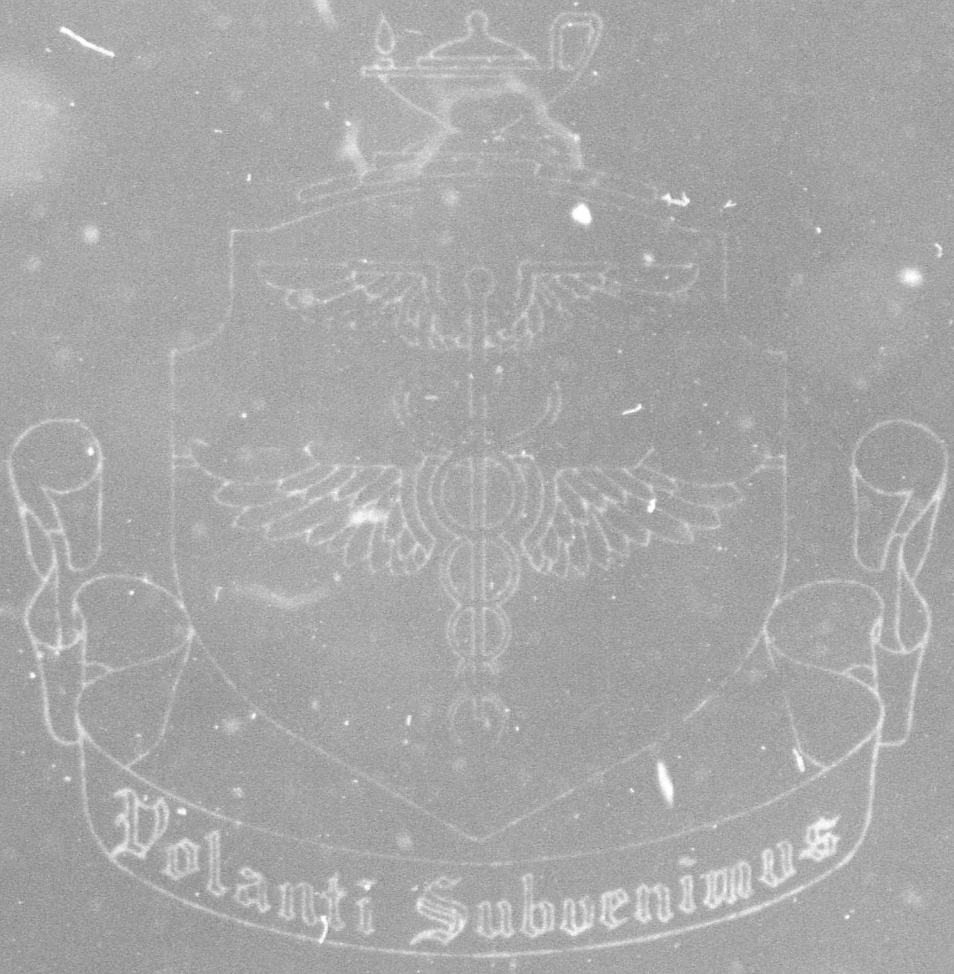

FLAME PROTECTION AFFORDED MICE BY A NONCOMBUSTIBLE GARMENT IN 100% OXYGEN ATMOSPHERES

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FOREWORD

This report was prepared in the Environmental Systems Branch under task No. 793002. The work was accomplished between 24 May 1967 and 8 June 1967. The report was submitted for publication on 12 July 1967.

The experiments reported herein were conducted according to the "Principles of Laboratory Animal Care" of the National Society for Medical Research.

The authors express their appreciation for the assistance of Miss Ann Roberts and Master Sergeant William Henderson in the conduct of this study.

This report has been reviewed and is approved.

GEORGE E. SCHAFER
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Commander

ABSTRACT

Thirty-nine mice, with hair clipped or unclipped, were clothed in a noncombustible garment, Beta cloth, and subjected to flame ignition in 100% oxygen atmospheres from 744 to 190 mm. Hg total pressure. The experimental results showed that the noncombustible garment afforded protection from combustion and flame propagation only if the animal's hair had been previously clipped. Further studies should be conducted in an effort to assure man's protection.

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I. INTRODUCTION

Since the tragic deaths of chamber occupants and astronauts owing to fires in enriched oxygen atmospheres in an Air Force research chamber, a Navy decompression chamber, and the Apollo capsule, much discussion has been carried out on the need for a noncombustible garment to protect the human body. It has been surmised that the protective garment should have two functions. First, it should be noncombustible; and second, by adhering closely to the body, it should prevent flame propagation by body hair and possibly the outer skin layer.

Before the tragic fires, much work had been accomplished on the combustion of many types of materials in various atmospheres, as surveyed by Roth (5). More recently, a description of flame propagation has been put forth by Huggett et al. (4), and the testing of several noncombustible cloths was reported by Cook et al. (1) in their extensive literature survey. Of special interest to all who work in research chambers are the combustion and flame propagation studies on animals. An early test by Hall and Fang (3) forewarned of the danger of fire in oxygen atmopheres, and the recent extensive and very dramatic tests by Denison et al. (2) vividly point to the need for effective fire prevention and fire suppression.

Several questions were raised during the USAF Aerospace Medical Division Conference on "Fire Hazards and Extinguishment" held at Brooks Air Force Base, 23 May 1967. Some of these questions, which are delineated below, were used as a guide in conducting the combustion tests in this report.

By using a noncombustible covering that adhered closely to the body:

1. Would a flame propagate beneath such a garment in a 100% oxygen atmosphere?

2. Would a combustion process occur beneath such a garment if a flame impinged on the garment?

3. Would there be a marked difference in the results to questions 1 and 2 if the animal's hair were removed?

4. Would there be a marked difference in the results to questions 1, 2, and 3 at different total pressures while maintaining a 100% oxygen atmosphere?

