EXTREME HEAT PROTECTION

FOR

PYROTECHNIC HANDLERS OF Mg FLARES

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1. INTRODUCTION

Because many stages in the production of infrared decoy flares (Mg/PTFE) require that the production workers operate close to many pounds of the flare material in both the granulated and pressed states, it is required that the workers wear fire suit type of protection at several stages of the process. Although the chemical reaction of an accidental ignition of this material does not generate large volumes of gas, so that blast is not a primary hazard, the heat of the reaction is above 4000^{o}F and the afterburning of the excess magnesium vapor in air can generate plume temperatures of over 5000^{o}.

This means that the major hazard is from the thermal radiation accompanying such high temperatures which is intense enough to ignite materials many feet away. Because the thermal pulse is relatively short (a few seconds), the hazard is quite different from that faced by the fireman or the steel mill worker for whom most suits were designed.

Furthermore, the worker has to perform many tasks where the stiffness, bulk and weight of the conventional fire suit make it very difficult for the worker to accomplish his task. If the exposure of a task requiring the use of a fire suit is relatively short, the worker may even be tempted to skip dressing properly in such a cumbersome outfit and thus subject himself to unnecessary hazard.

For all of these reasons, Tracor MBA and Star Glove and Safety Products Corporation set about looking at improved fire suit designs which were directed toward solving the pyrotechnic operator's safety problems. The pyrotechnic testing was carried out by Tracor MBA while the material design and samples were furnished by Olen Nelson of Star Glove.

Furthermore, since we had no quantitative data on how available suit materials performed in such an environment, we gathered samples from several present fire suit suppliers which could be subjected to a standard test to yield comparative data and guide our development tests

2. <u>The Test Environment</u>

The first task was to select a test environment that simulated the type of hazard we were interested in and at a level at which we could gather data showing the relative performance of various materials.

We chose as a baseline a magnesium/PTFE (polytetrafluoro-ethylene) pellet mounted in an open, steel lined box, with the fire suit sample mounted at one open side at a distance of 12" from the flare pellet (See Figure 1).

The sample was a 6" x 8" rectangle of material held firmly between steel jaws in a holder mounted on a retractor bench. In the initial tests, some of the samples were withdrawn along the bench after a one-second exposure to simulate a worker retreating. It was found, however, that a stationary sample using a smaller pellet gave more reproducible results, so fixed samples were used in all of the later tests.

Two pellet sizes were tried, a 500 gram pellet and a 100 gram pellet each of which burned in 4 to 6 seconds. The plume from the larger pellet enveloped and destroyed many of the samples so completely that quantitative evaluation was difficult, so most of the the tests were carried out with the 100 gram pellets.

The initial tests were all carried out out-of-doors but, because even small breezes seem to cause the data to scatter, the final test series was carried out in a closed building with just an exhaust fan providing a controlled, gentle air movement to sweep away the smoke.

