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Considerations in Establishing Performance Criteria for Structural Firefighters' Helmets

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U. S. DEPARTMENT OF COMMERCE
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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, ***Secretary***
Dr. Sidney Harman, ***Under Secretary***
Jordan J. Baruch, ***Assistant Secretary for Science and Technology***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Acting Director***

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Introduction

Helmets intended for use in fighting structural fires are designed to protect the wearer from injury caused by falling objects, flames, and heat. The helmet also should protect the user from serious head injury during falls from vehicles, down stairs, ladders or through collapsing floors. But in order to realistically satisfy the needs of the firefighters it is important that the protection be provided at reasonable cost and without seriously compromising comfort. The optimum helmet design, then, is one which combines the correct balance of protection, cost, and comfort.

Although many combinations of materials and designs are used to manufacture firefighters' helmets in the United States, all of the helmets can be divided into two major groups - sling suspension and fully lined. Details of helmet construction are discussed in the next section. For now, it is sufficient to point out that the sling suspension helmets utilize a nylon webbing which is fastened to the shell at four points and rests on the crown of the head, while the fully lined helmets have a foamed plastic lining in contact with the inside surface of the shell.

Helmet manufacturers, in designing their product, and users, in making their selection, must balance protection against cost, size, weight and comfort. This necessarily imposes constraints on helmet designs. The problem then reduces to the questions "How much protection is the user willing to trade for comfort, and how much is he willing to pay?" To get a better understanding of the needs of firefighters and the current state-of-the-art in firehelmet design a project was initiated by the National Bureau of Standards. Not long after the project began, the responsibility was transferred to the National Fire Prevention Control Administration who continued to support it.

This report summarizes the tests that were conducted on various types of fire helmets to determine their relative effectiveness in mitigating the effects of hostile fire environments. It also reflects the needs of users as perceived by firefighters, fire administrators and safety officers.

It is important to note that this study was restricted to the structural fire environment and does not address special needs of firefighters who devote most of their time to fighting brush fires or crash fires. Nor was this study intended to be an exhaustive evaluation of fire helmets manufactured in this country. Finally, the question of compatibility of helmets with other equipment such as breathing apparatus was not addressed.

The work described in this report culminated in a proposed standard for fire helmets which is included in appendix 3.

Helmet Construction

Fire helmets are designed with (1) a hard outer shell to shed water and debris, to protect against penetration and to distribute the energy of an impacting object; (2) an inner liner or suspension system to absorb any impact energy delivered to the shell and (3) a chin strap or retention system to hold the helmet securely on the head.

Shell

The outer shells of firefighters' helmets are constructed of polycarbonate, glass reinforced plastic (GRP), leather, aluminum or layered fabric in a phenolic matrix. The phenolic shells were discontinued for a while but have recently been reintroduced.

Polycarbonate is a tough thermoplastic material with outstanding resistance to impact. Because polycarbonate can be processed easily with conventional plastics molding equipment, helmets with polycarbonate shells can be manufactured at a reasonable cost. The combination of low cost and high strength to weight ratio makes polycarbonate a desirable material for helmet shells. However, some of the properties that make polycarbonate easy to process also make it a marginal material for firefighters' helmets. It starts to soften at about 150 C (300 F) and at about 200 C (390 F) many of the polycarbonate helmets on the market today will begin to deform. To compensate for the relatively low heat distortion temperature, some manufacturers have raised the thermal capacity by increasing the shell thickness. The trade-off for the resulting higher heat distortion temperature is higher cost and more weight. Another shortcoming of polycarbonate is its susceptibility to attack by some common organic solvents. Exposure to solvents such as carbon tetrachloride, benzene, and methylene chloride may cause the shell to crack.

Glass reinforced plastic (GRP) is also used as a shell material for fire helmets. Woven fiberglass is impregnated with a polyester resin, shaped and cured on a mandrel. Helmet shells fabricated of this material have demonstrated high resistance to heat, flames and chemicals. However, GRP is less resistant to impact damage than polycarbonate. Also, because shells fabricated from GRP must be essentially hand made, the cost is necessarily higher than shells molded of thermoplastic materials.

Leather shells are also hand-produced and are relatively expensive. Heat and chemical resistance of leather helmets is good and leather shells have the ability to deform and absorb some of the energy of impact. However, unless the user exercises considerable care in maintenance, the leather will dry out in time and become brittle.

Helmets made with aluminum shells are gradually disappearing. Although aluminum has the advantages of low cost, light weight, and ability to deform when impacted to absorb energy, it has the obvious disadvantage of being highly conductive to heat and electricity. Helmets with aluminum shells do not meet minimum performance requirements of any nationally recognized standard.

Energy Absorbing System

Between the head and the shell of the helmet is a system for absorbing impact energy. In firefighters' helmets produced today there are two types of energy absorbing system: (1) a webbing suspension similar to the type used in construction workers' helmets and (2) a foamed plastic liner (fully lined) which is usually found in motorcycle helmets.

Helmets utilizing the webbing suspension system are designed to meet the impact requirements of the ANSI Z89.1 standard for industrial hardhats and therefore offer excellent protection against impact to the top of the head but very little impact protection elsewhere. On the other hand, fully lined helmets, which are designed to meet the impact requirements of the ANSI Z90.1 standard for vehicular helmets, provide good protection to the front, sides and back of the head, but do not attenuate the energy of blows to the top of the head as well as the webbing suspension. Also, the fully lined helmets tend to restrict evaporative cooling about the head, and are generally heavier than suspension helmets.

Chin Strap

The function of the chin strap is simply to keep the helmet on the head. Most chin straps on firefighters' helmets are made of leather, nylon webbing or an elastic cotton material. Fasteners are usually "D" rings, snaps or spring clips.

Some helmets have a nape strap which fits around the lower back of the head to prevent the helmet from flipping off when the wearer bends forward. Depending on the design of the helmet retention system, this additional strap may or may not be necessary.

Ear Protectors

Generally, ear protectors are offered as an option for fire helmets and are designed to be tucked up into the helmet leaving the ears exposed, or pulled down over the ears for protection against heat.

Some firefighters object to the use of ear protection arguing that the ears serve as heat sensors to warn of dangerously high heat loads. Safety officers 1/& 2/ on the other hand, would prefer that fire helmets have integral ear protectors that would eliminate the prerogative of exposing the ears.

Head Protection

Before a helmet can be evaluated for its ability to protect the head it is important to identify the parameters which should be measured and the threats to which the wearer might be exposed. For any protective headgear this task is accompanied by some uncertainty, but the problems are compounded with fire helmets because of the demanding and variable environment a firefighter encounters during normal operations.

Any discussion of head protection would be neither complete nor meaningful without some discussion of the mechanism of head injury and tolerance of the human head to impact.

Head injuries can generally be grouped into three categories: scalp, skull and brain. Injuries to the scalp can cause discomfort, bleeding and disfiguration but are not likely to cause a fatality if there is no accompanying injury to the brain or skull.3/

Skull injuries can be categorized as linear, indented, depressed or crushed fractures. With all but the indented fracture, which occurs mainly in children when the bone is relatively flexible, the injury is identified by visible cracking in the skull. Fractures are usually caused by a blunt impact, and although they can occur without brain injury 4/, Guardjian reports that concussion is associated with 80 per cent of all linear skull fractures. 5/

Brain injury is the form of head injury that is of most interest to us because it is so common and covers the entire spectrum from mild, reversible concussion to fatal hemorrhage. It also establishes the threshold of serious head injury.

Brain injuries are usually identified as laceration (tearing or cutting of the brain matter), contusions (bruising) or concussion (loss of consciousness). Concussive brain injury is especially important because it is the most difficult injury to protect against; or stated another way, helmets that protect against concussion will generally protect against any serious head injury.

Concussion is probably caused by shear stress along the brain stem which results from intracranial pressure gradients induced by flow of the brain stem through the foramen magnum 6/, 7/ & 8/. There is evidence to show that pressure gradients will occur along the axis of acceleration of a fluid filled container 9/ which is a good representation of the human brain in a skull. Citing his own experiments and work performed by Seiller, Unterharnscheidt and Lindgres, Thomas 8/ infers that "acceleration is a potent cause of increased intercranial pressure" and "is a most important factor in concussion." Based on his laboratory studies with monkeys, Hodgsen 10/ claims that head acceleration is the one physical parameter most related to monkey head injury.

Predicting Head Injury

Tolerance to closed head injury is hard to establish because it can occur without visible injury to the skull. The Wayne State University tolerance curve, shown in figure 1, 11/ was developed in the early 60's to predict human tolerance to cerebral concussion. Based on experiments conducted on cadavers and animals, it is probably the best known device for predicting human tolerance to head impact. The WSU curve indicates that concussion is a function of time and acceleration. By replotting the WSU curve on log-log coordinates, figure 2, and using the slope of the resulting straight line as the exponent of acceleration, Gadd 12/ devised the Severity Index (SI) which represents a measure of human tolerance to impact. It is expressed mathematically as $SI = \int a^{2.5} dt$, where a is acceleration in units of g_n ($g_n = 9.80665$ meters per second squared) and t is time duration in seconds of the impact.

The Head Injury Criterion (HIC) was developed by Versace and may be considered a refinement of the Severity Index which has been criticized as being mathematically illogical. Newman 14/ points out that it is mathematically incorrect to represent the Wayne State University tolerance curve as a straight line defined by $a^{2.5}t$ and then use this expression in the integration of the acceleration-time impulse curve to obtain a Severity Index. The HIC avoids this by taking the average acceleration of a selected interval of the a-t curve, raising it to the 2.5 power and multiplying by the duration of the selected interval.

Mathematically, HIC is expressed as

$$HIC = \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a dt \right]^{2.5} (t_2 - t_1)$$

where a is the acceleration in g_n's and $t_2 - t_1$ is the time interval which maximizes HIC.

Both SI and HIC attempt to make maximum use of biomechanical information provided by the Wayne State tolerance curve. The NOCSAE* standard for football helmets 15/ uses an SI of 1500 as a rejection

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National Operating Committee on Sports and Athletic Equipment criterion. Other helmet standards such as FMVSS 218 15/ and ANSI** Z90.1 17/ acknowledge the existence of the WSU tolerance curve by including time limits as well as maximum acceleration in their rejection criteria.

Physiological Considerations

Comfort, to a firefighter,means more than being physically at ease. It also refers to the ability to perform tasks without suffering from overexertion or heat exhaustion.

Lives and property frequently depend on the firefighters' ability to do strenous work quickly under the most demanding environmental conditions. They must raise and scale ladders, pull hoses up stairs, cut holes in walls, ceilings or floors with power tools, pull down ceilings with hooks, and sometimes rescue comrades or occupants who have been overcome by smoke - all of this while wearing approximately 27 kg (60 lb.) of protective equipment and carrying an additional 7-9 kg (15-20 lb.) of tools

The IAFF Firefighter Mortality Report 18/ cites heart disease as the leading cause of firefighter death and disability, and in a study of the New York City Fire Department covering the period 1970-1973, overexertion accounted for 11 per cent of the service connected accidents and 42% of the time lost.

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*Federal Motor Vehicle Safety Standard

**American National Standards Institute

Comfort and weight then, are important considerations in helmet designs. Some of the factors associated with helmet comfort include location of center of mass, fit, mass moment of inertia, and ability to allow dissipation of body heat through evaporative cooling of the head. In general, current helmets trade off protection for weight and comfort. That is, the heavier and less comfortable helmets are generally less susceptible to heat damage and provide more impact protection.

Impact Attenuation

Considerations in Establishing a Test Method for Impact Attenuation

Berger 19/ suggests that an ideal test method should utilize a test head which duplicates the response of a human head to impacts. Such a headform was developed by Wayne State University 20/ and is now being used by NOCSAE in their standard test for football helmets. 15/ However, in two separate round robin tests 21/& 22/, data indicated that reproducibility with the headform was not satisfactory for a test method.

Probably the two best known and most used methods for testing helmets in this country are the falling ball/rigid headform method described in ANSI Z89.1 23/ (fig. 3) and the falling headform/rigid anvil method described in ANSI Z90.1 17/, Snell 24/, and FMVSS 218 16/ (fig. 4). The Z89 apparatus constrains impact tests to a small area on the top of the helmet while the Z90 apparatus allows impacts to be delivered to all areas - top, front, sides and back (fig. 5, 6, 7 & 8).

Although most impacts to firefighters heads may result from debris falling on the top of the head, there is also a very real threat of serious impacts to other parts of the head. For example, there have been reports of firefighters being struck on the side, front, and back of the head by errant hose nozzles (appendix 2, letters 1, 2), as a result of falls from ladders 25/, by collapsing walls and roofs 18/ and from vehicular accidents en route to or from the fire 18/ (appendix 2, letters 2 and 3).

Having established that an important parameter in assessing head impact injury is acceleration, and that impact tests on firefighters' helmets should not be limited to the top, a logical choice for the test apparatus was the ANSI Z90 set-up. The Z90 apparatus measures the deceleration of a helmeted metal headform when dropped in guided free-fall onto a steel anvil. A ball and socket arrangement (shown in fig. 4) permits positioning of the headform so that a helmet can be impacted at any location.

The magnesium Z90 headform has been criticized as being too rigid to respond to impacts in a manner similar to a human head. However, for a test device, simulation of human response may not be as essential as the requirement of reproducibility. ASTM Round Robin tests have indicated that the Z90 apparatus is a more reproducible system than the NOCSAE apparatus which uses a realistic headform. 21/ At the very least, the Z90 apparatus provides one measure of a helmet's ability to attenuate the energy of impact.

It must be emphasized that the lack of information on in vivo human tolerance to head impacts, the broad distribution of impact tolerance from person to person, and the failure of the metal headform to duplicate the response of the human head, make it virtually impossible to measure the actual protection provided by a helmet. Instead, the helmet's ability to absorb the energy of a given impact is measured.

As test headforms improve and more is learned about the tolerance of human heads to impacts, test methods will improve sufficiently to actually measure the amount of protection that a helmet affords in a given situation. Meanwhile, we must satisfy ourselves with the best available techniques. For fire helmets, the Z90 type apparatus appears to come closest to satisfying the need.

Impact Attenuation Tests

Helmets were subjected to environmental conditioning (room temp., high temp., low temp., and wet) and dropped from a height of 183 cm onto a steel anvil. Results of the impact attenuation test (appendix 1) show clearly that the suspension type helmets consistently perform better than fully lined helmets when impacted on the top. On side, front, and rear impacts, however, the fully lined helmets invariably perform better. Note also that the suspension type helmets were dropped from 92 cm rather than 183 cm (one half the impact energy) when impacted on locations other than the top. Even at this reduced impact level, headform accelerations exceeded 500 g. This demonstrates a design limitation of suspension type helmets which allows effective attenuation of impacts to the top of the head but minimal attenuation elsewhere. Typical acceleration-time curves are shown in fig. 10.

