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NONFLAMMABLE PBI FABRICS FOR PROTOTYPE AIR FORCE FLIGHT SUITS

STANLEY SCHULMAN
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TECHNICAL REPORT AFML-TR-70-178

NOVEMBER 1970

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The distribution of this report is limited because it protects technical know-how relating to critical products of manufacturing processes, tests and evaluation of military operational weapon systems.

FOREWORD

This report was prepared by the Fibrous Materials Branch, Nonmetallic Materials Division, and was initiated under Project Number 7320, "Fibrous Materials for Decelerators and Structures," Task Number 732002, "Fibrous Structural Materials." The work was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, with Stanley Schulman acting as Project Engineer.

The authors are indebted to personnel from both the Army Natick Laboratories and the Naval Air Development Center. Special appreciation is extended to the Test Directors, Mr. Earl Waldron of U. S. Army Natick Laboratories and Miss Alice Stoll of the Naval Air Development Center.

This report covers work conducted during the period of August 1969 through March 1970. The manuscript was released by the author in May 1970.

This technical report has been reviewed and is approved.


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ABSTRACT

Candidate flight suit fabrics have been evaluated along with current Air Force issue flight suit fabrics for personnel protection in simulated aircraft accident fires. Mannequins clothed in the various coverall fabrics were examined for average percent body area burned where second degree or worse burns occurred. Use of cotton and fire retardant treated cotton flight suits resulted in an average of greater than 60 percent body area burned. Nomex coveralls resulted in greater than 30 percent average body area burned. Polybenzimidazole (PBI), an experimental fiber developed by the Air Force Materials Laboratory, resulted on the average, less than ten percent body area being burned.

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SECTION II

INTRODUCTION

The Air Force Materials Laboratory is constantly looking for new and improved fibrous materials to meet the ever increasing needs of Air Force applications. Considerable research has been conducted by the Air Force and other cognizant organizations resulting in data on the thermal stability, weavability, yarn and fabric strengths, and heat transmission properties of experimental high temperature fibrous materials. Past studies have centered on personnel survival ranging from heat-resistant parachute packs and harnesses (Reference 1) to protection provided by wearing apparel (References 2-4). This investigation is concerned with the field evaluation of a series of candidate flight suit materials. The evaluations were conducted at the U. S. Army Natick Laboratories, Natick, Massachusetts and at the U. S. Naval Air Development Center, Johnsville, Pennsylvania test facilities.

The desirable characteristics for flight suit materials are nonflammability, low heat transmission, comfort, durability, and the ease of being fabricated into functional and desirable wearing apparel. Because of the lack of materials with the above qualities many lives have been lost or persons injured due to fires occurring in aircraft accidents.

Barring death upon impact or by asphyxiation the most common cause of death in a crash situation is immobilizing the victim due to injury from burns. Even those aircrewmembers that have escaped with their lives from fires have suffered severe incapacitating burn damage. Had a more effective thermal protection system been provided in the form of nonflammable materials some of the past injuries and fatalities could have been prevented. It is anticipated that through this type of evaluation, materials will be found that will provide superior thermal protection, as well as protection from direct flame contact, when compared to present commercial materials.

SECTION II

FIELD EVALUATION OF FLIGHT SUITS

1. OBJECTIVES

The purpose of the field evaluation was: (a) to study the behavior of single layer and double layer fabrics in flight suit configurations; (b) to make a comparison of standard issue cotton flight suits, Nomex flight suits, and Polybenzimidazole (PBI) flight suits; and (c) to determine the degree of protection provided by the flight suit assembly.

2. TESTING FACILITIES

a. U. S. Army Natick Laboratories, Natick, Massachusetts.

The U. S. Army test facility is a rectangular, ground level pit 30 feet in length and 20 feet in width. Twenty-five gallons of JP-4 Jet Fuel is floated on the surface of several inches of water which is used to provide an even dispersing system for the fuel. Three dividers are placed across the pit to ensure an even distribution of fuel. This system provides an excellent simulation of a "fuel-fed" fire. Fiberglass-epoxy mannequins were clothed in standard issue cotton underwear and flight suits. The clothed mannequins were drawn over the pit by a mechanical pulley system at the rate of ten feet per second to effect a resultant three second exposure time (Figure 1). The path of the mannequin is perpendicular to a fire wall coupled with an entrance doorway located at the far end of the pit. This prevents the possibility of exposing the dressed mannequin before the required entrance into the pit. The doors are mechanically opened by a "starter" approximately 75 feet away from the pit. A complete film description of this facility is on file at the Fibrous Materials Branch, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

The pit temperature has been recorded by a series of thermocouples placed in a vertical rack mounted in close proximity to the doors through which the mannequins are pulled. Temperatures of 1800 to 2300°F were recorded by these thermocouples.



Figure 1. U. S. Army Test Site

Calibrated paper temperature sensors were attached to the epoxy-coated mannequin and used to determine the average percent body area burned. The sensors have the following temperature indications:

169°F - No burn
200°F - 1st degree burn
221°F - 2nd degree burn
243°F - 2nd + degree burn
260°F - 3rd degree burn.