The authors felt that these queries could be probed by use of mice clothed in a Beta cloth garment. It was realized that the tests would not be conclusive or decisive, but would indicate whether further tests should be conducted. It was also hoped that a pattern might be observed which could evolve in further comprehensive research. Mice were chosen primarily because of availability and ease in handling, and also because they were of optimum size for the test apparatus. The small amount of Beta cloth required to cloth each mouse was a contributing factor in readily obtaining a swatch of this material from the Air Force Materials Laboratory. Beta cloth was selected because it is a prime contender for future protective garments.

Initially, 12 tests were intended, but because of several unexpected results, these tests had to be repeated; therefore, 39 combustion tests were performed to cover the spectrum of altitudes and configurations. The results from these experiments will be reported in this paper.

II. METHODS

The test apparatus (fig. 1) consists of an inverted desiccator jar (7.6 liters) sealed to an anodized aluminum plate with a silicon lubricant (Dow Corning, "High Vacuum Grease"). Ports are available through the aluminum plate opening into the desiccator jar for the vacuum pump (positioned beneath the test chamber), vacuum pressure gage, oxygen inlet, and electrical connectors. Applicable valves and switches are positioned beneath the test chamber. The desiccator jar is covered with a safety lid consisting of a heavy expanded metal screen inside a thick Plexiglas container.

A 100% oxygen atmosphere was achieved inside the test chamber by first reducing the chamber pressure to the desired millimeter of mercury reading and then performing a leak check. Next, an oxygen flush was performed by maintaining the desired millimeter of mercury pressure with 100% oxygen at a "12-pound" gage pressure setting with the vacuum valve in the full open position. It was previously determined by gas analysis that a 100% oxygen atmosphere was obtained in 3 minutes by this method. At the end of 3 minutes the valves were closed, the vacuum pump was turned off, and the oxygen line was disconnected before electrical power to the ignitor circuit was connected.

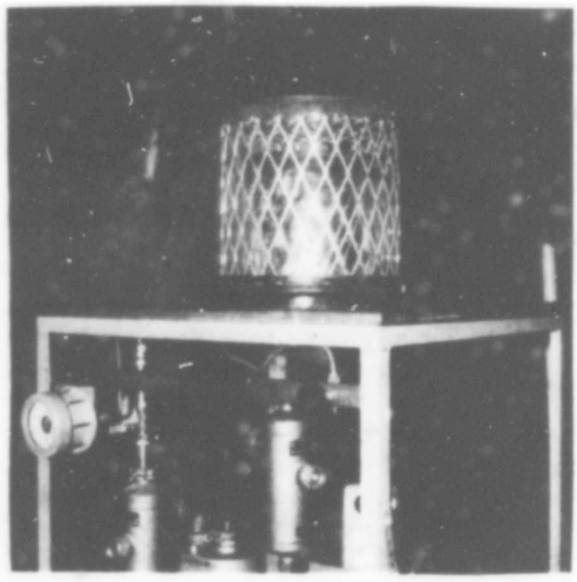

FIGURE 1

Test apparatus.

The flame for the tests was produced by using a paper safety match inserted headfirst into a coil of a space heating element. The safety match was cut to a length of 1 cm.

The space heating element (Eagle Brand, No. 660) was mounted in a ceramic receptacle. Teflon-coated wires were used internally in the chamber. The ignition actuating unit consisted of a fused, spring-loaded switch plugged into a wall outlet. In operation, the switch was held until the match ignited.

The mice were mounted on the vertical anodized aluminum support bracket by alligator clips clamped to the right front and right rear legs. In this manner, the mice were suspended horizontally and the match could be positioned vertically in the space heating coil unit which could be moved horizontally into the desired position.

White Swiss albino mice, averaging 35 gm. in weight, were used for the tests. All mice were killed with an injection of sodium pentobarbital. They were tested in three basic configurations: (1) with hair unclipped and wearing a Beta cloth torso tube; (2) with all the hair clipped and wearing a Beta cloth torso tube; and (3) with all the hair clipped and no Beta cloth covering. The hair was removed with standard electric hair clippers modified for small animals.

The Beta cloth (28 gage, 2 bar, tricot knit, Beta glass, style 2021, woven by Prodesco, Inc.) was sewed into snug-fitting tubes with Beta cloth thread. One edge of the cloth overlapped the other edge to make a seal. The mouse was pulled through the tube until the front legs were exposed. The tubes were cut to the desired length so that the hind legs were also exposed.

The flames on the mice were started at either of two positions for all tests, at 6 mm.

below the head in line with the ear for flame impingement on the unprotected surface, or at midtorso, 6 mm. below the body for flame impingement on the Beta cloth.

During the combustion process no attempt was made to maintain pressure, temperature, or oxygen concentration. After all traces of combustion had disappeared, room air was admitted to equalize the pressure and the mouse was removed for examination.

III. RESULTS

Of the 39 combustion tests performed, 37 tests were conducted in 100% oxygen atmospheres at four pressures (744, 380, 258, and 190 mm. Hg) and 2 tests were conducted in ambient atmosphere at ground level. The conditions for each test and the observed results are given in table I. In all the tests performed, it was observed that the portion of the animal lying against the vertical metal support bracket was not burned or even singed.

Test 1. Flame at exposed head.
Mouse unclipped.
Single layer of Beta cloth (tight fitting).
Test pressure: 380 mm. Hg, 100% oxygen.
Match burned for 13 seconds.
Mouse burned for 2 minutes, 30 seconds.

On ignition of the match there was an immediate flash fire of the head area followed by a sustaining hair fire. The fire progressed from the head to the hind legs beneath the Beta cloth. When the fire reached the exposed hind quarters, there was another flash fire followed by an intense hair fire. The animal was completely engulfed in flame within 25 seconds. Examination revealed that the hide had charred, leaving the muscle structure exposed but apparently not damaged. The Beta cloth did not burn; although in the area of the most intense fire, the cloth had become brittle and some small areas had melted away.