Considerations in Establishing Impact Performance Criteria

As indicated earlier, the optimum fire helmet design combines the correct balance of protection, cost, weight and comfort. But, as with any helmet, increased protection is generally obtained by sacrificing comfort, weight and cost. For example, to obtain more impact protection, the distance between the shell and head may be increased, permitting more stopping distance between the head and impacting object. But increased size is generally accompanied by increased weight and less comfort. Unlike the motorcyclist who expends little energy while riding and can afford to wear heavy helmets, the firefighter does strenuous work during routine structural firefighting and places a high premium on lightweight equipment. 28/

The impact requirements in the proposed standard (appendix 3) were based on biomedical information, test data obtained from various commercially available fire helmets (appendix 1) and our own assessment of the state-of-the-art in materials and helmet design. In addition, the needs of firefighters, safety officers and administrators were considered (appendix 2). Helmets that meet these requirements will substantially reduce the effects of blows to the head. Although none of the helmets tested meet the proposed impact requirements (appendix 3), we are convinced that they can be made without significantly compromising cost and comfort. All of the fire helmets in this country have been patterned after crash helmets (interior fully lined with an energy absorbing material such as foamed styrene) or industrial hard hats (sling suspension system)(see figs. 11 thru 17). Yet, the state-of-the-art in helmet design and manufacturing permits production of fire helmets that provide better protection than either the sling suspension or fully lined helmets that are currently available. Some examples of innovative design that might be employed in fire helmets are shown in figs. 18 thru 23. All of the helmets shown are football helmets.

Penetration Resistance

Protection against injury from penetrating objects can be viewed as a special case of impact protection where the impacting object is pointed. With pointed objects, however, the threat of injury is likely to be scalp (and possibly skull) penetration rather than closed head injury discussed earlier.

The proposed penetration resistance test is similar to the test described in ANSI Z90 17/ and FMVSS Z18 16/. It requires that a pointed steel cylinder be dropped in guided free fall from a height of 2.5 m onto a helmet which is mounted on a metal headform. Contact between the penetrator and the headform constitutes failure. Helmets were tested for resistance to penetration by dropping the penetration striker from various heights (appendix 1). Leather, glass reinforced plastic, and polycarbonate all have a good field record in providing protection against penetration by sharp objects. The requirements were set to prevent any lowering of present performance.

Heat Resistance

Comments from firefighters (appendix 2, letters 4 thru 11) indicate widespread dissatisfaction with some present helmets because of low resistance to heat. To substantiate complaints, deformed helmets and photographs of heat damaged helmets (figs. 24 and 25) were presented by fire departments in different geographical locations. In all cases, the helmets involved were thin shelled polycarbonate (approx. 0.190 cm). However, it should be noted that in investigating reports of deformed helmets, there were no cases of helmets having contributed to the injury.

On this basis, one manufacturer 26/ argues that the helmet has done its job in protecting the user. Some firefighters 27/ on the other hand, have expressed concern about the suitability of helmets that deform during structural firefighting operations which they do not consider to be extreme or unusual. It is also significant that there was not a single reported case of helmet deformation from departments using the helmets with thicker polycarbonate shells (approx. 0.400 cm to 0.500 cm). Field information, then, suggests that polycarbonate is a marginal material which may or may not be satisfactory, depending on thickness.

In a study by Grumman Aerospace Corporation 28/, temperature measurements were taken at the scene of structural fires. They reported the "typical fire scene temperature" to be in the range of 38-65°C (100-150°F) with a maximum of approximately 230°C (450°F) "for a short interval."

Radiant heat flux measurements made during the same study showed heat intensities ranging from 0.03 to 0.13 watts per square centimeter.

On the basis of data obtained from 72 fire incidents, Burgess 29/ reports that "maximum temperatures in excess of 80°C (176°F) can be expected in only 1% of all structural fires."

Simms and Hinkley 30/ describe several ranges of heat exposure for fire fighters. Under normal conditions the authors estimate temperatures of up to 55 C (131°F) and a radiation intensity of up to 0.14 W/cm^2; while during rescue operations, the study predicts firefighters might expect to encounter temperatures from 60 to 275°C (140-527°F) and radiant heat loads from 0.15 W/cm^2 to approximately 1.3 W/cm^2. During controlled tests with volunteer firefighters, Dupont 31/ reported that one subject withstood 221°C (430°F) for 3 minutes.

High Temperature Requirements

Guided by the published reports, comments from the field, and the evidence of heat damaged helmets, three minutes at 250°C was established as a reasonable test condition for high temperature performance. Under these conditions, it was possible to duplicate damage that occurred during actual field use. It is important to note that damaged field helmets that were used as a guide were all involved in incidents where the user survived. The only demand placed on the helmet during this test is that it not deform to such an extent that it becomes a hazard iteself. The intent of the high temperature requirement is to ensure that a firefighter can escape or be rescued from an extraordinarily high heat situation without having his helmet contribute to his injuries. Laboratory tests were conducted with various commercially available helmets (appendix 1). Helmets that deformed in the field failed the test, while helmets with no record of heat damage in the field passed.

A spearate heat load requirement is included as a part of the impact test to insure that a helmet will offer protection against impact at elevated temperatures. Specifically, a radiant heat load of 0.6 W/cm^2 is applied to the helmet for 3 minutes immediately prior to impact. Based on reports cited earlier, helmets that meet this requirement should perform satisfactorily if impacted while exposed to heat loads that one might normally encouter while fighting active fires. Laboratory tests show that some helmets currently produced will meet the impact requirement after exposure to radiant heat (appendix 1).

Flammability

Simultaneous exposure to direct flames and high radiant heat loads is not unlikely for firefighters. Therefore, the flammability test requires that the helmet and ear protectors be exposed to direct flame and a radiant heat load of 0.6 W/cm^2. The radiant heat load is well above the exposures anticipated for routine firefighting 28/ and well above any measurements recorded by Burgess during his study. After removing the flame (but not the radiant heat source) the helmet and ear protectors must extinguish themselves within five seconds. Laboratory tests (appendix 1) indicate that most of the fire helmets currently available will meet the proposed flammability requirements.

Chin Strap/Retention System

The function of the chin strap is simply to keep the helmet on the head. Current motorcycle helmet standards 16/, 17/ & 24/ require that the chin strap support a 1300 N (300 lb) static load. It is well within manufacturing capability to produce such a chin strap. However, firefighters expressed concern that neck injuries might result from unyielding straps. Some also favored breakaway devices.

The proposed criteria require that chin straps be capable of supporting a static load of 650 N (146 lb). This requirement is proposed to prevent helmets from being dislodged during moderate impacts. It also allows manufacturers to design chin straps that will break loose to avoid neck injury.

Electrical Resistance

Collapsing ceilings and walls are likely to expose live electric wires creating a serious hazard to firefighters. Helmets are therefore required to pass an electrical resistance test. The proposed requirement for electrical resistance is similar to ANSI Z89.1. 23/ Fire helmets that have met this requirement in the past have also performed satisfactorily in actual field use (appendix 3, p. 13).

Visibility

For both logistical and safety purposes it is important for firefighters' helmets to be highly visible. During the daytime this can best be accomplished by using light colored helmets such as white, yellow, orange, etc. At night, retro-reflective markings on the helmet can greatly increase visibility by reflecting light back toward the source. Proposed values for color and retro-reflectance of fire helmets (appendix 3, pg. 3) were based on the requirements for firefighters' turnout coats and the state-of-the-art in retro-reflectance.

Summary

In reviewing the test data and field information it is apparent that additional work is necessary in several areas.

Injury data. A comprehensive system of gathering firefighter injury information is essential. Specific injury data is necessary to determine weaknesses in present protective equipment and to establish a sound basis for development of new, improved protective gear.

The National Fire Prevention and Control Administration initiated a project during fiscal year 1977 to study firefighter injuries. It is anticipated that this study will help satisfy the need for specific injury information.

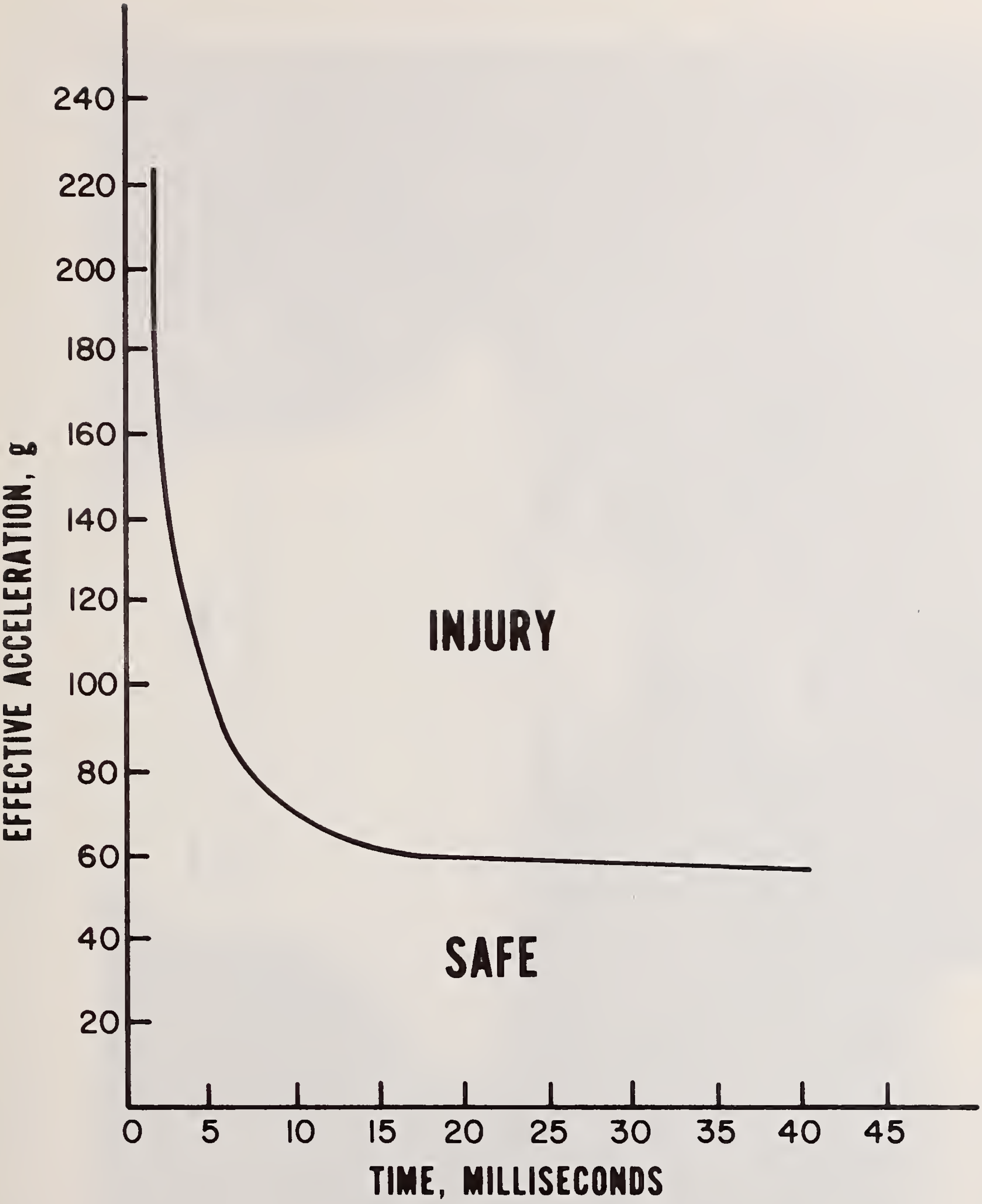
New helmet designs. Impact test results show that present helmets provide the user with two choices: (1) sling suspension helmets - excellent attenuation of impacts to the top of the head with minimal impact attenuation elsewhere; (2) fully lined helmets - good attenuation of impacts to front, sides, back and top of the head but considerably less impact attenuation on the top than is offered by the sling suspension helmet. A combination of the sling suspension and padding would incorporate the best features of both designs and provide firefighters with more protection against impact than either of the current choices. This is not a new concept but has been available in football helmets for many years. Yet, it has not been adapted to fire helmets. Other energy and heat absorbing systems should be evaluated to optimize comfort, weight, cost and protection.

New shell materials should be investigated to provide protection at high temperatures at a reasonable cost and weight.

Equipment compatibility. Helmets must be designed to be compatible with other equipment. Face shields sometimes interfere with breathing masks; chin straps on breathing masks interfere with helmet straps, breathing tanks carried on the back interfere with the brim of the helmet.

NASA and NFPCA have jointly sponsored a program to examine the requirements for a total firefighters' ensemble. A major part of this project will be the important problem of equipment compatibility but the solution is three to five years away.

Eventually, through the combined efforts of government, industry and users, fire helmets and other protective gear will advance to a level which all may consider acceptable. In the meantime, test methods and performance criteria must be established to ensure a reasonable level of protection within current technological limits.



WAYNE STATE UNIVERSITY
TOLERANCE CURVE FOR CEREBRAL CONCUSSION

Figure 1.