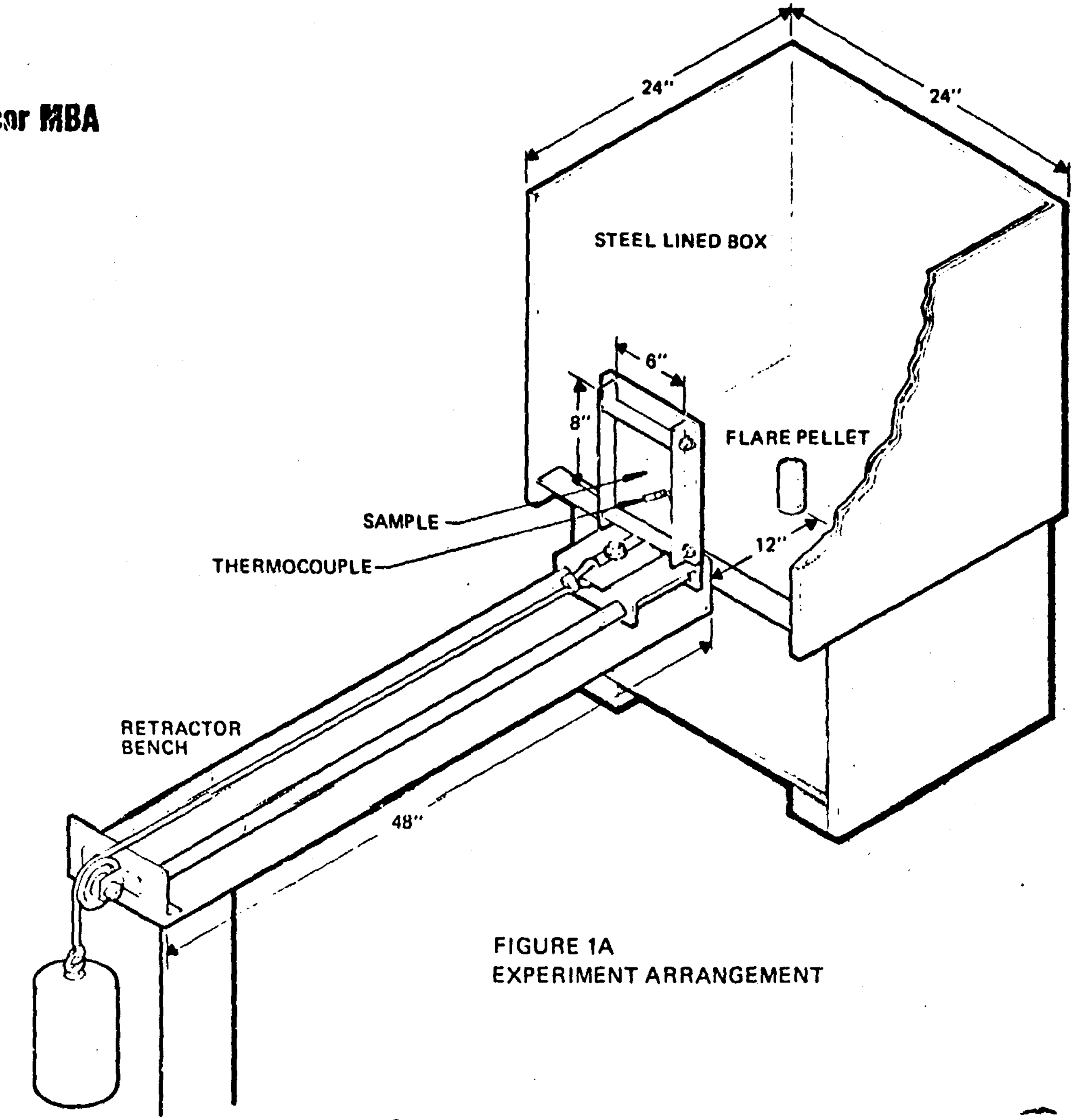

FIGURE 1A
EXPERIMENT ARRANGEMENT

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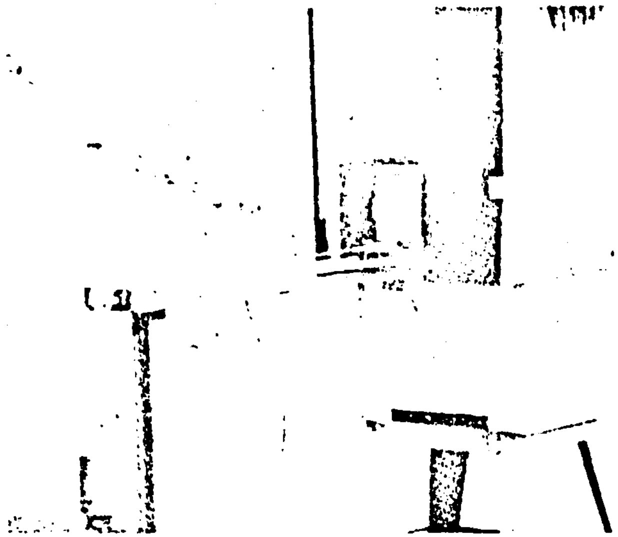
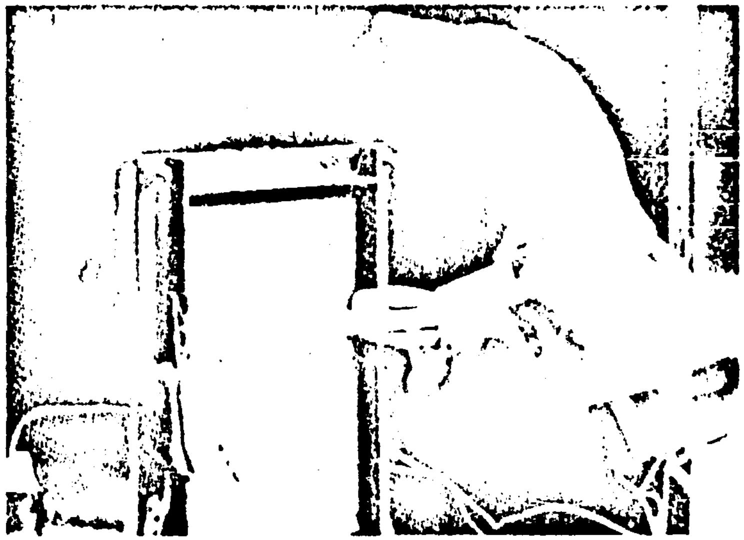
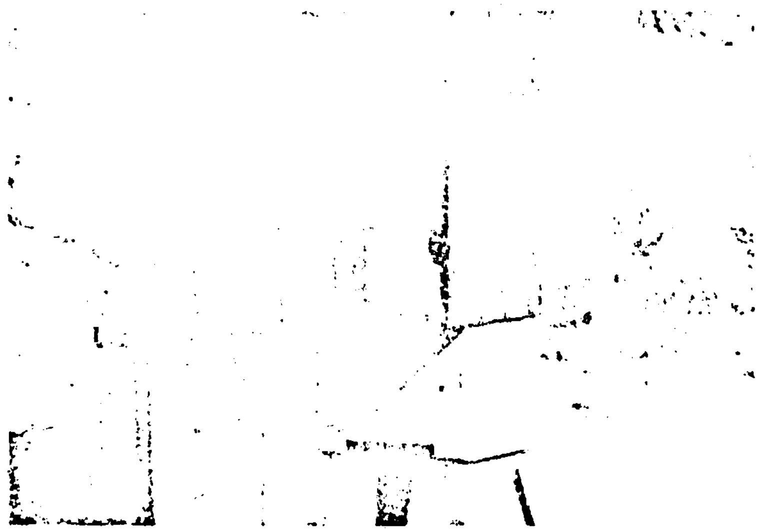


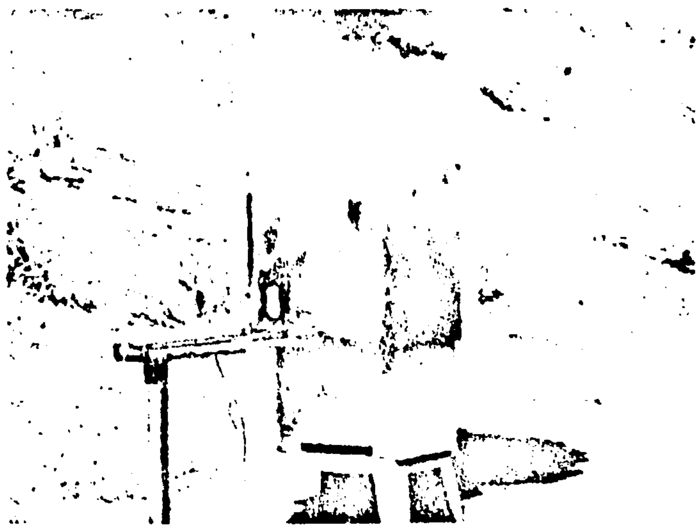
1b. TEST SETUP



1c. SAMPLE HOLDER



1d. 100 GRAM TEST



1e. 500 GRAM TEST

3. <u>The Materials Tested</u>

The available fire suit materials which were included in the test are shown in Table I.

4. <u>Comparison of Test Environments</u>

To obtain a comparison of the severity of the available test environments, a single type of fire suit sample (Emcon's Pyrasteel) was run with all three environments:

100g pellet with fixed sample @ 12"
100g pellet with sample retracted after 1 sec
500g pellet with sample retracted after 1 sec

The data for these tests are shown in Figure 2.