The sensors have white numerals on a black background. The white numerals disappear as the indicated temperature is reached. The sensors were calibrated by Natick Laboratories using Chester white pigs and a U. S. Army Solar Furnace.

b. U. S. Naval Air Development Center, Johnsville, Pennsylvania

The Naval Test Facility consists of a 25-foot square pit elevated approximately 1.5 feet above the ground (Figure 2). The test site is enclosed by a ten-foot solid fence with "port holes" for camera coverage. The dressed mannequin is rotated through the pit mechanically by a crane (Figure 3). The drive system is protected by a "fire wall." The mannequin is rotated from the backside of the fire wall to the pitside and then brought to a halt in the original starting position. This prevents further exposure of the mannequins due to radiant heat. The mannequin travels at ten feet per second through a circular path, across the 25-foot pit allowing a three second exposure in the flames. The speed of the mannequin can be controlled in two ways (a) the position of the mannequin along the crane arm and (b) the speed the crane arm moves across the pit. Since the exposure point is critical, NADC tries to maintain the path of the mannequin through the center of the pit. Twelve gallons of aviation fuel are used for each exposure.

Calibrated paper sensors are mounted on a leather covered mannequin to measure the amount and extent of burns. The paper sensors were calibrated against white rats and human skin; the "degree" of burn is recorded by color changes matched against a calibrated chart:

Neutral (green) - No burn recorded
Orange - 2nd degree burn
Red - 3rd degree burn.

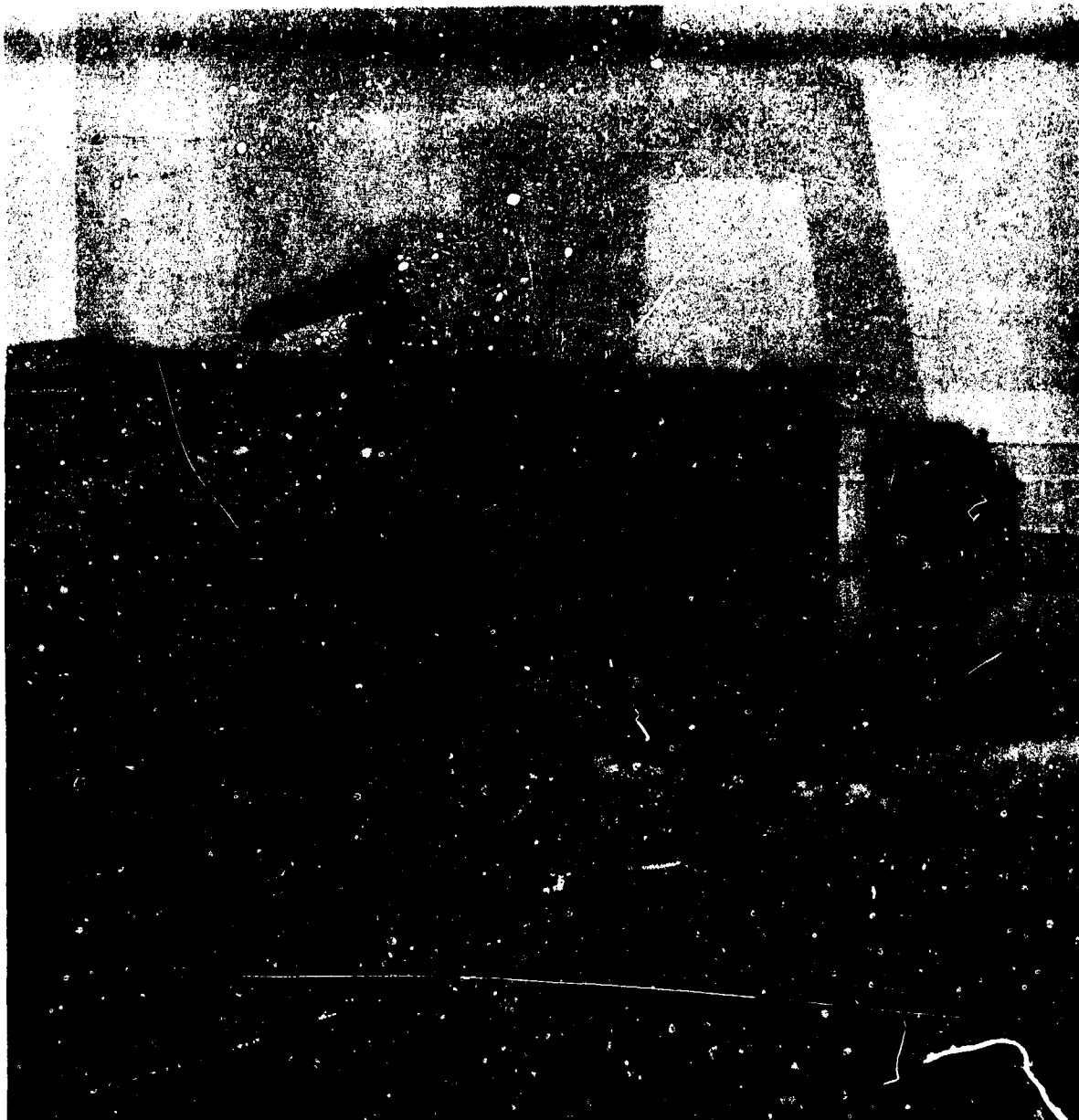


Figure 2. NADC Test Site - Front



Figure 3. NADC Test Site - Rear

3. TEST SCHEDULE

a. U. S. Army Natick Laboratory, Test Facility, Maynard, Massachusetts, 24-25 September 1969, suits 1 through 6.

b. U. S. Army Natick Laboratory, Test Facility, Maynard, Massachusetts, 16-18 November 1969, suits 7 through 16.

c. U. S. Naval Air Development Center, Johnsville, Pennsylvania, 8-10 December 1969, suits 19 through 31.

4. FABRICS

The fabrics and suit designations are listed in Table I.