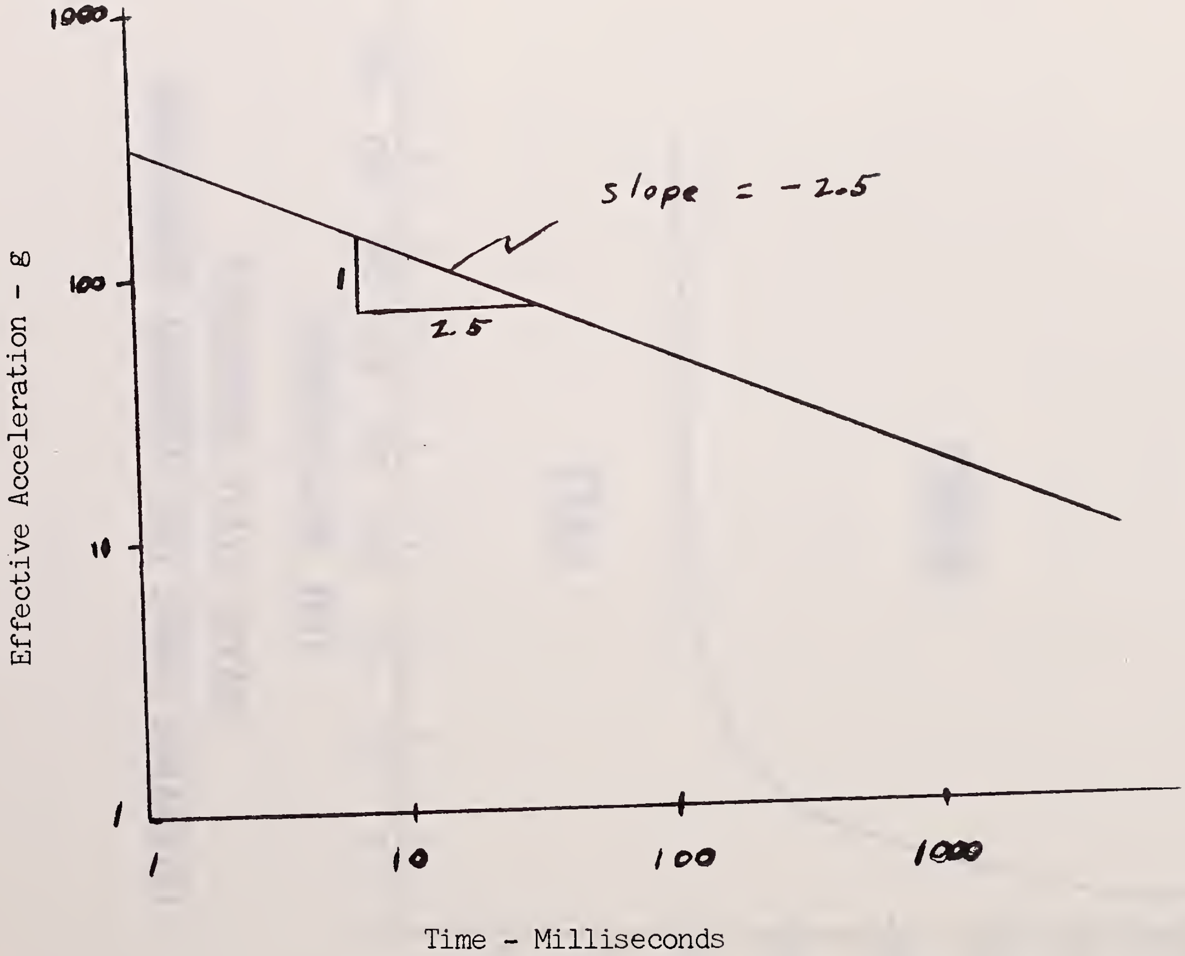


Figure 2. Log - Log Plot of Wayne State University Tolerance Curve

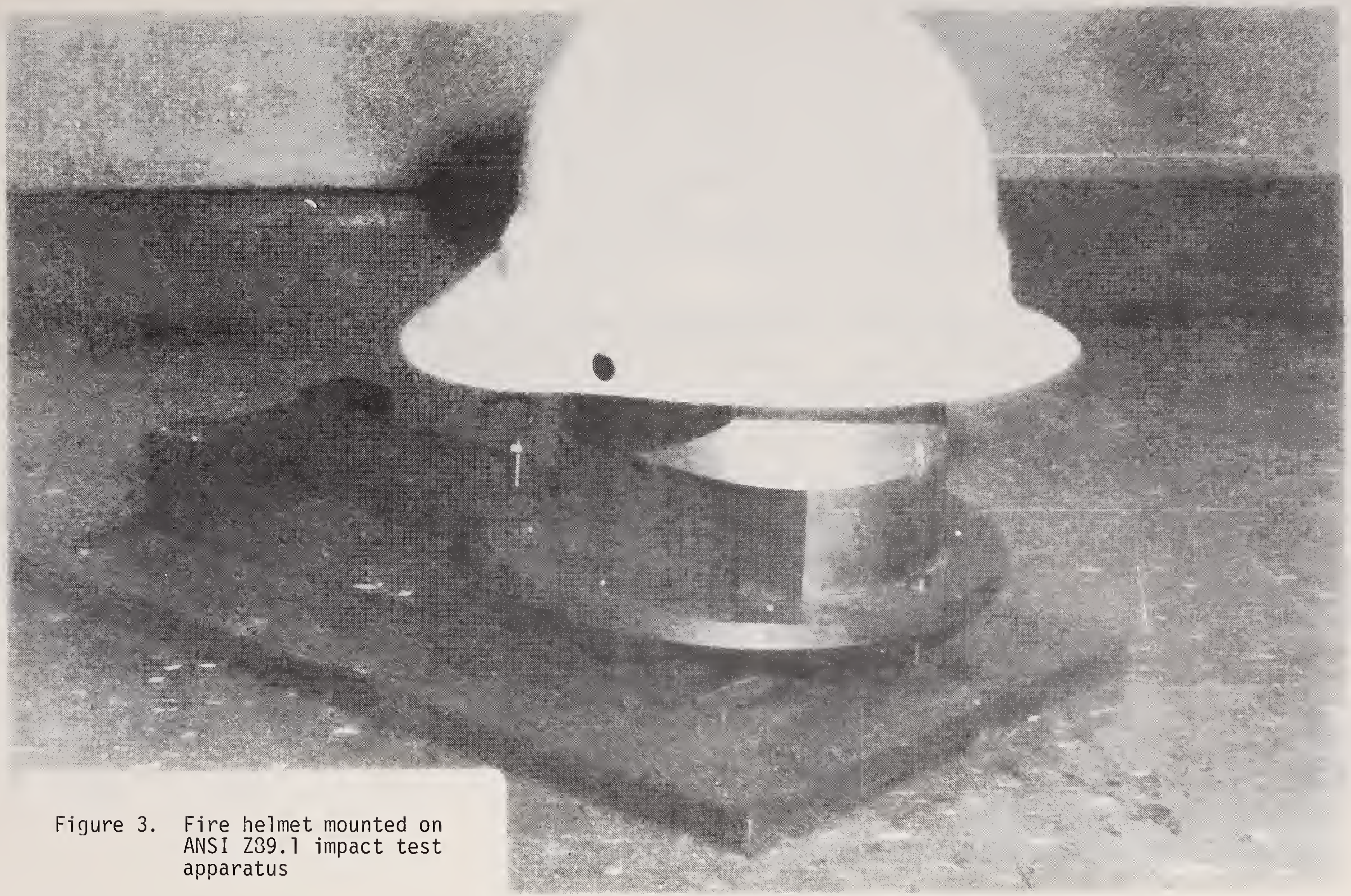


Figure 3. Fire helmet mounted on ANSI Z89.1 impact test apparatus

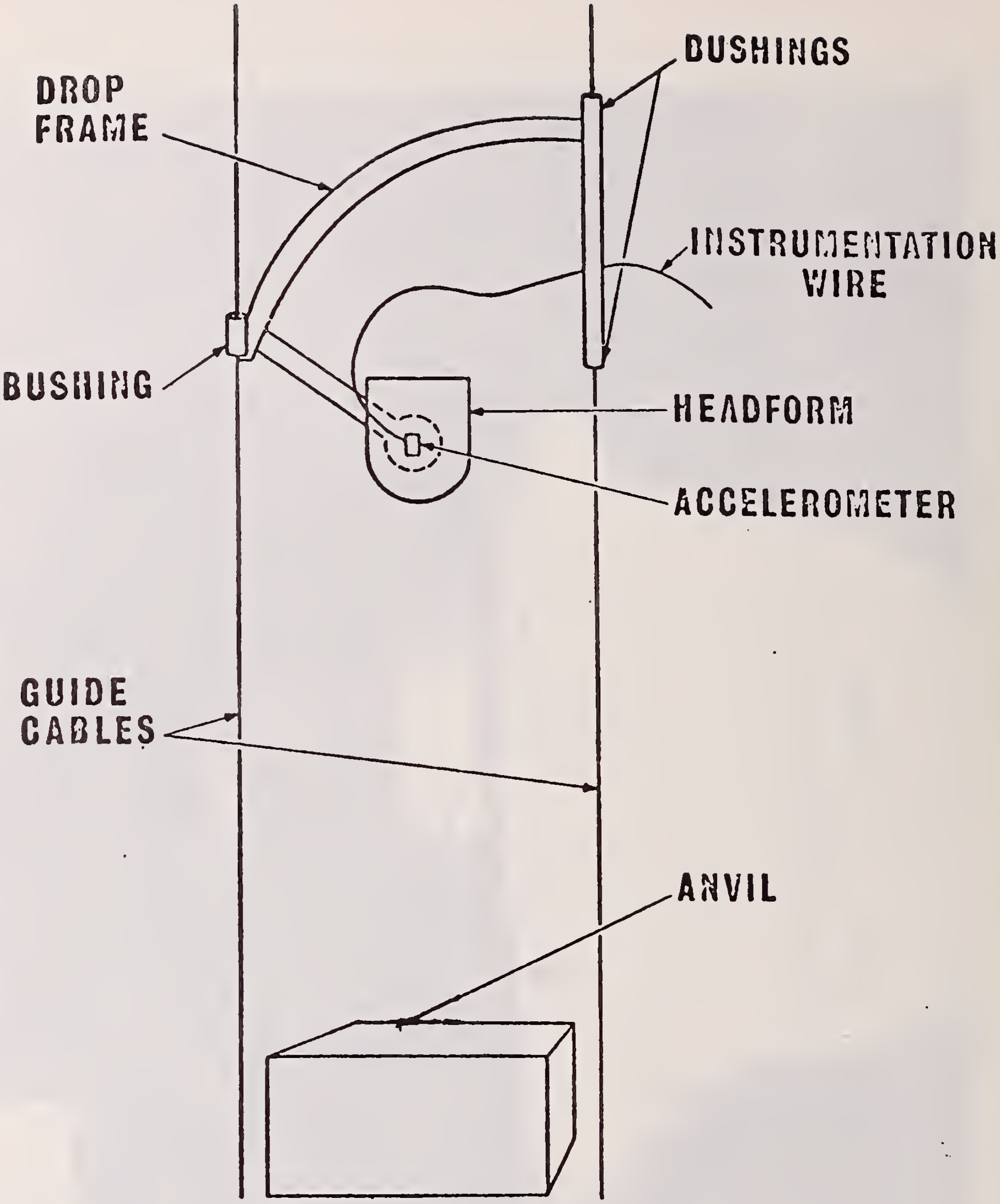


Figure 4. Z90.1 test apparatus

Figure 5. Helmet mounted on headform and positioned for front impact.

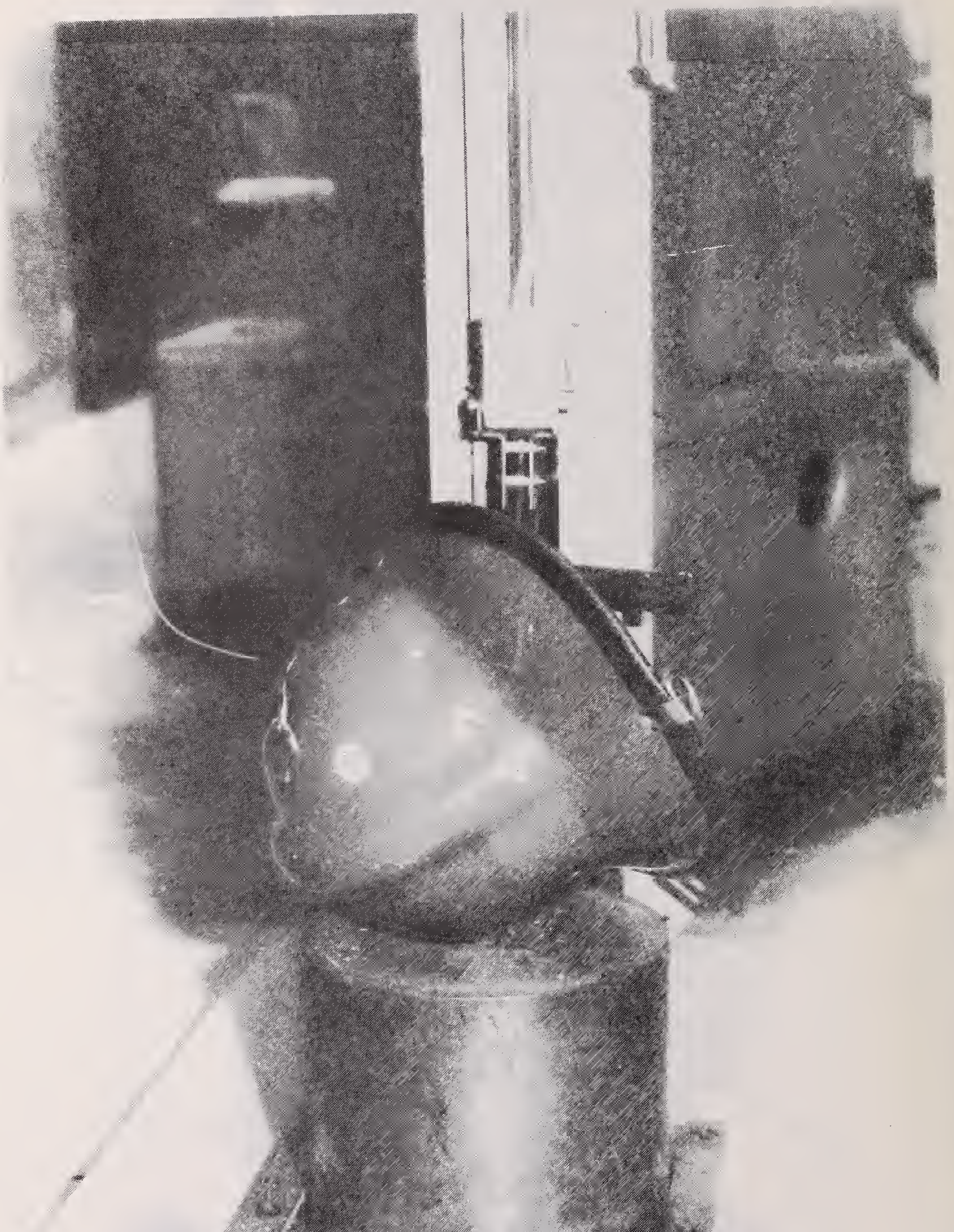


Figure 6. Helmet mounted on headform and positioned for rear impact.

