NASA TECHNICAL MEMORANDUM

NASA TM X-3147

NASA TM X-3147

(NASA-TM-X-3147) TESTS OF PROTECTIVE CLOTHING FOR THE SAFE HANDLING OF PRESSURIZED LAMPS (NASA) 20 p HC $3.25 CSCL 06Q
N75-14468
Unclas
H1/54 06918

TESTS OF PROTECTIVE CLOTHING FOR THE SAFE HANDLING OF PRESSURIZED LAMPS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1975

1. Report No. NASA TM X-3147	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TESTS OF PROTECTIVE CLOTHING FOR THE SAFE HANDLING OF PRESSURIZED LAMPS		5. Report Date January 1975 6. Performing Organization Code
7. Author(s) John G. Ewashinka		8. Performing Organization Report No. E-7933
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		10. Work Unit No. 502-25 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum 14. Sponsoring Agency Code

15. Supplementary Notes

Film supplement C-279 is available on request.

16. Abstract

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17. Key Words (Suggested by Author(s))	18. Distribution Statement
Protective clothing Safe handling, procedures High-pressure lamps	Unclassified - unlimited Category 05

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	19	$3.00

* For sale by the National Technical Information Service, Springfield, Virginia 22151

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SUMMARY

Tests were made to find a clothing material combination for use in handling high-pressure lamps. Monofilament nylon, ballistic nylon, and ballistic felt grouped into various multilayer combinations and chromed leather were positioned around and 30.5 centimeters (12 in.) away from exploding high-pressure lamps of different manufacturers and wattages.

The results are (1) 5024 nylon/ballistic felt/5024 nylon in a layered configuration was not penetrated by fragments of lamps as large as 6.5 kilowatts, (2) this layered combination is lightweight and pliable and offers greater mobility and comfort to the user than previous protective clothing, (3) Lexan plastic 1.6 millimeters (1/16 in.) thick to be used for face shield material showed no penetration for lamps as large as 20 kilowatts.

INTRODUCTION

Many installations at NASA Centers use high-pressure lamps for high-intensity light sources and for solar simulation. These lamps are commonly known as short- or compact-arc lamps. They vary in power from 0.05 to 20 kilowatts, and in the future higher powers are anticipated. The gases used are argon, mercury vapor, and xenon. Xenon is the most commonly used gas in short-arc lamps. Internal, cold (nonoperative) lamp pressures range from 0.1 to 2 MN/m^2 (1 to 20 atm) and depend on the lamp operating characteristics and also on the lamp size.

Cases of violent lamp explosions have been reported at various lamp installations in both government and industry. These lamp explosions are unpredictable and they have occurred in both the cold nonoperative and hot operative conditions. In order to protect personnel handling these lamps from quartz fragments resulting from a lamp explosion, various users have resorted to extreme protective clothing measures. Some clothe their personnel in two or three layers of flak suit materials with heavy face shields and gloves, thereby making them susceptible to accidents due to the cumbersome clothing. Others, not realizing the potential dangers, offer little or no protection at all for their personnel. Also, each prospective lamp user that realizes a danger exists has established his own safety clothing standards for protection of personnel from a high-pressure lamp explosion.

Since a clothing standard for compact-arc lamps did not exist, the Institute of Environmental Sciences (IES) designated a committee to conduct tests on various clothing materials and forms of face shield protection for high-pressure-lamp users. The author was asked to make recommendations to the committee for a standard on safety clothing that would protect personnel from quartz shrapnel from such an explosion. A study program was instituted at the NASA Lewis Research Center. The goal of this program was to find a clothing material combination which would be used with all high-pressure lamps and which would make clothing sufficiently lightweight and pliable to afford the user comfort and mobility with maximum protection from lamp explosions.

A 16-millimeter color motion-picture film supplement C-279 has been made which shows actual lamp explosions and tests of sample clothing. The film is titled "Protective Clothing for the Handling of Xenon Lamps." This film may be obtained on loan; a request card and a description of the film are included at the back of this report.

The U. S. customary system of units was used in collecting the data and making the calculations. Conversion to the International System of Units (SI) was done for reporting purposes only.