5. ANALYSIS OF TEMPERATURE SENSORS

Table II gives an analysis of the percent of body area damaged showing second and third degree burns. Verbal descriptions of some of the exposed suits, underwear, and mannequins are made in paragraph 6. These are general comments extracted from extensive descriptive and photographic coverage on file at the Fibrous Materials Branch.

6. ANALYSIS OF SUIT SYSTEM

The following analysis was conducted by personnel of the Fibrous Materials Branch at Natick Laboratories. A verbal description of each system was made followed by taking extensive photographs. The analysis was made in the following manner; first a description was prepared of the uniformed mannequin both front and rear, then pictures were taken recording the damage to the flight suit, next the flight suit was removed and a description of the undergarments was prepared followed by photographs. The nude mannequin was analyzed in a like manner.

The following comments are pertinent to suits evaluated at Natick and Johnsville:

a. Untreated Cotton Coveralls - all AF stock items, 5.0 oz/yd², fabric, FSN #8415-215-7383 (Figure 4) Natick Test Facility.

Uniform - entire back destroyed
- front partially destroyed and badly charred; only the seams and zippers remained intact

TABLE I
FABRICS AND SUIT DESIGNATIONS

ARMY FACILITY, 24-25 SEPTEMBER 1969		
1. Cotton Flight Suit		
Std. AF Issue 8415-215-7383, 2/1 twill weave, 4.5 oz/yd ²		IC
2. Nomex Flight Suit		
CWU 27/P, 4.4 oz/yd ² , 2/2 twill weave		2N
3. Same as IC		4C
4. Same as 2N		5N
5. PBI Flight Suit		
4.8 oz/yd ² , 3/3 twill weave		6PBI
ARMY FACILITY, 16-18 NOVEMBER 1969		
1. Cotton - Issue same as IC		7C
2. Hooker Treated Cotton		
6.2 oz/yd ² , 2/1 weave		9H
3. PBI 1106		
4.8 oz/yd ² , 3/3 twill weave		10P
4. PBI 1116		
2.8 oz/yd ² , 2/1 twill weave, 2 layers		12P
5. FRL Treated (stabilized)		
6.2 oz/yd ² , 2/1 twill weave		13TP
6. PBI 1109		
2.8 oz/yd ² front, 4.7 oz/yd ² back and pockets		14P
7. PBI 1112		
6.2 oz/yd ² front, 2 layers of 2.8 oz/yd ² back		15P
8. PBI 1114		
4.7 oz/yd ² front, 2 layers of 2.8 oz/yd ² back		16P
NAVY FACILITY, 9-10 DECEMBER 1969		
1. Nomex - Issue same as 2N		20N
2. PBI 1103A		
4.7 oz/yd ² , 2/1 twill weave		22P
3. PBI 1104 - Same as 6P		23P
4. PBI 1108 - Same as 11P		24P
5. PBI 1113 - Same as 16P		
4.7 oz/yd ² front, 2/1 twill, 2 layers 2.8 oz/yd ²		27P
6. Navy Flight Suit / Nomex Thermo Underware		
3.2 oz/yd ²		29N
7. Navy Suit - Nomex		
Single front, double back, 4.5 oz/yd ² , 2/1 twill weave		30N
8. Cotton - Same as IC; PBI Summer Underwear		31CP

TABLE II
FLIGHT SUIT VARIATIONS
(10 fps - 3 seconds)

Suit No.	Fabric Weight (oz./yd ²)	2" burns (%)	3" burns (%)	Total burns (%)	Fabric	Conditions Facility-Exposure	Remarks
1C	5.0	27	27	54	Cotton (MIL-C-5039)	Natick - good	Suit destroyed.
4C	5.0	10	74	84	Cotton (MIL-C-5039)	Natick - good	Suit destroyed.
7C	5.0	37	20	57	Cotton (MIL-C-5039)	Natick - good	Suit destroyed.
9H	4.9	48	17	65	Fire retardant Cotton (MIL-C-18387)	Natick - good	Suit egressed in-tact. Fell apart when mannequin was moved.
2N	4.3	14	28	42	Nomex (MIL-C-43600)	Natick - good	Suit partially destroyed.
5N	4.3	8	26	34	Nomex (MIL-C-4360C)	Natick - good	Suit partially destroyed.
20N	4.3	9	4	13	Nomex (MIL-C-43600)	Johnsville - very poor	Left side of suit showed most damage.
6P	4.8	8	12	20	PBI (16-24)	Natick - good	Suit intact.
10P	4.8	4	0	4	PBI (16-24)	Natick - good	Suit showed very little damage.
23P	4.8	-	-	28	PBI (16-24)	Johnsville - poor	Left side of suit showed minor scorching.

TABLE II (CONTD)

Suit No.	Suit Configuration	2° burns (%)	3° burns (%)	Total burns (%)	Conditions Facility-Exposure	Remarks
29N	Navy (Nomex) summer flight suit over Nomex Thermo underwear	3.5	0	3.5	Johnsville - good	Suit continued to burn after it was removed from the fire pit area. Suit was completely destroyed.
30N	4.5 oz/yd ² front/2 ² layers of 4.5 oz/yd ² back, all Nomex	6.7	10.5	17.2	Johnsville -good	Suit continued to burn after removal from pit area. The outer layer on the rear was completely burned off.
12P	2 layers of 2.8 oz/yd ² PBI, entire suit	0	0	0	Natick - good	Outer layer scorched; under-layer was undamaged.
14P	4.7 oz/yd ² pocket fabric and suit back fabric with 2.8 oz/yd ² suit front fabric	0	0	0	Natick - fair	Very little damage to suit. Slight wind.
15P	6.2 oz/yd ² front and 2 layers of 2.8 oz/yd ² back	0	0	0	Natick - fair	Suit showed very little damage. Slight wind.
16P	4.7 oz/yd ² front and 2 layers of 2.8 oz/yd ² back	1.9	0	1.9	Natick - good	Very good exposure. Suit showed little scorching.
24P	6.2 oz/yd ² PBI entire suit	0	0	0	Johnsville - good	Suit showed minor damage. Good exposure
27P	4.7 oz/yd ² front and 2 layers of 2.8 oz/yd ² back PBI	3.5	0	3.5	Johnsville - good	Suit showed uniform exposure. Good exposure.

