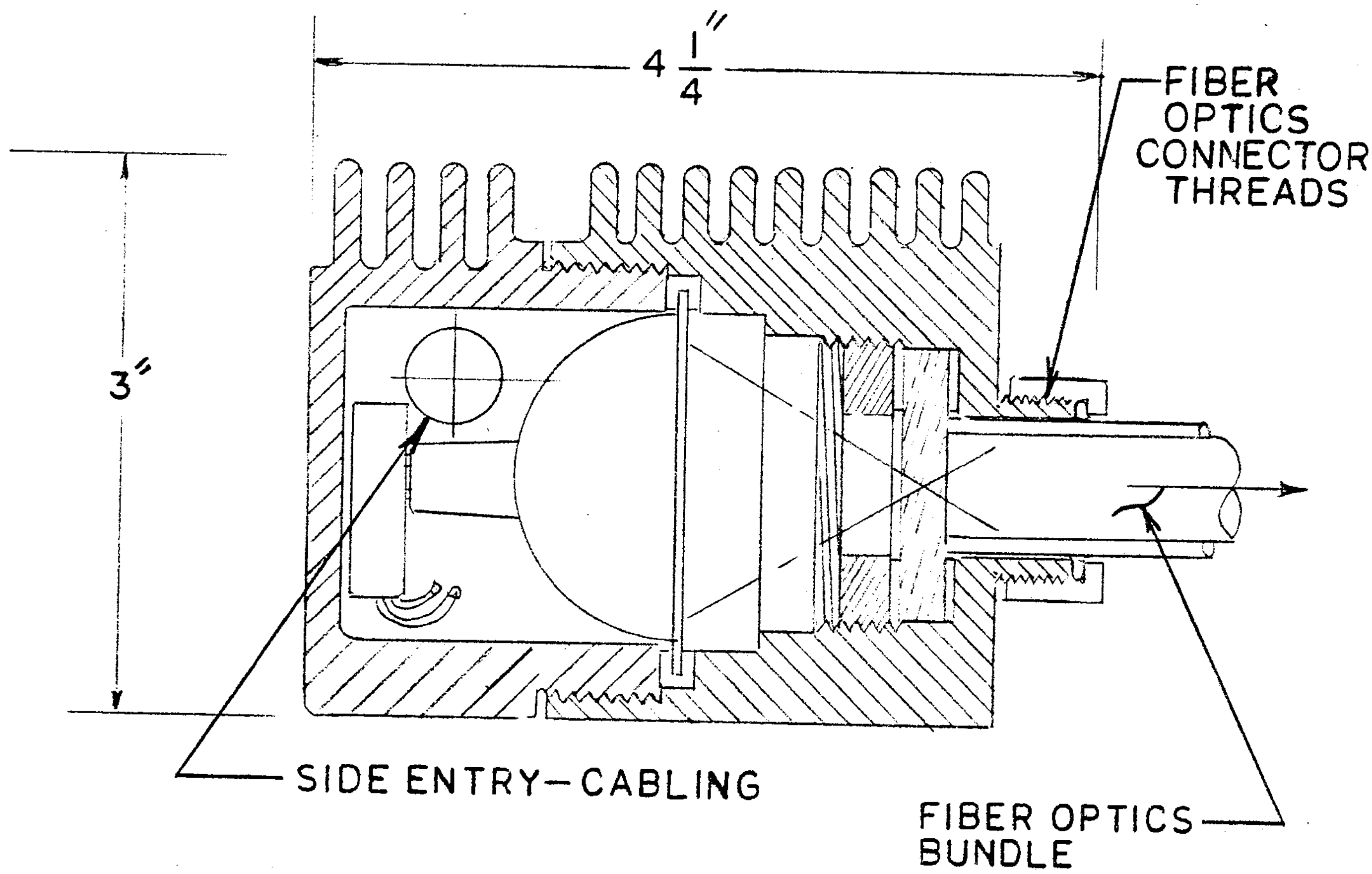


FIGURE 6-4 FIBER OPTIC LAMP ENCLOSURE

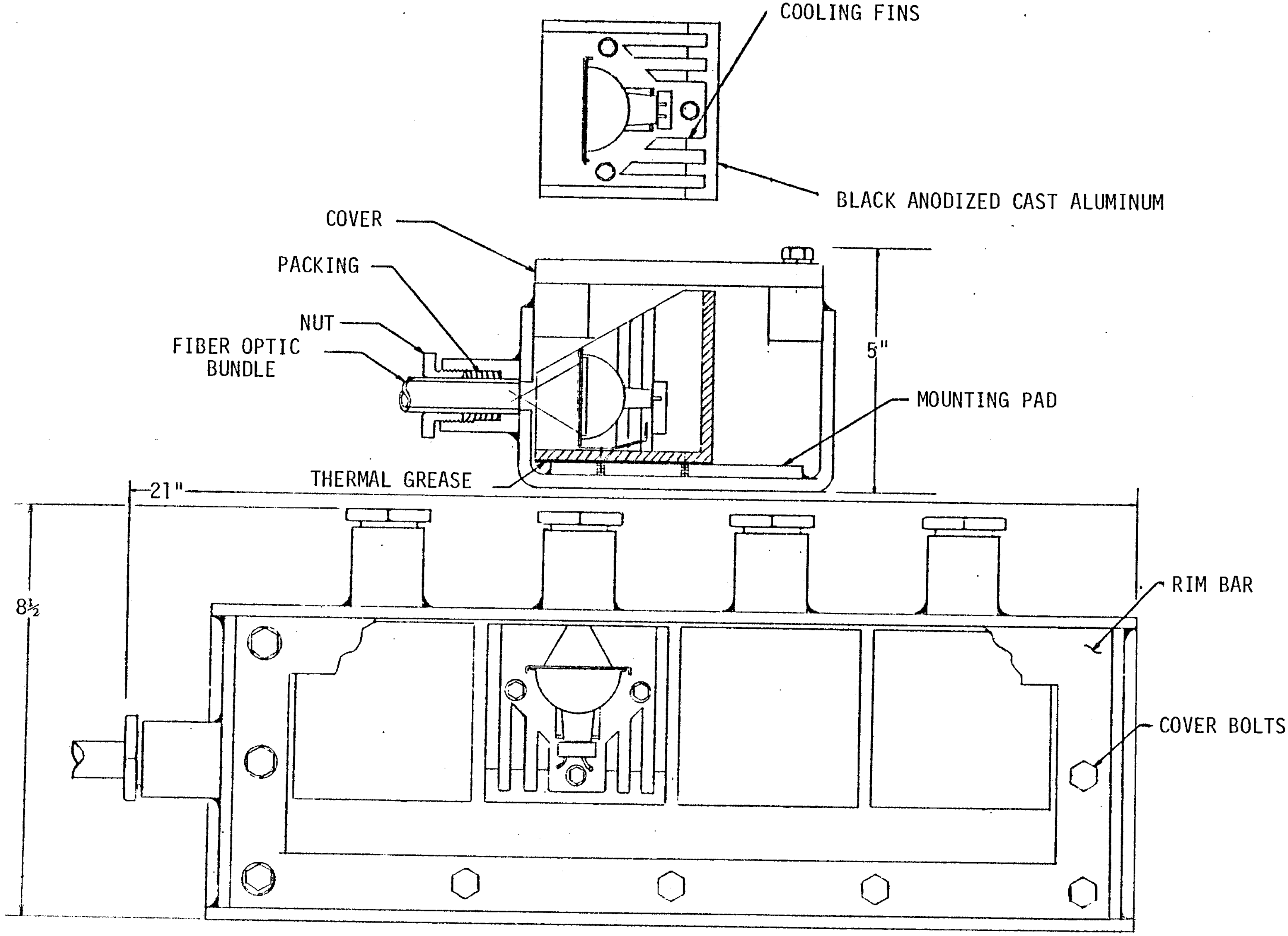


FIGURE 6-5 ENCLOSURE FOR FOUR LAMPS

TABLE 6-2 TEMPERATURE READINGS - FIBER OPTICS INVESTIGATION - LAMP SOCKETS & ENCLOSURE SURFACE

TEST	RESULTS	CONCLUSIONS
Closed Aluminun Housing Simulating a single-lamp type enclosure Lamp - 60 watts Room Temperature - 80°F	Equilibrium after 45 minutes Socket - 303°F Surface - 210°F	Limiting temperature for socket - 426°F and surface - 302°F would not be exceeded if a single-lamp type enclosure were used with a 60 watt lamp.
Closed Aluminum housing Simulating a single-lamp type enclosure Lamp - 120 watts Room Temperature - 75°F	Equilibrium after 70 minutes Socket - 460°F Surface - 230°F	Limiting temperature for socket - 426°F would be exceeded if a single-lamp type enclosure were used with a 120 watt lamp.
Closed Steel Explosion-proof Enclosure 6" x 8" x 10" to simulate a multiple-lamp type enclosure 2 Lamps - 120 watts each Room Temperature - 75°F	Equilibrium after 125 minutes Socket - 230°F Surface - 180°F These results were projected as equal to 6 lamps in a housing with 3 times the volume.	Limiting temperatures for sockets and surface would not be exceeded if six 120 watt lamps were enclosed in a housing 6 x 16 x 19.

to use bundles made with DuPont's plastic Crofon. The maximum operating temperature of the material is rated at 175°F and heat absorbing glass filters and cold mirrors were planned to take care of this limitation. It was reported newer material would have 40 - 45% transmission of light.

6.2 Fluorescent Conceptual Design

Figure 6-6 is an assembly drawing of the concept with all parts identified. Overall dimensions are approximately 3-½ x 9-½ x 17 and weight, 7 pounds. The concept is made almost entirely of plastic and requires a high level of injection molding tooling. Light is furnished by 2 standard F8T5 CW lamps.

6.2.1 Explosion-proof Enclosure

Mining standards require fluorescent lamp enclosures to be explosion-proof. Polycarbonate injection molded into a cylinder with end threads is recommended for the following reasons:

- Requires minimum volume and a wall thickness as small as 1/8" can be used for minimum cost.
- Polycarbonate has high strength in tension and compression.
- Threaded seals have minimal cost and are accepted by MSHA and mining personnel.

Feed-through bushings are sealed in one end for the inverter module. A threaded section for a hex cap is on the other. The cap is locked by a tab on the lamp housing as shown on the end view of Figure 6-6. A track on the top of the explosion-proof enclosure locates the assembly by sliding in a groove in the lamp housing.

6.2.2 Lamp Housing

The lamp housing is injection molded from diffuse plexiglass. Slide tracks shown on the end view of Figure 6-6 mount the reflectors to form a W shape. One or more of the reflectors can be removed if a modified light pattern is desired out the side of the unit.

6.2.3 Entry Housing

This contains the cable entry holes and cable strain relief and provides a junction point for series wiring. Toggle clamps fasten it to the lamp housing and an O-ring between the two secitons is for dust sealing. Electrical connectors contact the feed-through bushings of the explosion-proof enclosure.

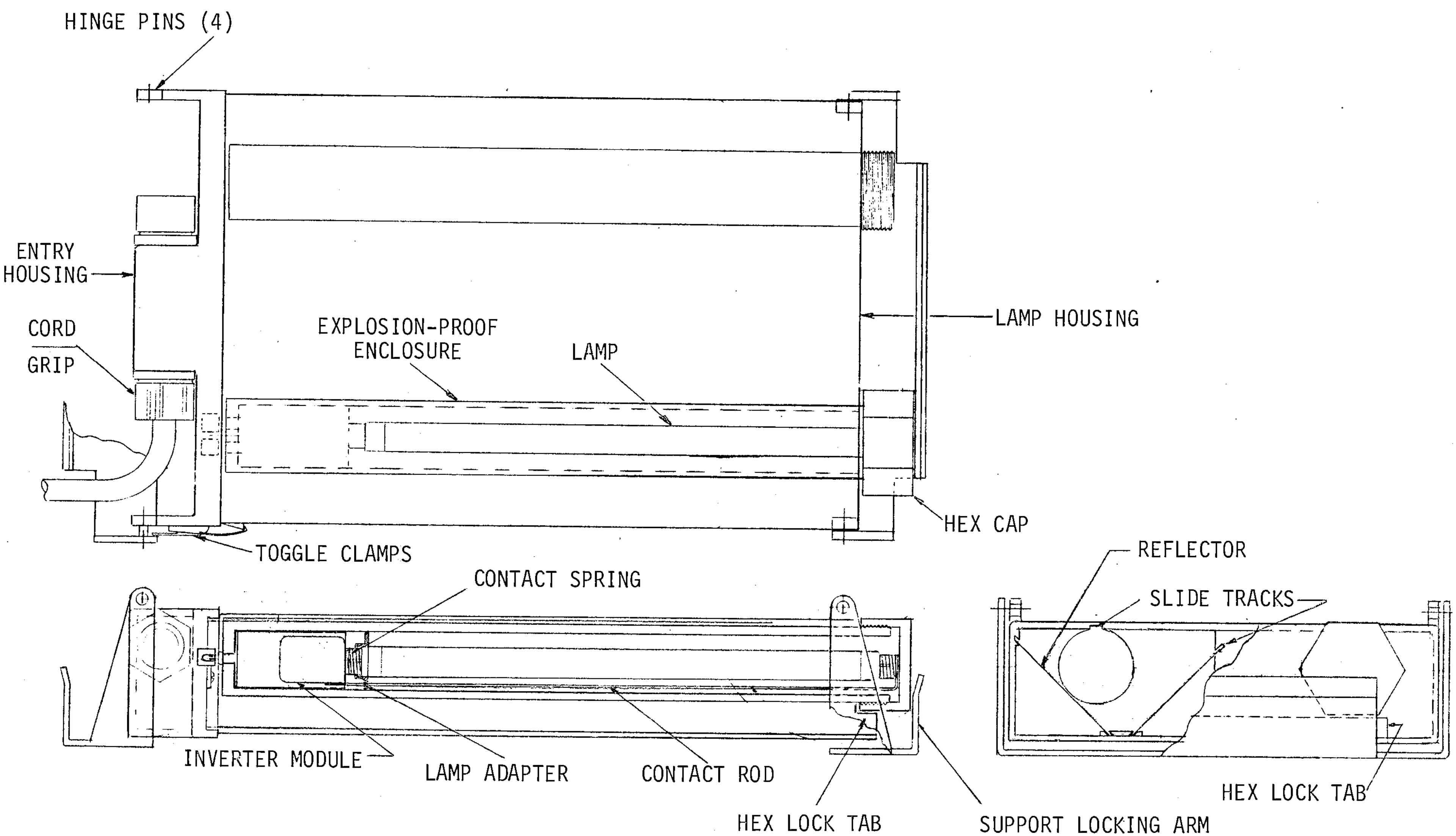


FIGURE 6-6 FLUORESCENT CONCEPT

6.2.4 Support/Locking Arms

The support/locking arms are the only parts of the concept made from sheet steel. With removable pins they act both as hinge points and as a lock in place for the explosion-proof enclosures in the lamp housing.

6.2.5 Accessibility

Access is through either end of the assembly. After removing pins from either end, the unit is lifted up (or out from the side of a machine) while still hinged on the opposite arm. This enables access to the lamps on one end, or to the wiring on the other end without removing the unit.