Test 2. Flame at exposed head.
Mouse unclipped.
Two layers of Beta cloth (tight fitting).
Test pressure: 380 mm. Hg, 100% oxygen.
Match burned for 13 seconds.
Mouse burned for 2 minutes, 20 seconds.

On ignition of the match there was an immediate flash fire of the head area followed by an intense hair fire. The fire progressed from the head to the hind legs beneath the Beta cloth. When the fire reached the exposed hind legs, there was a flash fire followed by intense burning. Examination revealed that the hide had charred, leaving the muscle structure exposed but undamaged. The Beta cloth did not burn; although in the area of the intense fire, the cloth was brittle and had melted away in some areas.

Test 3. Flame at protected torso.
Mouse unclipped.
Two layers of Beta cloth (encasing total animal).
Test pressure: 380 mm. Hg, 100% oxygen.
Match burned for 13 seconds.
Mouse burned for 3 minutes, 10 seconds.

After the match had burned for 4 to 5 seconds, a burning glow could be seen inside the closed Beta cloth tube. After approximately 30 seconds, a flame appeared on the outside of the Beta cloth tube. This flame continued to burn inside the lower surface of the closed Beta cloth tube until self-extinguishment at 3 minutes, 10 seconds from ignition. Examination of the external surface of the Beta cloth tube showed a blackened area ringed by yellow oily material. The Beta cloth was intact and had not burned. In the area of the most intense fire, the cloth was not flexible; however, no melted holes were observed. When the Beta cloth was removed from the mouse, the hide adjacent to the external fire area was consumed, leaving the muscle structure exposed. The mouse was burned over its entire surface. It appeared that the Beta cloth acted as a wick for the body lipids which melted and that enough heat from the combustion within the closed tube ignited the lipids and oils on the outside of the closed tube.

TABLE I

Results of combustion tests

Configurations	Total pressure and atmosphere				
	747 mm. Hg/ambient	744 mm. Hg/100% O_2	380 mm. Hg/100% O_2	258 mm. Hg/100% O_2	190 mm. Hg/100% O_2
Beta cloth garment—mouse hair not clipped					
Ignition at exposed head of animal; single layer of Beta cloth.			Tests 1 and 8: hair and skin burned.	Test 38: hair and skin burned.	Test 16: hair and skin burned on head.
Ignition at protected midtorso; single layer of Beta cloth.		Tests 22 and 23: hair and skin burned.		Test 11: hair and skin burned.	Test 30: hair and skin burned.
Ignition at protected midtorso; animal totally encased in Beta cloth; single layer of Beta cloth.			Test 3: hair and skin burned.	Test 14: hair burned, no propagation; test 15: hair and skin burned.	Test 31: hair and skin burned.
Ignition at exposed head of animal; double layer of Beta cloth.			Test 2: hair and skin burned.		
Beta cloth garment—mouse hair clipped					
Ignition at exposed head of animal; single layer of Beta cloth.		Test 21: hair and skin burned.	Test 6: hair and skin burned on head.	Tests 9 and 39: flash fire on head, ears burned.	Test 17: flash fire on head, ears burned.
Ignition at protected midtorso; single layer of Beta cloth.		Tests 19 and 20: no fire; test 24: flash fire on head.	Test 7: no fire.	Test 37: flash fire of hair.	Test 18: no fire.
Ignition at protected midtorso; animal totally encased in Beta cloth; single layer of Beta cloth.		Tests 25, 26, and 27: no fire.			Test 32: no fire.
Ignition at exposed head of animal; double layer of Beta cloth.			Test 4: hair and skin burned on head.		
Ignition at protected midtorso; double layer of Beta cloth.			Test 5: no fire.		
No Beta cloth garment					
Mouse hair clipped; ignition at midtorso.	Test 28: no fire, skin burned in flame area.		Tests 13 and 34: flash fire of hair.	Test 10: no fire; test 12: flash fire of hair on head; test 36: flash fire of hair.	Tests 33 and 35: no fire.
Mouse hair not clipped; ignition at midtorso.	Test 29: hair burned, restricted to flame area.				

Test 4. Flame at exposed head.

Mouse clipped.

Two layers of Beta cloth (loose fitting).

Test pressure: 380 mm. Hg, 100% oxygen.

Match burned for 12 seconds.

Mouse did not propagate the fire.

On ignition of the match an immediate flash fire on the head of the mouse occurred and lasted for 2 seconds (fig. 2); no burning other than the match was observed after that. Examination showed that the remaining hair on the exposed head of the mouse had burned and that the hide in the area of the flame had been consumed, leaving muscle structure exposed (fig. 3). Removal of the Beta cloth torso revealed that neither the hair nor the hide had burned. The exposed hind legs did not burn.

Test 5. Flame at protected torso.

Mouse clipped.

Two layers of Beta cloth (loose fitting).

Test pressure: 380 mm. Hg, 100% oxygen.

Match burned for 13 seconds.

Mouse did not burn.

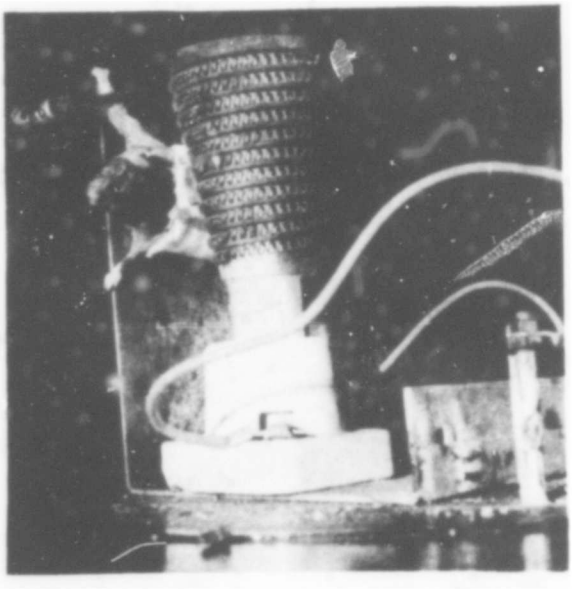

FIGURE 2

Ignition at head.