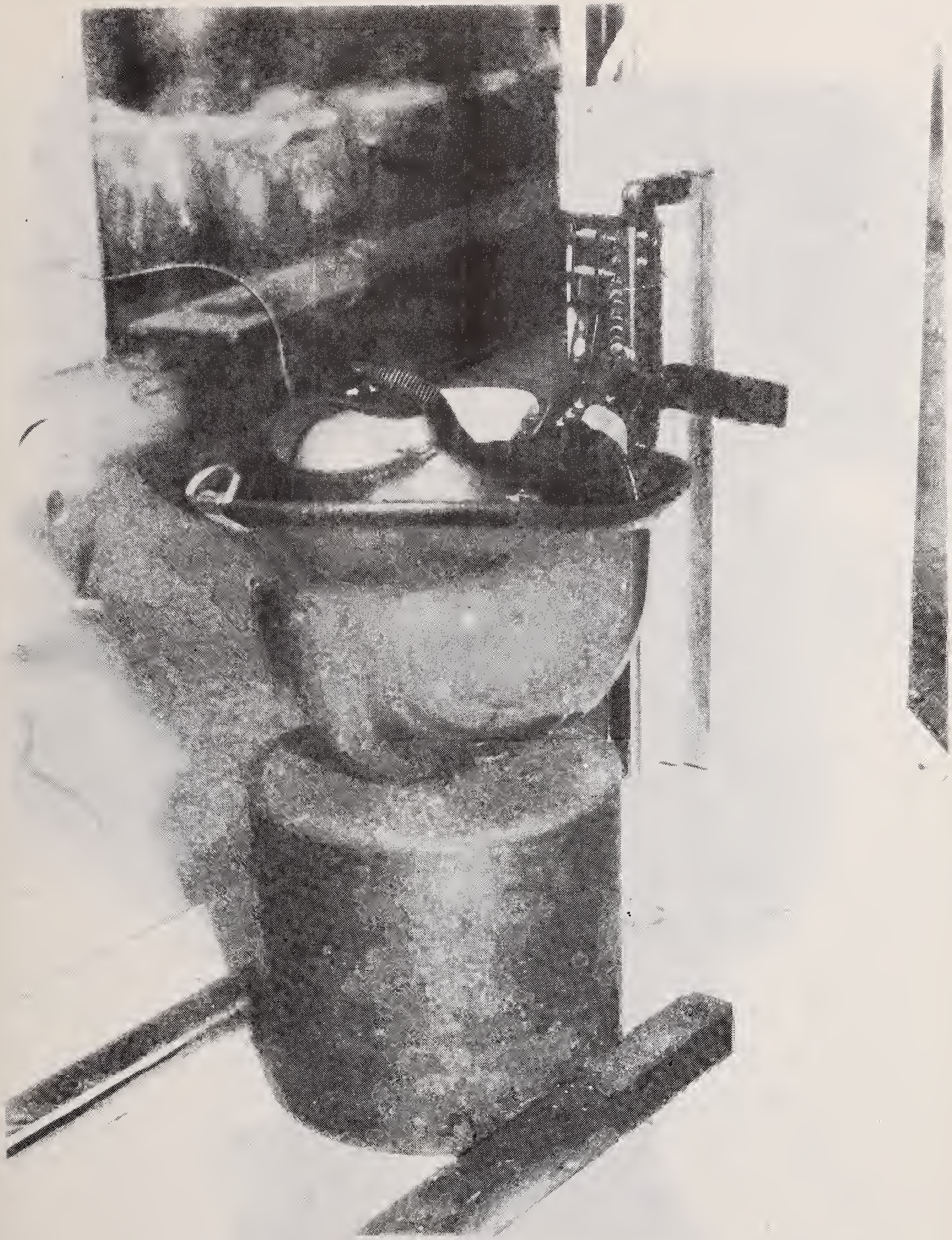


Figure 7. Helmet mounted on headform and positioned for top impact.

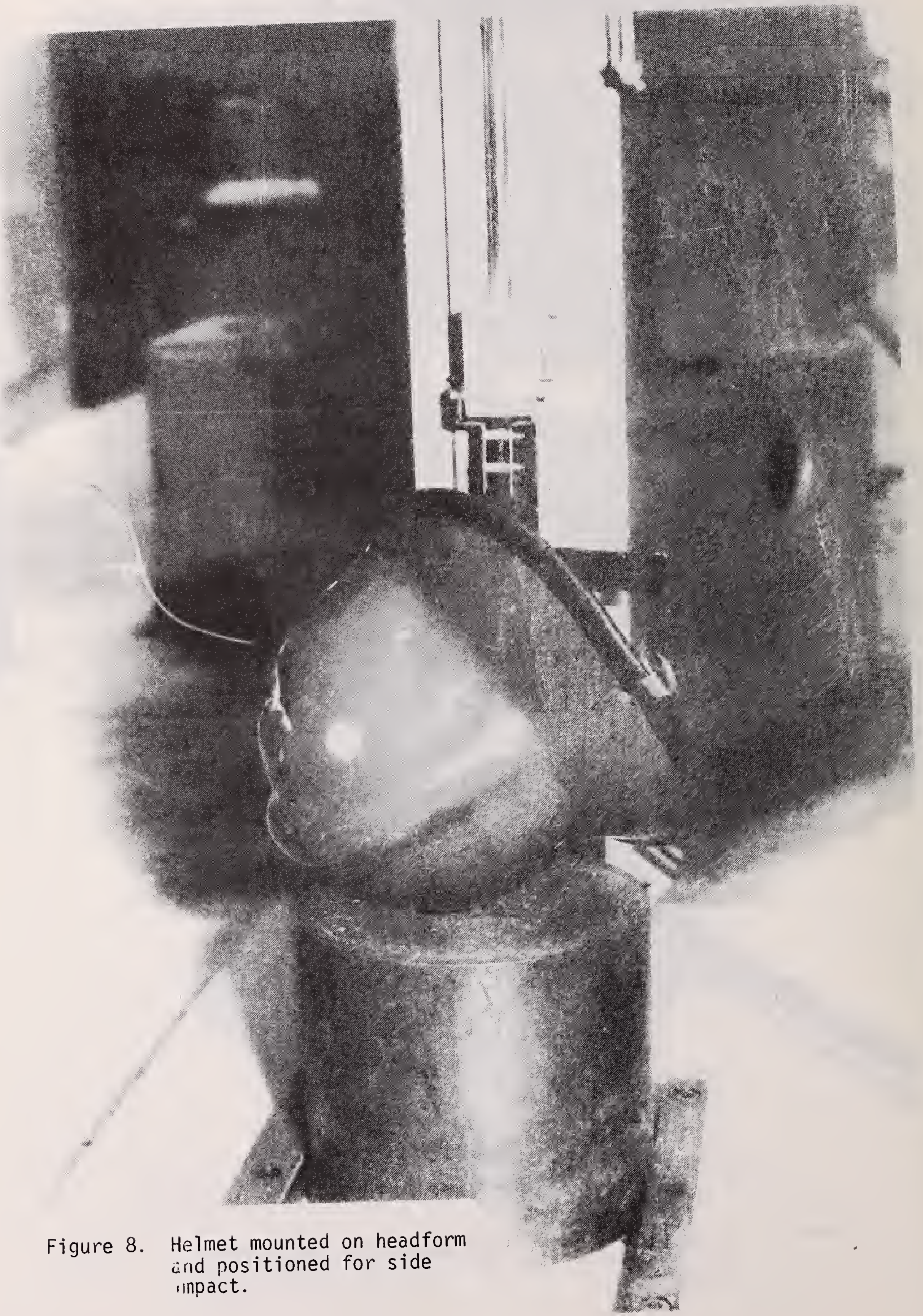


Figure 8. Helmet mounted on headform and positioned for side impact.

Figure 9. Metal headform (Z90) with ball and socket.

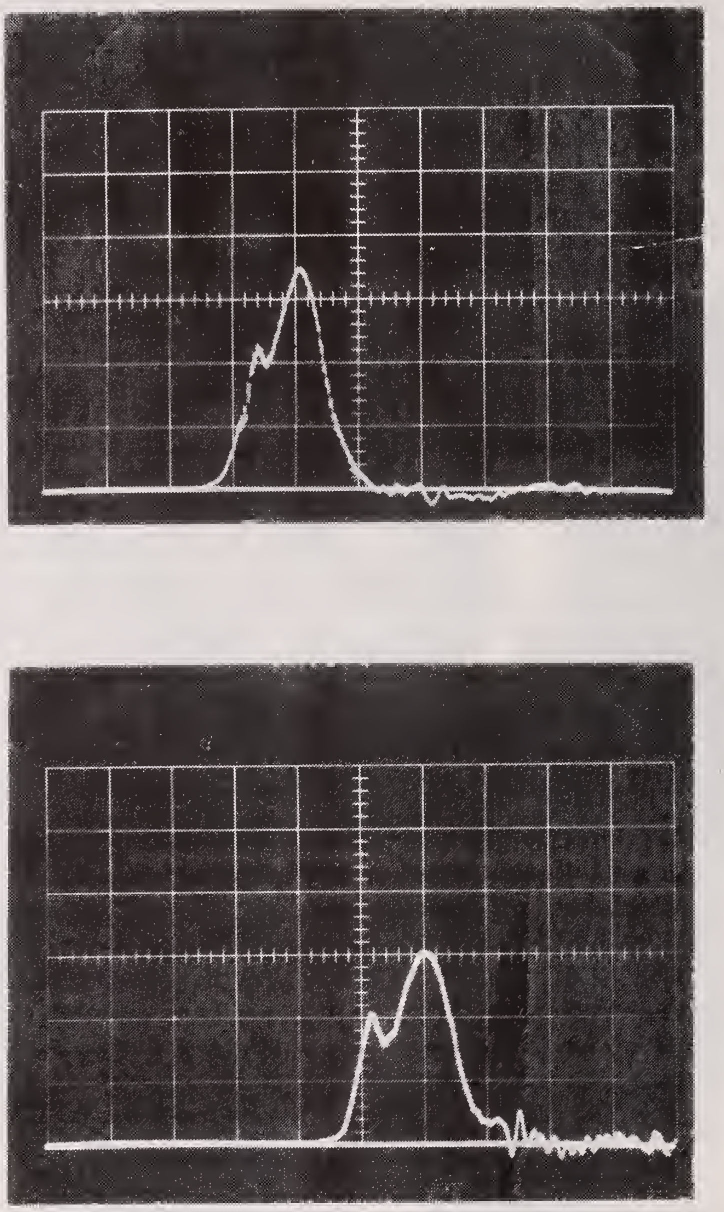


Figure 10. Typical acceleration-time curves

ordinate: acceleration - 100 g's/division
abcissa: time - 1 millisecond/division

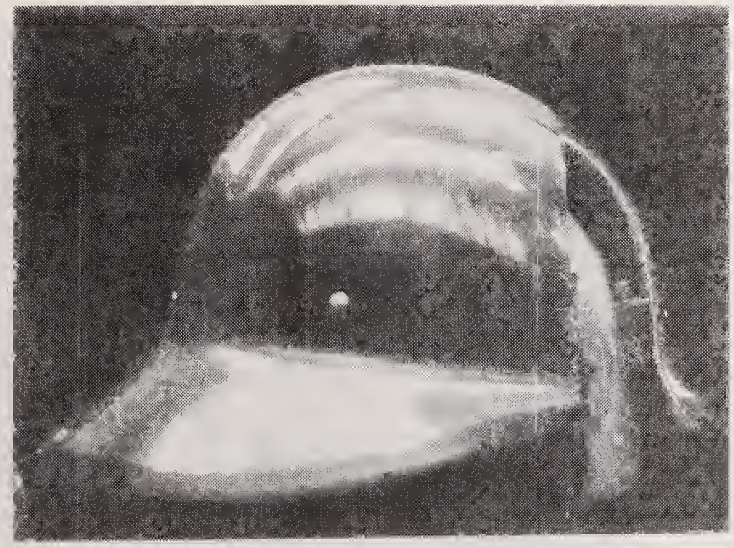


Figure 11. Fully lined fire helmet with glass reinforced plastic shell.

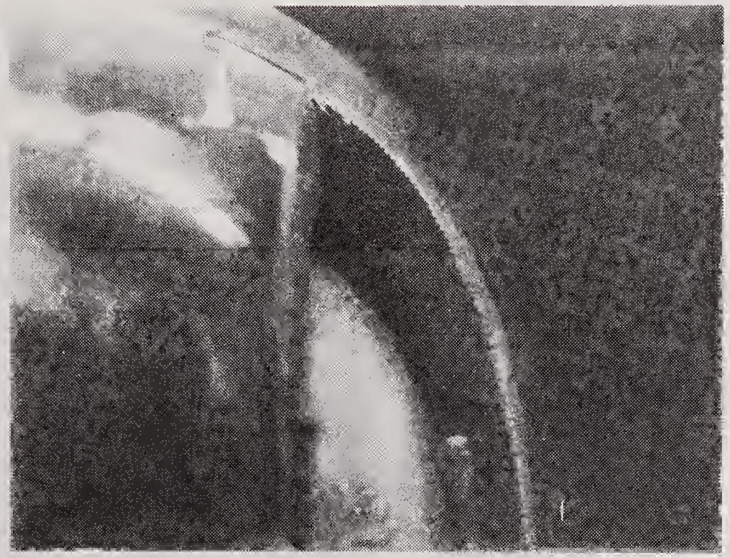


Figure 12. Close-up of cutaway section showing foamed plastic lining.

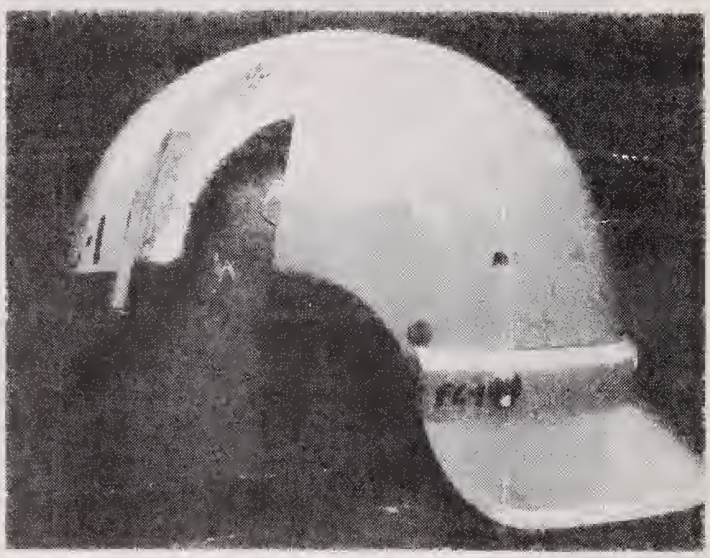


Figure 13. Fully lined fire helmet with polycarbonate shell.