The 100 gram pellet with the sample retracted after one second gave only a 35°F temperature rise while the 500 gram pellet with sample retraction gave about 250° temperature rise before the thermocouple detached from the sample. The fixed sample with the 100 gram pellet would appear to give some intermediate value but the thermocouple shorted out after about three seconds so a complete trace was not obtained.

Although this data is sketchy at best, when combined with the photos of Figure 1 which showed the extended fireball of the 500 gram flare, we concluded that the best basis for comparison would be the fixed sample with the 100 gram pellet. This would give a response which was great enough to make comparisons based on thermocouple response yet moderate enough not to completely destroy the sample.

TABLE I - FIRE SUIT TEST MATERIALS

Pyrasteel	Encon	9.7 oz/yd^2	Al Coated Fabric	
P-29 Panotex	Encon	9.4 oz/yd^2	Black Coated Fabric	Withstand 1650°F for 3 - 5 min, 170 w/cm^2 for 2 sec
Protex III Felt	Encon	18.3 oz/yd^2	Black Coated Felt	Withstand 1650°F for 10 min - designed as an insul. liner for Pyrasteel material
Fyrepel #1	Fyrepel		Al Coated Fiberglass w/Nomex felt backing	
Fyrepel #2	Fyrepel		Al Coated Kevlar/Fiber-glass w/Nomex felt backing	
Fyrepel #3	Fyrepel		Al Coated PBI*/Kevlar w/Nomex felt backing	
PBI Knit	Star Glove	9½ oz/yd^2	50% PBI plus 50% permanent flame retardant rayon (PFR rayon)	
Aluminized PBI Knit	Star Glove	12 oz/yd^2		
Aluminized Kevlar Knit	Star Glove	6 oz/yd^2	Blend of PBI, PFR rayon and Kevlar	
PBI Glass Felt	Star Glove	12 oz/yd^2	3/16" thick 50/50 blend of PBI and β glass	

* Polybenzimidazole

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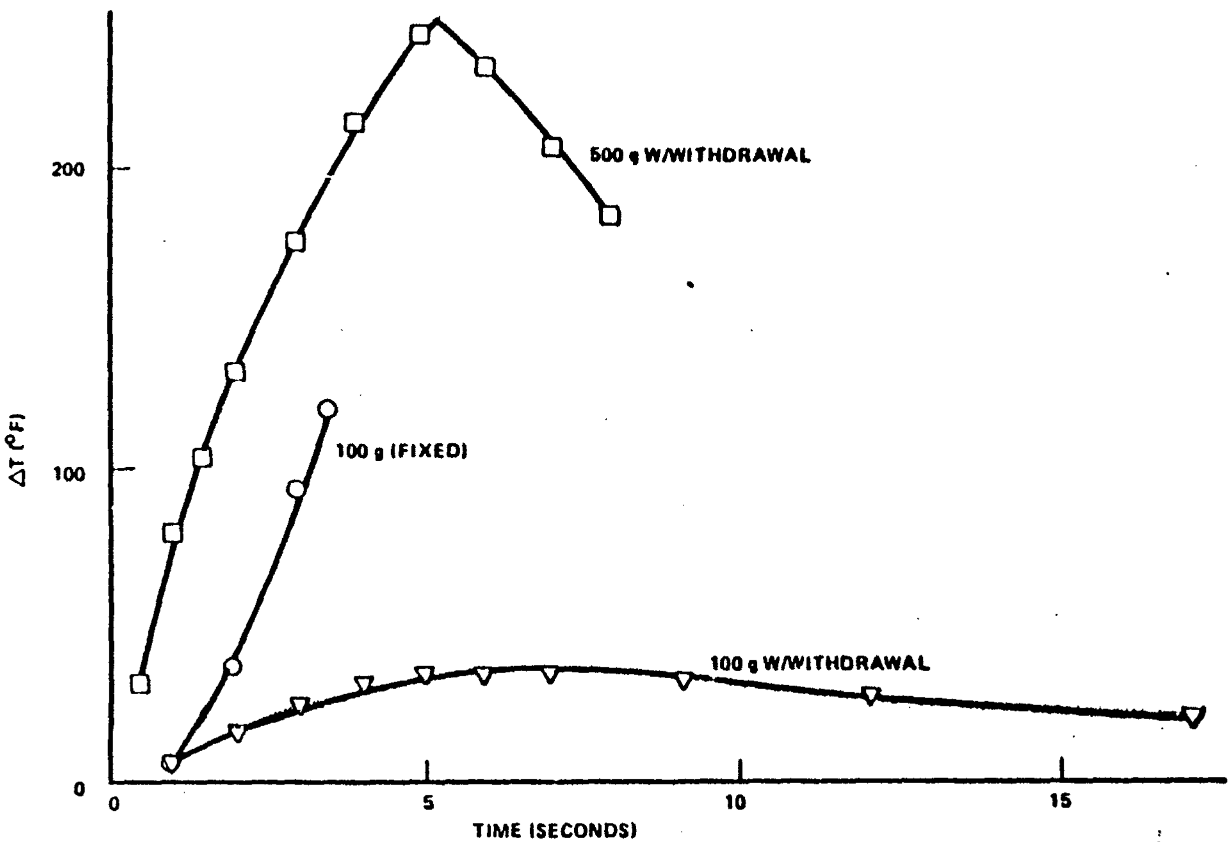

FIGURE 2
COMPARISON OF ENVIRONMENTS

5. First Test Series

A. 500 Gram Tests

Additional tests were carried out with the 500 gram pellets (with sample removal after one second) just for information and they are given in Figure 3. The samples used were the Encon which had no felt backing, the Protex III which is designed as a backing felt, and three aluminum coated fabrics which had felt backings.

These tests confirm that with a felt backing, this scenario gives fairly modest peak temperatures, but because of the variability in the shape of the plume produced by the mild breezes, the quantitative results were regarded as suspect. In the case of the two Fyrepel fabrics, the aluminum coatings were not even scorched which indicated that the plume did not expand as rapidly toward the sample as in the other cases. This again indicates that this scenario is too non-reproducible to use for sample comparison or evaluation.