DESCRIPTION OF FACILITY

A partial view of the test chamber and control room used to conduct the tests on safety clothing and face shields is shown in figure 1. This installation consists of a steel-lined chamber with walls 5 centimeters (2 in.) thick that is covered with an earth mound. This area also has a protected control room with a specially constructed window where test personnel can look into the chamber. Figures 2 to 4 show the clothing test fixture located inside the test chamber. The test fixture was a wooden hexagon that allowed six clothing samples to be tested simultaneously during a single lamp explosion. The fixture was 61 centimeters (24 in.) across the flats and 1.2 meters (4 ft) high. The six individual panels located on the test fixture were removable so that clothing material samples or face shield materials could be fastened to the panels easily. Also this method allowed inspection of the individual test panels after a test had been made. Inside the test fixture, the six individual test panels were 30.5 centimeters (12 in.) by 61 centimeters (24 in.). All panels were backed by a 2.5-centimeter- (1-in.-) thick horsehair packing material to simulate the resistance of the human body. Figure 5 shows a typical cross section of a test panel with test materials attached. The test fixture was designed so that all lamp fragments resulting from an explosion would be directed toward the test clothing samples mounted on all sides of the fixture. Each side was compartmentalized so that lamp fragments which struck a given test panel would be retained within the compartment of that side. This permitted a study of the size and number of lamp fragments that struck the individual panels.

A nonoperative pressurized lamp was suspended firmly in the center of the facility and exploded by a 1.6-centimeter- (5/8-in. -) diameter rod actuated pneumatically and driven at right angles to the lamp anode and cathode. Figure 3 shows a 20-kilowatt lamp mounted in the test fixture with one of the test panels removed. High-speed motion pictures (8000 frames/sec) were taken of the exploding lamp and the lamp fragments striking the clothing panels. The size of the lamp fragments and the number of strikes can be determined from the film. Three cameras were used, each covering two panels. Figure 4 shows the test fixture, the pneumatic rod, and the location of the three high-speed cameras.

DESCRIPTION OF MATERIALS TESTED

The materials chosen for testing were 5018 and 5024 ballistic nylon, M-34 monofilament nylon, chromed leather, and a ballistic felt successfully used by the military combat forces. These materials were selected for their high cutting resistance, high strength, light weight, and flexibility. Multiple layers of the same material or different combinations of materials could be used. The materials chosen and the number of layers depended on the lamp size chosen for the test.

The 5018 ballistic nylon is a scoured and heat-set 210-denier nylon warp yarn with 210-denier nylon filling yarn. This material weighs 0.41 kg/m^2 (12 oz/yd^2). The 5024 ballistic nylon is a scoured and heat-set 420-denier nylon warp yarn with a 420-denier filling yarn. This material weighs 0.23 kg/m^2 (6.75 oz/yd^2). The M-34 monofilament nylon is a 100-percent monofilament nylon mesh weave with a 381-micrometer (15-mil) spacing. The felt is a needle-punched "ballistic" felt 2.1 to 2.3 millimeters (0.08 to 0.09 in.) thick made of 100-percent high-tenacity fibers and weighing 0.34 to 0.41 kg/m^2 (10 to 12 oz/yd^2). The chromed leather used in the tests consisted of cowhide leather splits with steel staples spaced approximately 6.4 millimeters (1/4 in.) apart. The chromed leather weighs 1.2 kg/m^2 (36 oz/yd^2). The six multiple-layer configurations that were tested are listed in table I. Included are weight and cutting resistance (ref. 1) for the material combinations. The cutting resistances shown in table I for a particular clothing configuration were obtained by adding the minimum values of each material together. Since reference 1 does not give a cutting resistance value for ballistic felt, the cutting resistance for those clothing configurations containing felt is probably higher than the value given. An interesting point on the cutting resistance of the ballistic felt is illustrated by the following experience: In conducting tests where the ballistic felt was to be used, it was necessary to cut a 1.9-centimeter- (3/4-in.-) diameter hole in the felt to accommodate the pneumatic plunger. This was done with a great deal of effort and difficulty, an indication that the cutting resistance for the material was very high.

The lamps to be used in this test program were from several lamp manufacturers, and the lamp sizes that were picked were those most commonly used. The lamp sizes tested were 0.5, 1, 2.5, 4.2, 6.5, and 20 kilowatts. The total number of lamps used in the tests was 75; twenty were of the 2.5-kilowatt size. The 2.5-kilowatt lamps were selected as a reference

(1) Because this lamp is the most widely used pressurized lamp in government and industry

(2) Because the stored energy (pressure times volume, or PV) within these lamps is approximately in the middle of the PV range for all the lamp sizes involved

Figure 6 is an average PV curve for cold lamps from several lamp manufacturers. The 2.5-kilowatt lamp has an average PV value of 14.1 N-m (125 lbf-in.) as compared with 32.8 N-m (290 lbf-in.) for a 20-kilowatt lamp. However, the PV rating is not an indication of the severity of the explosion or the damage to the test clothing panels. Explosions of 1-kilowatt lamps may be as severe as explosions of 20-kilowatt lamps.

TEST PROCEDURE

Clothing Tests

In order to detect quartz fragment penetrations of the multilayer clothing samples, 8.9-micrometer- (250-μin.-) thick aluminum foil was used behind each layer (fig. 5). A clothing combination was considered a failure if penetrations were made through the last layer of clothing and its respective aluminum detection sheet.