TABLE II (CONTD)

Suit No.	Suit Configuration	2" burns (%)	3" burns (%)	Total burns (%)	Conditions Facility-Exposure	Remarks
31CP	5 oz/yd ² cotton flight suit over PBI long underwear	0	0	0	Johnsville - poor	Suit undamaged except on left side
13TP	Heat stabilized PBI 6.2 oz/yd ² flight suit	0	0	0	Natick - good	Multiple exposures. Suit showed no damage.
19C	5 oz/yd ² cotton flight suit over PBI long underwear	13.0	23.2	36.2	Johnsville	First exposure suit undamaged; second exposure suit was totally destroyed. Only zippers remained. PBI underwear was completely exposed. Underwear was intact.



Figure 4. Cotton (USAF Issue) - 1C

Underwear - badly charred, scorched, and partially burnt
Mannequin - badly stained, scorched, and charred. The sensors indicated severe burns - Items 1C, 4C, 7C; three mannequins had an average burn area of 65%.

One mannequin, 19C, was dressed with a standard cotton uniform and PBI long underwear. The suit was totally consumed but the PBI underwear remained intact and the burn area was reduced to 36.2%. This mannequin was evaluated at the Navy Johnsville Facility (Figure 5). In all cases the cotton suits were on fire when they egressed from the test pit. Fire extinguishers had to be used to put out the burning areas.

- b. Treated (Hooker) Cotton Coveralls - 6.2 oz/yd², 8415-421-1870, CWR-76/p

The mannequin dressed in the treated cotton sustained 65% body burns (9H); (Figure 6) Natick Test Facility.

Uniform - badly charred and brittle; the uniform remained intact but came apart when handled

Underwear - charred and scorched

Mannequin - heavy staining (tar deposits); scorching.

The mannequin emerged from the fire with flames emanating from the suit, but they were self extinguishing; a large amount of smoke evolved as it traveled away from the fire.

- c. Nomex Coveralls - 4.5 oz/yd², USAF issue CWU 27/p (Natick Test Facility).

Uniform - back badly scorched, brittle, and destroyed in large areas
- zippers, velcro, and seams intact
- front scorched and brittle; some areas destroyed
- entire uniform badly shrunken.

The flight suits egressed from the pit on fire and fire extinguishers or wet sponges had to be used to put out the burning or smoldering areas (Figure 7).