6.2.6 Inverter Module/Contact Rod

The inverter module and contact rod assembly are shown on the side view of Figure 6-6. Located inside the explosion-proof enclosure, the inverter is molded cylindrically and has two pins for contacting the feed-through bushings. On the other end are a contact button in the center and a female threaded contact near the edge. The contact rod is screwed into the threaded contact near the edge. The rod serves to insert and extract the module and furnishes a contact to the far end of the lamp.

6.2.7 Lamp Adapter/Contact Spring

The lamp adapter and contact spring are also shown on the side view of Figure 6-6. This assembly is located at each end of the lamps and connects the fluorescent lamp to the inverter as a spring loaded device.

6.2.8 Reflector

The reflector consists of four mirrors positioned at 90° to each other in slide tracks as shown on the end view of Figure 6-6. Light reflected from two fluorescent lamps has the appearance of eight lamps, uniformly spaced. To get approximately the same luminance from the eight, the direct forward output of the main lamps is attenuated by the guide pieces on the explosion-proof enclosures.

6.2.9 Illumination Tests

A model of the lamps and reflector was mocked up and diffusing covers were added to get the lighted surface approximately to 800 footlamberts. Footcandle measurements made in a simulated mine are given in Table 6-3 and isointensity curves are given in Figure 6-7. It was apparent that

TABLE 6-3 FLUORESCENT CONCEPT FOOTCANDLE MEASUREMENTS

FACE

14'

0.5	0.9	1.3	1.8	1.8	1.3	0.9	0.5	
0.5	1.0	1.5	2.2	2.2	1.5	1.0	0.5	4'
0.5	0.9	1.3	1.8	1.8	1.3	0.9	0.5	
7'	5'	3'	1'	1'	3'	5'	7'	

FLOOR

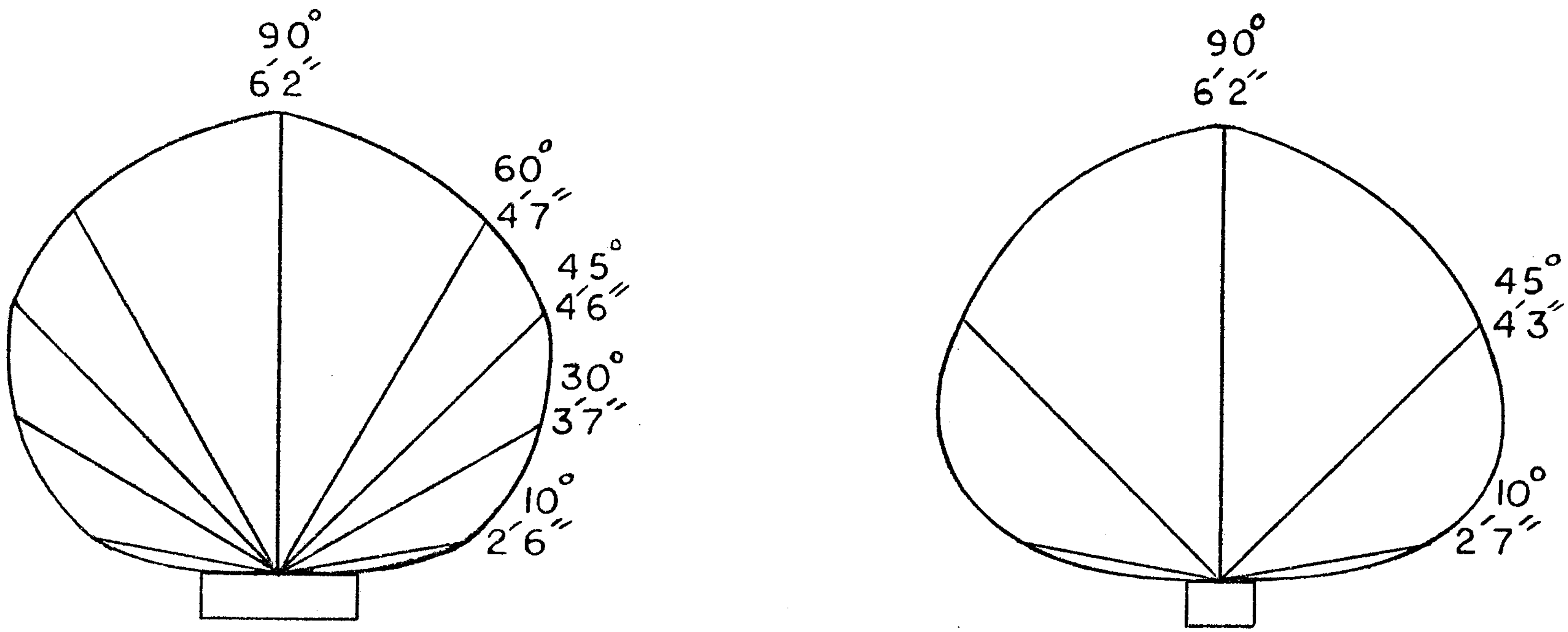
0.5	0.9	1.3	1.8	1.8	1.3	0.9	0.5	
0.5	0.9	2.2	4.0	4.0	2.2	0.9	0.5	6'
0.2	0.5	1.7	4.7	4.7	1.7	0.5	0.2	
7'	5'	3'	1'	1'	3'	5'	7'	

SOURCE

ROOF

0.5	0.9	1.3	1.8	1.8	1.3	0.9	0.5	
0.5	0.9	2.2	4.0	4.0	2.2	0.9	0.5	6'
0.2	0.5	1.7	4.7	4.7	1.7	0.5	0.2	
7'	5'	3'	1'	1'	3'	5'	7'	

SOURCE



LUMINAIRE LONG AXIS
PARALLEL TO FLOOR

LUMINAIRE SHORT AXIS
PARALLEL TO FLOOR

FIGURE 6-7 FLUORESCENT ISOINTENSITY DIAGRAM FOR 2 FOOTCANDLES three luminaires of this system, separated by 10 ft. would overlap their projected illumination at a distance of 6 ft. The overlapping would furnish a space 22 ft. x 42 in. with more than two footcandles.

6.2.10 Electrical Design

Each lamp will have an inverter ballast operating from 12 volts D.C. Figure 6-8 is a typical blocking oscillator type design. This design is not sensitive to D.C. polarity. It has a minimum number of components making it suitable for compact molding. The inverter output is matched with the lamp characteristics with capacitors C1 and C2. These provide maximum light output per watt and optimum wave shape for longest lamp life. The lamp is operated in an instant start cold cathode mode which does not require an external starter transformer.

The lamps each require less than one ampere of current. Power required for each luminaire will be approximately 22 watts. External wiring will be to intrinsically safe standards.

6.3 Incandescent Conceptual Design

Figure 6-9 is an exploded drawing of the concept. The concept includes a plastic luminaire coupled to a Tungsten Halogen light source. The light source housing may require additional cooling fins. However, the overall height of the assembly will not be more than 3 inches. The assemblies' total weight will be about 14 pounds.

6.3.1 Luminaire

The luminaire is solidly molded from plastic. Included in the molding is a reflector and a diffuse outside surface. A metal front plate is fastened to the plastic with screws for mounting the lamp housing. The luminaire is fastened to the machine with four mounting bolts.

6.3.2 Light Source

Tungsten Halogen projector lamps were investigated as the light source for the incandescent system. They are usually easy to obtain for replacement, are rugged, and have good lumen to watt characteristics. The lamps have dichroic coated glass reflectors which allows much of the heat to pass through for dissipation at the rear.

For mock-up testing an 80 watt, 19 volt lamp was used. It was operated at 15-½ volts to extend the life and minimize heat. Power was about 60 watts and the output was calculated to be 1200 lumens.

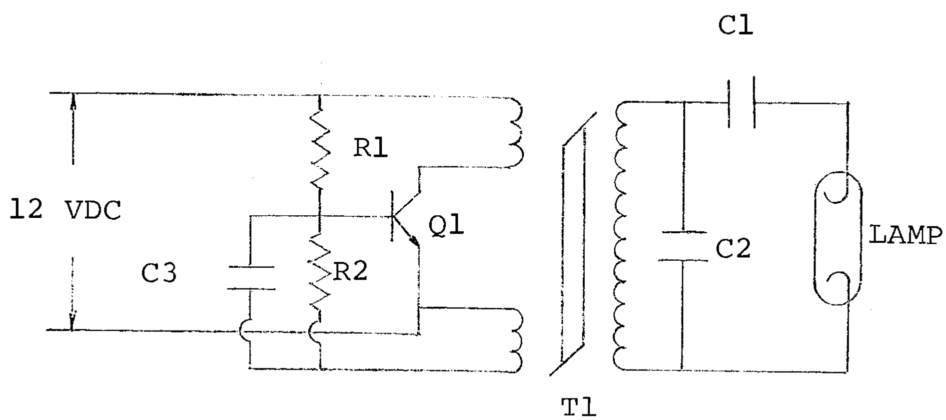


FIGURE 6-8 TYPICAL INVERTER BALLAST SCHEMATIC

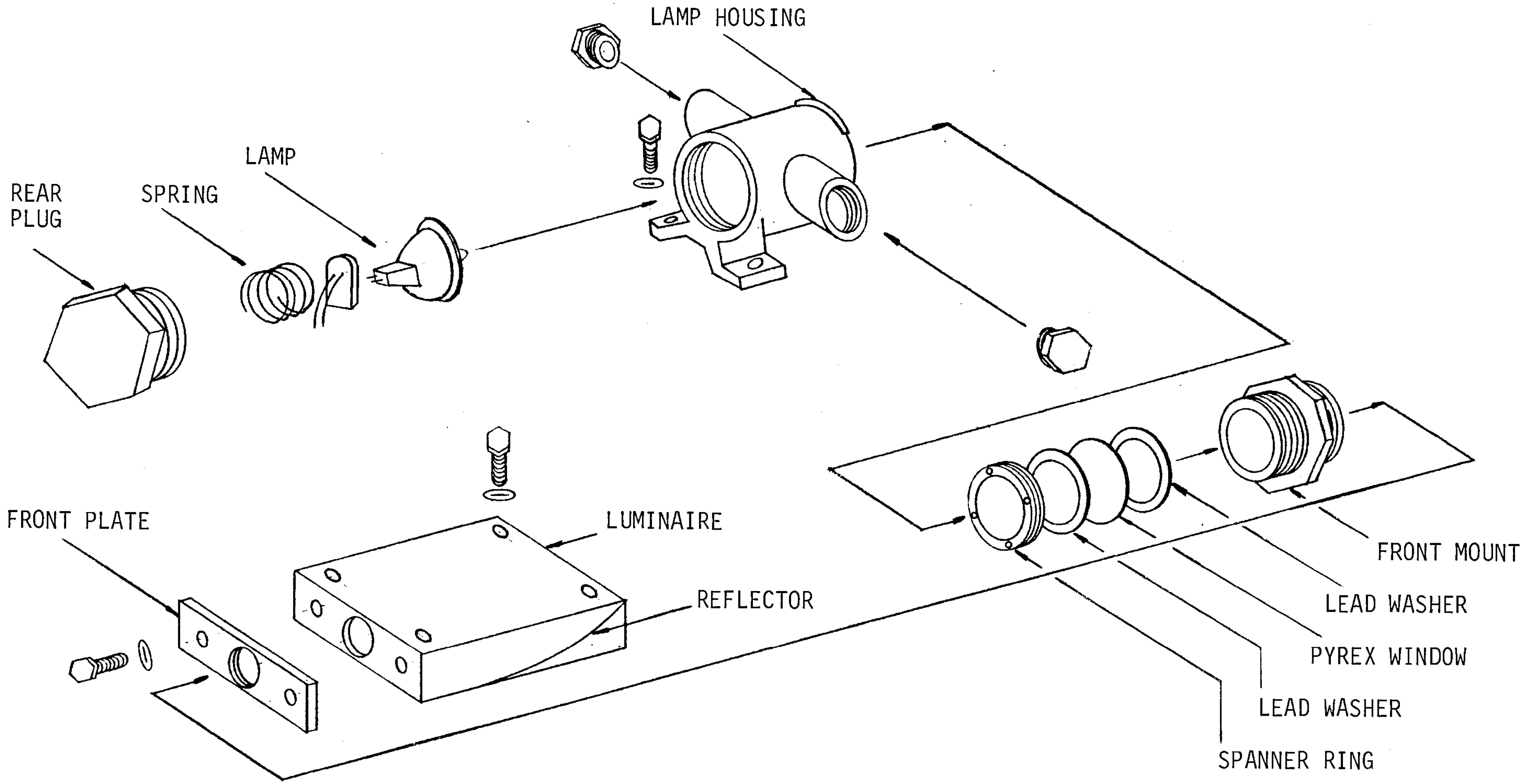


FIGURE 6-9 INCANDESCENT CONCEPT

6.3.3 Luminance and Illumination

Figure 6-10 is a mock-up used to determine the surface luminance and illumination that was expected with this system. A more uniform distribution of light was obtained with the use of a piece of diffuse Mylar above the light entrance and a darkened area below. Photometric brightness of the lighted surface ranged between 600 and 900 footlamberts. Table 6-4 and Figure 6-11 show data and isointensity diagrams for footcandles measured in a simulated mine.

6.3.4 Lamp Housing

Mining standards require this type of lamp's enclosure to be explosion-proof. Lead washers, a Pyrex window and a spanner ring make the explosion-proof window assembly. The housing will have side cable entries to facilitate series connecting of luminaires. A spring and rear plug arrangement will position the lamp and socket.

Emphasis was placed on heat transfer as in the single-lamp type housing for the fiber optics concept. The first test in Table 6-2 on page 29 concluded components and surface temperature would be within specification.

6.4 Projected Manufacturing Costs

Projected Manufacturing Costs are often used with appropriate multipliers to arrive at a selling price. Multipliers are known to vary with different companies between 1.66 and 3.0. Selling price for complete machine lighting systems are known to vary from about $1,100 to more than $5,000. The cost figures in the three tables in this section show that the selling price for any of the concepts would be competitive within this price spread.

6.4.1 Fiber Optics Concept

Fiber optics had the middle estimated manufacturing cost. The cost is based in part on six fiber optics bundles estimated at $35 each and manufactured by the light system manufacturer. Fiber costs from DuPont were $1.87 per foot and miscellaneous finishing costs were estimated at $.50 per foot. This is a total of $2.37 per foot or $35.55 for a 15 ft. length. It was noted that the cost of ready made bundles would be more than $100.00 each. Table 6-5 gives the estimated projected manufacturing costs, system components cost and tooling costs for the fiber optics design.