A starting clothing configuration was chosen arbitrarily. Then it was necessary to determine if the clothing selection offered any protection; if not, the selection could be modified by either adding layers or changing materials. For the initial tests, the combination of 5024 nylon/M-34 nylon/ballistic felt was selected because it is approximately in the middle of the cutting resistance range for all the clothing combinations tested (table I). Each sample was tested in all six test cell positions. If no penetration was noted through the primary detection sheet for a clothing combination, the next less protective clothing configuration was similarly tested. If penetration was noted through the first layer of material, secondary detection sheets were examined for penetrations.

The clothing configuration could then be adjusted for more or less protection until there were no penetrations for the lightest weight clothing. After completion of the tests using reference 2.5-kilowatt lamps, the tests were repeated for other lamp sizes.

Face Shield Tests

After the tests on the clothing samples were concluded, the remaining lamps were used to test the face shield material. A high-strength plastic face shield material with the trade name Lexan was selected for testing. Lexan sheets 30.5 centimeters (12 in.) by 61 centimeters (24 in.) and 1.6 millimeters (1/16 in.) thick were used. Because no penetrations were made through this material, thicker samples were not tested.

RESULTS

As in any situation where handling of dangerous materials is involved, prevention of injury is important. Motion pictures of the clothing tests showed that exploding lamps will shower an area with various-sized lamp fragments, some of them traveling at speeds of 45 m/sec (100 mph). The fragments also tumble, exposing even more sharp edges to any object or personnel that they may strike.

Clothing Tests

The results of the clothing tests are shown in table II. The initial test, using a 5024 nylon/M-34 nylon/ballistic felt clothing combination and a 2.5-kilowatt lamp, showed that this combination was effective for protection (test 1). In tests 2 to 5, the M-34 monofilament nylon material was removed because of its stiffness and poor wearability. Some lamp fragments penetrated through the felt layer (test 3 and 4), so in the following tests the material combination was ungraded. The selection was a 5024 nylon/ballistic felt/5024 nylon clothing combination. Tests 6 to 10 showed penetrations through the first 5024 layer but little penetration through the felt layer. This same combination was then tested with a 6.5-kilowatt lamp, and the results were again satisfactory (tests 11 and 12), with some penetration through the first layer of 5024 but not through the ballistic felt. Tests 11 and 12 were just two of many tests conducted with 6.5-kilowatt lamps; only these two tests are reported as representative samples. Tests with 6.5-kilowatt lamps were also made on heavier clothing combinations. An additional top layer of 5024 in test 13 resulted in no penetrations of even this top layer. The considerably heavier combination of four layers of 5018 in test 14 suffered two penetrations through all four layers. The chromed leather in test 15 suffered surface cuts but no penetrations, even though it is slightly lighter and has lower cutting resistance than the four layers of 5018. Although it is possible that the lamp explosion in test 14 was especially severe, these results suggest that cutting resistance is not an adequate parameter for rating resistance to penetration.

In tests 16 to 19 a 5024 nylon/ballistic felt/5024 nylon clothing combination and 20-kilowatt lamps were used. Surprisingly little damage to the clothing was found. In three tests, no layers were penetrated, and in the fourth test there was only one penetration of all the layers. More damage was expected with these lamps because the average pressure-volume value is 32.8 N-m (290 lbf-in.). A survey of five manufacturers of 20-kilowatt lamps indicated that their cold lamp pressures were, respectively, 0.29, 0.36, 0.41, 0.47, and 0.71 MN/m^2 (2.9, 3.5, 4, 4.6, and 7 atm). The lamps that were used in these tests had a cold internal pressure of 0.29 MN/m^2 (2.9 atm), which was the lowest pressure reported by the five manufacturers. For tests 20 to 22, empty Hanovia 20-kilowatt lamp envelopes were obtained and then filled to higher internal pressures. Lamps pressurized to 0.71 MN/m^2 (7 atm) were chosen for tests 20 and 21 and produced extensive damage on all clothing panels for both tests. There was extensive penetration and damage by quartz fragments through the last layer of 5024 material. One lamp envelope was pressurized to 0.41 MN/m^2 (4 atm) since lamps from three of the five manufacturers have an average cold pressure at or below this level. The results for this pressure condition (test 22) showed that four of the six panels had at least one quartz fragment penetration through the last layer of 5024 material. No further clothing tests were performed with 20-kilowatt lamps.

Smaller lamp wattages of 0.5 and 1.0 kilowatt were also tested against the 5024/felt/5024 combination, and no penetrations were noted through the last layer (tests 23 to 30).

Face Shield Tests

Table III shows the results of tests on the 1.6-millimeter- (1/16-in.-) thick Lexan face shield material. A total of 12 tests were performed, with tests 11A and 12A using 20-kilowatt lamps pressurized to 0.71 MN/m^2 (7 atm). The results showed that the Lexan sheets were usually surface scuffed by the quartz fragments. One cut and one spallation on the rear surface were observed in the first test with the 2.5-kilowatt lamps. There were no penetrations for lamps of all wattages including 20 kilowatts.