B. 100 Gram Tests

Figure 4 shows the results of the tests with the fixed sample with the 100 gram pellets. Again the samples without felt backing showed very rapid temperature rises, whereas the samples with a felt backing showed quite tolerable temperature rises with the Fyrepel materials being best. Since neither the Protex III or Star Glove material were aluminum coated, the tests suggest the importance of an aluminum coating in reducing the radiation input when dealing with such high temperature inputs. In the Fyrepel 2 test, the movies indicate that the 100 gram pellet came loose and moved toward the sample in the middle of the burn. This probably accounts for its relatively high temperature compared to the values seen with the other two Fyrepel fabrics.

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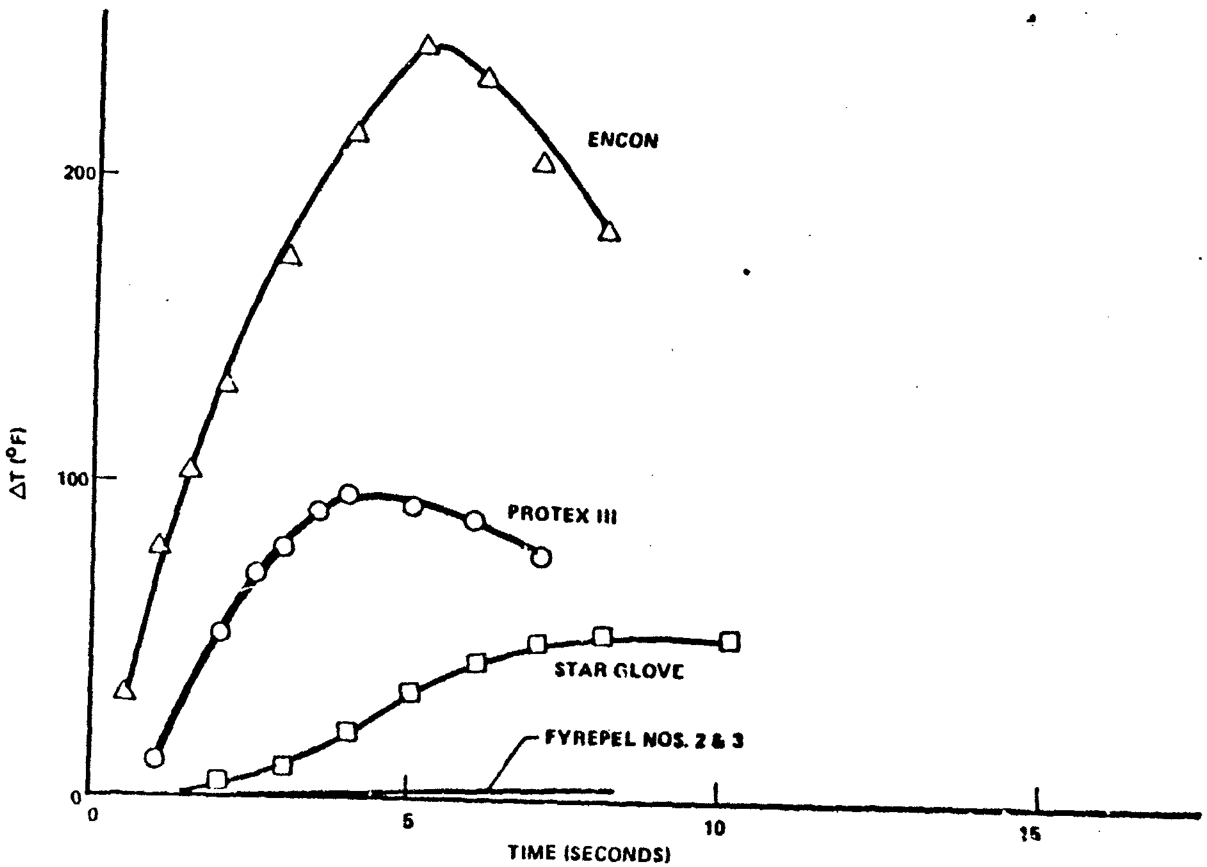

FIGURE 3
500 GRAM PELLET W/WITHDRAWAL OF SAMPLE

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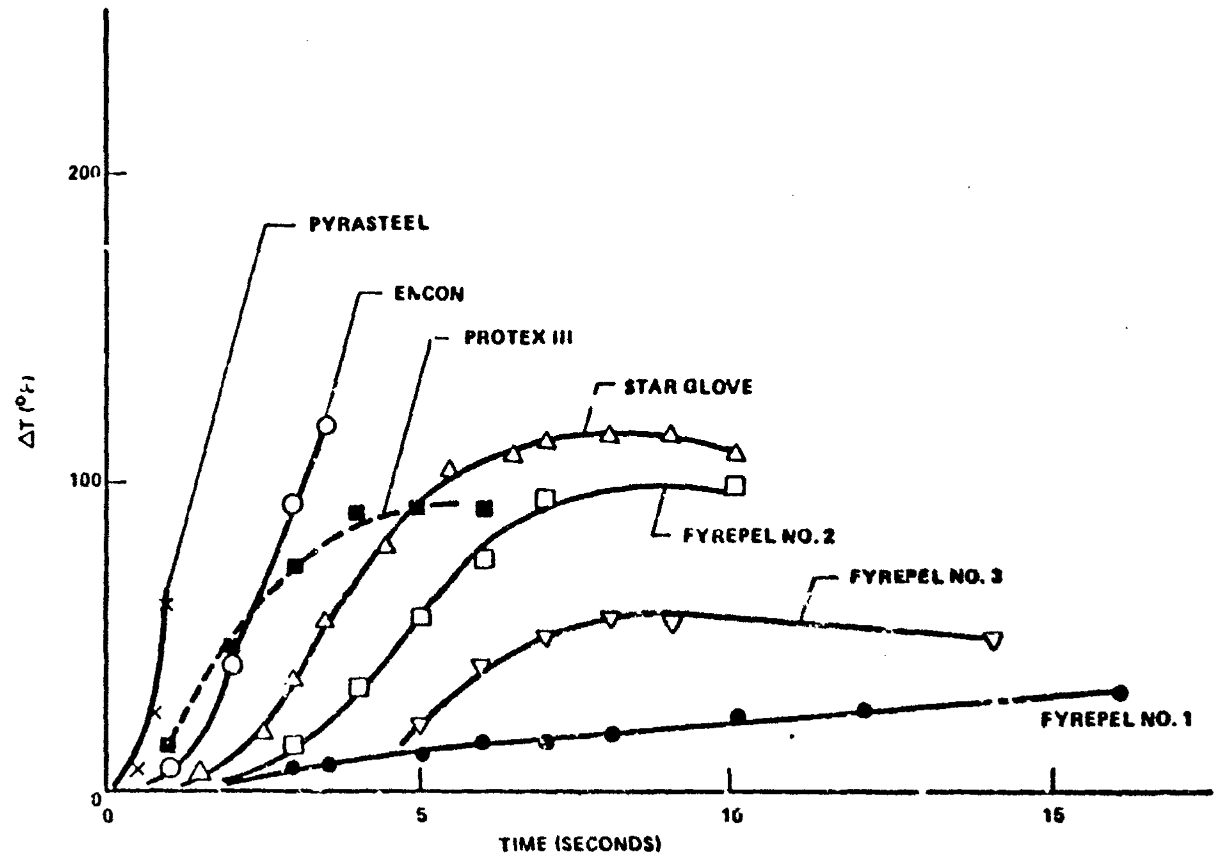