The match burned for 13 seconds with no other visual signs of combustion (fig. 4). Examination showed a slight gray discoloration on the exposed Beta cloth in the area of the match flame (fig. 5). When the Beta cloth was removed from the mouse, the only sign of any change was a small area, the size of a dime, where the hairs were singed and the skin slightly darkened at the point of the flame impingement (fig 6). No flash fire of the hair nor tissue burns were evident. The exposed hind legs did not burn.

Test 6. Flame on exposed head.

Mouse clipped.

Single layer of Beta cloth (loose fitting).

Test pressure: 380 mm. Hg, 100% oxygen.

FIGURE 3

Results of ignition at head. Clipped mouse wearing Beta cloth in 100% oxygen at 380 mm. Hg total pressure.

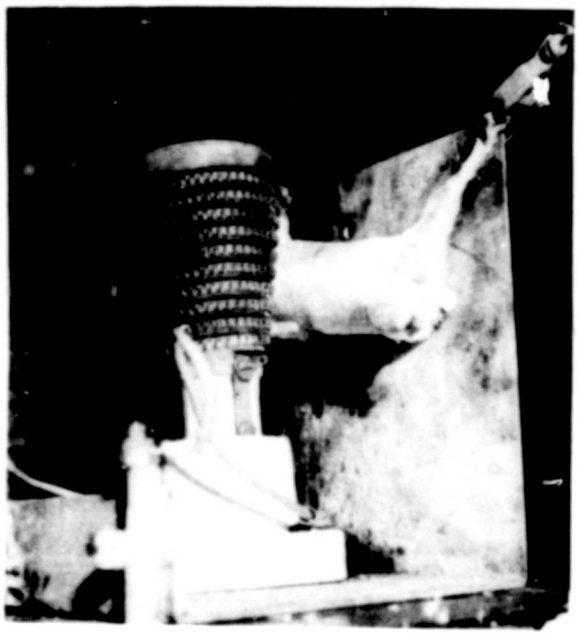

FIGURE 4

Ignition at midtorso.

Match burned for 13 seconds.

Mouse did not propagate the fire.

Immediately upon ignition of the match a flash fire on the head of the mouse occurred and lasted 2 seconds. No other fire was observed. Examination showed that the remaining hair on the mouse's head had burned. In the area of the match flame, there was intense destruction of the hide, leaving the muscle structure exposed. The hair and hide beneath the Beta cloth, the exposed hind legs, and the Beta cloth were not burned.

Test 7. Flame at protected torso.

Mouse clipped.

Single layer of Beta cloth (loose fitting).

Test pressure: 380 mm. Hg, 100% oxygen.

Match burned for 13 seconds.

Mouse did not burn.

Other than the match flame, no other burning was seen. Examination showed discoloration on the Beta cloth in the area of flame

FIGURE 5

Discoloration of Beta cloth at area of flame impingement.

impingement. The hair and skin showed considerable damage owing to the heat under the cloth in the limited area of the flame; otherwise, hair and tissue under the cloth were undamaged as were the exposed head and hind legs.

Test 8. Flame at exposed head.

Mouse unclipped.

Single layer of Beta cloth (loose fitting).

Test pressure: 380 mm. Hg, 100% oxygen.

Match burned for 12 seconds.

Mouse burned for 2 minutes, 25 seconds.

On ignition of the match there was an immediate intense flash fire followed by an intense fire. Periodically, blue and greenish

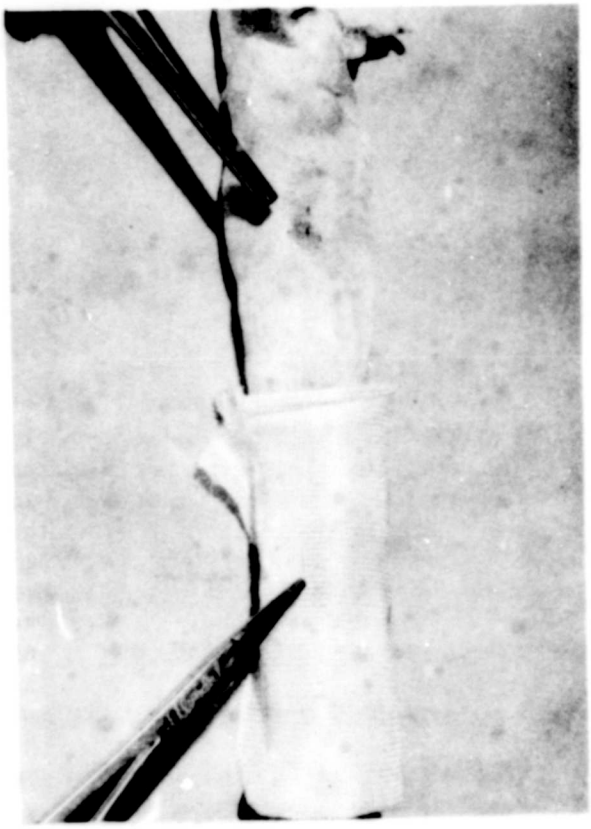

FIGURE 6

First-degree burns received from flame impingement on Beta cloth; clipped mouse in 100% oxygen at 380 mm. Hg total pressure.

flames shot out from the mouse. Examination showed complete combustion of the animal hide, with portions of the muscle structure exposed. The Beta cloth did not burn, but it was brittle and had melted in several areas.

Test 9. Flame at exposed head.
Mouse clipped.
Single layer of Beta cloth (loose fitting).
Test pressure: 258 mm. Hg, 100% oxygen.
Match burned for 14 seconds.
Mouse burned for 53 seconds.