DISCUSSION

The 5024 nylon/ballistic felt/5024 nylon clothing configuration had no failures, that is, no penetration through all three layers, for lamps with wattages to 6.5 kilowatts. However, 20-kilowatt lamps posed a special problem. This clothing combination experienced no penetrations only for 20-kilowatt lamps with less than 0.3-MN/m^2 (3-atm) cold internal pressure. Above 0.3 MN/m^2 (3 atm) the 5024 nylon/ballistic felt/5024 nylon failed; that is, fragment penetration was noted through the last layer of clothing in all cases tested. It is important for the user to realize that all 20-kilowatt lamps do not have the same internal pressures; it varies with the lamp manufacturer. Most lamp manufacturers do not list the lamp internal gas pressures for any lamp size, either hot or cold, in their literature. For a 20-kilowatt-lamp application, it is possible for the user to add layers of ballistic felt to the 5024 nylon/ballistic felt/5024 nylon clothing configuration to ensure some protection when handling 20-kilowatt lamps. However, no data exist to show that these additional layers will afford protection to the user.

The 0.5- to 20-kilowatt lamps used in these tests exploded with variable severity. Some of them exploded violently, while others were less severe. The severity of the lamp explosions is not as dependent on the lamp wattage as it is on the internal gas pressure and the volume of the lamp envelope. Explosions of lower wattage lamps, such as the 0.5 kilowatt, were just as loud and violent as those of a 20-kilowatt lamp with 0.71-MN/m^2 (7-atm) pressure. Of course, the smaller wattage lamps have smaller envelopes, and therefore, less quartz fragments can strike an object. But these lamps are still dangerous and can do harm.

Chromed leather was not penetrated in its one test with a 6.5-kilowatt lamp. However, this material is heavy and stiff and is very cumbersome to personnel. Clothing of this material in use at Lewis weighs 4.5 kilograms (10 lbm) compared with a weight of 1.4 kilograms (3 lbm) for the equivalent in 5024 nylon/ballistic felt/5024 nylon clothing combination. Also, clothing constructed of the 5024/felt/5024 combination can completely cover vulnerable areas such as the neck, wrists, legs, and ankles and thus afford better protection than chromed-leather clothing. Figure 7 shows the 5024/felt/5024 clothing combination made into a protective suit covering all these vulnerable areas.

The face shield protection tested, a 1.6-millimeter- (1/16-in. -) thick Lexan sheet was not penetrated by any lamp explosions. It is possible that this material could replace 1.3-centimeter- (1/2-in. -) thick Lucite now in use for face shields.

CONCLUDING REMARKS

Handling of high-pressure lamps is a hazardous business. The protective clothing developed from the Lewis Research Center's test program does not substitute for careful handling techniques and safe installation, but, when properly used, does provide lightweight personnel protection with little sacrifice of mobility.

SUMMARY OF RESULTS

A test program was conducted at the NASA Lewis Research Center to evaluate the effectiveness of various clothing materials and a face shield material in protecting personnel from fragments of exploding high-pressure lamps. Samples of the materials were exposed to exploding lamps at a distance of 30.5 centimeters (12 in.) and were then examined for penetrations. Sample clothing materials were not tested against hot operating lamps. The lamps were cold and were shattered mechanically. The following results were obtained:

1. A clothing combination of 5024 nylon/ballistic felt/5024 nylon in a layered configuration was not penetrated by quartz fragments for lamps as large as 6.5 kilowatts.
2. The 5024 nylon/ballistic felt/5024 nylon clothing combination is lightweight and pliable and offers greater mobility and comfort to the user than previous protective clothing. This clothing covers vulnerable areas such as legs, arms, wrists, and neck.
3. Lexan plastic, 1.6 millimeters (1/16 in.) thick, to be used as a face shield material, showed no penetrations for lamps as large as 20 kilowatts.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 12, 1974,
502-25.

REFERENCE

1. Destefano, James T.: Material, Design Tests Produce Protective Sleeve for Glass Handlers, Am Soc. Safety Engrs. J., vol. 14, no. 5, May 1969, pp. 14-17.

TABLE I. - CLOTHING CONFIGURATIONS TESTED

Configuration[a]	Weight		Minimum cutting resistance	
	kg/m^2	oz/yd^2	N	lbf
Chromed leather	1.2	36	11.1	2.5
5024/felt	.53	$15\frac{3}{4}$	11.1	[b]2.5
5024/felt/5024	.74	$21\frac{3}{4}$	22.2	[b]5.0
5024/M-34/felt	.74	$21\frac{3}{4}$	33.4	[b]7.5
5024/5024/felt/5024	.99	$29\frac{1}{4}$	33.3	[b]7.5
5018/5018/5018/5018	1.6	48	53.4	12.0

[a]Materials include 5018 and 5024 ballistic nylon, ballistic felt, and M-34 monofilament nylon.