FIGURE 4
100 GRAM PELLET WITH FIXED SAMPLE AT 12 INCHES

5. Importance of Aluminized Coating - Second Test Series

In order to gather further information on the importance of the aluminized coating for this scenario in which the fabric is not directly in the flame, we looked at further combinations. Since we were interested in as light and comfortable a suit as possible, we used the PBI material in both knit and felt forms. The results are shown in Figure 5.

If one compares the results of using only the lightweight PBI knit material, with and without the aluminized coating, it is seen that both give very fast temperature rises which reach unacceptable temperature levels.

When one backs the aluminized knit with another knit layer, the temperature rise becomes much slower and reaches tolerable levels. When the aluminized knit is backed by the PBI felt, the temperature rise is almost trivial and compares favorably with the best of the Fyrepel results obtained previously.

In this test we also exposed one of the Star Glove gloves which has no aluminized coating but does have the PBI felt backing. In this case the thermocouple was mounted inside the glove in the palm which was located about where the other samples were mounted. The temperature rise can be compared to that obtained with the aluminized knit with the felt backing and one sees the significantly greater temperature rise one gets without the aluminum coating. The glove results are comparable to those one gets when backing an aluminized knit with only a knit.

When these results are compared with the previous Star Glove data with non-aluminized materials, one can see the importance of an aluminized coating, when the hazard is largely a radiative source.

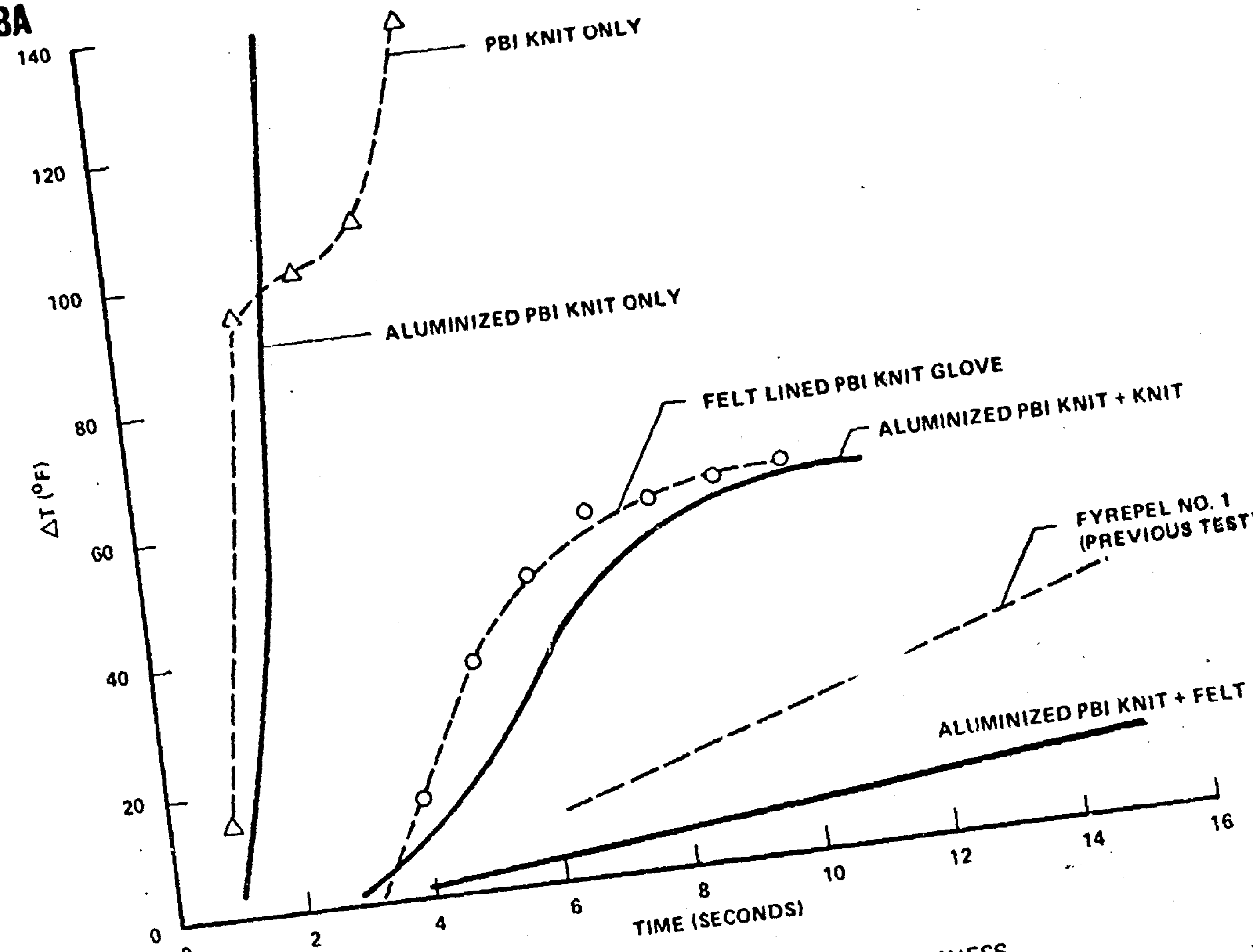

FIGURE 5
TESTS OF ALUMINIZED KNIT EFFECTIVENESS

6. Optimizing the Design

At this stage we felt we had a qualitative feel for the performance parameters and needed to get more quantitative data in order to select an optimum design. The test setup was moved indoors in order to obtain better reproducibility. The important design parameters considered for optimization were a) protection, b) comfort, and c) cost. The PBI seemed to give the best protection and comfort but was the most expensive of the materials. Therefore it was decided to test various felts with the aluminized PBI knit to establish the level of protection that could be achieved.