When the match ignited, an immediate flash fire of the hair on the head occurred and lasted about 2 seconds. Combustion continued in the area of ignition after the match burned out. Examination revealed that the left ear and the immediate skin areas on the head were consumed, leaving the muscle structure exposed. No other burning was evident. The flash fire stopped at the Beta cloth; the areas beneath the Beta cloth, the exposed hind legs, and the Beta cloth were not burned.

Test 10. Flame at exposed hind legs.
Mouse clipped.
No Beta cloth covering.
Test pressure: 258 mm. Hg, 100% oxygen.
Match burned for 14 seconds.
Mouse did not burn.

There was some evidence of singeing on the hairs of the exposed area, but no hair fire nor tissue burns were evident.

Test 11. Flame at protected torso.
Mouse unclipped.
Single layer of Beta cloth (snug fitting).
Test pressure: 258 mm. Hg, 100% oxygen.
Match burned for 14 seconds.
Mouse burned for 1 minute, 9 seconds.

The mouse hair ignited and the burning progressed beneath the Beta cloth from the area of the match flame impingement on the Beta cloth. When the burning reached the unprotected head, there was an immediate flash fire of the hair followed by an intense burning. The fire, however, did not reach the exposed hind legs. The Beta cloth had "rolled" at the hind leg area, and the burning did not progress beyond this roll. There was no damage of hair or tissue on the side of the mouse adjacent to the vertical metal support.

Test 12. Flame at exposed head.
Mouse clipped.
No Beta cloth covering.
Test pressure: 258 mm. Hg, 100% oxygen.
Match burned for 12 seconds.
Mouse did not propagate the fire.

There was an immediate flash fire of the hair on the head. The fire consumed the hide in the area where the ignition was started but did not propagate along the exposed animal.

Test 13. Flame at exposed torso.
Mouse clipped.
No Beta cloth covering.
Test pressure: 380 mm. Hg, 100% oxygen.
Match burned for 12 seconds.
Flash fire of the hair over the entire animal.

As soon as the match was ignited, there was a flash fire of the hair over the exposed mouse. The hide did not propagate the fire even though there was severe burning of the match. The skin appeared to have only singed hair with slight skin discoloration from the flash fire of the hair.

Test 14. Flame at protected torso.
Mouse unclipped.
Mouse totally encased in Beta cloth (tight fitting).
Test pressure: 258 mm. Hg, 100% oxygen.
Match burned for 14 seconds.
Mouse did not propagate the fire.

Examination revealed a discoloration of the Beta cloth in the flame area. The mouse hair burned in the limited area of the flame, but no burning was evident outside the area of flame impingement.

Test 15. Flame at protected torso.
Mouse unclipped.
Mouse totally encased in Beta cloth (loose fitting).
Test pressure: 258 mm. Hg, 100% oxygen.
Match burned for 15 seconds.
Mouse burned for 45 seconds.

A small fire was observed progressing toward the hind legs from the point of flame impingement. Examination revealed that the hair and skin had burned in this area and where the flame had propagated beneath the loose-fitting Beta cloth. The burn area was, however, very limited, and there was no propagation of the fire toward the head where the Beta cloth was in close contact with the mouse.

Test 16. Flame at unprotected head.
Mouse unclipped.
Single layer of Beta cloth (loose fitting).
Test pressure: 190 mm. Hg, 100% oxygen.
Match burned for 12 seconds.
Mouse burned for 33 seconds.

Most noticeable in this test was the intense orange color of the match flame compared to the flames at 380 and 258 mm. Hg. When the match ignited, there was an immediate flash fire of the hair on the exposed head. The fire ignited the ear and adjacent skin and was observed for 11 seconds after the match was extinguished. No fire progressed beneath the Beta cloth, and the Beta cloth was not damaged.

Test 17. Flame at exposed head.
Mouse clipped.
Single layer of Beta cloth (loose fitting).
Test pressure: 190 mm. Hg, 100% oxygen.
Match burned for 14 seconds.
Mouse burned for 1 minute, 9 seconds.

On ignition there was an immediate flash fire of the hair on the exposed head, and the resulting fire consumed both ears. A very narrow band of slightly singed hair was found along the loose-fitting seam, starting at the head and going toward the hind legs. The singed line was 1.9 cm. long.

Test 18. Flame at protected torso.
Mouse clipped.
Single layer of Beta cloth (loose fitting).
Test pressure: 190 mm. Hg, 100% oxygen.
Match burned for 15 seconds.
Mouse did not propagate the fire.

Examination revealed a discoloration of the Beta cloth and hair and skin burns in the limited area of the ignition flame.

Test 19. Flame at protected torso.
Mouse clipped.
Single layer of Beta cloth (snug fitting).
Test pressure: 744 mm. Hg, 100% oxygen.
Match burned for 8 seconds.
Mouse did not propagate the fire.

Most noticeable in this test was the blue-white color of the match flame. Examination of the mouse revealed discoloration of the Beta cloth in the flame area and hair and skin burns beneath the Beta cloth. There was no other damage to the animal.

Test 20. Flame at protected torso.
Mouse clipped.
Single layer of Beta cloth (snug fitting).
Test pressure: 190 mm. Hg, 100% oxygen.
Match burned for 9.5 seconds.
Mouse did not propagate the fire.

Examination of the mouse revealed a discoloration of the Beta cloth in the area of the attempted ignition. The animal had hair and skin burns under the Beta cloth where the flame had been. There was no flame propagation on the animal itself.

Test 21. Flame at exposed head.
Mouse clipped.
Single layer of Beta cloth (snug fitting).
Test pressure: 744 mm. Hg, 100% oxygen.
Match burned for 9 seconds.
Mouse burned for 8 minutes, 45 seconds.

On ignition there was an immediate flash fire of the hair followed by a rapid and intense tissue fire at the exposed head; the fire then progressed slowly beneath the Beta cloth. There was a second flash fire of the hair when the burning reached the exposed hind legs followed by an intense tissue fire in this area. The Beta cloth did not burn but was brittle when the animal was removed. Skin and extremities were consumed, but muscle structure and viscera were apparently intact.