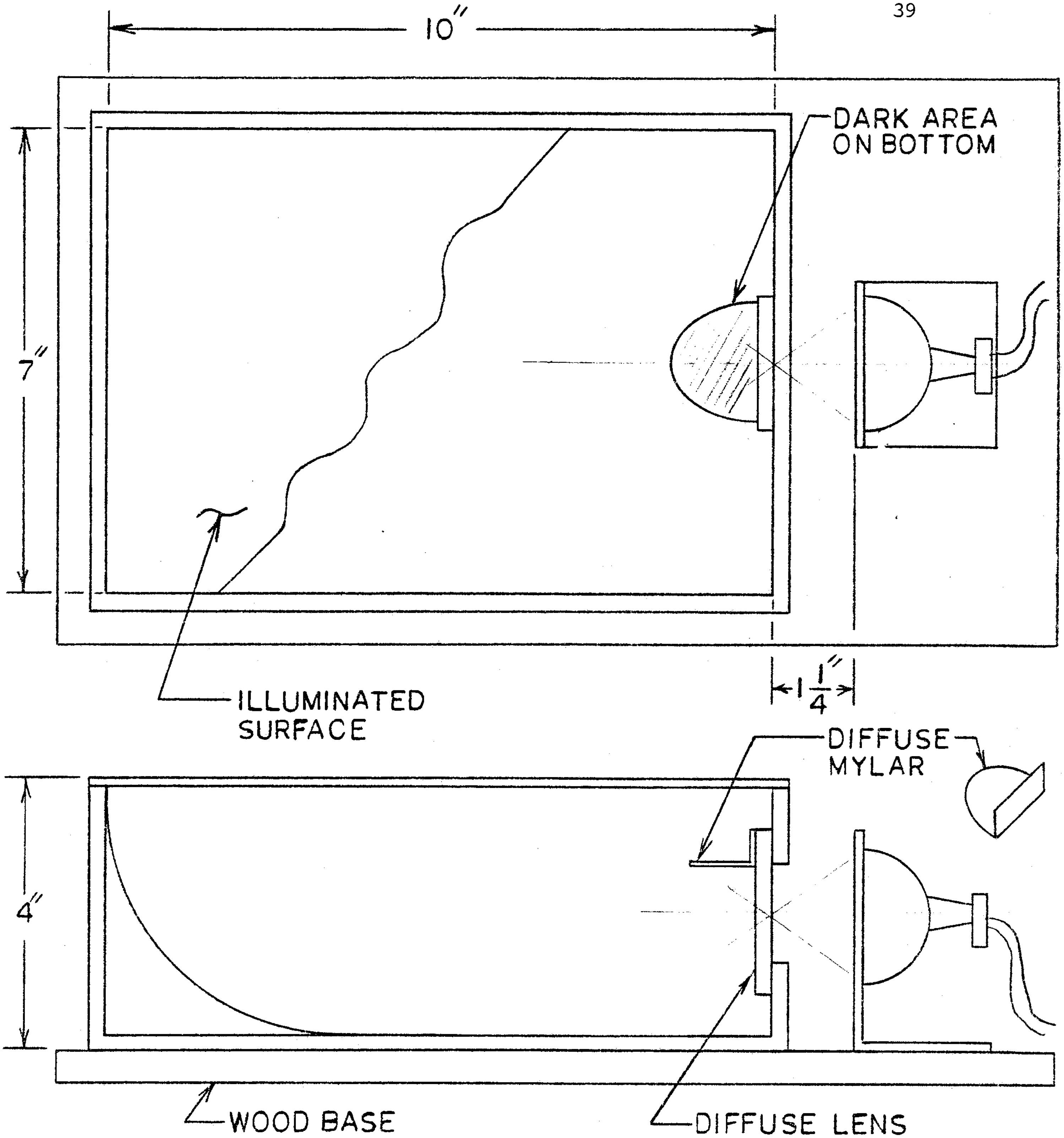


FIGURE 6-10 INCANDESCENT MOCKUP

TABLE 6-4 INCANDESCENT CONCEPT FOOTCANDLE MEASUREMENTS

FACE (13' × 4')

1.1	2.0	3.1	3.5	3.1	2.0	1.1
1.2	2.3	3.4	4.0	3.4	2.3	1.2
1.1	2.0	3.1	3.5	3.1	2.0	1.1
6.5'	4'	2'	0'	2'	4'	6.5'

FLOOR (6')

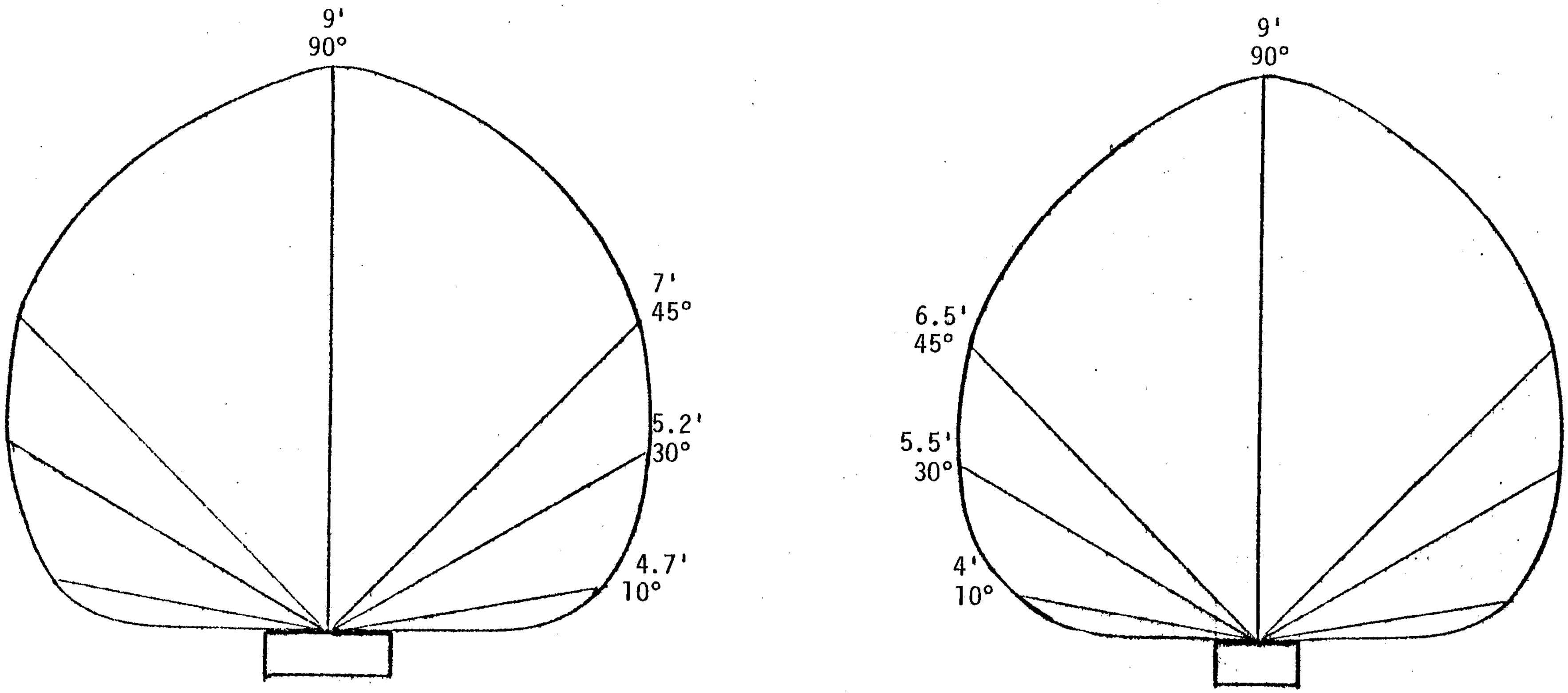
1.1	2.0	3.1	3.5	3.1	2.0	1.1
0.8	2.3	5.4	8.0	5.4	2.3	0.8
0.3	0.5	0.8	1.0	0.8	0.5	0.3
6.5'	4'	2'	0'	2'	4'	6.5'

SOURCE

ROOF (6')

1.1	2.0	3.1	3.5	3.1	2.0	1.1
0.8	2.3	5.4	8.0	5.4	2.3	0.8
0.3	0.5	0.8	1.0	0.8	0.5	0.3
6.5'	4'	2'	0'	2'	4'	6.5'

SOURCE



LUMINAIRE LONG AXIS
PARALLEL TO FLOOR

LUMINAIRE SHORT AXIS
PARALLEL TO FLOOR

FIGURE 6-11 INCANDESCENT ISOINTENSITY DIAGRAM FOR 2 FOOTCANDLES

6.4.2 Fluorescent Concept

Fluorescent had the highest estimated manufacturing cost. It also had several injection molded parts for which the tooling costs result in a much higher total. Table 6-6 gives the estimated projected manufacturing costs, system components cost, and tooling costs for the fluorescent design.

6.4.3 Incandescent Concept

Incandescent had the lowest estimated manufacturing costs. Table 6-7 gives the estimated projected manufacturing costs, system component costs and tooling costs.

6.5 Relative Merits

6.5.1 Fiber Optics Concept

- Low Electrical Hazards - The fiber optics bundles are non-electrical and can be cut or crushed with no hazard. A freedom of choice for locating the light source will allow maximum protection against electrical damage.

- Luminaire Features - The luminaire is easiest to install and replace with only 4 bolts fastening it to the machine. It operates with no heat and is cool to touch. It is easily handled because of its nine pound weight. Being molded into one piece, it is more rugged than the fluorescent model. Its low profile will allow some damage contacts to be avoided.

- Maximum Lumen Output - Lumen output is the product of surface area and surface luminance. The fiber optics concept can provide the maximum area since it does not need a space for cable entry, wiring, or a close light source.

6.5.2 Fluorescent Concept

System Wiring - The fluorescent's low voltage - current relationship for each luminaire allows an intrinsically safe classification.

Lamp Life and Replacement - The fluorescent lamps have normal life expectance of 10,000 to 15,000 hours. Easy steps for lamp replacement are: 1) remove 2 clip pins, 2) swing the luminaire clear of the support/locking arm, 3) slide out the lamp enclosure, and 4) unscrew the cap. The lamp will spring out a little for easy removal. After inserting a new lamp, the four steps are performed in reverse.

TABLE 6-5

FIBER OPTICS CONCEPTUAL DESIGN - ESTIMATED COSTS

Light Source and Luminaire
(Projected Manufacturing Costs)

Description	Quantity	Total Cost	
Lamp Enclosure	1	$100.00	
Cover	1	20.00	
Window Holder	6	10.50	
Window	6	6.00	
Lamp Casting	6	36.00	
Lamp	6	84.00	
Socket	6	9.60	
Lamp Mount	6	7.20	
Mirror	6	48.00	
Terminal Strip	1	5.00	
Switch	1	12.00	
Solid Luminaire	6	90.00	
Fiber Optic Bundle	6	210.00	
Hose Conduit	90 ft.	81.00	
Miscellaneous	-	10.00	
Labor	-	10.00	
		$739.30	Total
System Components			
Transformers	1	63.00	
10' 14/3 SO Cable	1	4.60	
10' Hose Conduit	1	9.00	
Miscellaneous	-	5.00	
Labor	-	5.00	
		$ 86.60	Total
Tooling			
Solid Luminaire - mold		$2,000.00	
Lamp Casting - pattern & matchplate		2,000.00	
Window Holder - pattern & matchplate		1,000.00	
Misc. Jigs & Fixtures		1,000.00	
		$6,000.00	Total

TABLE 6-6

FLUORESCENT CONCEPTUAL DESIGN - ESTIMATED COSTS

LUMINAIRES

(Projected Manufacturing Costs)

Description	Quantity	Extended OEM Cost	
Explosion-proof Enclosure	12	$54.00	
Lamp Housing	6	57.00	
Entry Housing	6	42.00	
Cable Strain Relief	6	3.00	
Support/locking Arm	12	30.00	
Locking Pins	24	3.00	
Inverter Module	12	174.00	
Lamp Adapter	24	3.60	
Enclosure Cap	12	9.00	
Contact Rod	12	4.20	
Contact Strip	24	8.40	
Reflector	24	9.60	
Contact Spring	22	2.40	
Lamp	12	8.40	
Toggle Clamp	12	12.00	
Miscellaneous	-	24.00	
Labor	-	66.00	
		$510.60	Total

SYSTEM COMPONENTS

Transformer	1	35.00	
Explosion-proof Enclosure	1	130.00	
14/3 SO Cable	110 ft.	38.50	
3/4" Hose Conduit	110 ft.	99.00	
Switch	1	12.00	
Rectifier/Regulator	1	35.00	
Miscellaneous	-	10.00	
Labor	-	20.00	
		$379.50	Total

TOOLING

Lamp Housing injection mold	$16,000.00	
Explosion-proof enclosure injection mold	10,000.00	
Entry Housing injection mold	6,000.00	
Inverter potting molds & test jigs	1,000.00	
Lamp adapter injection mold	2,000.00	
Cap injection mold	1,500.00	
Connector rod bend and thread jig	100.00	
Support/locking arm cut and bend dies	300.00	
	$36,900.00	Total

TABLE 6-7

INCANDESCENT CONCEPTUAL DESIGN - ESTIMATED COSTS

LUMINAIRES

(Projected Manufacturing Cost)

Description	Quantity	Total Cost	
Solid Luminaire	6	$ 90.00	
Front Plate	6	18.00	
Lamp and Socket	6	93.60	
Main Housing	6	42.00	
Housing Front	6	36.00	
Lead Washers	12	9.60	
Window	6	30.00	
Annular Ring	6	15.00	
Rear Plug	6	15.00	
Miscellaneous	-	30.00	
Labor	-	36.00	
		$415.20	Total

SYSTEM COMPONENTS

Transformer	1	50.00	
14/3 SO Cable	110 ft.	38.50	
3/4" Hose Conduit	110 ft.	99.00	
Explosion-proof Switch	1	82.00	
Miscellaneous	-	10.00	
Labor	-	20.00	
		$299.50	Total

TOOLING

Main Housing (Pattern, Core Box, match mold)	$3,000.00	
Housing Front (Pattern, Core box, match mold)	3,000.00	
Annular Ring (machine tool)	200.00	
Solid Luminaire (mold)	2,000.00	
	$8,200.00	Total

- Luminaire Features - The lamp loses little energy as heat and the luminaire operates very cool. The luminaire is easily replaced by removing 4 clip pins and disconnecting 8 screw type wire terminals. Explosion-proof lamp enclosures are conveniently located within the luminaire.

- Other Uses - A combination of several features make it suitable for longwall and other machine uses: 1) lightweight, 2) easy maintenance, 3) intrinsically safe wiring, 4) reflector configuration can be changed by sliding out plates, 5) design can be modified to one or three lamps and longer or shorter dimensions.

6.5.3 Incandescent Concept

- Ease of Lamp Replacement - Easy steps for lamp replacement are: 1) remove 2 bolts from luminaire front piece, 2) remove 2 bolts from lamp housing, 3) unscrew housing front for access to lamp. After lamp replacement, assembly is in reverse order.

- Uniform Diffusion of Light Output - A more uniform distribution of light output is possible. Lamp end light loss as in the fluorescent lamp is not present.

- Luminaire Damage - Being molded into one piece, the luminaire is more rugged than the fluorescent model.

6.6 Problems

6.6.1 Fiber Optics Concept

- Lamp Life and Replacement - Approximately 600 to 1000 hours are expected. In a large explosion-proof enclosure housing several lamps, many cover bolts would be handled when relamping. Considerable care would be needed to maintain the cover seal when replaced.

- Locating the Lamp Enclosure - All low coal machines may not have room for the enclosure when several lamps are housed together. Small single-lamp enclosures require vulnerable wiring and many packing glands.

6.6.2 Fluorescent Concept

- Damage Susceptability - The injection molded polycarbonate luminaire and the steel support/locking arm are more easily damaged by ribbing and roofing.