Figure 6 shows the results using PBI, fiberglass and Kevlar felts behind the aluminized PBI knit. Note in this case the actual temperatures are plotted instead of the temperature increases. Although the data is not complete since the thermocouples detached from the fabrics about 200°F, it is seen PBI is clearly best with Kevlar knit second and fiberglass probably not acceptable.

In the fourth case we attempted to use an aluminized Kevlar knit as the protection for the fiberglass felt and found that the Kevlar burned from the intense radiation and gave temperatures of about 300°F. This indicates the intense nature of the radiation field and why materials such as PBI are useful in this application.

At this stage of the test it was suggested that we consider a second aluminized layer in case the heat transfer from the front aluminized knit layer to the second layer was predominantly radiation since contact between the layers was random at best. The results are shown in Figure 7.

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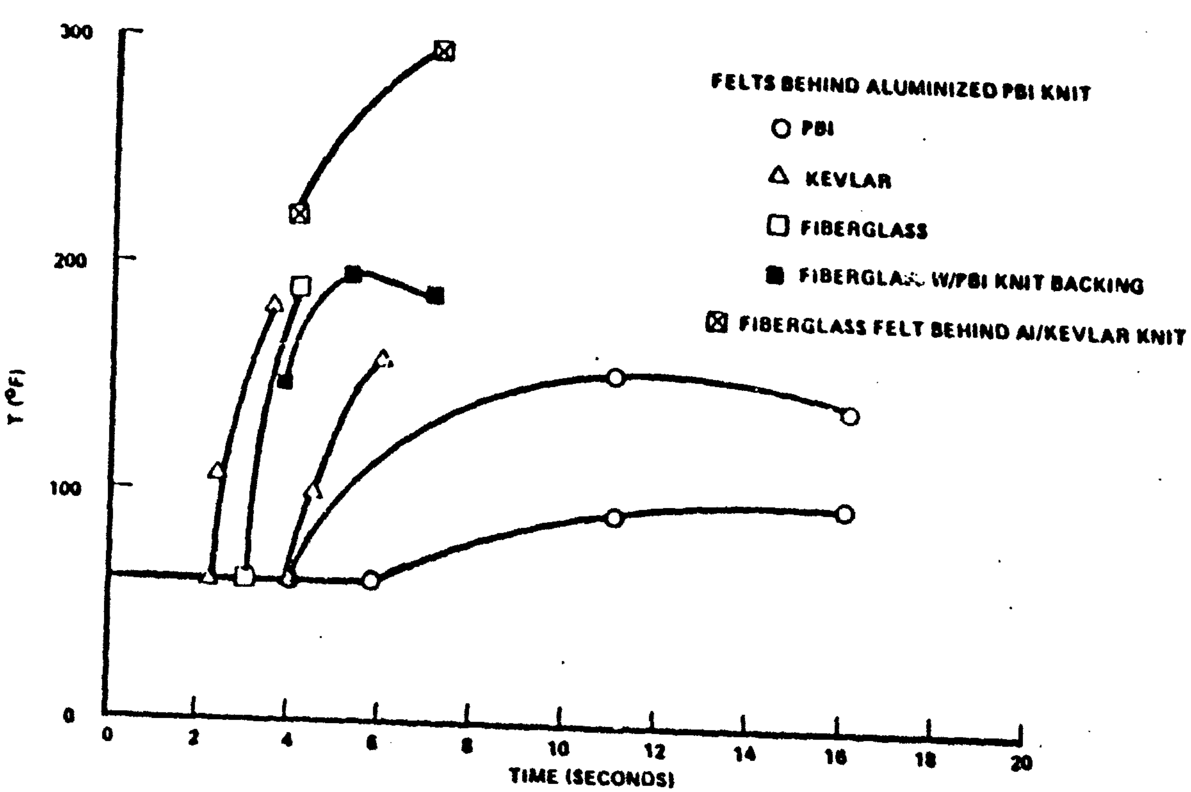