[b]Minimum value does not include cutting resistance of ballistic felt, for which data are not available.

TABLE II. - TYPICAL DAMAGE TO VARIOUS CLOTHING CONFIGURATIONS FROM HIGH-PRESSURE-LAMP EXPLOSIONS

Test	Lamp power, kW	Lamp manufacturer	Clothing configuration	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6
				Penetration damage to clothing layers, number of penetrations/layer penetrated					
1	2.5	Osram	5024/M-34/felt	None	1/1st	None	None	None	None
2		Osram	5024/felt	None	None				
3		PEK		None	1/2nd				
4		Westinghouse		1/2nd	None				
5		Osram		None		1/1st	1/1st		
6		Westinghouse	5024/felt/5024	None		None	None		
7		Hanovia				None	None		
8		Hanovia				None	None		
9		Osram				4/1st	6/1st	1/1st	1/1st
10		Osram			1/1st	1/1st	None	3/1st	1/1st
11	6.5				None	None		None	None
12				2/1st	2/1st	2/1st		None	None
13			5024/5024/felt/5024	None	None	None		None	None
14			5018/5018/5018/5018	6/1st, 3/2nd, 1/4th	3/1st, 1/4th	1/2nd	3/1st, 1/3rd	1/2nd	4/1st
22	20	Special - Hanovia envelope at 0.4 MN/m^2 (4 atm)		5/1st, 3/2nd, 1/3rd	3/1st, 1/2nd, 1/3rd	2/1st, 2/2nd, 1/3rd	1/1st	5/1st	3/1st, 2/2nd, 1/3rd
23	1.0	PEK		None	1/1st	1/2nd	1/2nd	None	1/2nd
24					None	None	None	1/1st	None
25					None	1/2nd	1/1st	1/1st	None
26					3/1st	3/1st	1/1st	1/1st	None

TABLE II. - Concluded. TYPICAL DAMAGE TO VARIOUS CLOTHING CONFIGURATIONS

FROM HIGH-PRESSURE-LAMP EXPLOSIONS

Test	Lamp power, kW	Lamp manufacturer	Clothing configuration	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6
				Penetration damage to clothing layers, number of penetrations/layer penetrated					
15	6.5	Osram	Chromed leather	Surface cuts only	Surface cuts only	None	Surface cuts only	Surface cuts only	Surface cuts only
16	20	Durotest	5024/felt/5024	None	None	None	None	None	None
17				1/3rd		1/1st	1/2nd		1 pen. thru 1st layer
18				None		None	None		None
19				None		None	None		None
20		Special - Hanovia envelope at 0.71 MN/m^2 (7 atm)		4/1st, 2/2nd, 1/3rd	3/1st, 1/2nd	6/1st, 1/2nd, 1/3rd	2/1st	5/1st, 2/2nd 1/3rd	6/1st, 3/2nd, 2/3rd
21		Special - Hanovia envelope at 0.71 MN/m^2 (7 atm)		2/1st, 1/2nd, 1/3rd	5/1st, 1/2nd, 1/3rd	1/1st	2/1st 2/2nd, 1/3rd	8/1st, 5/2nd, 3/3rd	6/1st, 3/2nd, 2/3rd
27	.5	PEK		None	1/1st	1/1st	2/1st	1/1st	None
28	1.0	Hanovia		None	None	None	None	None	None
29	1.0	Hanovia		None	None	None	None	None	None
30	.5	PEK		1/1st	None	1/1st	None	1/1st, 1/2nd	1/1st

TABLE III. - RESULTS OF HIGH-PRESSURE-LAMP EXPLOSIONS ON LEXAN FACE SHIELD MATERIAL - NO DAMAGE

[Face shield material, 1.6-mm- (1/16-in.-) thick Lexan sheet.]

Test	Lamp power, kW	Lamp manufacturer	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6
			Number of scuff hits					
1A	2.5	Osram	7	(a)	(b)	0	2	Panel not present
2A	2.5	Osram	3	2	7	4	3	↓
3A	4.2	[c]Ushio	---	---	---	---	---	↓
4A	4.2	[c]Ushio	---	---	---	---	---	↓
5A	1.0	Hanovia	1	5	3	4	2	↓
6A	1.0	[c]Hanovia	---	---	---	---	---	↓
7A	1.0	Hanovia	1	---	3	3	1	↓
8A	.5	PEK	2	6	3	8	7	↓
9A	.5	[c]PEK	---	---	---	---	---	↓
10A	.5	PEK	8	9	10	5	5	↓
11A	20	Special - 0.71 MN/m^2 (7 atm)	Several	Several	Several	Several	Several	↓
12A	20	Special - 0.71 MN/m^2 (7 atm)	Several	Several	Several	Several	Several	↓

[a]One cut, not through.
[b]One reverse spallation.
[c]Poor explosion, no damage to panels.