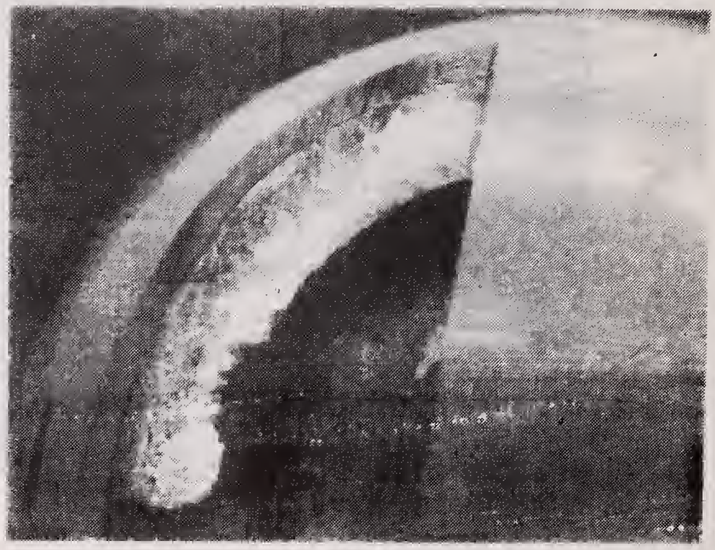


Figure 14. Closeup of cutaway section showing foamed plastic lining.

Figure 15. Sling suspension fire helmet - glass reinforced plastic shell with nylon webbing - 4 point suspension

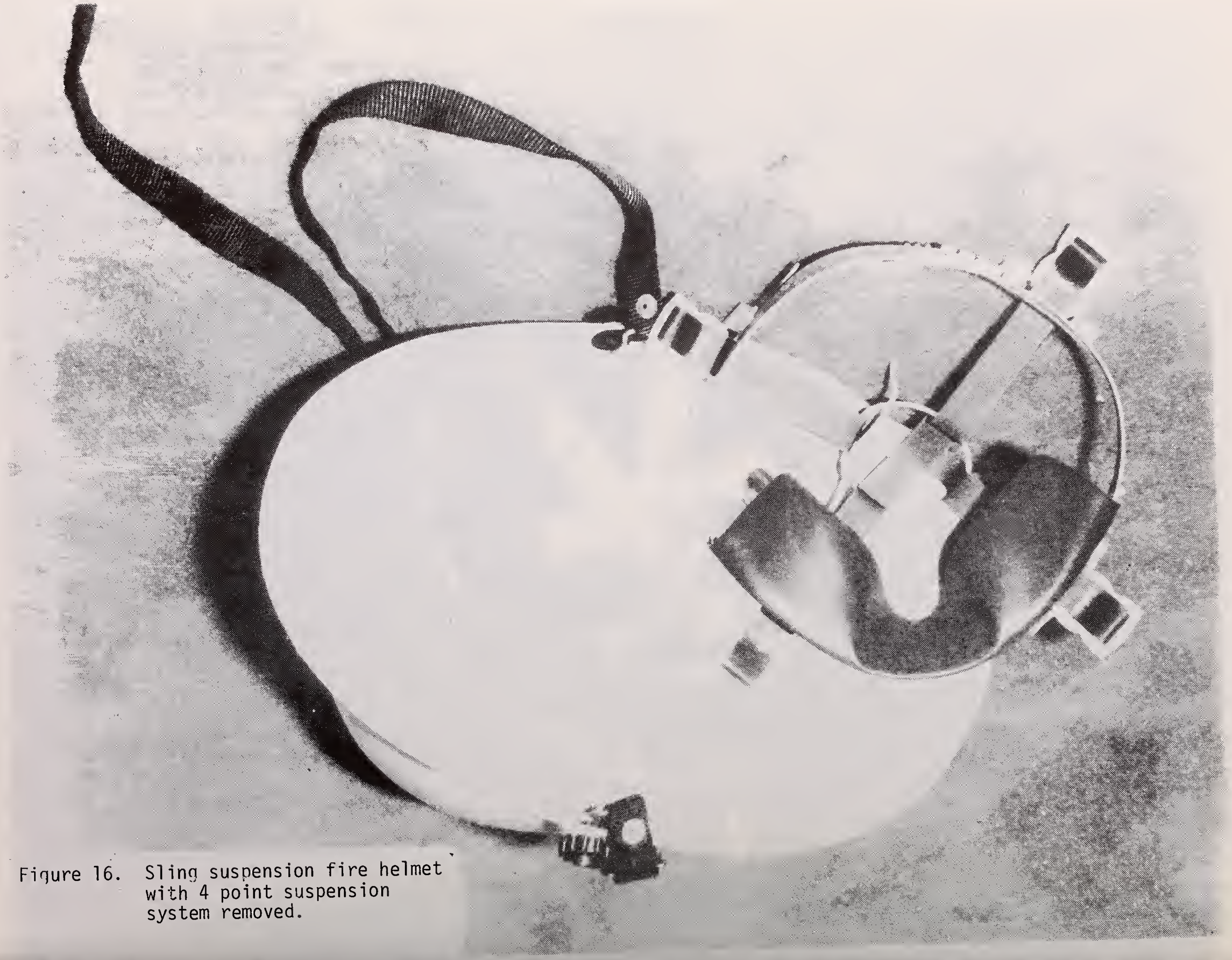


Figure 16. Sling suspension fire helmet with 4 point suspension system removed.

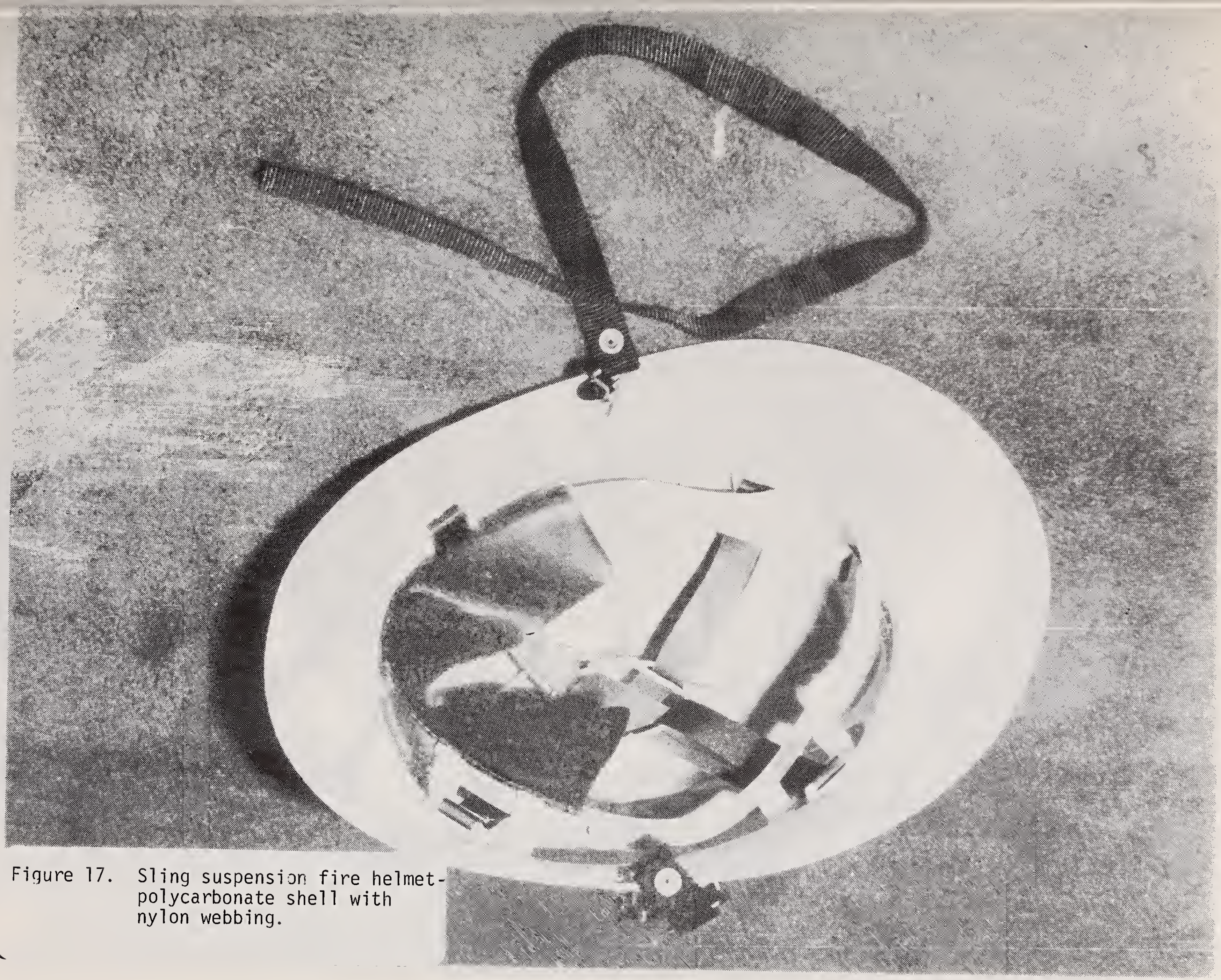


Figure 17. Sling suspension fire helmet-polycarbonate shell with nylon webbing.

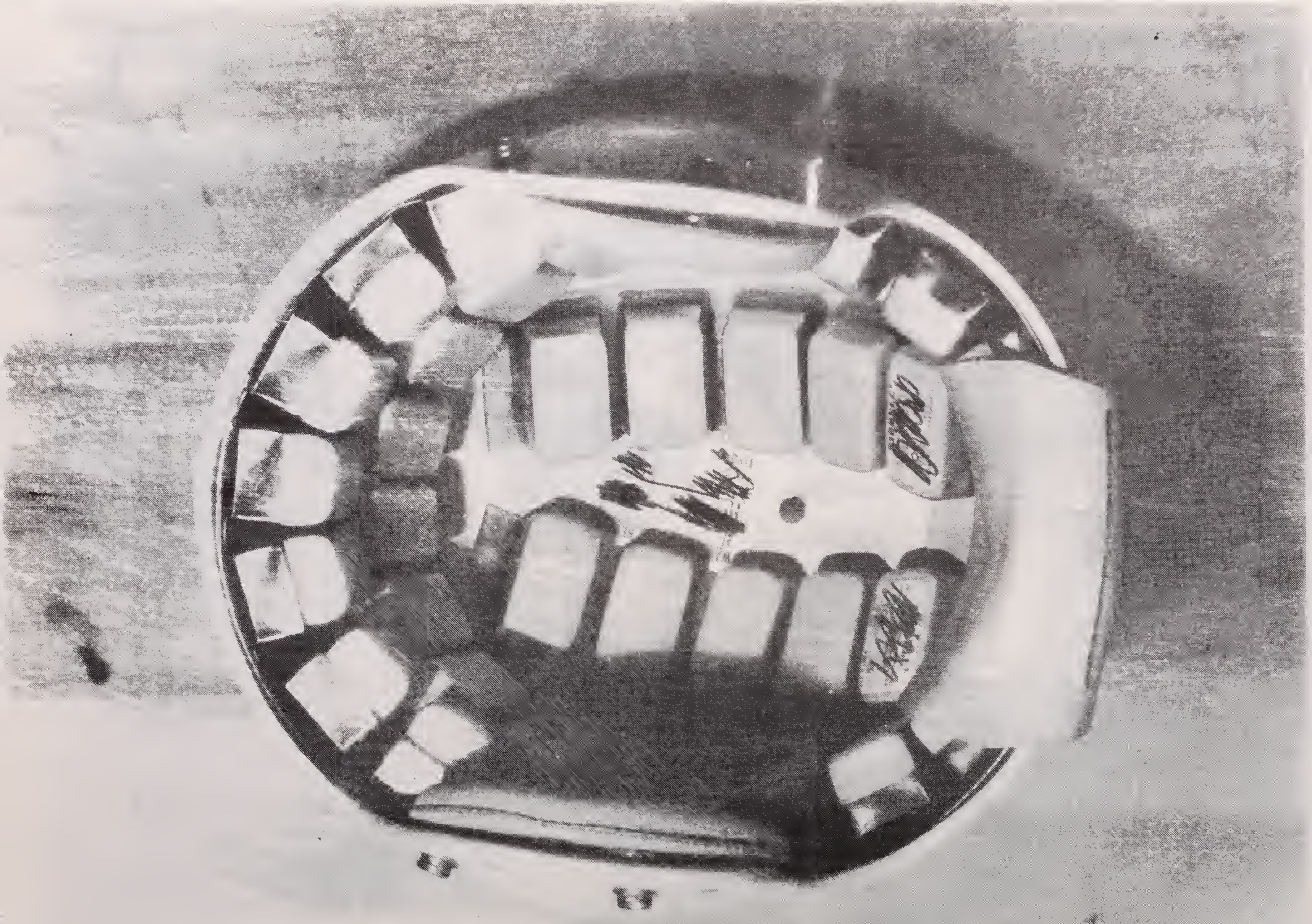


Figure 18. Football helmet - dual padding system consisting of a low density foam for protection against low energy impacts and a high density foam for high energy impacts.

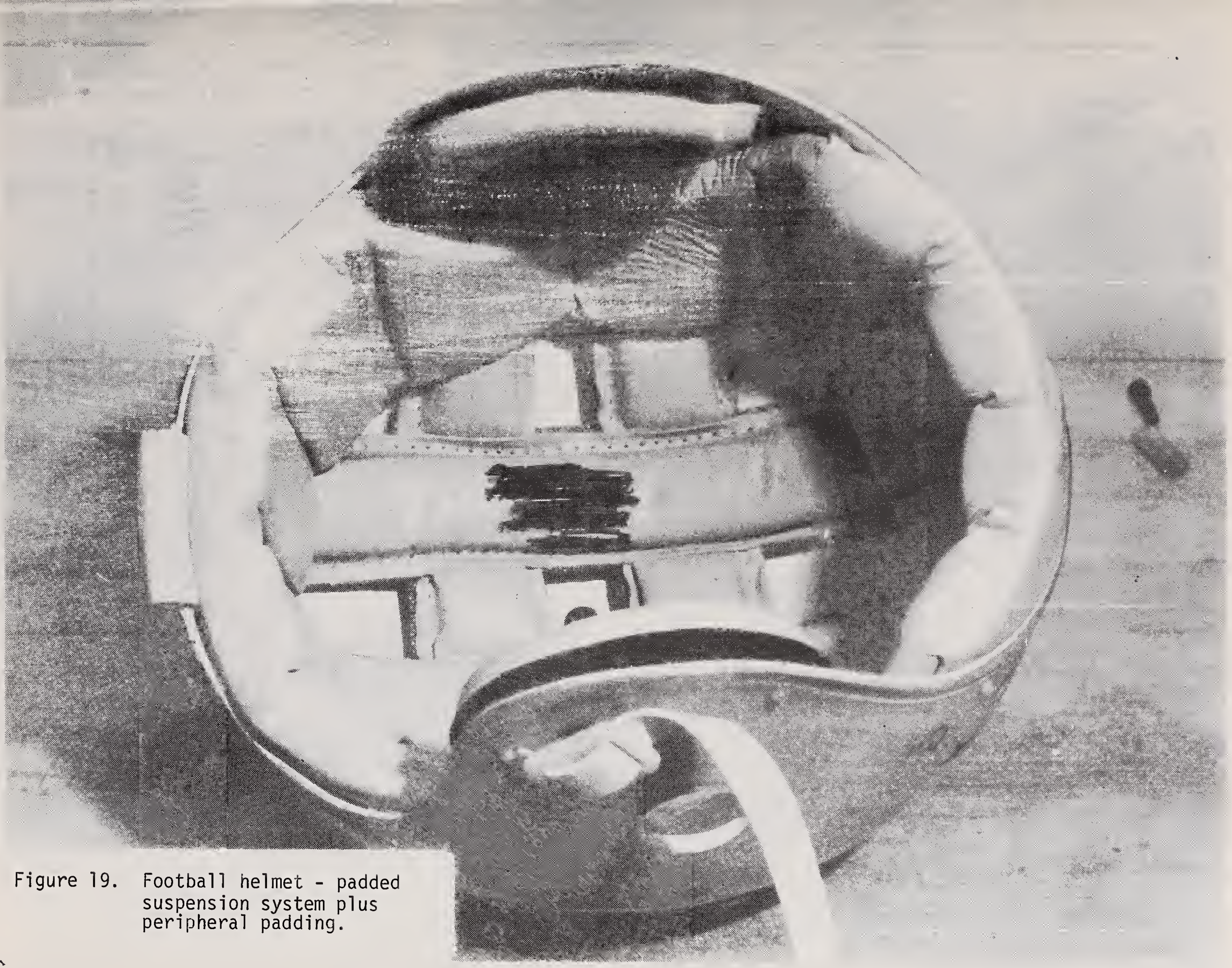


Figure 19. Football helmet - padded suspension system plus peripheral padding.