- Non-uniform Diffusion of Light - There is less uniformity because of the end losses of the lamp and the close proximity to the diffusing lens.

- Government Approval - The concept is more complex, and obtaining approval will be more difficult. Discussion will transpire regarding encapsulation, chemistry and intrinsically safe wiring.

6.6.3 Incandescent Concept

- Operating Temperature - The lamp housing will approach $180^{\circ}F$ and be uncomfortable to touch. Heat sinking mountings will add restrictions to where the luminaire can be located.

- Wiring - The system has the greatest number of explosion-proof cable entrances.

- Minimal Lumen Output - Lumen output is the product of lighted area and surface luminance. The incandescent concept will provide the least amount of lighted area since it requires its light source to be mounted at the end.

7.0 FIBER OPTIC DESIGN DEVELOPMENT

After considering the preceding information, the Bureau designated that complete development of the Low Glare Illumination System should center on the fiber optic concept. The following technical descriptions give the final designs for the light source, lamp enclosure, fiber bundles, luminaires, MSHA requirements and the power supply. Also as directed, a prototype system and four final systems were delivered to the Bureau's Pittsburgh Research Center.

7.1 Light Source

The system's light comes from prefocused Tungsten Halogen lamps. The lamps are cemented in dichroic coated glass reflectors 2" in diameter. Similar lamps are available from a number of manufacturers. Catalog data was used to select nine that had features most likely to benefit this program. Following a detailed study and testing, the code DDS was selected. The DDS is rated at 80 watts with 21 v applied. It is reported to have 1,000 hours average rated life and 1500 footcandles at a distance of 39 inches.

Concerns most important to the program are:

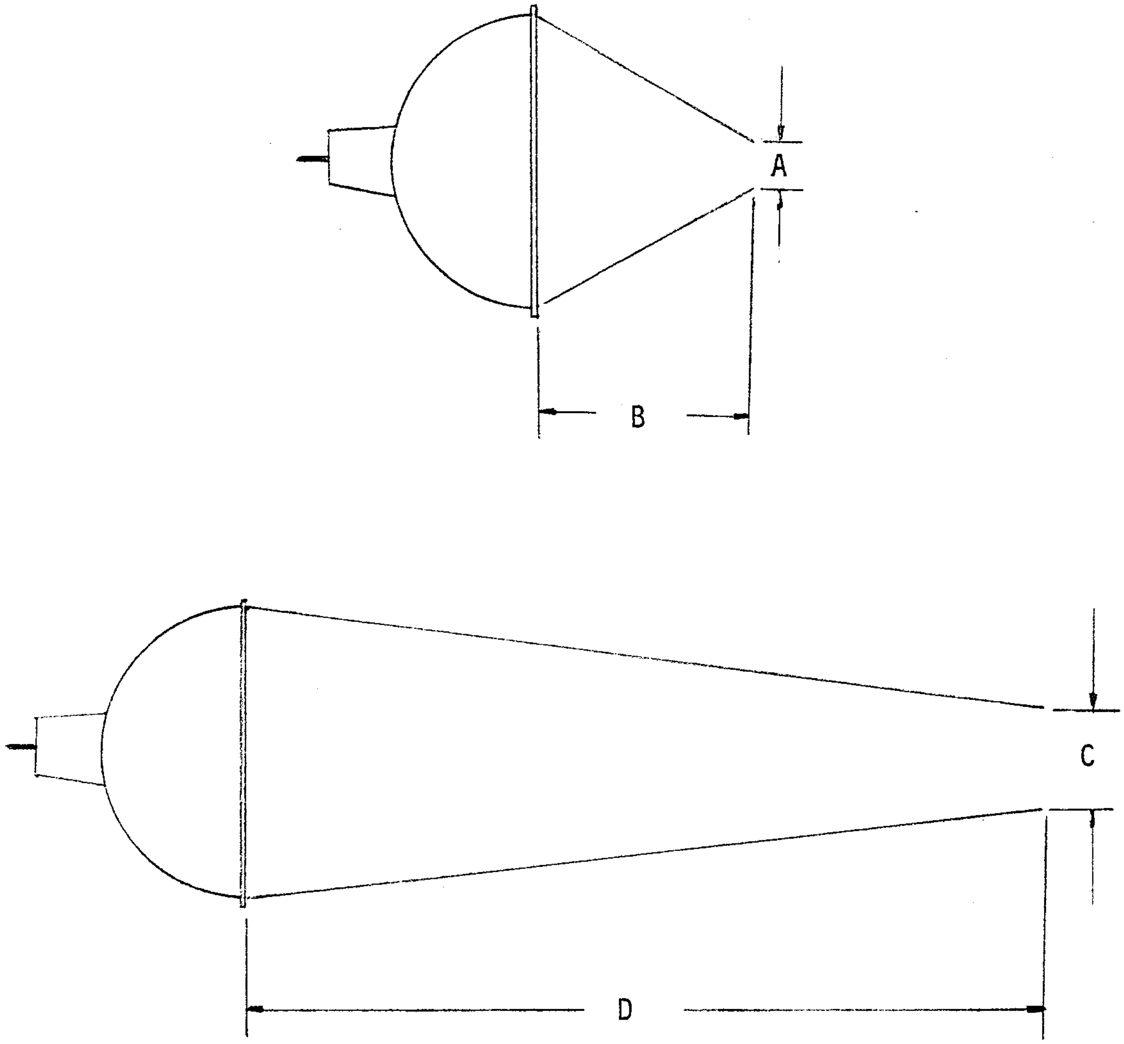
- Wattage - above 80 watts manufacturers specify fan cooling.
- Life and light output - high values of both are required.
- Beam pattern - light must be focused to 1/2" diameter.

7.1.1 Beam Pattern

The fiber optic application requires light to be focused to a 1/2" diameter at a point close to the reflector. Light beam patterns for the lamps investigated are shown in Figure 7-1. With lamps ELB, EJY and EJA, the beams converge to about 1/2" at less than 2". Lamps DDS, DED, EKG, EKP and ENW have a much more gradual convergence. With the latter beams a converging lens must be used to get a suitable 1/2" diameter light. Although ELB, EJY or EJA lamps converge very close and have considerably more light output, they have life of less than 40 hours. It was judged this life span would be too short for practical mine use.

7.1.2 Test Data

Table 7-1 compares footcandle readings for the nine lamps. Measurements were made in the laboratory with dark draperies, drawn shades and all lights off. Output at the luminaire surface was measured at eleven points and the maximum photometer reading recorded. Hours of life expectancy at more and less than rated lamp voltage were calculated.



APPROXIMATE DIMENSION (Inches)

LAMP	A	B	C	D
DDS	-	-	3/4	4-3/4
DED	-	-	3/4	4-3/4
EJA	1/2	1-1/4	-	-
EJY	1/2	2	-	-
EKG	-	-	3/4	3
EKP	-	-	3/4	2
ELB	1/2	1-1/4	-	-
ENW	-	-	3/4	3

BEAM PATTERNS

FIGURE - 7-1

TABLE 7-1

LAMP COMPARISON TESTS

LAMP	TEST VOLTAGE	FOOTCANDLES (1)	HOURS EXPECTANCY	NOTES
		LENS FOCUS		
DDS 80 w 21 v	rated	480	1000	none
	+5%	520	500	none
DED 85 w 13.8 v	rated	460	1000	none
	+4%	500	500	none
EJA 150 w 21 v	-17%	550	500	(2)
EJY 80 w 19 v	rated	600	25	(3)
EKG 80 w 19 v	rated	560	25	(3)
EKP 80 w 30 v	rated	550	25	(3)
ENW 80 w 19 v	rated	290	200	none
		DIRECT FOCUS		
EJA 150 w 21 v	-17%	620	500	(2)
EJY 80 w 19 v	rated	640	25	(3)
ELB 80 w 30 v	rated	800	18	(3)
	-20%	410	360	(4)
P-810 80 w 21 v	rated	300	1000	(5)

(1) Footcandles were measured at the brightest point on the luminaire surface. A 15 ft. 1/2" dia. fiber optic bundle transmitted the light.

(2) Units were operated at 110 watts. A blower system would be needed for cooling.

(3) Life span was judged too short for practical mine service.

(4) Voltage is too low to guarantee a good halogen cycle.

(5) This is an engineering sample using a DDS lamp in EJY reflector.

Table 7-2 compares the DDS and lens with the direct focus ELB. The tests were made with the same laboratory conditions as Table 7-1. Readings were made at a distance six feet directly in front and 45° from the luminaire. While the ELB gave intensity closer to the goal of 2 and 1.2 footcandles, it would have a life of only 18 hours. The following conditions were noted in accepting the lesser DDS illumination intensity from these results.

- In actual mining work, light levels less than two footcandles may be acceptable.
- A new fiber optics was expected to decrease light losses 10 - 20%.
- The final systems could be relamped to higher output short life lamps if necessary.

Final footcandle measurements were made in a compartment with reflectance close to coal reflectance. The results are less than was expected from the above testing. It appears that the former laboratory reflectance conditions introduced more than expected error, and there are possibly more than the allowed 1% of broken fibers in the bundles. The final footcandle readings are tabulated in Table 7-3

7.1.3 Mounting

Standard commercially available mounting brackets and high temperature sockets are used to mount the lamp. Figure 7-2 shows the arrangement. The open type construction gives maximum exposure of critical lamp seals and sockets to cooling air. It allows easy lamp replacement by sliding the lamp from under its hold-down spring. Slotted holes in the aluminum angles and mounting plates permit adjustments in all directions for beam centering.

7.2 Lamp Enclosure

The six lamps are placed in a standard permissible enclosure that has ten 1-1/8 x 12 electrical cable packing glands. Six of these glands are modified for fiber optics as described on page 72, Section 7.5. The enclosure's inside dimensions are approximately 6" x 16" x 18". There is room enough for the power supply along with the lamps. The enclosure and its contents have several temperature restraints related both to mine safety and failure of parts. Manufacturer's data and Schedule 2G give the following limits:

TABLE 7-2

PRELIMINARY ILLUMINATION INTENSITY

(Footcandles 6 ft. from Luminaire)

Axis (1)	LAMP DDS WITH LENS (2) Fiber Optic Bundle Length				LAMP ELB DIRECT FOCUS (2) Fiber Optic Bundle Length			
	10 ft.		20 ft.		10 ft.		20 ft.	
	Front	45°	Front	45°	Front	45°	Front	45°
Long	1.15	1.06	.75	.62	2.15	2.00	1.40	1.20
Short	1.15	1.02	.75	.60	2.15	2.00	1.40	1.20

(1) Long axis readings were taken with long axis of luminaire parallel with floor.

Short axis readings were taken with short axis of luminaire parallel with floor.

(2) Rated voltage.

TABLE 7-3

FINAL ILLUMINATION INTENSITY[1]

(Footcandles 6.5 ft. from Luminaire - Front)

Bundle Length[2] Feet	Bundle Orientation[3] A-B	B-A	Average Footcandles
3	.35	.35	
3	.40	.36	.375
3	.38	.41	
5	.38	.38	
5	.37	.35	.358
5	.35	.32	
10	.16	.20	
10	.27	.25	
10	.28	.29	.268
10	.28	.30	
10	.31	.28	
10	.29	.30	
15	.23	.25	
15	.23	.24	.235
15	.23	.23	
20	.20	.18	
20	.17	.17	.190
20	.22	.20	

(1) Final design at rated voltage using DDS lamp with lens.

(2) Bundles made from lowest light attenuation type LF-5 glass fibers.

(3) Second measurement with same bundle with light entering opposite end.

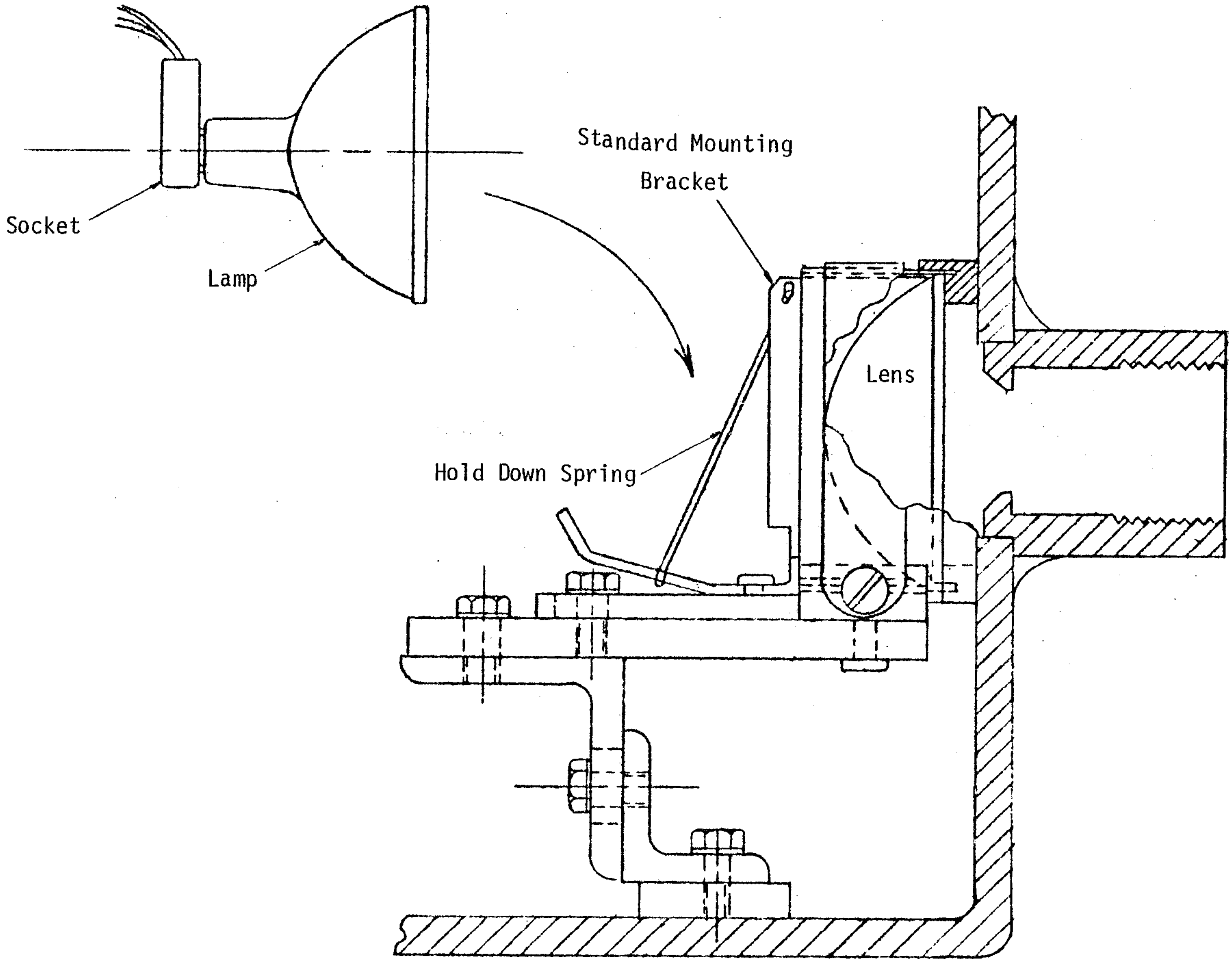


FIGURE 7-2 - LAMP MOUNTING

- Surface temperature of enclosure, 302°F
- Lamp seal, 662°F
- Lead wire, 302°F
- Lamp socket contacts, 426°F
- Transformer, 248°F

7.2.1 Heat Transfer

The enclosure at first was painted standard high visibility yellow. The lamps were recessed within tube-like mountings as shown in Figure 7-3. This type of mounting trapped radiant energy passing through the dichroic reflector. The tubes, unpainted inside, and the yellow enclosure offered poor absorptivity for accepting radiant energy from the lamps and poor emissivity for rejecting heat to the environment. As a result, the first assembly could be operated only 30 mintues before critical temperatures were reached.