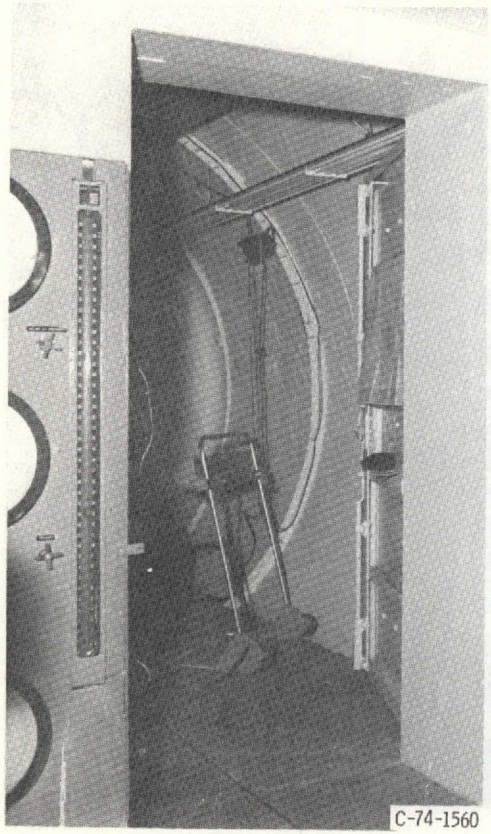

Figure 1. - Control room and test chamber.

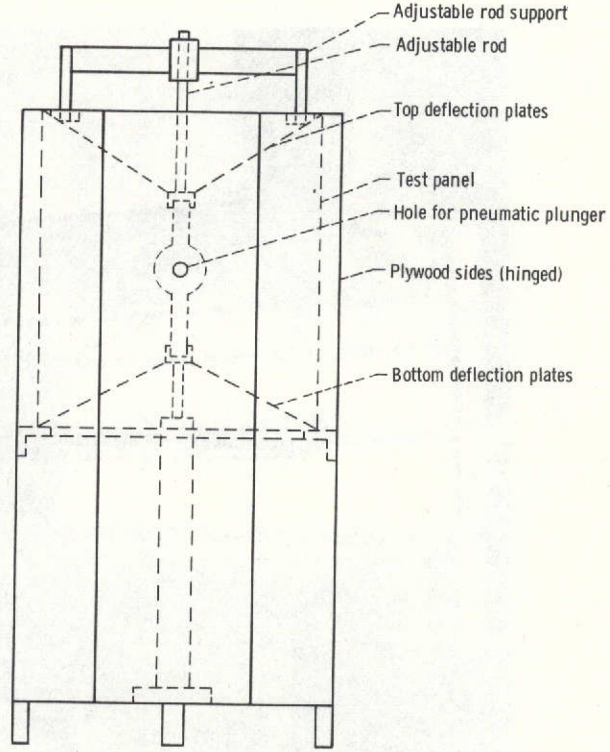

Figure 2. - Clothing test fixture.