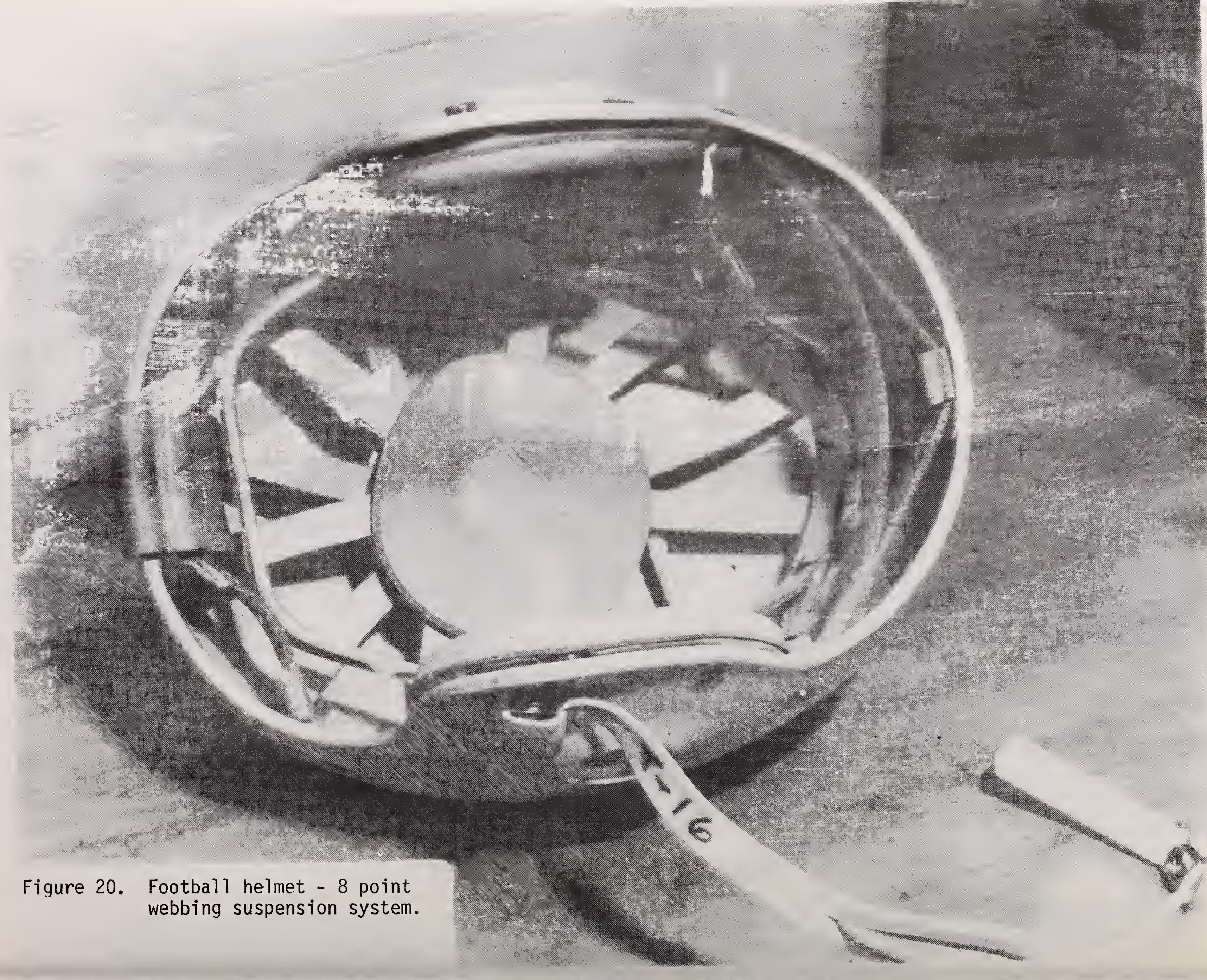


Figure 20. Football helmet - 8 point webbing suspension system.

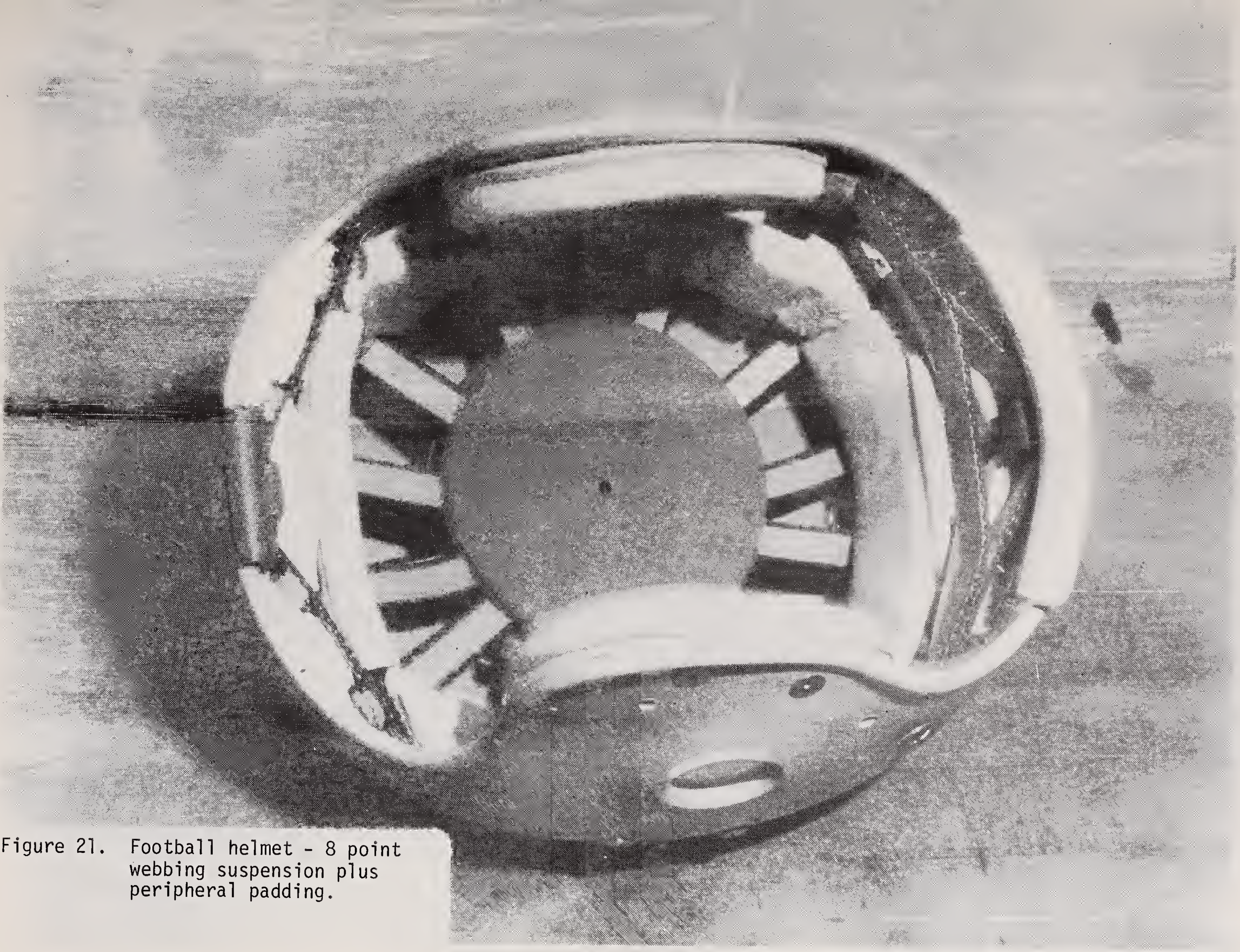


Figure 21. Football helmet - 8 point webbing suspension plus peripheral padding.

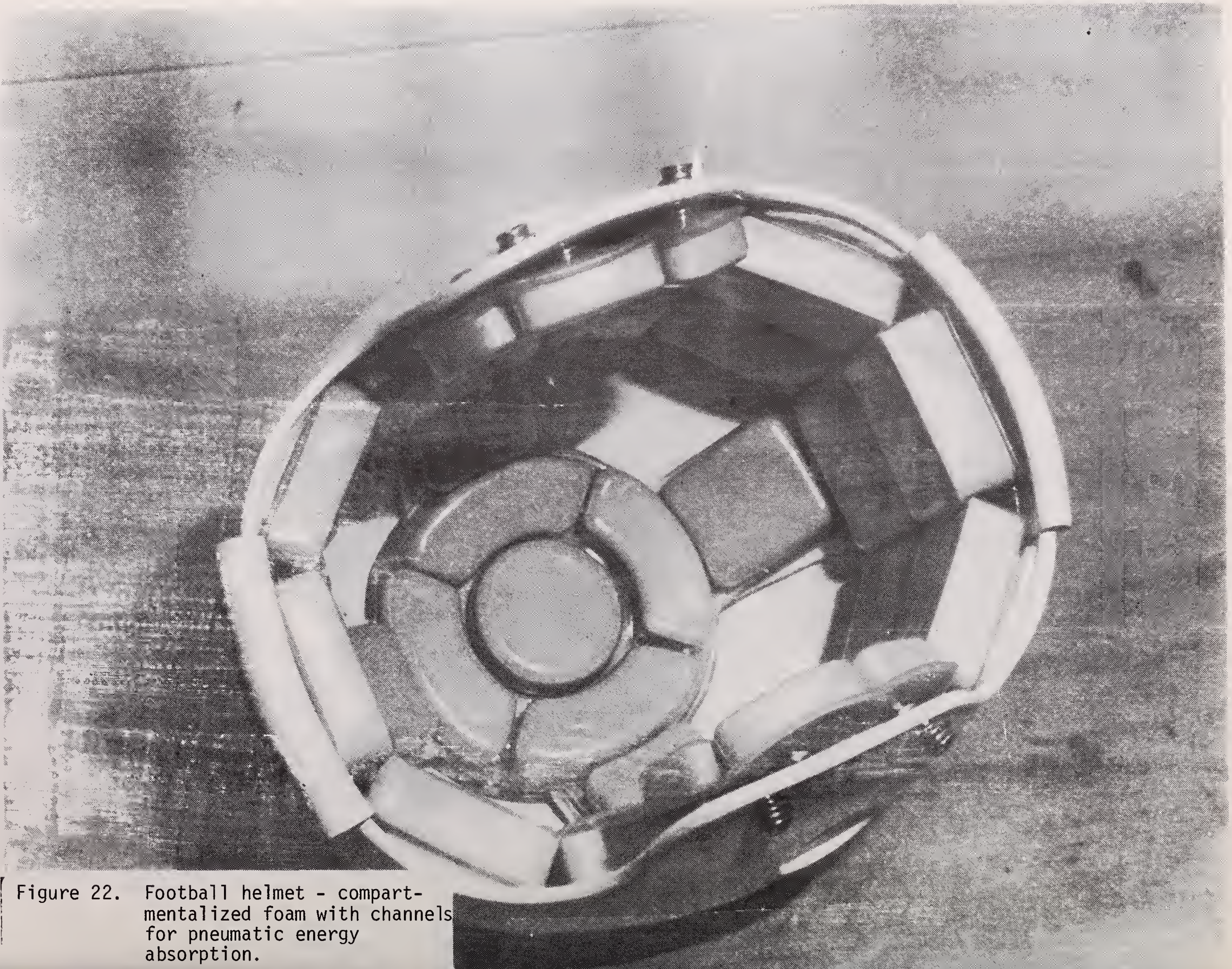


Figure 22. Football helmet - compartmentalized foam with channels for pneumatic energy absorption.