Two reliable, efficient fans, available with high temperature insulation were installed to improve the convection heat transfer around the lamps. The complete enclosure also was painted flat black to aid in radiant heat transfer. Heating curves of principal thermocouples for this improved assembly are shown in Figure 7-4. Data for all thermocouples and a sketch of their placement are given in Table 7-4 and Figure 7-5. Temperatures taken from the rear surface of the lamp sockets were later estimated to be 70°F below the contact temperatures. The assembly was operated for two periods of three hours. Further investigation of fans was omitted when it was felt it would be too difficult to obtain acceptance in the mining industry.

Open type lamp fixtures shown in Figure 7-2 on page 54 were installed. Radiation from the lamp in the new mounting had an improved view of the enclosure. The new fixture also allowed unimpeded natural convection around the lamp. Performance curves of principal thermocouples are shown in Figure 7-6. The 2-1/2 hour data for all thermocouples and a sketch of their placement are in Table 7-5 and Figure 7-7. Sockets F and D had thermocouples imbedded to accurately measure their contact temperatures. All other sockets had thermocouples on the rear surface. There is approximately a 70°F difference between the two locations. This final operation shows with one exception that principal thermocouples will reach equilibrium before the critical values are reached. The lamp seal temperature would level at around 550°F and the socket contacts at around 400°F. The transformer winding temperature did not show indication of leveling.

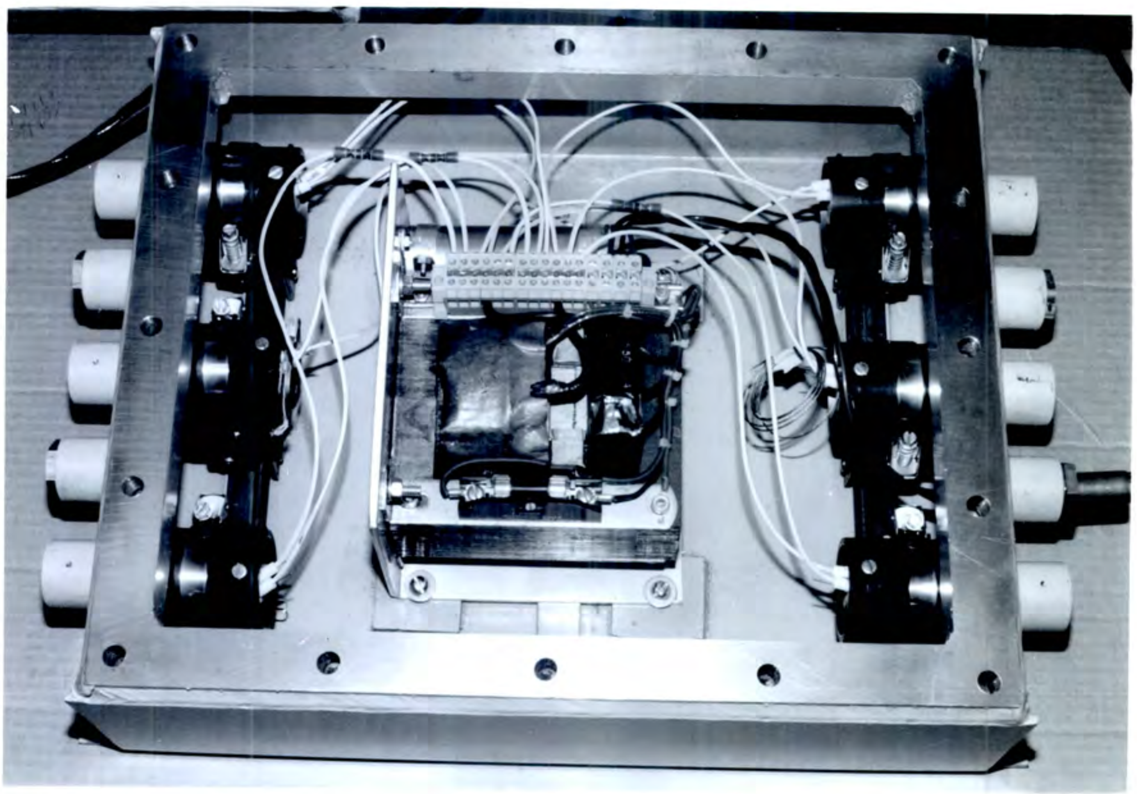


FIGURE 7-3 ENCLOSURE WITH TUBE-TYPE LAMP MOUNTINGS AND YELLOW PAINT

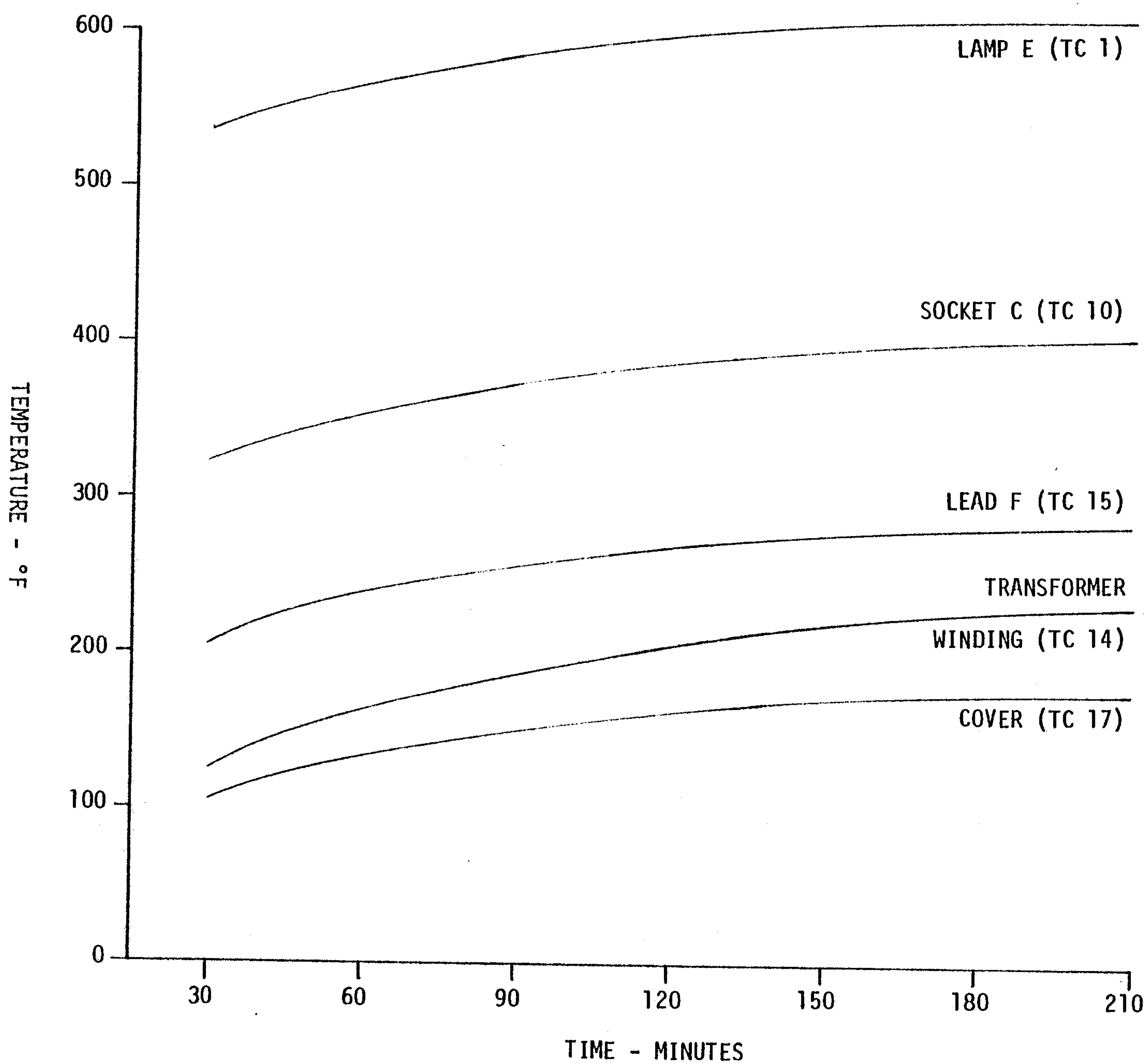


FIGURE 7-4 - HEATING CURVES FOR LAMP ENCLOSURE USING TWO FANS

TABLE 7-4 TEMPERATURE READINGS
OF
ENCLOSURE WITH TWO FANS - °F

TC ↓	TIME→ MIN→	8:45 30	9:15 60	9:45 90	10:20 125	10:50 155	11:15 180	11:45 210
LAMP	1	537	569	586	598	605	608	610
SOCKET	2	312	347	367	381	390	394	397
WINDOW	3	253	276	290	299	304	307	309
O.S. TUBE	4	180	214	236	250	258	263	266
SADDLE	5	146	180	202	217	225	228	233
LAMP	6	368	400	422	435	444	447	452
SOCKET	7	177	211	233	248	257	261	264
O.S. TUBE	8	162	196	217	232	241	245	248
SADDLE	9	135	167	189	203	211	215	219
SOCKET	10	322	354	375	389	396	401	404
SOCKET	11	251	285	306	321	328	333	336
WINDOW	12	181	206	221	233	241	243	246
TRF. CORE	13	122	158	183	201	211	216	221
TRF. WDG.	14	125	162	189	208	220	226	231
LEAD	15	203	236	256	271	278	282	285
FAN	16	132	163	184	199	207	211	215
BOX COVER	17	106	133	150	162	170	172	176
ROOM TEMP	18	73	76	77	78	80	81	82