Test 22. Flame at protected torso.
Mouse clipped.
Single layer of Beta cloth (tight fitting).
Test pressure: 744 mm. Hg, 100% oxygen.
Match burned for 8 seconds.
Mouse burned for 18 seconds.

A spark from the match started a flash fire of the hair on the hind legs. This fire was restricted to the exposed hind legs and did not progress beneath the Beta cloth. The mouse skin did not catch on fire on the hind legs, but severe blistering was evident. In the area of the match flame there was discoloration of the Beta cloth and the hair and skin showed evidence of fire damage where the heat had been intense. The unprotected head was not affected.

Test 23. Flame at protected torso.
Mouse clipped.
Single layer of Beta cloth (snug fitting).
Test pressure: 747 mm. Hg, 100% oxygen.
Match burned for 7.5 seconds.
Mouse burned for 8 minutes, 10 seconds.

On match ignition there was an immediate flash fire of the hair; the fire spread beneath the Beta cloth. The left hind leg rapidly became consumed by the flame, and this initiated a skin fire, which slowly progressed toward the head. Examination of this animal revealed that the Beta cloth had not burned per se but had become very brittle. The skin and extremities of the animal were consumed; however, the muscle structure on the torso and the viscera apparently were not damaged.

Test 24. Flame at protected torso.
Mouse clipped.
Single layer of Beta cloth (loose fitting).
Test pressure: 747 mm. Hg, 100% oxygen.

Match burned for 9 seconds.

Mouse burned for 12 seconds.

A spark from the match ignited a flash fire of the hair on the head, but no skin tissue ignited on the head, although a few burn spots were evident in this region. The Beta cloth was discolored in the area of the match flame, and the animal had burned hair and skin beneath the cloth. There was no flame propagation beneath the Beta cloth, nor was there any burning on the exposed hind legs.

Test 25. Flame at protected torso.

Mouse clipped.

Mouse totally encased in single layer of Beta cloth.

Test pressure: 747 mm. Hg, 100% oxygen.

Match burned for 8 seconds.

Mouse did not propagate the fire.

There was discoloration on the Beta cloth in the area of the match flame, and hair and skin burns were observed in this area. No flame propagation was observed.

Test 26. Flame at protected torso.

Mouse clipped.

Mouse totally encased in single layer of Beta cloth.

Test pressure: 747 mm. Hg, 100% oxygen.

Five matches burned for 7.5 seconds.

No flame propagation.

There was discoloration of the Beta cloth in the area of the initiating flame, and the animal had hair and skin burns. No flame propagation was observed, even though the heat intensity was increased by using five matches.

Test 27. Flame at protected torso.

Mouse clipped.

Mouse totally encased in single layer of Beta cloth.

Test pressure: 747 mm. Hg, 100% oxygen.

Five matches burned for 9.5 seconds.

No flame propagation.

The Beta cloth had a discoloration where the match flames were initiated, and the animal had slight burns in this region. No flame propagation was observed, even though five matches were ignited simultaneously.

Test 28. Flame at unprotected head.

Mouse clipped.

No Beta cloth covering.

Test pressure: 747 mm. Hg, normal atmosphere.

Match burned for 18 seconds.

No flame propagation.

The animal had hair and skin burns in the flame area, but the hair did not produce a flash fire. Likewise, there was no flame propagation.

Test 29. Flame at unprotected torso.

Mouse unclipped.

No Beta cloth covering.

Test pressure: 747 mm. Hg, normal atmosphere.

Match burned for 15 seconds.

No flame propagation.

The hair burned in the area of the flame impingement but did not propagate. The skin had moderate burns in the flame area. The hair did not produce a flash fire.

Test 30. Flame at protected torso.

Mouse unclipped.

Single layer of Beta cloth (loose fitting).

Test pressure: 190 mm. Hg, 100% oxygen.

Match burned for 16 seconds.

Mouse burned for 14 seconds.

There was an immediate flame progression beneath the Beta cloth along a loose-fitting area of the cloth toward the hind legs. The fire line was 8 mm. wide, and only the hair burned. When the fire reached the exposed hind legs, there was a flash fire of the hair. No tissue burned and the hair fire extinguished 2 seconds before the match extinguished. No other part of the animal burned.

Test 31. Flame at protected torso.

Mouse unclipped.

Mouse totally encased in single layer of Beta cloth.

Test pressure: 190 mm. Hg, 100% oxygen.

Match burned for 16 seconds.

Mouse burned for 1 minute, 18 seconds.

A fire was observed to propagate beneath the Beta cloth toward the lower hind leg, but the fire was limited to the left side of the animal. Both the hair and the skin of the animal burned in this area, exposing the muscle structure. Furthermore, flames appeared outside the Beta cloth apparently as the result of combustion of lipids and oils liberated by the burning tissue. The head area of the animal was untouched by the fire.

Test 32. Flame at protected torso.

Mouse clipped.

Mouse totally encased in a single layer of Beta cloth.

Test pressure: 190 mm. Hg, 100% oxygen.

Match burned for 15 seconds.

No flame propagation.

The Beta cloth was discolored in the area of the ignition, and the animal had some hair singeing and slight skin burns where the flame impinged on the cloth. There was no flame propagation.

Test 33. Flame at exposed torso.

Mouse clipped.

No Beta cloth covering.

Test pressure: 190 mm. Hg, 100% oxygen.

Match burned for 11 seconds.

No flame propagation.

The unprotected animal showed slight singeing of the hair and slight skin burns in the area of flame impingement, but no flame propagation took place.

Test 34. Flame at unprotected torso.

Mouse clipped.

No Beta cloth covering.

Test pressure: 380 mm. Hg, 100% oxygen.

Match burned for 10 seconds.

Flash fire of the hair.

On match ignition an immediate flash fire over the whole animal occurred and lasted for 4 seconds. The skin in the path of the flash fire showed areas of slight burns, while the skin in the area of the ignition point burned completely, exposing the underlying muscles.