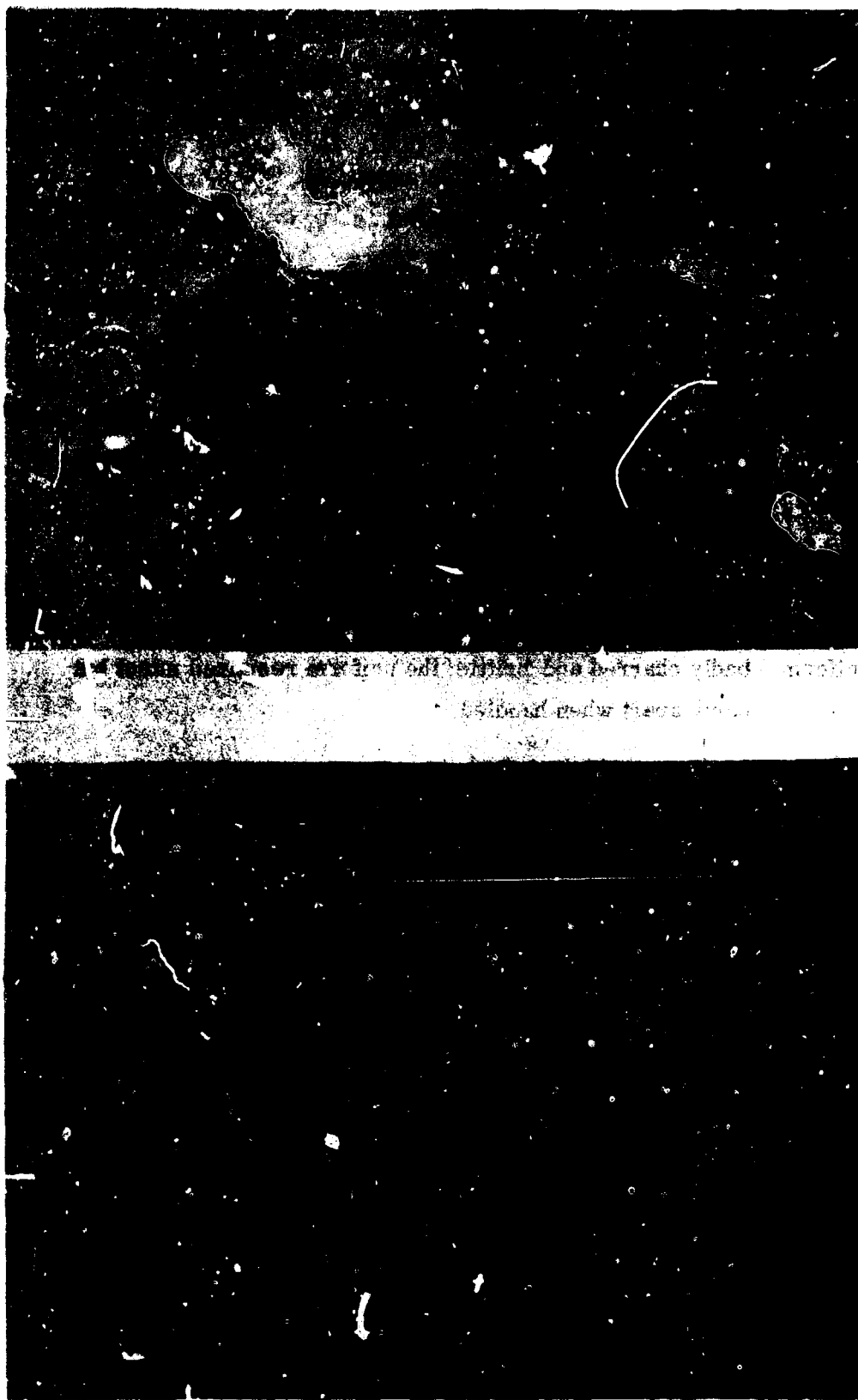


Figure 5. Cotton (USAF Issue) Over PBI Long Underwear - 31CP



Figure 6. Fire Retardant (Hooker) Cotton - 9H



Figure 7. Nomex (USAF Issue) - 5N

- Underwear - partially destroyed, smoke stained, and charred
 - green dye stains prevalent
- Mannequin - dye and smoke stained; back of thigh and buttocks badly scorched.

The burn area for the Nomex flight suits was 38% (flight suits 2N and 5N). The exposure of suit 20N, as shown by film coverage, was very poor.

The ability of a double layer of fabric to provide increased thermal protection over conventional single layer construction suits was evidenced by suit 30N. The double layer of 4.5 oz/yd² fabric on the backside of the suit limited the burn area and resulted in overall average of 17.2% body area burned (Figure 8). This was a 4.5 oz/yd² fabric.

The use of thermoknit underwear further increased the thermal protection as evidenced by 29N. The temperature sensors registered 0% body area burned. The Nomex suit (3.2 oz/yd²) was badly burned and destroyed in sections, yet the underwear was intact and relatively undamaged (Figure 9). Suits 29N and 30N were evaluated at the Johnsville (Navy) Test Facility.

d. PBI Flight Suit - 4.7, 4.8 oz/yd² fabrics (Figure 10)

Uniform - entire uniform was intact in all cases. Some surface areas were charred and stiff; this was mainly on the backside of the suit around the buttocks and thighs. Shrinkage was observed around the feet.

Underwear - minimum scorching around buttocks.

The 6.2 oz/yd² and double layer suits were not averaged because the suits exhibited very little damage and the underwear was undamaged. The average body burns recorded on the mannequins at Natick and Johnsville, ranged from zero to 3.5%. The suits fabricated from a double layer of lightweight PBI fabric (2.85 oz/yd²) had the outer layer charred and brittle but the underlayer of the same material was undamaged. Various combinations of constructions and weights were evaluated, 12P (Figure 14), 14P, 15P, 16P, 24P (Figure 15), and 27P (Figure 16), and % body area burned for all cases was significantly below other PBI burn data.

Exploratory development is continuing to "heat stabilize" PBI yarn and/or fabric in order to prevent shrinkage. Pieces of fabric were treated and fabricated into a flight suit. The fabric was extremely stable and the mannequin showed no (0%) burn damage (Figure 17).

The average burn area for the 4.7 and 4.8 oz/yd² fabric suits for a single three second exposure was 8%. The suits were scorched (Figure 11) but very little heat passed through the clothing ensemble. One mannequin was provided with a PBI flight glove fabric and an equivalent Nomex glove fabric (Figure 12). The PBI fabric did not shrink nor become brittle. The Nomex fabric burned, had to be extinguished, and the fabric shrank away from the fingers becoming brittle.

One suit, at Johnsville, was exposed twice for a total of six seconds and received (due to poor wind conditions) most of the exposure on the left side. The suit allowed 28% body burns but this value is very doubtful. The suit egressed from the pit in good condition and showed very little charring. The extreme heat conditions can be seen in Figure 13.