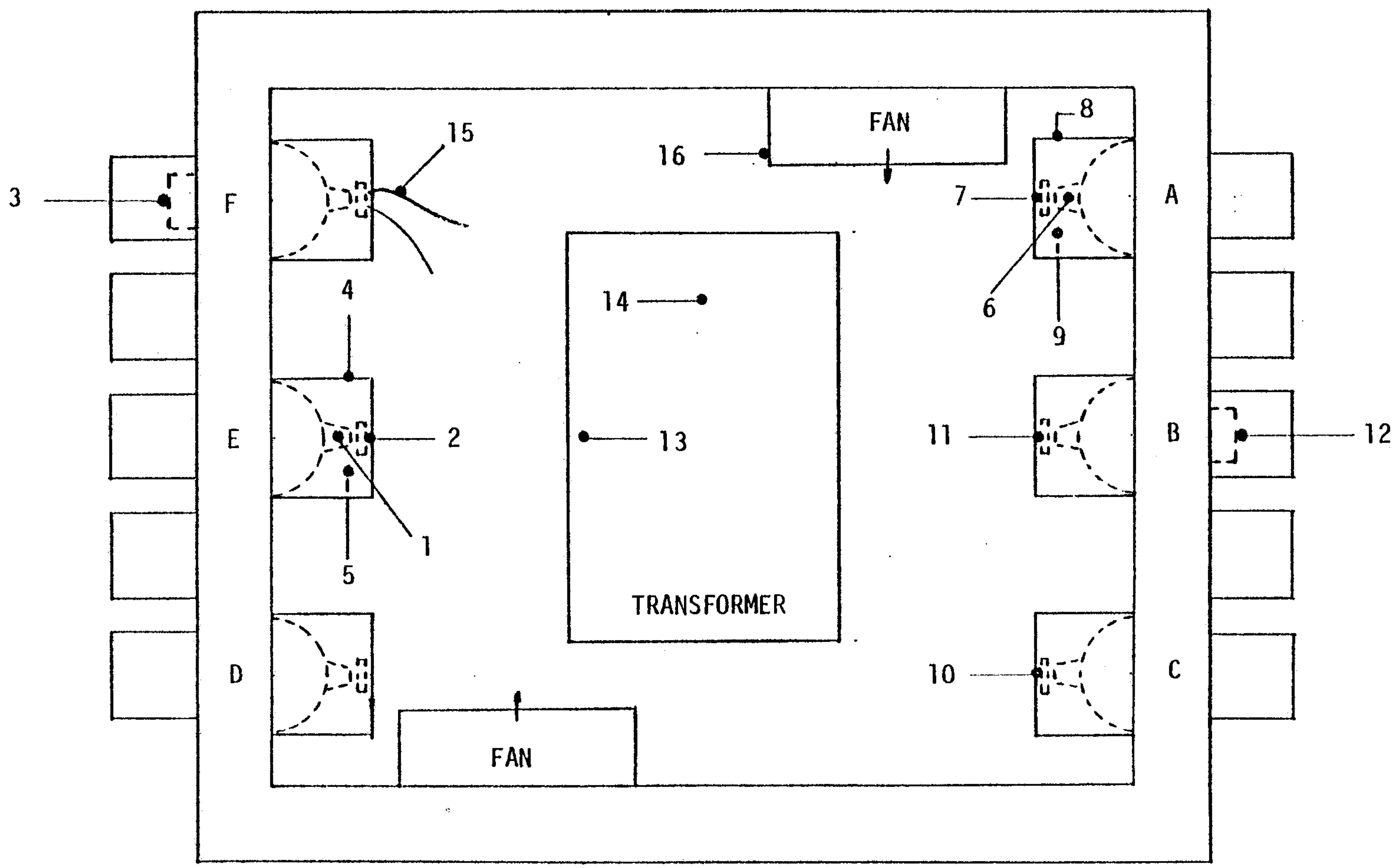


FIGURE 7-5 THERMOCOUPLE LOCATION FOR DATA OF TABLE 7-4 AND CURVE FIGURE 7-4

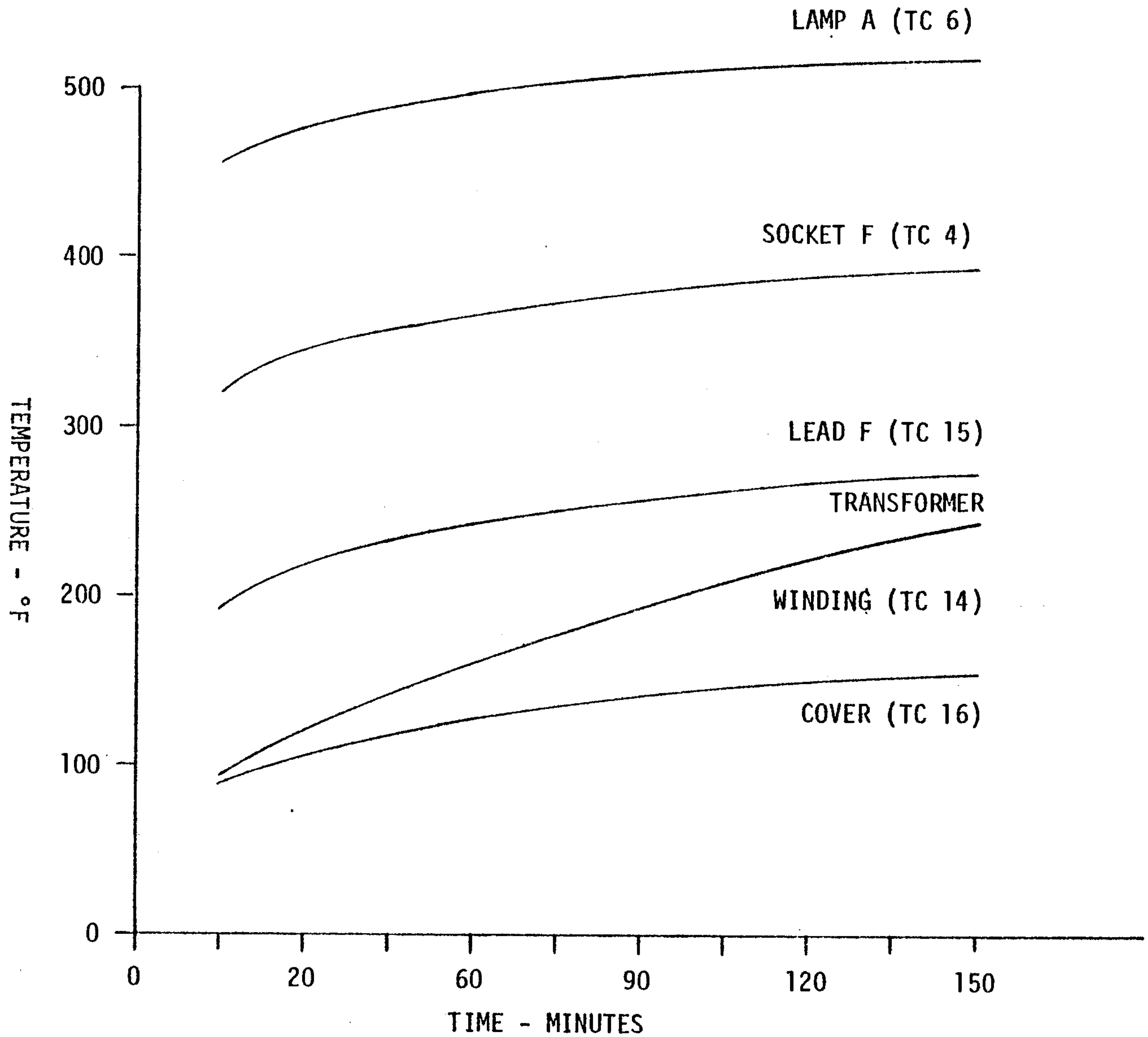


FIGURE 7-6 HEATING CURVES FOR LAMP ENCLOSURE USING OPEN LAMP MOUNTINGS

TABLE 7-5 TEMPERATURE READINGS OF ENCLOSURE WITH OPEN LAMP MOUNTING - °F

TC ↓	TIME→ MIN.→	2:50 0	3:05 15	3:20 30	3:35 45	3:50 60	4:05 75	4:20 90	4:35 105	4:50 120	5:05 135	5:20 150
LAMP E	1	159	432	452	465	474	481	487	491	496	499	501
SOCKET E	2	81	238	261	276	286	296	302	308	313	317	321
WINDOW F	3	163	198	217	231	240	246	251	255	257	258	261
SOCKET F	4	131	322	345	359	370	376	383	387	391	394	396
SOCKET D	5	133	314	332	347	356	363	369	373	376	379	382
LAMP A	6	214	458	479	491	497	504	509	512	514	517	519
SOCKET A	7	96	258	281	295	303	312	317	322	325	329	332
INS. AMB-1	8	71	95	114	131	141	151	159	165	170	174	177
INS. AMB-2	9	77	134	155	172	181	189	196	200	204	207	210
SOCKET C	10	104	247	266	280	288	296	302	306	310	313	316
SOCKET B	11	109	255	276	291	301	309	315	321	325	330	332
WINDOW B	12	137	170	188	203	211	218	223	227	231	233	235
TRF. CORE	13	71	95	115	135	151	165	180	192	202	210	218
TRF. WDG.	14	71	96	120	142	161	179	195	211	222	232	242
LEAD F	15	96	193	216	231	241	250	256	263	265	268	271
BOX COVER	16	72	90	105	116	125	136	140	147	151	152	155
F.O. A	17	76	105	119	129	136	144	148	153	154	158	158
F.O. B	18	78	107	123	133	142	149	154	159	160	164	165
F.O. C	19	73	78	83	86	88	88	88	90	91	91	92
F.O. D	20	73	78	83	86	86	88	88	90	90	90	91
ROOM TEMP	21	71	73	74	76	76	76	76	77	78	78	78

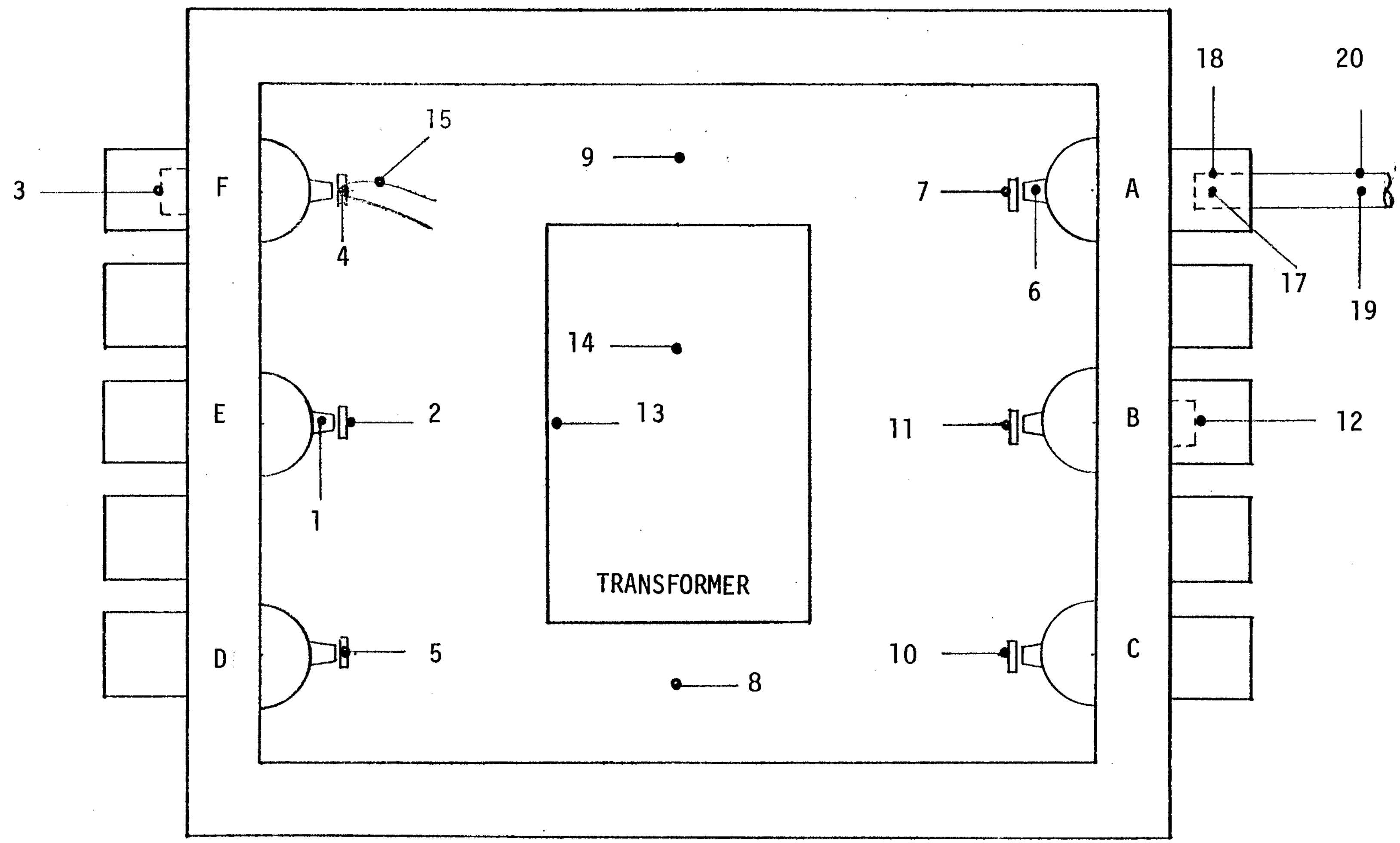


FIGURE 7-7 THERMOCOUPLE LOCATION FOR DATA OF TABLE 7-5 AND CURVE FIGURE 7-6

7.3 Fiber Optics

The illumination system uses bundle lengths of 3, 5, 10, 15 and 20 ft. for luminaires at varying distances from the light source. Bundle protective covering is 3/4" size Greenfield flexible electrical conduit. The end pieces use snap rings and gland nuts for installation in the lamp housing and in the luminaire. The mounting arrangement is shown in Figure 7-8.

Individual glass fibers are .002" dia. and are bundled to a diameter of 1/2". Strain relief to protect against broken fibers is added with Aramid yarn. The fibers are made with type LF-5 core glass giving the lowest attenuations known to be possible. The numerical aperture is .50 which gives a light cone of 62°. The manufacturing method is called the rod-in-tube process. Figure 7-9 shows photographs of the rod-in-tube heaters, the drum for taking up the continuously formed fiber, and the work table for preparing the bundle. Bundles such as these can be manufactured by many suppliers, however a large difference in pricing practice has been found.

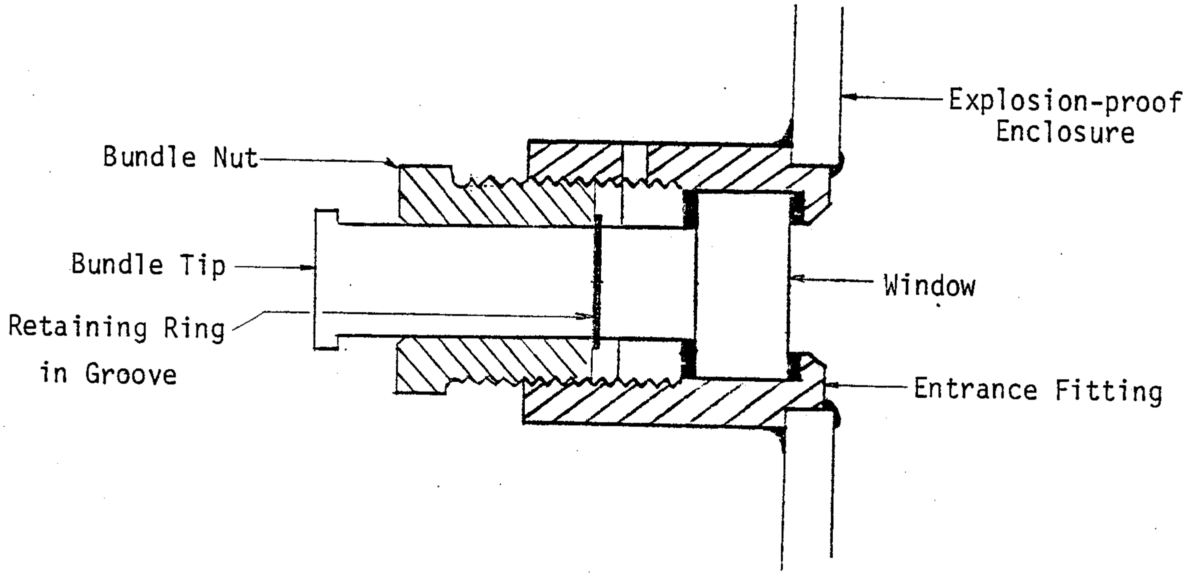
7.3.1 Cost

A cost of $35 for each 15 ft. bundle was first estimated in the concept stage of the program. This was based on in-house manufacturing using plastic fibers. Manufacturing difficulties after the development started caused the estimate to be revised however. New information for quantity less than 100 was as follows:

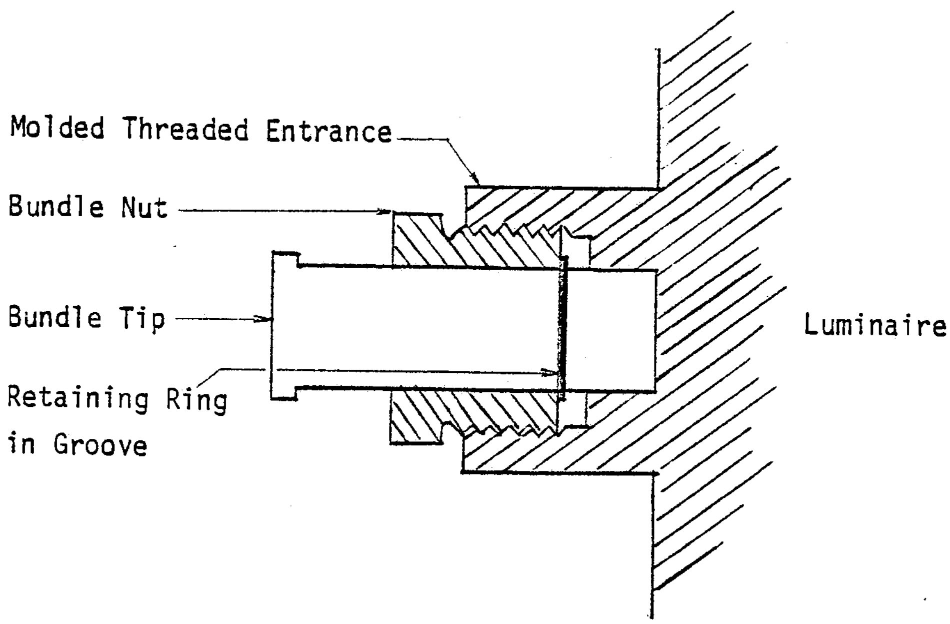
Bundle Length (ft.)	Cost
10	$370
5	229
3	167

Continued searching of fiber optic bundle manufacturers resulted in more suitable glass fiber bundles becoming available. They had an improved heat withstand to 1000°F. Sample comparison with the plastic material showed that light transmission would be improved 10 - 15%. Their costs were quoted as follows:

Bundle Length (ft.)	Cost
20	151.90
15	107.70
10	86.10
5	65.80
3	55.40

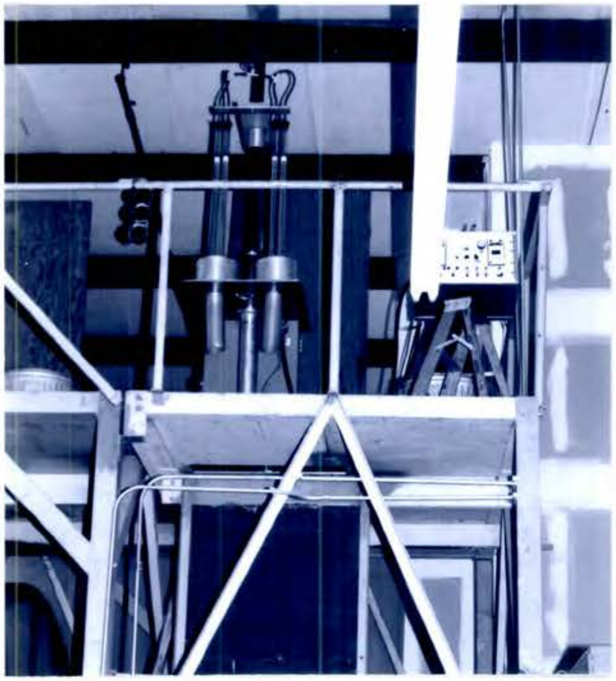


(a)