Test 35. Flame at unprotected torso.

Mouse clipped.

No Beta cloth covering.

Test pressure: 190 mm. Hg, 100% oxygen.

Match burned for 14 seconds.

No flame propagation.

Singed hair and slight burns were observed at the point of ignition, and no other burning was evident on the mouse.

Test 36. Flame at unprotected torso.

Mouse clipped.

No Beta cloth covering.

Test pressure: 258 mm. Hg, 100% oxygen.

Match burned for 12 seconds.

Mouse did propagate flame.

On ignition of the match, an immediate flash fire of the hair occurred and lasted for 3 seconds. The fire spread from the point of ignition and covered the front half of torso and head but did not progress to the hind quarters of the mouse. Moderate burns were noted on the skin at the point of ignition.

Test 37. Flame at protected torso.

Mouse clipped.

Single layer of Beta cloth (loose fitting).

Test pressure: 258 mm. Hg, 100% oxygen.

Match burned for 12.5 seconds.

A flash fire of the hair progressed beneath the Beta cloth to the left hind leg. The right

hind leg, although exposed, did not burn, nor did the head. The hair fire extinguished itself in 4 seconds, while the match continued to burn for a total of 12.5 seconds. The animal had only slight superficial burns in the region of this ignition point. The Beta cloth did not burn but showed discoloration in this area.

Test 38. Flame at unprotected head.
Mouse unclipped.
Single layer of Beta cloth (loose fitting).
Test pressure: 258 mm. Hg, 100% oxygen.
Match burned for 12 seconds.
Mouse burned for 5 minutes, 30 seconds.

On ignition of the match, there was an immediate flash fire of the hair followed by an increasing skin combustion at this point. The skin combustion progressed beneath the Beta cloth to the hind legs. Another flash fire of the hair occurred when the combustion reached the exposed hind legs followed by an overall combustion of the skin. The Beta cloth did not burn but was brittle and showed small areas of melting. The skin and extremities were consumed, but the muscle structure and viscera were not visibly burned.

Test 39. Flame at unprotected head.
Mouse clipped.
Single layer of Beta cloth (loose fitting).
Test pressure: 258 mm. Hg, 100% oxygen.
Match burned for 18 seconds.
Animal burned for 3 minutes, 55 seconds.

On match ignition there was an immediate flash fire of the hair. The ears of the animal began to burn, and this skin combustion intensified and progressed beneath the Beta cloth toward the hind legs where another flash fire of the hair ignited the exposed hind legs. The Beta cloth did not burn but was brittle and showed small areas of melting.

IV. DISCUSSION

It appears from these results that the intensity of combustion and rate of flame propagation are proportional to the amount of combustible material present and the readiness of the material to combust even if covered by a noncombustible garment. This is also directly affected by the partial pressure of oxygen present in the test environment.

During the combustion tests the flame paths were varied and irregular. Since it was not our purpose to measure the complex interactions of the combustion process, we will not try to explain the results. We can only report the results of the combustion process and postulate why the flame stopped where it did, or jumped to another area, or did not burn at all (such as was observed in tests 16 versus 22, in tests 14 versus 15, and again with tests 3 versus 31). These combustion tests tend to enforce our belief that the combustion process is unpredictable and that we are not able to be decisive as to whether or not flame propagation will occur (as seen in test 10 versus tests 12 and 36). In reviewing all the test results (table I), in light of the questions which prompted this study, a more direct comparison is made in subsequent tables in which similar results are compiled.

In question 1, it was asked if a flame would propagate beneath a close-fitting, noncombustible garment in a 100% oxygen atmosphere. It is very evident from the results (table II) that if enough combustible material is present, a flame will propagate beneath a noncombustible garment regardless of atmospheric pressure. This took place whether a single or double layer of a close-fitting torso garment was worn.

In question 2, it was asked if a combustion process would occur beneath a noncombustible garment if a flame impinged upon the garment. Again, it is very evident from the results (table III) that if enough combustible material is present within the noncombustible garment, a flame will propagate beneath it. This was evidenced by the fact that mice that were completely encapsulated in Beta cloth were burned when a flame impinged upon the garment.

In question 3, it was asked if there would be a marked difference in flame propagation if

TABLE II

Fire propagation beneath a noncombustible garment in 100% oxygen atmospheres at various total pressures

Mouse hair not clipped; ignition at exposed head	380 mm. Hg	258 mm. Hg	190 mm. Hg
Single layer of Beta cloth	Tests 1 and 8: hair and skin burned.	Test 38: hair and skin burned.	Test 16: only hair and skin on head burned.
Double layer of Beta cloth	Test 2: hair and skin burned.		

TABLE III

Ignition of mammalian tissue through a noncombustible garment in 100% oxygen atmospheres at various total pressures

Mouse hair not clipped; ignition at protected mid-torso	744 mm. Hg	380 mm. Hg	258 mm. Hg	190 mm. Hg
Single layer of Beta cloth; torso garment	Tests 22 and 23: hair and skin burned.		Test 11: hair and skin burned.	Test 30: hair and skin burned.
Single layer of Beta cloth; total encasement		Test 3: hair and skin burned.	Test 14: hair burned, no propagation; test 15: hair and skin burned.	Test 31: hair and skin burned.

the animal's hair were removed. From looking at the results of these experiments, it is quite evident that there is unquestionably a marked difference in flame propagation (tables IV and V) when the animal's hair is removed; however, no exact line of demarcation can be drawn between combustion or no combustion and flame propagation or no flame propagation because of the uncontrolled variables.

In question 4, it was asked if there would be a marked difference in the answers to the above questions if different total pressures were used while still maintaining a 100% oxygen atmosphere. These experiments show (tables II and VI) that there is a definite difference when the total pressures are varied while still maintaining a 100% oxygen atmosphere.

From these tests, there are indications that the astronaut would have a fair amount of "natural" protection during extravehicular activity owing to the similarity of configurations.