FIGURE 6
COMPARISON OF VARIOUS FELTS

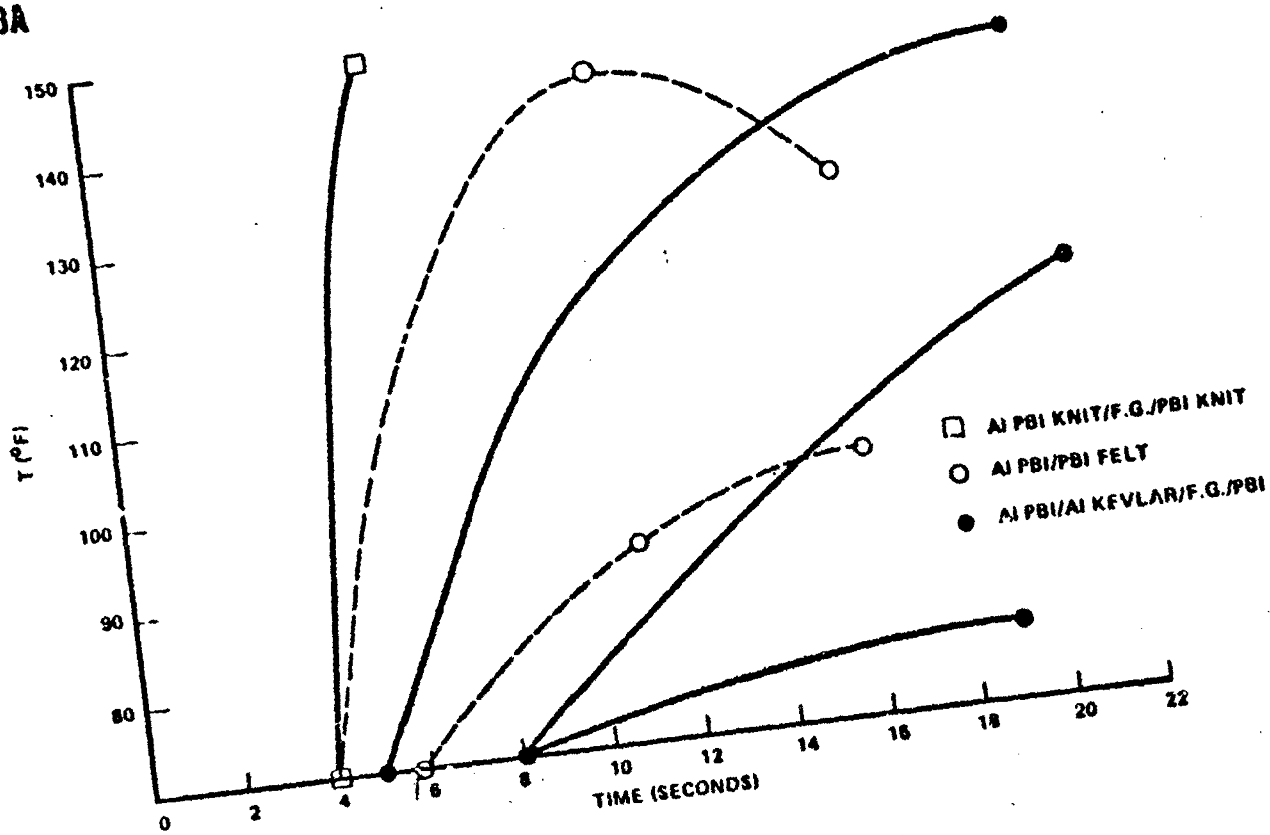


FIGURE 7
EFFECT OF SECOND ALUMINIZED LAYER

The temperature scale in this graph has been expanded to make it easier to read the results. A single aluminized layer over fiberglass with a knit backing was rerun for comparison and appears as the steepest curve rising above 200°F. (Note again these are measured temperatures with a base temperature of 60°F.) The two curves for a single aluminized PBI knit in front of PBI felt were transferred from the previous curve for comparison. Then three samples were run with an aluminized PBI knit backed by an aluminized Kevlar knit, a fiberglass felt, and a final PBI knit for comfort.

Although the reproducibility leaves something to be desired, it is clear that this four-layer sandwich compares favorably with the pure PBI material. In this case the aluminized Kevlar as a second layer was able to withstand the temperature and served well as an isolation barrier. It delayed the start of the temperature rise by 2 to 4 seconds and cut the peak temperature down to a very modest level.

7. Fabric Test Conclusions

The PBI materials provide an excellent resistance to temperature so are ideal for the backing for an aluminum coating layer. Because they are comfortable, the PBI's knits form an excellent liner material for a fire suit. If one inserts a second aluminized layer in front of the felt to reduce radiation transfer, one may use the low cost fiberglass felts and still obtain excellent fire protection.

8. Fire Suit Design

The fire suit construction was designed to protect the wearer against the accidental ignition of 50 - 100 pounds of magnesium/Teflon flare granules contained in a pot on a low table or cart.

The criteria for construction were taken from two major areas - the protection that the suit would offer against this thermal load and the usability of the suit by a wearer in the work environment. Only a proper melding of these sometimes conflicting requirements can an acceptable suit be designed.

The previous tests had shown that the PBI based hybrid fabrics could provide the thermal stability usually found only in the much heavier glass fabrics and with a great deal more comfort and flexibility. This stability is provided by the high decomposition temperature of the PBI material and the fact that it slowly carbonizes under excess thermal load maintaining its fibrous nature.

The PBI also has a remarkable moisture absorbance capability (50% greater than cotton) which makes it a very comfortable static-free fabric against the skin even when blended with 50% PFR rayon.

The four layer protective design tested in the previous experiments used knit fabrics in front of and behind the felts since they offer a great deal more flexibility than woven fabrics and would make it much easier for the wearer to perform his necessary tasks. At the same time, the knit fabrics provide over 50% more air space in the fabric than a woven material so one gains additional insulation without additional weight.

Finally, the four layer design provides both the two aluminized layers and the three air interfaces which are very effective insulators with a minimum of added weight.

The suit construction itself provides for improved user comfort in several ways. The new hood design provides the user with a large 8" x 14" gold coated window for excellent downward visibility as well as peripheral with a hood weight reduction of 25%. The visor gives minimum distortion and is coated to provide anti-fogging protection. Hood vents designed for the pyrotechnic type exposure aid in wearer comfort without sacrificing safety.

The storm flap design on the front of the suit provides an easy protection for any possible exposed area of the chest, while the hood and shoulder drape provide additional seals at joints. An internal spandex system at coat bottom provides a seal at this juncture, but allowing full freedom and movement. The sleeves and cuffs have an internal double knit thumb type wristlet and anklet to provide seals in this areas.

Gloves are gauntlet type and include the layered concept for protection. Dexterity is the prime concern here and the gloves are capable of handling the small parts and functions necessary for this type of job.

The coat is designed without a collar to reduce weight. The necessity of a collar was not evident. The coat pattern is also a special design for shoulder and arm freedom. Properly sized garments have no restriction in total movement of all parts of the body.

Integral spats were designed for the shoes to allow for the special conductive shoes worn. The general suit design has a continuous outershell of the aluminized STAR/PBI knit fabric. The inner liner concept is positioned on the front half of the total garment structure only, with the sleeves fully insulated.

The final suit designed for the test is shown in Figure 8. The hood assembly weighs about 5 pounds while the rest of the assembly weighs only 11-1/4 pounds. The suit would retail for about $1500.00.

FIGURE 8
FIRE SUIT DESIGN

9. Fire Suit Test

To test the complete suit against a possible accidental ignition, it was instrumented with thermocouples, placed on a dummy mounted at 3 feet from a barrel with 37 pounds of granulated Mg/PTFE blend (See Figure 9).