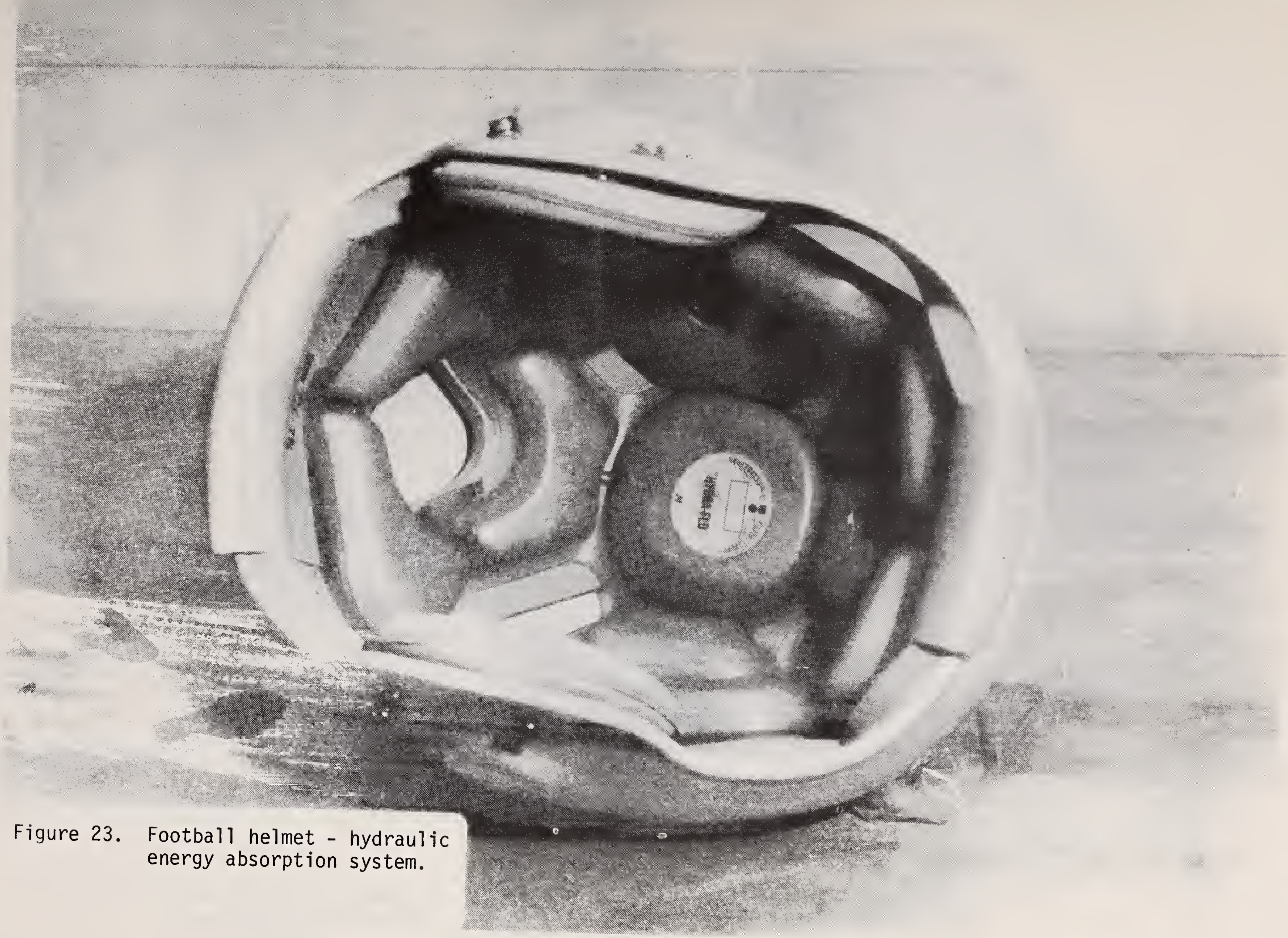


Figure 23. Football helmet - hydraulic energy absorption system.

Figure 24. Heat damaged helmet recovered from injured firefighter.

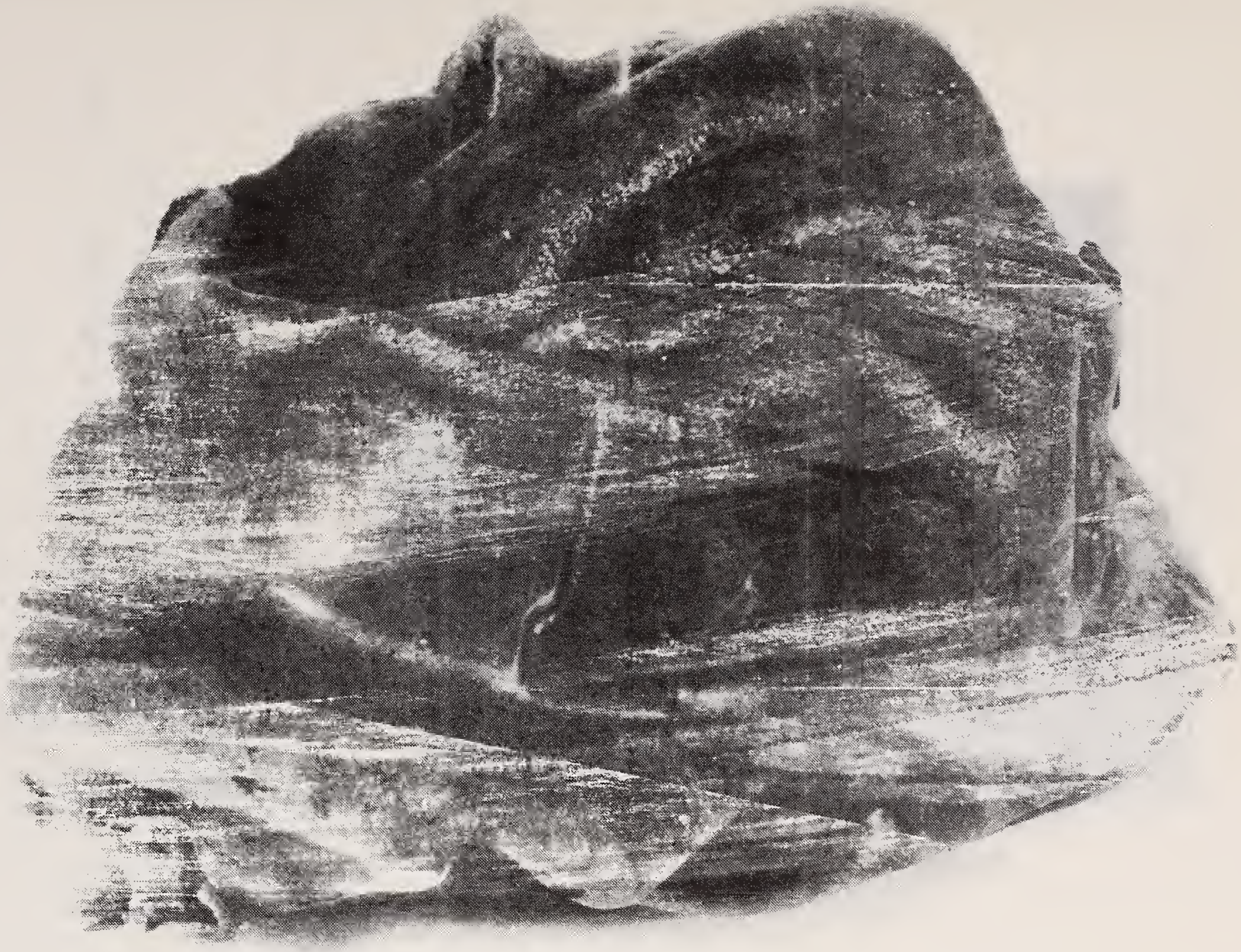


Figure 25. Heat damaged helmet recovered from injured firefighter.

Figure 26. Polycarbonate shell (thin wall)

High Temperature Test (250 C - 3 min.)

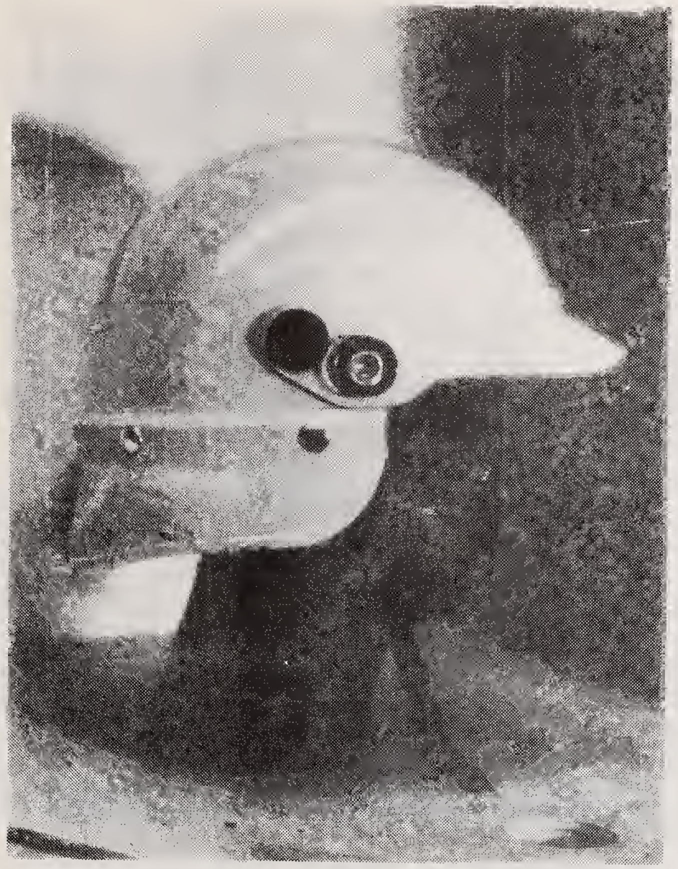


Figure 27. Polycarbonate shell (thick wall)
High temperature test (250 C - 3 min.)

Figure 28. GRP shell

High temperature test (250 C - 3 min.)

Figure 29. Polycarbonate shell (thin wall)

High temperature test (250 C - 3 min.)

Figure 30. Polyethylene shell (discontinued)
High temperature test (250 C - 3 min.)

Figure 31. Leather shell

High temperature test (250 C - 3 min.)

Figure 32. Polycarbonate shell (thick wall)

High temperature test (250 C.- 3 min.)

Figure 33. GRP shell

High temperature test (250 C - 3 min.)

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APPENDIX 1. Test Results

DATA SUMMARY - FIRE HELMETS

Impact Attenuation Tests; Room Temperature

Drop No.	Height (cm)	Location	Peak Acceleration (g_n)	Time Above 150 g_n	Time Above 200 g_n	Comments
HELMET No. 5 - Fully lined						
1	183	Back	340	2.5	2.0	Removed face shield
2	183	Side	310	2.5	2.0	
3	183	Side	380	3.25	2.0	
4	183	Top	320	3.5	1.0	
5	183	Front	320	2.5	2.0	
HELMET No. 1 - Sling suspension						
1	183	Top	-	NO	TRACE	
2	183	Top	120	-	-	
3	92	Side	> 800	-	-	Estimate; off scale
4	92	Back	1200	-	-	Estimate; off scale
HELMET No. 7 - Sling suspension						
1	183	Top	160	-	-	Part of suspension broke loose
2	92	Back	1200			Crack in shell; suspension fasteners broke in two places
HELMET No. 2 - Sling suspension						
1	183	Top	120	-	-	
2	92	Side	1200	-	-	Estimate; off scale

Room Temperature Tests Continued

Drop No.	Height (cm)	Location	Peak Acceleration (g_n)	Time Above 150 g_n	Time Above 200 g_n	Comments
HELMET No. 3 - Sling suspension						
1	183	Top	240	2	1	
2	92	Back	>500	-	-	Crack along rib in mid-sagitta plane approximately 15 cm
3	92	Side	>500			Discontinue
HELMET No. 4 - Sling suspension						
1	183	Top	120			
2	92	Side	>500			Off scale
3	92	Back	>500			Off scale; discontinue
HELMET No. 9 - Sling suspension						
1	183	Top	140	-	-	
2	92	Back	>500	-	-	
3	92	Side	>500	-	-	Discontinue
HELMET No. 6 - Fully lined						
1	183	Top	320	3	2.3	
2	183	Side	380	2.5	1.25	
3	183	Front	410	2.75	2.5	
4	183	Back	360	2.25	1.5	

Impact Attenuation Tests; Low Temperature - 15 C (5 F)

Drop No.	Height (cm)	Location	Peak Acceleration (g_n)	Time Above 150 g_n	Time Above 200 g_n	Comments
HELMET No. 5 - Fully lined						
1	183	Top	300	2.2	1.4	
2	183	Side	320	2.6	2.4	
3	183	Rear	320	2.0	1.6	
4	183	Front	350	2.6	2.2	
HELMET No. 6 - Fully lined						
1	183	Top	340	2.8	2.5	
2	183	Side	310	2.2	1.8	
3	183	Rear	320	2.4	1.8	
4	183	Front	360	2.8	2.2	
HELMET No. 4 - Sling suspension						
1	183	Top	110			

Impact Attenuation Test, H.T. 0.6 W/cm^2 - 3 min.

Drop No.	Height (cm)	Location	Peak Acceleration (g_n)	Time Above		Comments
				150 g_n	200 g_n	
HELMET No. 2 - Sling suspension						
1	92	Back	>500			Off scale
HELMET No. 5 - Fully lined						
1	183	Top	320	4.0	2.5	
2	183	Back	340	4.0	2.6	
3	183	Side	340	4.4	2.8	
4	183	Front	360	4.0	2.4	
HELMET No. 7 - Sling suspension						
1	92	Back	> 500			Off scale
HELMET No. 3 - Sling suspension						
1	92	Back	> 500			Off scale
HELMET No. 4 - Sling suspension						
1	92	Back	> 500			Off scale
HELMET No. 6 - Fully lined						
1	183	Top	380	4.8	2.6	
2	183	Side	320	4.8	2.8	
3	183	Back	320	4.2	2.4	
4	183	Front	360	4.6	2.4	
HELMET No. 1 - Sling suspension						
1	92	Back	> 500			Off scale

Impact Attenuation Tests; Wet

Drop No.	Height (cm)	Location	Peak Acceleration (g_n)	Time Above 150 g_n	Time Above 200 g_n	Comments
HELMET No. 5 - Fully lined						
1	183	Top	310	3.2	1.2	
2	183	Side	360	2.6	2.4	
3	183	Rear	290	3.7	0.8	
4	183	Front	380	2.3	2.2	
HELMET No. 6 - Fully lined						
1	183	Top	310	2.8	2.1	
2	183	Side	440	3.0	1.0	
3	183	Rear	300	2.4	2.0	
4	183	Front	-	-	-	Noise
5	183	Rt. front	-	-	-	Noise - adjusted equipment
6	183	L. front	290	2.2	1.5	
7	183	Opposite side	340	3.0	1.4	

Data Summary - Fire Helmets

Penetration Tests, R.T.