The question of the effect of the duration of ignition flame on the test results will always be a problem to consider when combustion is studied. Any material will change or be altered if enough heat is applied long enough. The intensity of the flame will be the result of the combustion process. The durations of ignition flame for these tests ranged from 8 seconds at 744 mm. Hg to 14 seconds at 190 mm. Hg. The safety program implemented by the Air Force Systems Command for conducting research in oxygen-enriched atmospheres requires not only that personnel be clothed in a noncombustible garment but also that a fire extinguishment system be operational. Automatic fire sensing and extinguishing systems tested at Brooks Air Force Base, Tex., in a 100% oxygen atmosphere actuated within 5 to 6 seconds. For this reason, it was

TABLE IV

Propagation of fire on animal in 100% oxygen atmospheres at various total pressures

Ignition at exposed head; single layer of Beta cloth	744 mm. Hg	380 mm. Hg	258 mm. Hg	190 mm. Hg
Mouse hair not clipped		Tests 1 and 8: hair and skin burned.	Test 38: hair and skin burned.	Test 16: only hair and skin on head burned.
Mouse hair clipped	Test 21: hair and skin burned.	Test 6: only hair and skin on head burned.	Test 9: only hair on head and ears burned.	Test 17: only hair on head and ears burned.

TABLE V

Ignition of mammalian tissue through a noncombustible garment in 100% oxygen at various pressures

Ignition at protected mid-torso; single layer of Beta cloth	744 mm. Hg	380 mm. Hg	258 mm. Hg	190 mm. Hg
Mouse hair not clipped	Tests 22 and 23: hair and skin burned.		Test 11: hair and skin burned.	Test 30: hair and skin burned.
Mouse hair clipped	Tests 19 and 20: no fire.	Test 7: no fire.	Test 37: flash fire of hair.	Test 18: no fire.
	Test 24: flash fire on head.			

decided by the authors that the duration of the ignition flame was an adequate test of the protection offered by a noncombustible garment under these safety test results in that, hopefully, no actual fire will go undetected for 8 to 14 seconds, and by using the present fire extinguishment system, a fire can be extinguished in this time interval. Furthermore, in this series of experiments, it was decided to use a flame rather than a heated wire element since a flame would be the more drastic and would be closer to the actual design test requirement for a noncombustible garment.

The animal's hair was clipped and not shaved because there will always be hair growing on the body and by clipping some hair, hair would remain in varying amounts on the animal. This was particularly true of the head area around the eyes and ears and of the legs. This was the reason for the flash fires of the hair on tests 4, 6, 9, 12 ,17, and 24; whereas, the torso of the animal was clipped very short and flash fires did not occur there except for test 37.

The clipped hair was not measured or weighed because of the variables involved in making any comparisons when considering flame propagation and combustion. To try to delineate between what mass of remaining hair would or would not be combustible is not solely dependent on the mass of hair. A few factors that would affect the combustion process are: the amount of oil on the hair; the area of the body where the hair is located; discrepancy in

TABLE VI

Fire hazards in 100% oxygen atmospheres as related to different total pressures

No Beta cloth; ignition at midtorso	380 mm. Hg	258 mm. Hg	190 mm. Hg
Mouse hair clipped	Tests 13 and 34: flash fire of hair.	Test 10: no fire; tests 12 and 36: flash fire of hair.	Tests 33 and 35: no fire.

the length of the remaining hairs; and whether the hair has split, exposing more material to combustion.

There are obvious drawbacks when an extrapolation of animal data is made to man and the protection that a noncombustible garment would afford man in a 100% oxygen atmosphere. Some of the obvious questions are:

1. Is there a difference in combustion and flame propagation between mouse hair and human hair?

2. What is the difference in combustion and flame propagation on the skin of a mouse and the skin of man? (A marked anatomic difference is that the mouse has a pelt, whereas man has skin through which he perspires.)

In this study it would have been very beneficial to have measured the energy released by the match flame, especially in test 27. More important would have been the amount of energy required to start a flash fire of the hair and the amount of energy required to start a fire propagating along the skin. The most important aspect, however, would have been to measure the amount of energy absorbed or reflected by the noncombustible garment and at what intensity and duration the noncombustible garment would allow combustion to proceed.

This study indicates that more refined investigations are necessary to compare the protection afforded animals that are physiologically closed to man, to ascertain the energy dissipated by a noncombustible garment, and to measure the energy required for flame propagation of human hair and skin.

Another area for investigation is the feasibility of a noncombustible lotion or cream that might afford protection to the skin and hair by one of several mechanisms. From the results of tests in this report, elimination of the hair is the safest course of action at this time.

It was observed in this series of experiments that the areas of the mice closest to the metal support bracket were invariably protected from fire damage. This phenomenon should be investigated to ascertain if the support bracket can be developed into an operation protective device since it apparently acts as a heat dissipater.

In designing personal protection, one should remember that it must be readily accepted by the user, especially when he will be wearing or using the device for long durations in very limited quarters.

V. CONCLUSION

This study demonstrated the effectiveness of a noncombustible garment in preventing combustion and flame propagation of mouse hair and skin in 100% oxygen atmospheres. This protection is afforded only when all of the hair of the animal is removed.

It is concluded that further studies should be conducted to assure that man is afforded the same flame protection when wearing a noncombustible garment in conjunction with a fire extinguishing system effective in a 100% oxygen atmosphere. Further investigations should be conducted on the "natural" protection observed on dehaired mice exposed to 190 mm. Hg total pressure and 100% oxygen atmosphere.

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13. ABSTRACT

Thirty-nine mice, with hair clipped or unclipped, were clothed in a noncombustible garment, Beta cloth, and subjected to flame ignition in 100% oxygen atmospheres from 744 to 190 mm. Hg total pressure. The experimental results showed that the noncombustible garment afforded protection from combustion and flame propagation only if the animal's hair had been previously clipped. Further studies should be conducted in an effort to assure man's protection.

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