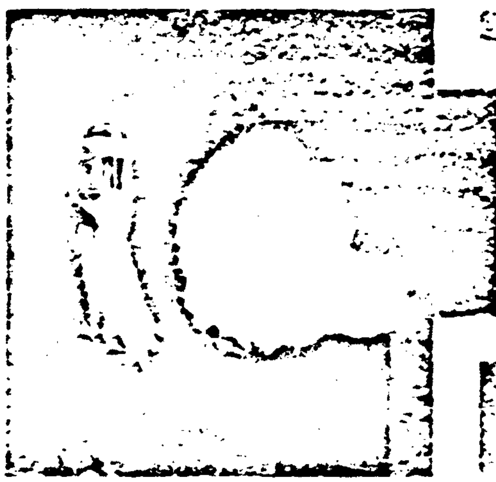
Thermocouples were attached to the inside surface of the suit for the leg, body, arm and hand, and to the dummy surface for the lip and ear locations. The lip location was chosen as an area looking directly through the gold-coated face shield so it would show direct response to the radiation, while the ear location was directly opposite a helmet vent and would see mostly the hot air entering through the vent.

The thermocouple responses from the test are shown in Figure 10. The lip and ear thermocouples responded the quickest and gave the highest readings which were only 20 - 30^{o}F above ambient. All of the other thermocouples showed very slow rises to only 10 - 15^{o} above ambient.

The development and size of the plume are shown in Figure 9. It is seen that the plume grows in size as it rises and the excess magnesium vapor is oxidized in the air. This is graphically indicated by the scorched areas on the suit being largely limited to the face shield and upper portions of the helmet (Figure 8).

These results also indicate the importance of using a high ceiling room for pyrotechnic operations so that the plume can rise rapidly away from the worker and reduce the radiation exposure. Since radiation intensity falls off nearly as the cube of the distance, it doesn't take much distance to make a radical reduction in the intensity. This is seen in the difference in the scorch obtained on the helmet compared to very little discoloration seen on the hand which was also facing upward.

0 SECONDS



0.2 SECONDS

1.0 SECONDS

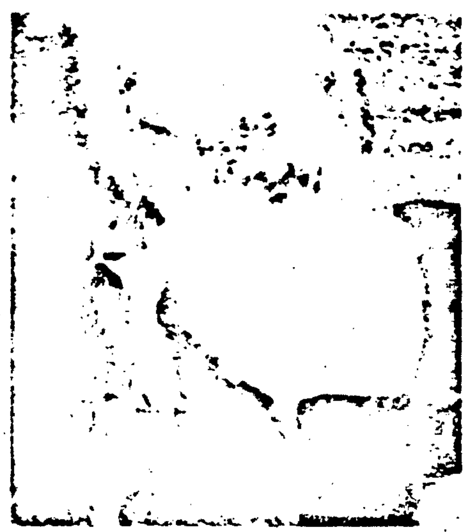


FIGURE 9
FIRESUIT TEST

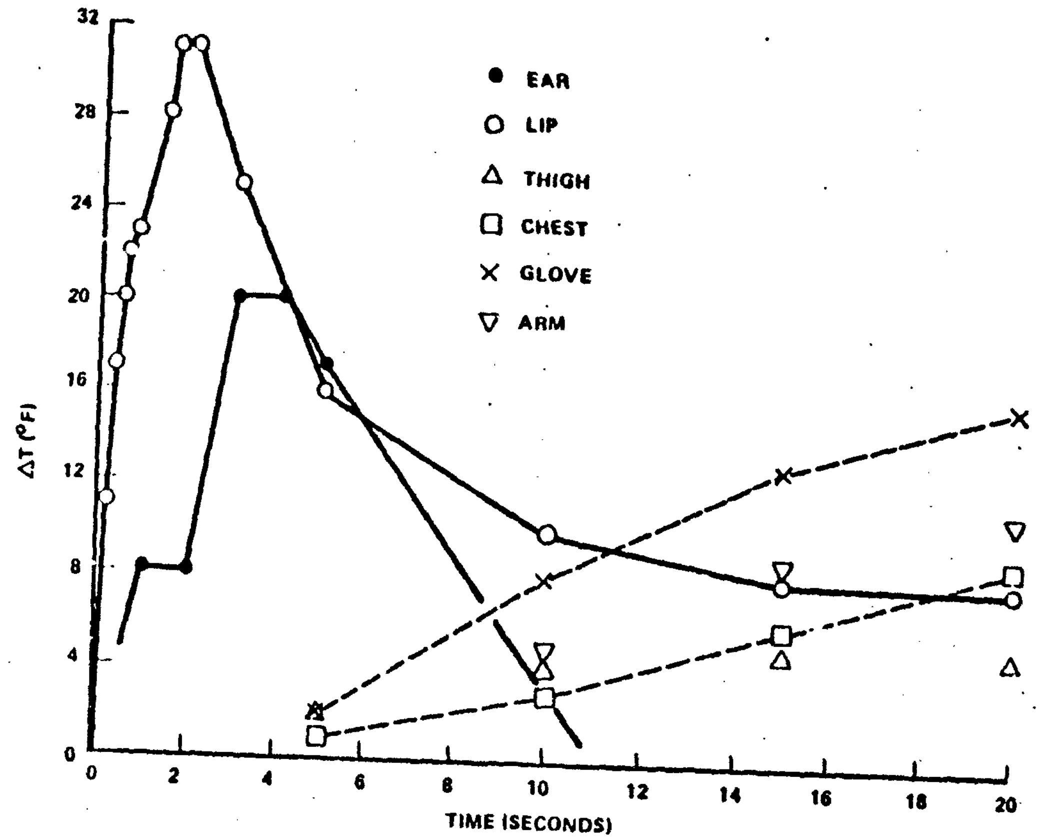


FIGURE 10
TEMPERATURE PROFILES INSIDE FIRE SUIT

10. CONCLUSIONS

A fire suit designed with two aluminized layers and a fiberglass felt has been shown to provide a more than adequate shielding against the accidental ignition of pyrotechnic in its most hazardous form - rapidly burning granules. Simpler and less costly designs seem feasible, if the double aluminized design is maintained by placing the second aluminized layer on the fiberglass felt and eliminating the second fabric layer.

Although this suit was especially designed for highly radiative pyrotechnic events, the double aluminized layer concept should be helpful in the lower temperature fire and furnace applications.