Figure 8. Nomex (Single Layer Front/Double Layer Back) - 30N

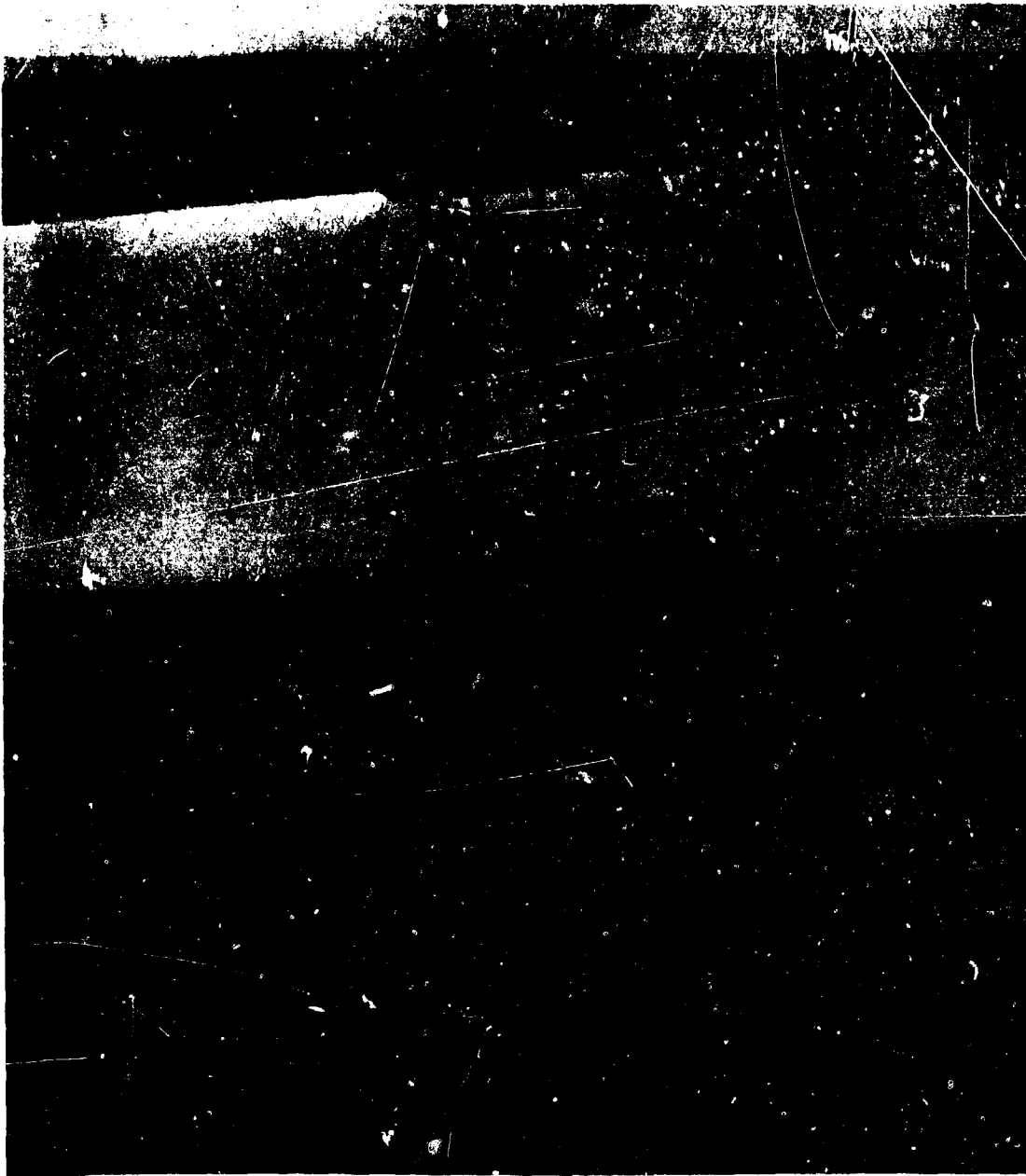


Figure 9. Nomex (Navy Issue) Over Nomex Thermal Underwear - 29N