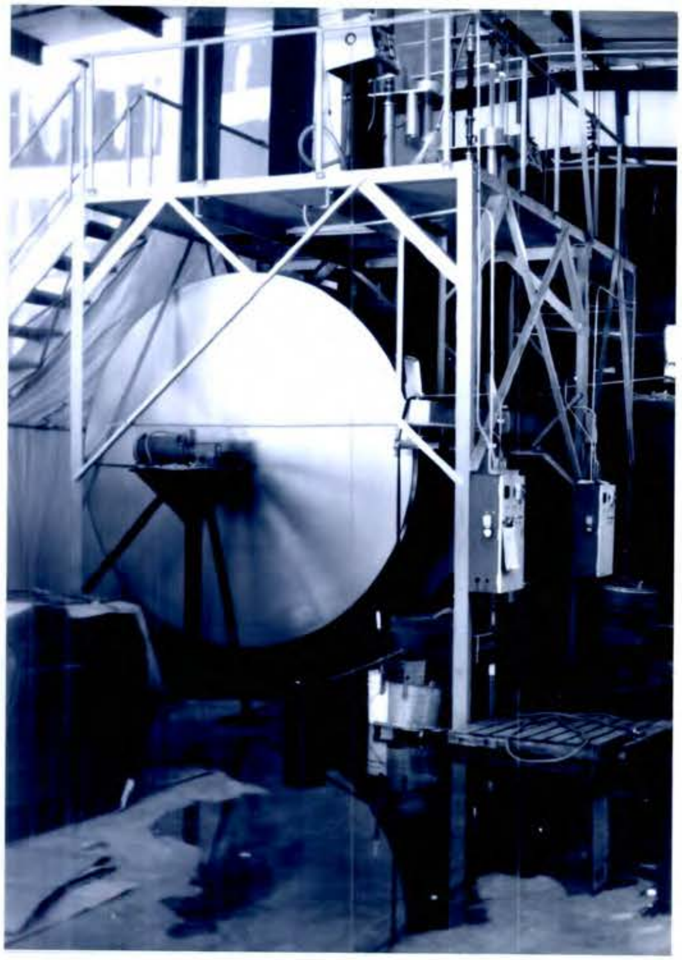


(b)

FIGURE 7-8 (a) FIBER OPTIC BUNDLE MOUNTED IN LAMP ENCLOSURE
(b) FIBER OPTIC BUNDLE MOUNTED IN LUMINAIRE



(a)



(b)

(c)

FIGURE 7-9 (a) ROD-IN-TUBE HEATERS
(b) FIBER TAKE-UP DRUM
(c) WORK TABLE

7.3.2 Bending Radius

The minimum bending radius for the bundles furnished is 12". The limitation comes from the Greenfield conduit in which they are housed. If the bundles are bent to less radius there is danger of extensive fiber breakage or the epoxy bond at the tip will break. A more flexible conduit is available that will allow bending to an 8" radius. It will add between $.50 and $3.00 to the bundle cost.

7.3.3 Transmission of Light

Light transmission is a complex process involving absorption, scatter and reflectance and is dependent on the light wavelength. Light transmission in optical fibers is most influenced by the transmittance property of the fiber core material. This is determined by material manufacturing process and ingredients. Two types of core glass were offered for the fibers. The first type is called F2 and a latter type is called LF-5. Type LF-5 is reported to have the least attenuation to light known to be possible. Its improvement when compared to F2 is shown in the comparison test of Table 7-6. LF-5 filters very little of the light and its transmission is almost white. F2 filters more frequencies and its transmission is yellow.

7.3.4 Manufacturer Instructions

Special instructions were prepared to insure the manufacturer's cooperation in furnishing bundles with low light loss. Minimal broken fibers and careful preparation of the bundle ends was stipulated. A totally smooth optical end polish is required to minimize the loss that accompanies the entrance and exit of light. The instructions are summarized in Table 7-7.

7.4 Luminaires

The luminaires were molded from urethane resin. The resin is almost clear so the top surface is abraded uniformly to 600 grit to provide diffusion. The molded section is fastened with four 1/4 x 20 bolts to a 1/4" steel plate which serves as a weld pad for machine mounting. Within the luminaire, reflection of the light comes from gloss white paint. The white paint in turn is covered by bright aluminum paint to reflect any light leakage. Figure 7-10 gives the drawing of the luminaire.

TABLE 7-6

COMPARISON TESTS
TO VERIFY IMPROVED TRANSMISSION
OF LF-5 CORE GLASS(1)

	Test #1 Footcandle Readings(2)		Test #2 Footcandle Readings(2)	
	F-2 (High Loss)	LF-5 (Low Loss)	F-2 (High Loss)	LF-5 (Low Loss)
	2.5	2.8	2.4	2.6
	3.1	3.8	3.2	3.8
	3.2	4.0	3.2	4.3
	10.5	10.0	9.0	9.0
	9.5	11.4	10.2	11.8
	5.8	8.0	6.0	8.2
	5.0	6.5	4.8	6.5
	5.0	7.8	4.8	7.8
	3.0	3.1	2.7	3.0
	3.4	4.3	3.4	4.3
	3.4	4.5	3.3	4.2
Average	4.95	6.02	4.82	5.95
Improvement	(3)	21.6%	(3)	23.4%

(1) Tests were made with a bench mounted light source focused for maximum light into the end of 15 ft. bundles.

(2) Footcandles were measured at the surface of the luminaire at 11 points. Photometer was placed at the same points for each test.

(3) % improvement calculated from average of LF-5 compared to average of F-2.

TABLE 7-7

INSTRUCTIONS TO SUPPLIERS OF FIBER OPTIC BUNDLES

1. Bundles to be furnished with a minimum of broken fibers. Maximum permissible - 1%.

2. Extra care is required to furnish end surfaces that are a totally smooth optical polish.

3. Extra care is required to furnish end pieces accurately to all specified dimensions.

4. Kevlar 29 (ARAMID yarn) shall be used in each bundle as a strain relief.

5. Lowest loss glass shall be used for core material.

6. A chart of light measurement data shall be furnished to show the manufacturer's test results of each bundle.

7. Acceptance test will be made. Unsatisfactory bundles will be returned to supplier for replacement.

8. Payment will be held until a receiving report of satisfactory bundles is obtained.

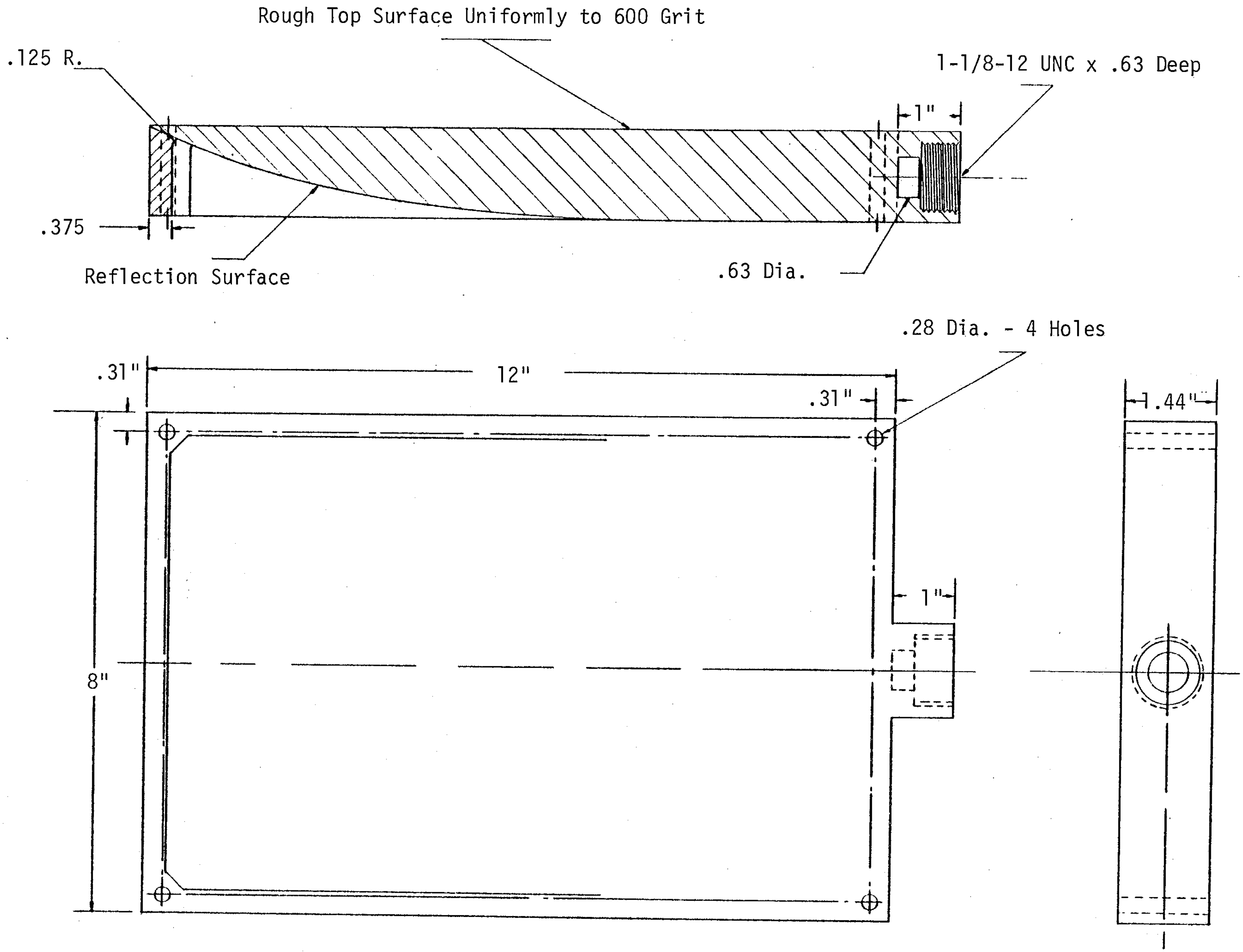


FIGURE 7-10 LUMINAIRE DRAWING

7.4.1 Material

A two-part urethane resin, Allied Resin Corporation EU500, was used for the low quantity production required for this program. It is a very tough material, however, it can be worked with cutting tools and drilled with minimum difficulty.

The early design was higher than the present 1.44" and required considerably more resin. Exotherming was a serious problem and resulted in large bubble-like voids and surface irregularities. To prevent this condition, pouring of the resin was done in several small pours with four hour curing between. The unit was redesigned and now has small enough volume so only one pour is made. Minimum exotherming results and less time is required for manufacturing.

When luminaires are manufactured in a large quantity, it is possible that injection molding would give better, more uniform results. Methyl methacrylate or styrene is recommended for injection molding. Such material can be formed by heat and pressure, has good transmission properties and is very rugged.

7.4.2 Manufacturing Cautions

Careful attention to the following is required for luminaire production that will give maximum performance.

- If preliminary vacuum treatment of the resin is too short, exotherming will not be minimized.
- If bright aluminum paint is omitted it greatly reduces the reflection of light.
- Paint must be completely dry. If it sticks and is pulled or rubbed off it greatly reduces the reflection of light.
- Mounting holes must be drilled accurately.
- Fiber optic nut threads must be dressed for easy installation.

7.4.3 Quantity Manufacturing

The following companies have expressed interest in large quantity production of this luminaire:

- Kenson Plastic Products, Pittsburgh, PA 15233
- Lexalite International Corporation
  Charlevoix, MI 49720

- Magee Plastic Co., Warrendale, PA 15086
- MSA, Pittsburgh, PA 15235
- C. W. Thomas, Inc., Philadelphia, PA 19136

7.5 MSHA Requirements

Special MSHA approval is required for the fiber optic window. Drawings of the construction were discussed at the Approval and Certification Center. The opinion was expressed that the design is satisfactory and the following requirements have been satisfied:

- Minimum length of flame path - .75"
- Maximum diametric clearance - .006"
- Spanner nut held with 3 threads and locked in place
- Tempered glass .5" thick

Please refer to Figure 7-11 for clarification on the following five paragraphs.

7.5.1 Flame Path

Figure 7-11 is a section drawing of the window assembly and shows the flame path design. The path follows the .17" wide inside lead washer, the .5" thick window, and the .20" outside lead washer. The sum of these parts is .87".

7.5.2 Diametric Clearance

Tolerances specified for machining the inside of the gland allow openings between 1.048 and 1.049. Tolerances specified for grinding the window allow diameters between 1.043 and 1.046. Diametric clearances therefore range between .002" and .006" maximum.

7.5.3 Spanner Nut

The threaded length of the nut is .28" $\pm$ .01. Each of the 1-1/8 - 12 UNC threads require approximately .084". Therefore, approximately 3.2 threads are furnished. Although the slot in the nut interrupts the required threads, the MSHA review concerning it was satisfactory.

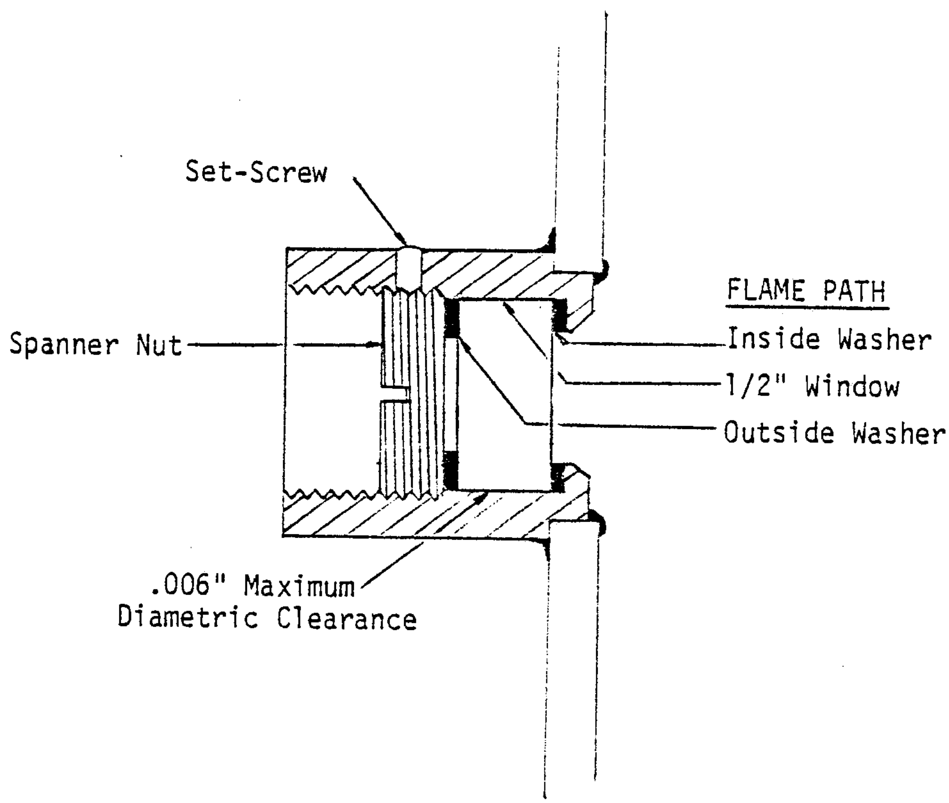


FIGURE 7-11 FIBER OPTIC WINDOW

The spanner nut was locked in place with one 6-32 UNC setscrew. This arrangement was satisfactory. It is felt however that future models for explosion testing should be furnished with two such screws, 180° apart.