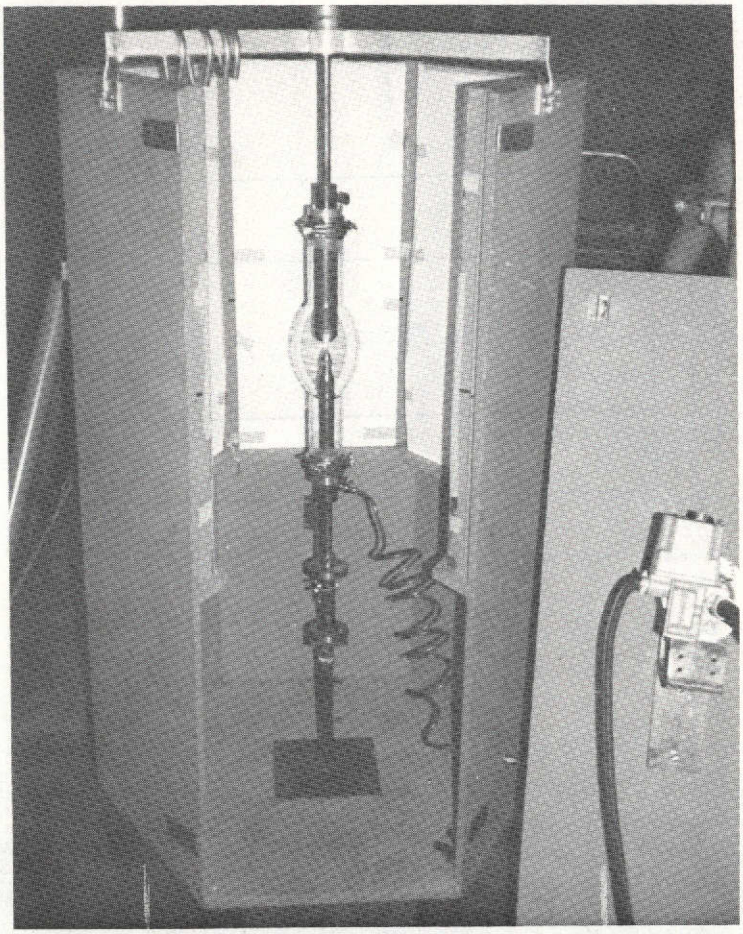

Figure 3. - A 20-kilowatt lamp mounted in test fixture.

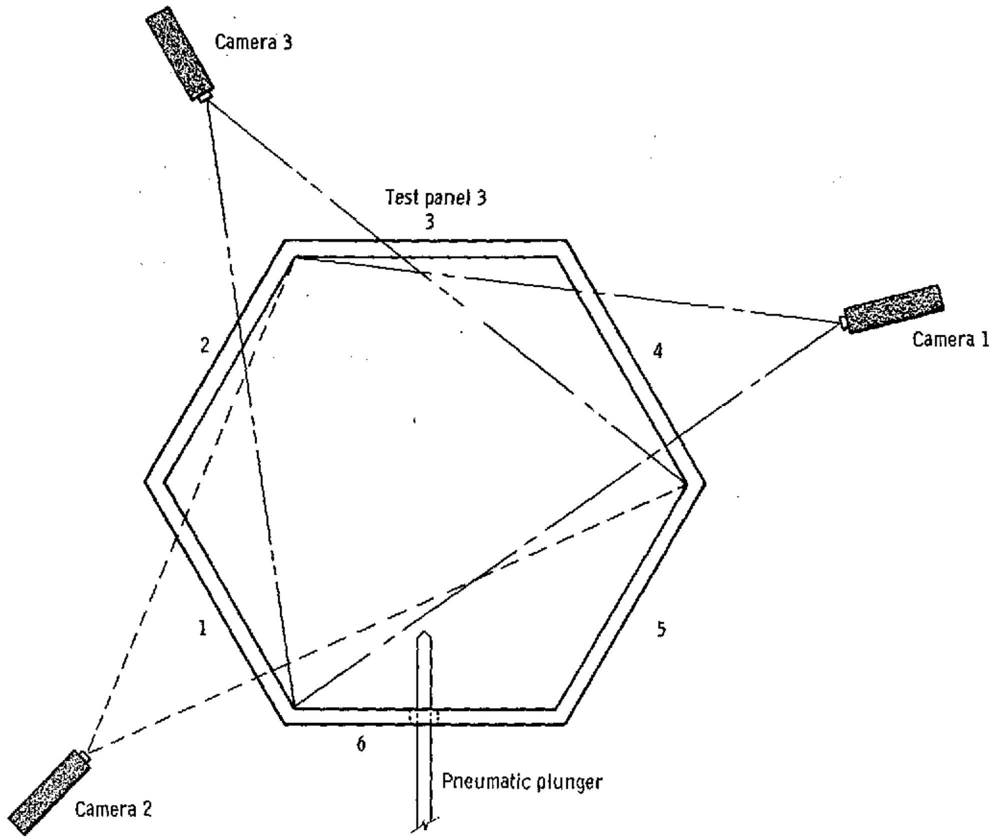

Figure 4. - Top view of test fixture and location of three high-speed motion-picture cameras.

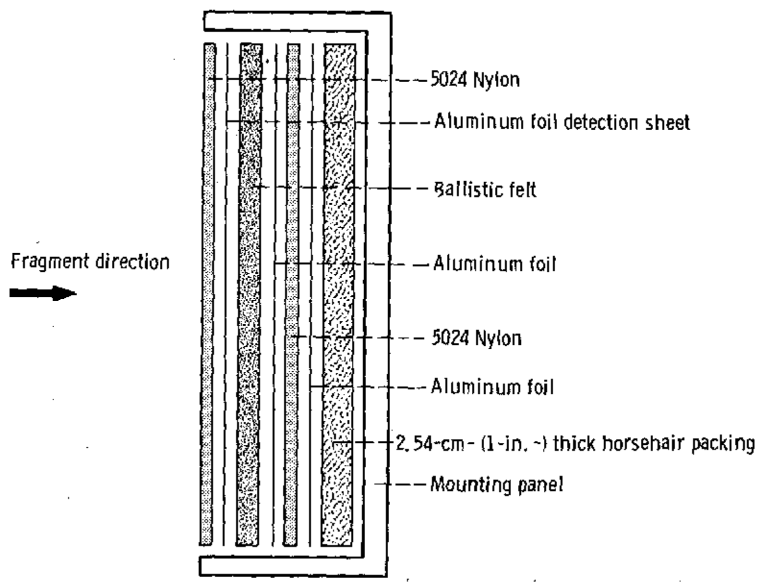

Figure 5. - Typical cross section of a test panel.