Figure 10. PBI -6P (PBI Simplex Glove Fabric Removed from Left Hand)

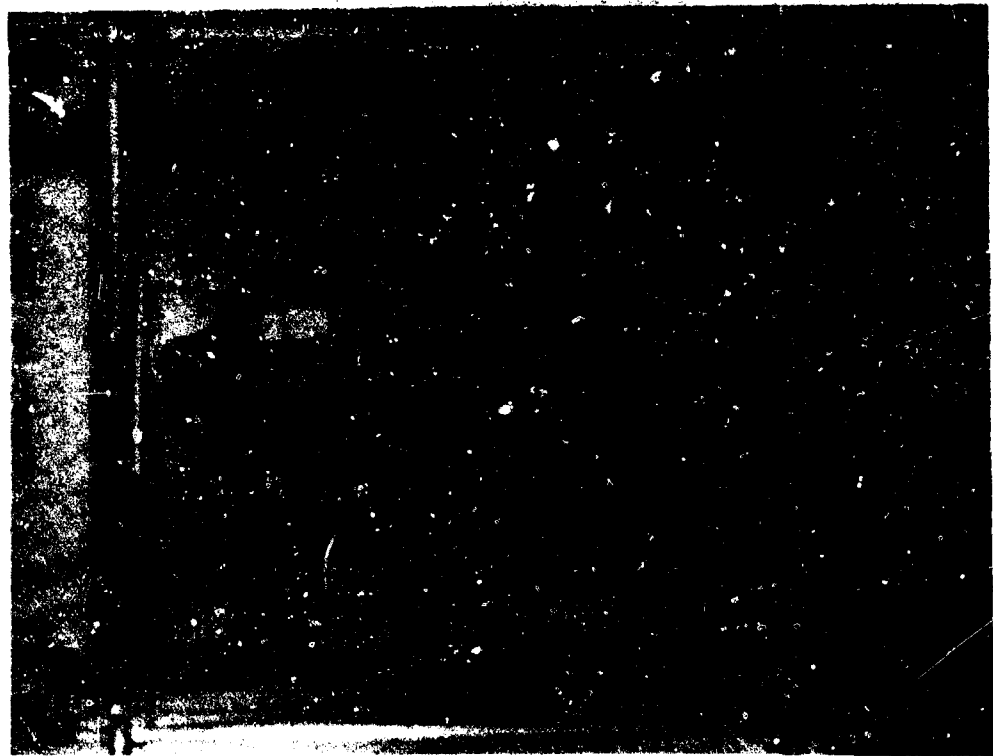
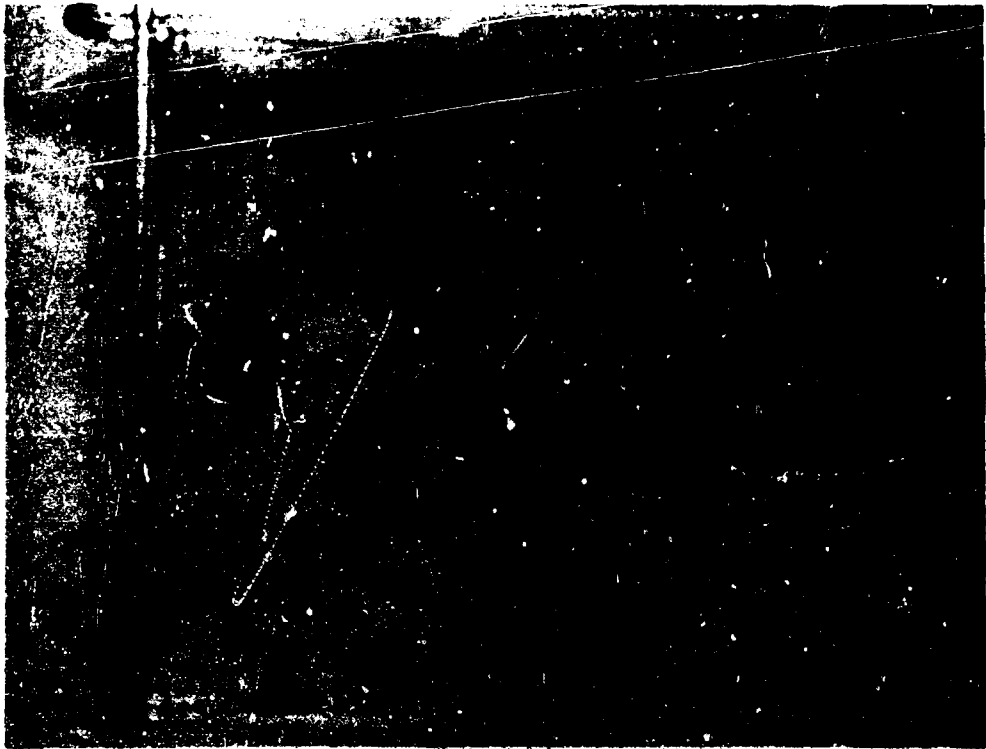