7.5.4 Window Glass

The glass specifications follow the Code of Federal Regulations for mining machine headlights. The regulations state that "Lenses for headlights shall be glass or other suitable material with physical characteristics equivalent to 1/2" thick tempered glass such as 'Pyrex'." Material used for manufacturing the fiber optic window is Pyrex 7740 tempered glass from Corning Glass Works.

7.5.5 Special Machining

The following companies expressed interest in furnishing the special glands on the explosion-proof enclosure. The first three companies are machine shop operations. They would rework the machining on existing glands in ready-made enclosures. The latter four companies are suppliers of explosion-proof enclosures.

- H. P. Gazzam Machine Company - Pittsburgh, PA 15201
- Industrial Machine, Inc. - Zelienople, PA 16063
- MSA - Evans City, PA 16033
- Ensign Electric Co. - Huntington, WV 25778
- General Energy Dev. Co. - Needham Heights, MA 02194
- Service Machine Co. - Huntington, WV 25702
- Stonebridge Corporation - Holliston, MA 01746

7.6 Power Supply

Stable voltage is required for proper operation of the Tungsten-Halogen lamps. Lower than rated voltages sacrifice light, higher than rated voltage sacrifices lamp life. To take care of usual voltage fluctuation in mining, Constant Voltage Transformers have been furnished with the low glare lighting systems. These transformers are a rugged economical means for regulating lamp voltage to $\pm$ 2% over a primary fluctuation of $\pm$ 15%. Regulation comes from the capacitor-terminated control winding on the secondary portion of the core. The transformers are rated at 600 va, weigh about 45 pounds, and take about one-fifth of the volume of the lamp enclosure. They can be manufactured for any primary AC voltage normally found in mine service. Figure 7-3 on page 56 shows the unit installed in the lamp enclosure.

7.6.1 State-of-the-Art

The power supply furnished is heavy, rather bulky, and the winding and core losses contribute heat to the lamp enclosure. Power supply state-of-the-art was investigated for a suitable alternative. Information from 12 representative manufacturers of both solid state and electromagnetic devices was solicited. From their information it was concluded that this transformer is at present without a superior alternative.

7.6.2 Transformer Life

The manufacturer estimated a life of 10,000 hours if operation is continuous in a lamp enclosure internal ambient of approximately 250°F

7.7 Components

Table 7-8 lists the major assemblies that make up a fiber optic low glare illumination system for operation on 117 v AC.

TABLE 7-8 MAJOR COMPONENT ASSEMBLIES

Required	Description	Drawing No.
1	Block Diagram	B07-10620
6	Fiber Optics Assembly	B01-10583
6	Luminaires	C01-10597
1	Lamp-Power Supply Enclosure	C01-10600
1	Power Supply	C01-10587
6	Lamp and Mounting Assembly	C01-10622
1	Switch	A01-10462
1	Schematic Diagram	C00-10584

7.8 Estimated Cost

The cost to the end user is usually determined by manufacturing costs and appropriate multipliers. These factors vary with different companies. Typical multipliers were used in the following estimate and are subject to change. For comparison it is noted that the selling price for complete machine lighting systems vary from about $1,100 to more than $5,000 depending on many variables. Total cost for the fiber optic low glare system including two headlights is estimated to be $4,598.56.

TABLE 7-9 ESTIMATED COST

1	Enclosure with lamp, optics, and power supply	$1,936.71
1	Switch	382.50
6	Fiber optics assemblies	822.00
6	Luminaires	768.00
1	Cable Entry Kit	30.25
2	150 W Incandescent Headlights	659.10
		$4,598.56

8.0 CONCLUSIONS

This program applied the present state-of-the-art to furnishing a viable fiber optic lighting system. Even so, as reported in Section 7.1.2, there are two goals that could not be reached:

- The system is not capable of generating an incident luminous flux density of 2 footcandles at a radial distance of 6 feet along an axis perpendicular to the main plane of the luminaire.

- At an angle of 45 degrees from a perpendicular to the main plane of the luminaire, the luminous flux density is less than 1.2 footcandles at a radial distance of 6 feet.

The sections on Light Sources and Fiber Optics give support to a discussion that within the framework of contract limitation, everything possible was done to meet the above goals. In summary:

- Light sources commercially available and suitable to fiber optics were studied and tested; the most promising type was selected; it was applied to the lighting task with cost effective manufacturing consideration.

- Fiber optic bundles with core glass having the least light attenuation known possible were obtained; careful manufacturing methods contributed to maximizing transmission of light.

Success reported in sections on the Luminaires and MSHA Requirements will probably be applied to all future mine lighting work with fiber optics:

- Luminaires have a very low profile; they are made of plastic in small quantities by hand molding; quantity production is possible by injection molding.

- MSHA requirements for the fiber optic window are met; flame path is more than .75"; maximum diametric clearance is provided; a spanner nut holds a 1/2" Pyrex window.

In the areas of the Lamp Enclosure and the Power Supply there is additional investigation required:

- Lamp Enclosures must be checked for satisfactory installation on the mining machine; thermal performance can be improved if the machine acts as a heat sink.

- Power supplies probably need to be redesigned for a lower thermal gradient.

The work experienced costs that exceeded the original estimate beyond the control of MSA. For these costs there was only limited additional government funding available. The Bureau of Mines cooperated in every way by changing to less costly specifications. The final specifications focused on the most essential parts of the development. Areas where additional work is needed are:

- Operation in a simulated mine to evaluate the work place illumination.

- Continuous operation for a period of 200 hours or more.

- Acquisition of an approved Statement of Test and Evaluation.

- Machine operation in a 42" coal mine for three months for complete evaluation.

- Lamp enclosure heat transfer with machine mounting.

- Psychophysical aspects from Illumination Engineering Research Institute.

8.1 Recommendations

Development and investigation should continue to deal with disability and discomfort glare and maintenance cost. These are the most pressing problems associated with today's lighting systems in low coal mining. Four specific suggestions follow which are related directly to the fiber optic work reported.

8.1.1 Aluminized Reflectors will transfer much of the heat toward the outside of the lamp enclosure. The lower internal temperature will increase the life of enclosed parts. On the outside the fiber optics are reported to withstand 1000°F.

8.1.2 Plastic Fiber Optics manufacturers should be encouraged to develop low loss, low cost fibers. Plastic fibers would break less than glass and would better stand the rigors of mine use.

8.1.3 Fiber Optics reportedly can be furnished with three or more bundles packed together at one end. Further development should be undertaken for one large light source to provide for several bundles.

8.1.4 Metal Halide Lamps using approximately the same reflector size as the Tungsten Halogen lamps in this program and providing more light with less heat seem to be a possibility. These lamps would possibly improve thermal conditions in the enclosure and light output at the luminaire. The Bureau already has an interest in having such a lamp developed and it should be encouraged.

APPENDIX A

Addendum to Phase I Report

MSA-82-02

MINE SAFETY APPLIANCES COMPANY

ADVANCED SYSTEMS DIVISION

MSA-USBM Contract J0113006

MSA Job No. A-106

ADDENDUM

to

PHASE I REPORT

to

U. S. BUREAU OF MINES

LOW GLARE ILLUMINATION SYSTEM

March 19, 1982

OPINION BY MSA - ADVANCED SYSTEMS DIVISION

Phase I effort has included a detailed evaluation of three concepts within the current climate of budget restrictions. A cost effective approach in research and development is necessary more than ever and greatest return for each dollar expended is most important. Development of the fiber optic concept offers the potential for development of hardware having application also in an effective incandescent system. It is therefore a more effective utilization of research and development funds. The fluorescent system does not offer a comparable cost benefit potential. For this reason MSA - Advanced Systems Division recommends that efforts on this contract focus on the fiber optic system including the development of a small single lamp enclosure.

Recommendation is made that the contract be modified to develop such a system with the current funding limit as a goal. It is estimated that a single lamp enclosure can be developed, a prototype system assembled, 4 finished systems delivered to the Bureau, and a final report furnished, for close to the funding that remains. It is estimated this work can be finished using less than 13 months from authorization to start. After 4 illumination systems are complete (11 months) a review is planned. An evaluation will be made and further resolution can be made at that time for such considerations as the 200 hour life test, in-mine test, and MSHA approvals and STE's. The final report will be completed after test and approval information is obtained.

This addendum presents the following document requested by USBM:

Evaluation Chart - The chart on page 83 evaluates the three concepts and is followed by a brief discussion of each parameter. The chart shows highest score rating for the fiber optics system using small single lamp enclosures.

Parameter	Weighting Factor	CONCEPT: INCANDESCENT Order of Merit*	INCANDESCENT Weighted Score	FLUORESCENT Order of Merit*	FLUORESCENT Weighted Score	FIBER OPTICS Order of Merit*	FIBER OPTICS Weighted Score
1. Cable Safety	10	9	90	9	90	10	100
2. Selling Price	9	10	90	9	81	8	72
3. Luminaire Locating	9	7	63	8	72	9	90
4. Lamp Life	8	8	64	10	80	5	40
5. Ease of Lamp Replacement	8	7	56	8	64	5	40
6. Susceptibility to Damage	7	8	56	7	49	10	70
7. Uniform Diffusion	7	8	56	6	42	8	56
8. Glands per System	7	6	42	8	56	6	42
9. Ease of Installation	6	8	48	8	48	10	60
10. Luminaire Temperature	6	6	36	9	54	10	60
11. Luminaire Replacement	6	6	36	7	42	10	60
12. Luminaire Shaping	6	8	48	5	30	10	60
13. Intrinsically Safe Wiring	5	6	30	10	50	8	40
14. 250 VDC Power	4	7	28	3	12	7	28
15. 650 VDC Power	3	6	18	2	6	6	18
TOTAL WEIGHTED SCORE			761		776		836

*Order of Merit
10 = Maximum Merit
0 = Minimum Merit

LOW GLARE ILLUMINATION CONCEPTS EVALUATION TABLE

1. CABLE SAFETY
(weighting factor 10)

The fluorescent and incandescent systems will have power cables difficult to protect from physical damage. The fiber optics system will have a power cable to each of 6 lamp enclosures but with best possibility of locating it for maximum protection. The fiber optics bundle transmitting the light can be cut or crushed with no resulting electrical hazard.

2. SELLING PRICE
(weighting factor 9)

The incandescent system is least expensive chiefly because of the threaded metal type enclosure and solid molded luminaire. The fluorescent system is more complex and therefore more expensive. The electronic inverters, threaded polycarbonate, and two explosion-proof enclosures contribute largely to this. The fiber optics is estimated to have the highest selling price by considering the incandescent system with the addition of optical bundles and provisions for extra lamp enclosure cooling.

3. LUMINAIRE LOCATION
(weighting factor 9)

The fiber optics luminaire would be easiest to locate for best illuminating because it is smallest and could have its shape altered to fit unusual machine cavities. The fluorescent luminaire is largest and cannot be shaped and therefore is not as easily located. The overall incandescent luminaire also is larger than fiber optics and requires consideration for heat sinking the lamp enclosure.

4. LAMP LIFE

(weighting factor 8)

Fluorescent is 10,000 - 15,000 hours, inverter driven, cool and least subject to shock and vibration. Incandescent (Tungsten Halogen) is 1000 - 2000 hours estimated and operates at considerably higher temperature. Tungsten Halogen lamps with the fiber optics system would be shortest lived. Estimates from derating curves indicate operation for approximately 600 to 1000 hours may exist.

5. EASE OF LAMP REPLACEMENT

(weighting factor 8)

For the fluorescent system, remove clip pins (two pins), slide out lamp enclosure and unscrew cap for access to lamp. For the incandescent system, remove lamp housing from luminaire and machine mounting (four bolts), unscrew face for access to lamp. The fiber optics system is rated lowest for lamp change because of the possibility of the housing being in a location with difficult access as a means for physical protection.

6. SUSCEPTIBILITY TO DAMAGE

(weighting factor 7)

The fiber optics has the lowest profile and a solid molded luminaire. The incandescent also has a solid luminaire, but has a higher profile because of the lamp housing. In the fluorescent system the injection molded plastic is more easily damaged than the solid luminaire on the other concepts.

7. UNIFORM DIFFUSION

(weighting factor 7)

The fluorescent luminaire is the most difficult to diffuse because of lamp end-losses and lamp location close to the diffuser. The incandescent and fiber optics have the solid luminaire and are expected to have somewhat better uniformity than fluorescent.

8. GLANDS PER SYSTEM
(weighting factor 7)
The incandescent and fiber optics systems will have 2 glands, one for the supply and one for the lamp housing. The fluorescent system also has 2 glands, but the intrinsically safe wiring gives it a higher rating.

9. EASE OF INSTALLATION
(weighting factor 6)
The fiber optics system is easiest to install because of the relatively unrestricted positioning possible for the lamp housing. The fluorescent and incandescent concepts are rated about equal and just a little lower. They each have little weight and only a few mounting bolts.

10. LUMINAIRE TEMPERATURE
(weighting factor 6)
The fiber optics luminaire will have no noticeable heat from its source. The fluorescent luminaire has very little energy lost as heat because of low power input and high efficacy. The incandescent luminaire will show some temperature rise because of the 60 watt lamp input. It should stabilize at less than 180°F.

11. LUMINAIRE REPLACEMENT
(weighting factor 6)
The fiber optics should be fastest. Remove the light bundle and unbolt the luminaire. No down time since other light units can remain on. Fluorescent is a little more difficult, remove

pins, disconnect screw wire terminals. Incandescent is the most difficult because of gland entry and unbolting from heat sink.

12. LUMINAIRE SHAPING
(weighting factor 6)

The luminaire of the fiber optics can be shaped to some extent to fit unusual cavities. In the incandescent system, changing the luminaire is limited by the light source fixture mounted on the end. The fluorescent luminaire is changeable only by engineering and manufacturing modification. Reflector changes are possible by removing plates if desired.

13. INTRINSICALLY SAFE WIRING
(weighting factor 5)

Intrinsic wiring is possible for the fluorescent system because it requires only 2 amps at 12 VDC. Higher power ratings for the incandescent and fiber optics systems prevent this. Fiber optics bundles are inherently non-electrical to give this concept some advantage however.

14. 250 VDC POWER
(weighting factor 4)

This is most difficult for the fluorescent and requires obtaining converters or inverters to handle mine power transients. For the incandescent and fiber optics it should be suitable with series connected lamps and a voltage dropping resistor.

15. 650 VDC POWER
(weighting factor 3)

This is most difficult for the fluorescent and requires obtaining converters or inverters to handle mine power transients. For the incandescent and fiber optics it should be suitable with series connected lamps and a voltage dropping resistor.