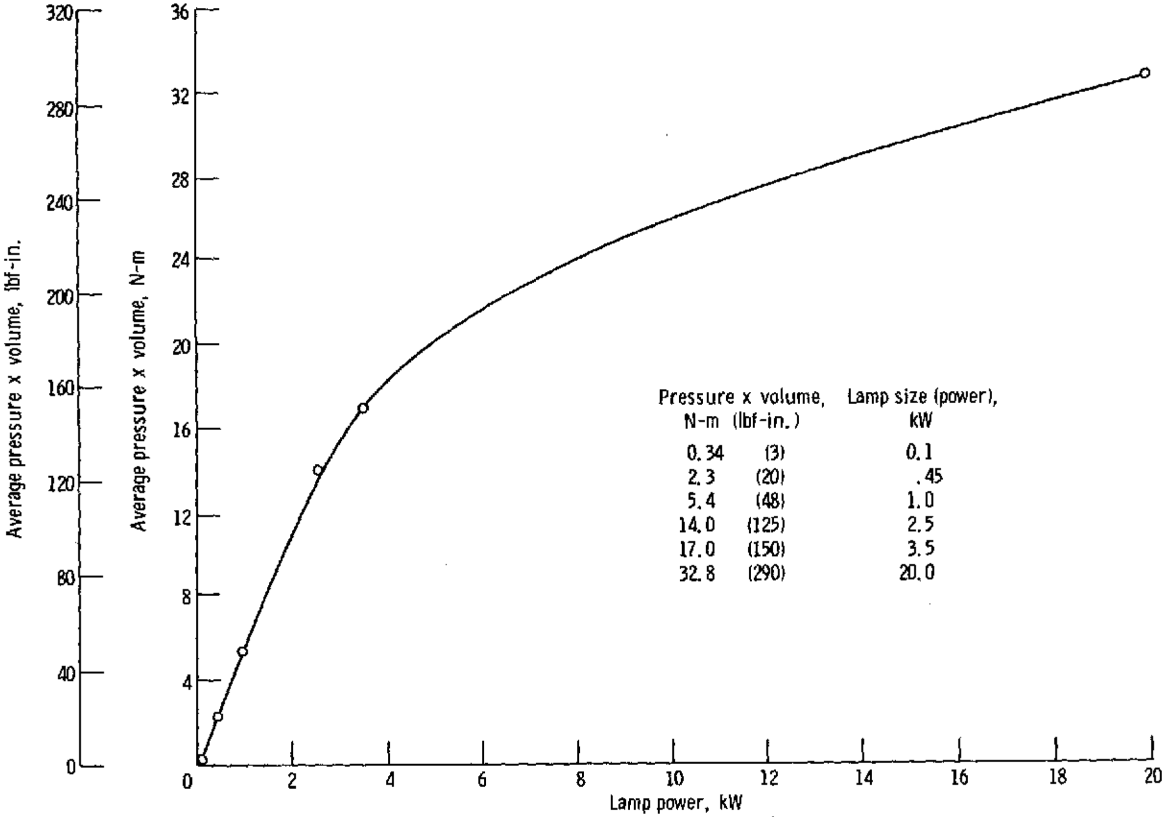

Figure 6. - Average pressure-volume curve as a function of lamp power. (Data obtained from V. L. Vaughan, NASA Langley Research Center.)

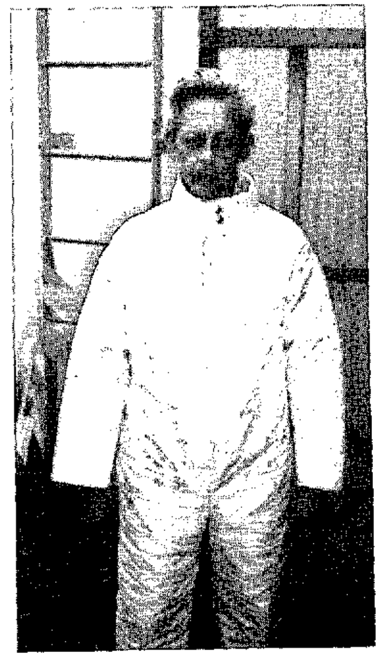

Figure 7. - New protective clothing (5024 nylon/ballistic felt/5024 nylon combination).

NASA-Langley, 1975 E-7933