Figure 11. PBI - 10P



Figure 12. PBI (PBI Glove - Left Hand, Nomex Glove - Right Hand) - 6P



Figure 13. PBI - 23P



Figure 14. PBI - 12P

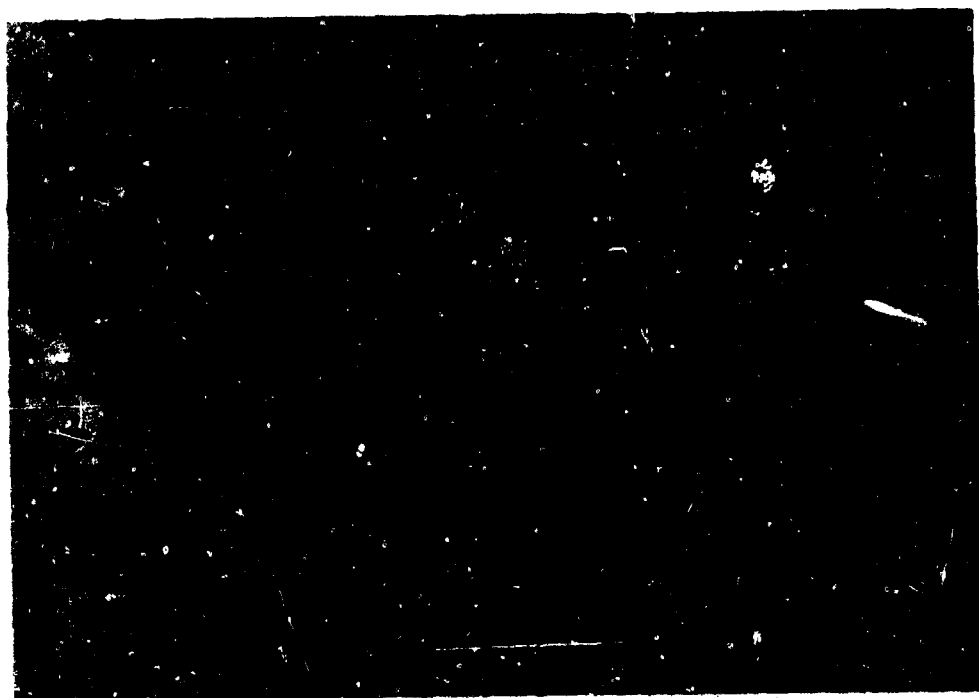


Figure 15. PBI - 24P



Figure 16. PBI - 27P

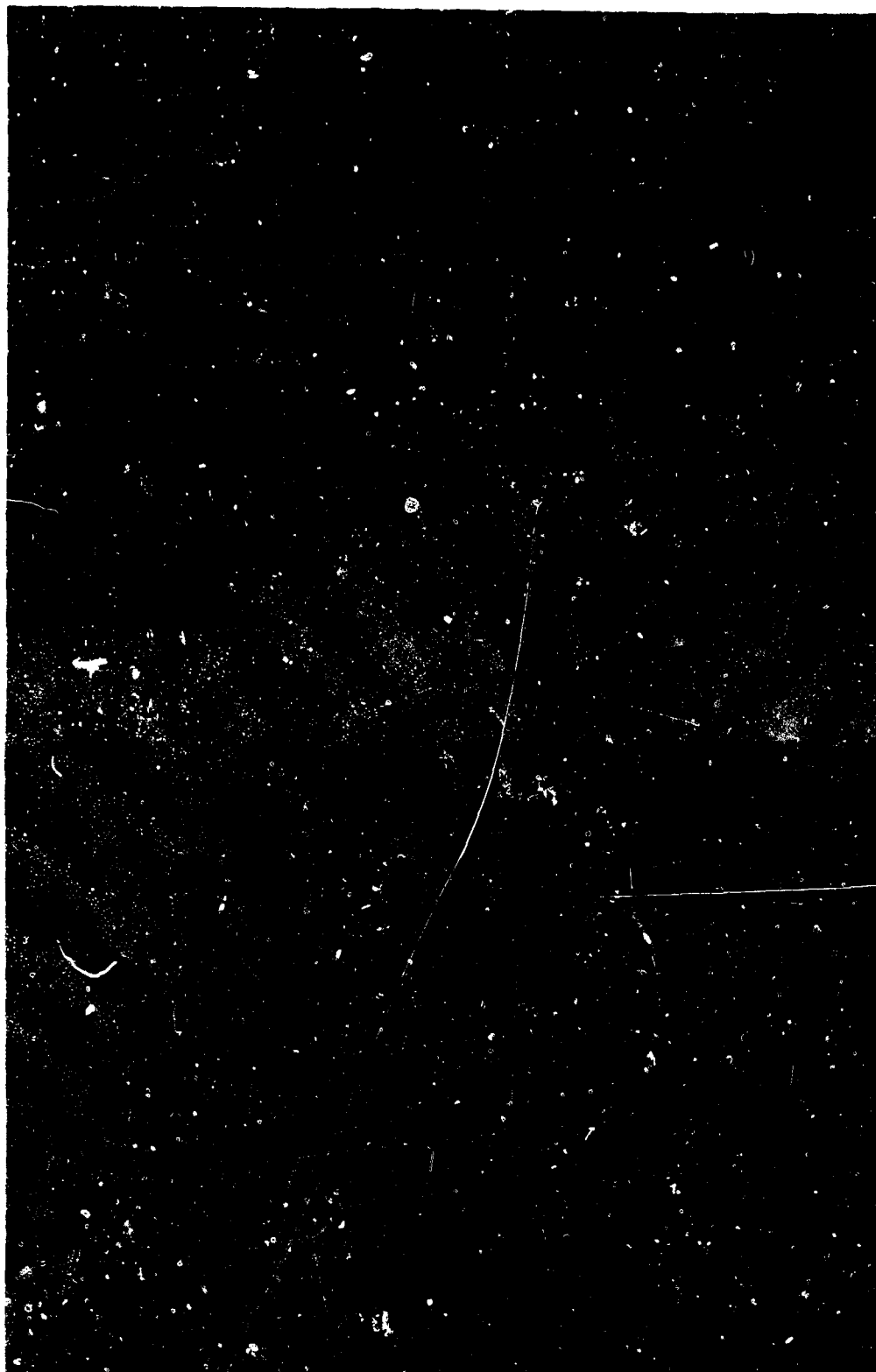


Figure 17. PBI (Heat Stabilized) 15RP

SECTION III

OBSERVATIONS AND CONCLUSIONS

The results of the field evaluation using JP-4 fuel or Aviation Gasoline show the PBI fabrics in flight suit configurations to be superior to all materials presently being used or that are being considered for use at the time of these tests. The fabrics exhibited properties predicted from laboratory tests. (Heat transfer data on the fabrics evaluated in this field test and other new materials will be published in the near future in an AFML Technical Report.)

It is quite evident from the field data, personal observations, and pictorial coverage that the evaluations conducted at the Natick Test Facility were quite reliable and reproducible. In all cases the weather conditions had to be considered before interpretation of the data could be made. It should be noted that in all tests the Nomex covering for the hands and feet burned severely and left the extremities exposed. In all exposures the Nomex flight suit fabrics emerged from the test pit burning regardless which facility was used. The Nomex fabrics shrank severely and broke apart leaving large areas of the mannequin exposed.

The tests conducted at the Johnsville Facility resulted in very questionable data. This was due to the adverse weather conditions and the newness of the test site. The wind and method of fuel dispersion created an uneven fire. For all tests, the left side of the coverall received more damage. This could be from heat "feed-back" from the U shaped wall.

Changing the fabric weave, density, permeability, or thickness can alter the thermal protection. The suit fabricated from the 3/3 twill showed less heat transmission than the 2/1 twill. This fabric was thicker than the 2/1 twill but it lacked abrasion resistance. The combination of double layer lightweight fabrics and those with a single layer front and a double layer back showed superior thermal protection (Table I) as compared to single layer flight suits.

The PBI material for flight suits showed excellent thermal protection and fire resistance. This fiber has better nonflammability characteristics than any candidate material evaluated to date. A 600-suit wear test of flight suits of 4.7 ounce/sq yd, 2/1 twill PBI fabric will be initiated in 1970.

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13. ABSTRACT Candidate flight suit fabrics have been evaluated along with current Air Force issue flight suit fabrics for personnel protection in simulated aircraft accident fires. Mannequins clothed in the various coverall fabrics were examined for average percent body area burned where second degree or worse burns occurred. Use of cotton and fire retardant treated cotton flight suits resulted in an average of greater than 60 percent body area burned. Nomex coveralls resulted in greater than 30 percent average body area burned. Polybenzimidazole (PBI), an experimental fiber developed by the Air Force Materials Laboratory, resulted on the average, less than ten percent body area being burned.			

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14. KEY WORDS	LINK A		LINK B		LINK C	
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