Mass	Drop Ht. 2.25 m		Drop Ht. 2.5 m
Helmet	3.0 kg	2.0 kg	1.0 kg
3	pen	no pen	no pen
		pen*	no pen*
7	pen	no pen	no pen
		pen*	pen*
5	pen	pen	no pen
			no pen*
6	no pen		
	no pen*		
4	pen	no pen	no pen
		pen*	no pen*
9	pen	pen	no pen
		pen*	no pen*
2	pen	pen	no pen
		pen*	pen*
1	pen	pen	no pen
			pen

*Second drop

Penetration Test, 50°C; Striker mass 1.0 kg, Drop Height 2.5 m

	Drop No.	Location	Comments
6	1	Back, 5 cm above reference plane	No pen
	2	Side, 5 cm above reference plane	No pen
	3	Opposite side	No pen
5	1	Back, 5 cm above reference plane	No pen
	2	Side, 5 cm above reference plane	No pen
	3	Opposite side	No pen
2	1	Back, 5 cm above reference plane	Pen
	2	Side, 5 cm above reference plane	Pen
4	1	Back, 5 cm above reference plane	No pen
	2	Side, 5 cm above reference plane	No pen
	3	Opposite side	No pen
7	1	Back, 5 cm above reference plane	Pen
3	1	Back, 5 cm above reference plane	No pen
	2	Side, 5 cm above reference plane	No pen
	3	Opposite side	No pen
1	1	Back, 5 cm above reference plane	Pen

Penetration Tests; High Temperature (100°C); Striker

Mass 1 kg, Drop Height 2.5 m

Helmet	Drop No.	Location	Comments
1	1	Top/side	No pen
	2	Back/side	Pen
2	1	Front/side	Pen
3	1	Front/side	No pen
	2	Top/side	No pen
4	1	Back/side	No pen
	2	Front/side	No pen
5	1	Back/side	No pen
	2	Top/side	No pen
6	1	Front/side	No pen
	2	Back/side	No pen
7	1	Front/side	Pen

Flammability Test; radiant flux 0.8 W/cm^2, bunsen flame - 15 s

Helmet	Comments
1	No flame
2	No flame
3	No flame
4	Paint burns; extinguishes after flame is removed
5	No flame
6	Paint flames; extinguishes after removal of flame
7	No flame

Convective Heat Test: 250°C, 3 min.

(Discontinued) 8	Front, sides and back deformed. Back brim flowed onto neck of head form.
1	Suspension melted onto floor of oven. Brim deformed 9.2 cm below basic plane.
3	Brim deformed. Back brim curled toward headform and down 7 cm below basic plane.
2	Entire shell softened and deformed. Back brim dropped 8.6 cm below basic plane.
6	Edging smoked. No visible distortion. Ear flaps blistered.
5	Back brim softened and deformed 7.5 cm below basic plane.
4	Paint blistered.
7	No visible distortion in shell. Suspension system melted onto oven floor.

Helmet Construction

Helmet No.	
1	Polycarbonate shell; nylon webbing/polyethylene suspension
3	Polycarbonate shell; nylon webbing suspension
2	Polycarbonate shell; nylon webbing/polyethylene suspension
6	GRP shell; foamed inner lining
5	Polycarbonate shell; foamed inner lining
4	Leather shell; nylon webbing suspension
7	GRP shell; polyethylene/nylon webbing suspension

APPENDIX 2. Correspondence from firefighters

SUBJECT: Firefighter Helmets

Sir:
The following is related to the above subject.

Taking a position of no price compromise on safety to our personnel, the leather helmet is the best head protective gear available at the present time.

Personal injury experience of (2) line officers demostrated the effectivness of the leather helmet.

1. A sash weight dropped from a undetermined height on the wearers helmet produced a concussion and prevented a possible fractured skull.

2. A hose clamp's sudden release crushed the side of the wearers helmet and although the wearer suffered lacerations, the skull was unharmed due to excellent coronal plane protection of the rib designed helmet.

The criteria for testing helmets is excellent and we find no fault or recommend any changes at this time.

SORRY TO BEEN SO LONG IN GETTING BACK TO YOU ON SOME OF THIS HELMET INFORMATION. I WILL ATTEMPT TO GIVE THESE TO YOU IN THE FOLLOWING MANNER BY REFERING TO THESE CASE HISTORIES:-

16-1

(1) ROSEBURG, 1957 DURING THE NOW "FAMOUS DISASTER". ASST CHIEF McFARLAN WAS KILLED BY A BLOW TO THE LOWER SECTION OF HIS SKULL BEHIND HIS RIGHT EAR WHEN THE BRIM OF HIS HELMET FAILED. THIS WAS FROM A 4"X4" STOP SIGNPOST BLOWN THROUGH THE AIR FROM THE AMMONIUM-NITRATE EXPLOSION. HIS DEATH WAS A DIRECT RESULT OF HELMET FAILURE.

(2) PORTLAND, CAPTAIN IN OPEN CAB LADDER TRUCK KILLED WHEN TRUCK COLLIDED WITH A TROLLY-BUS AT AN INTERSECTION, THE CAPTAIN WAS THROWN OUT OF THE APPARATUS AND HIS HEAD STRUCK THE PAVEMENT. HIS HELMET CAME OFF HIS HEAD.

(3) PORTLAND, FIRE FIGHTER SKULL CRUSHED WHEN STRUCK BY WHIPPING 2½" NOZZLE. IN THIS CASE THE TRADITIONAL HELMET FAILED. THIS INJURY WAS TO THE FOREHEAD JUST ABOVE THE HELMET BRIM. THIS FIRE FIGHTER IS NOW

ON PERMANENT DISABILITY BECAUSE OF A HELMET FAILURE. THE HELMET ACTUALLY COLLASPED (CAVED IN) WHEN STRUCK BY THE WHIPPING 2½" NOZZLE.

(4) CASE NO 4 IS A RESULT OF A 8"X8" BARN BEAM FALLING 20' FROM A LOFT ONTO THE HEAD OF A NORTH PLAINS VOLUNTEER. IN THIS CASE THIS FIRE FIGHTER WAS WEARING A ________ , HELMET WITH THE CHIN STRAP IN PLACE. THE BEAM STRUCK THIS MAN ACROSS THE TOP OF THE HELMET TO THE RIGHT OR CENTER ABOVE THE RIGHT EAR. THE HELMET DID WHAT IT WAS INTENDED TO DO. IT PREVENTED ANY HEAD INJURY BY ABSORBING THE DIRECT BLOW AND DIVERTING THE BEAM AWAY FROM THE MAN. THE IMPACT WAS ABSORBED BY THE INNER LINER, HOWEVER, THE MAN WAS DRIVEN DOWN TO HIS KNEES FOR A MOMENT. FROM THIS HE RECEIVED NO INJURY.

(5) IN THIS CASE AN ASSISTANT CHIEF OF THE FOREST GROVE FIRE DEPARTMENT WAS STRUCK BY A FALLING 2"X8" CEILING JOIST THAT STRUCK HIS HELMET JUST ABOVE THE LEFT TEMPLE AREA. AGAIN THIS WAS A ________ HELMET WITH THE CHIN STRAP IN PLACE. THE BLOW TORE THE FACE SHIELD SWIVAL FROM THE HELMET AND THE IMPACT

KNOCKED THE MAN TO THE FLOOR IN A DAZED CONDITION. THE MAN SUFFERED NO INJURY, HOWEVER, THE INNER LINER OF THE HELMED DID SHOW THE POINT OF IMPACT. WE REPLACED THE FACE SHIELD, STUD AND INNER LINER AND PLACED THE HELMET BACK INSERVICE.

(6) IN THIS CASE IT WAS TO OUR FIRE FIGHTER WHO FELL FROM THE AERIAL WHILE WE WE AT BEND. IN THIS INCINDENT THE FACT THAT HIS HELMET STAYED ON HIS HEAD SAVED HIM FOR INJURY TO HIS HEAD THAT MEDICALLY SHOULD HAVE CAUSED DEATH. THE FACT THAT THIS . . . HELMET ONCE AGAIN DID JUST WAT IT WAS SUPPOSE TO DO, THAT WAS STAY ON AND PROTECT THE MANS HEAD. THE FACE SHIELD DID COME OFF SOMETIME DURING HIS FALL AND WAS SUSPECTED TO HAVE CAUGHT A SPOTLIGHT. UPON IMPACT ON THE GROUND THE NECK SHIELD SPLIT AND POPPED OFF ON ONE SIDE ABSORBING A GOOD AMOUNT OF THE IMPACT AGAINST THE GROUND SURFACE.

THESE ARE THE 6 CASES THAT I CAN GIVE YOU NOW. WE HAVE SENT OUT TO ALL FIRE DEPARTMENT IN THE STATE VIA THE "FIRE LINE" FROM DICK SMALL'S

OFFICE A REQUEST FOR ANY CASES THAT HAVE OCCURED REGARDING ANY HELMET FAILURES OR GOOD SAFETY FEATURES THAT HAVE PREVENTED FAILURES. THIS INFORMATION WILL BE SENT EITHER TO ME OR DIRECTY TO YOU.

I WILL KEEP ON SEARCHING OUT INFORMATION ON THIS, HOPEFULLY IN TIME TO DO YOU SOME GOOD. I WILL BE GETTING BACK TO YO SOON

National Bureau of Standards
A255 Polymer Building
Washington, D.C. 20234

Dear Sir:

The type of helmet which the Littleton Fire Dept. Gives us to wear is the fire helmet. There are a number of bad points related to this helmet. The main one is its inability to absorb blows and impacts from the side. This defect is caused, I believe, by the sling type harness which these helmets have. The sling harness also causes the helmet to fly off or become dislodged after any blow received from above, the side or the back.

If the fire-fighter who is wearing this helmet in a fire is well protected from the heat the helmet will start to deform and melt while on his head. This has happened twice, in the past four years, to different fire-fighters on this department, which has only 60 members.

helmet doesnot previde any protection to the ears or neck of the wearer. When the Helmet is adjusted to fit the fire-fighters head without a mask it covers his head fairly well; however when a mask is put on, the helmet sits way up on the top or his head, where it can be easily knocked off even with the chin strap inplace.

The type of helmet which I have ordered for myself, even-though it is against the departments tried and true method, is the new

But this helmet still lacks some innovations which would allow it to be even safer and easier to use. One would be to build into the helmet a radio and a light. In other words, build a helmet which would be like the one worn by the fighter pilots of W.W. II. Another idea would be to build into the helmet the face-piece of the mask.

I believe that no matter what color,type or style of helmet is used by a department for which a person is working, he should be allowed to wear a safer, better, and more-compatible-with-masks, helmet if it is introduced onto the market, even if the fire-fighter has to purchase it with his own money.

January 31, 1975

Mr. Nicholas Calvano
National Bureau of Standards
A 255 Polymer Building
Washington, D.C. 20234

Dear Sir:

The following is information regarding the helmets that are worn by the firefighters.

One hundred fifty-five helmets of the described in the enclosure were purchased and placed in service by the Department.

Our men are satisfied with them with the exception of three problems.

1. The eyeshield fittings are not structurally adequate for the fire service.
2. The liner is not removable for washing.
3. The ear and neck protection is not long enough.

One of the helmets was worn by a ladder truck operator when involved in an accident in which our 85' Seagrave Ladder truck was hit on the front wheel at an intersection and forced into a concrete pillar at 25 mph. The truck drivers head hit the windshield with enough force to break the glass with no head injury resulting.

This helmet design affords more lateral protection than the which the replaced.

The features we are looking for in a helmet are:

1. Lateral as well as vertical protection.
2. Light weight.
3. Neck and ear protection from heat and cold.
4. Ease of cleaning - in and out.

Attached are the specifications for the 1000 series helmets that were purchased for our department.

Please advise if we can be of any further service.

Sincerely,

RECEIVED
APR 17 1975
INT'L ASSOC. OF FIRE FIGHTERS

Mr. Walter Lambert
Director, Research Department
IAFF Headquarters
1750 New York Ave., N.W.
Washington, D.C. 20006

Dear Sir and Brother;

This letter is in reply to your request for information concerning our complaints with our protective helmets. Our department supplies us with black helmets. A survey of our members brought the following complaints:

1. It is too bulky, you can't get through narrow places with helmet on.
2. Helmet doesn't fit over MSA self-contained air mask and if you attempt to use your helmet with a mask on, the helmet keeps falling off.
3. Helmet offers very little protection upon impact of even small falling objects.
4. Helmet melts at temperatures commonly encountered in interior fires.
5. "Plectron" shields on our helmets trap smoke between your face and the shield.
6. Bracket on the shield breaks the helmet under very little stress.
7. "Plectron" shields are not easily operated and when they are not down in front of your face, they are bulky and make it difficult to get into and out of apparatus.
8. Black helmets are not visible at night unless reflective tape is put on helme

Generally, I would say that tradition has kept our helmets the same in design while materials and research has advanced. We need a close fitting helmet design to protect the firefighter and not the tradition of the firefighter.

November 5, 1974

Nicholas Calvano
National Bureau of Standards
A255 Polymer Building
Washington, D.C. 20234

Dear Sir:

In response to your article in Fire Engineering magazine, we also have a complaint.

We had helmets buckle on us at a fire. Neither man was burned. Both men were performing tasks near the fire.

I feel equipment should withstand more heat than an individual.

Wishing you success in your undertaking,

Mr. Nick Calvano
National Bureau of Standards
Rt. 705 Quince Orchard Road
Gaithersburg, Maryland 20760

Dear Nick:

I am sending, under separate cover, helmet that melted on a man while he was fighting a fire at the school. Also, I am sending a film on the explosion and fire that occurred in Houston in a train derailment.

Sincerely yours,

January 28, 19

Mr. Nicholas Calvano
National Bureau of Standards
A255 Polymer Building
Washington, D.C. 20234

Dear Sir,

Enclosed are 3 pictures of my fire helmet. It is a helmet. I was wearing this helmet in the early morning hours on June 7, 1974 when in the attempt to rescue a man from a burning room I was caught in the room and had to be pulled out myself. It was a very brief period and did not last longer than a minute. Even in the intense heat in the room I do not believe that this could happen. I am now very dismayed at these results. So are a number of my fellow firemen. I spent 33 days in a burn unit with about 40% burns on my body and was off work for 4 months. This helmet is said to meet the present federal standards and if this is so, then I believe something should be done to make the standards much higher.

Respectfully,

October 15, 1974

Mr. Nicholas Calvano
National Bureau of Standards
A255 Polymer Building
Washington, D.C. 20234

Dear Sir:

The September 1974 issue of "Fire Chief" magazine contains an article requesting information and comments regarding fire-fighter's helmets. I would like to comment.

We have received many comments from fire-fighters in the State of Michigan voicing their disapproval of many helmets approved by OSHA. They distort upon the application of low heat (less than 150°F), they will ignite, etc. This office has tried to find documentation of any incident of a fire-fighter being injuried or killed while wearing a metal helmet or one with metal rivets, whereby the headpiece contributed to the accident. We can find none. Considering the numbers of fire-fighters who have worn this style headgear and the length of time each wore it, the record is outstanding in favor of the helmets worn in the past.

The leather helmet has a record even better than the metal. This style is worn by the fire-fighters in communities where the number of fires are the greatest; Chicago, Boston, New York, Kansas City, etc. The only reason other cities did not use them was the cost.

I believe that a fire-fighter's helmet should be designed for use by a fire-fighter and not for use by a police officer, construction worker, truck driver or any other occupation. Thus, helmets worn by others are not designed to be worn by fire-fighters. The hazards of fire-fighting are similar in many ways, but different in the matter of water, heat and smoke. I firmly believe fire-fighters should be consulted when helmets are tested and designed.

Electricity should not be a significant factor in considering tests to be conducted. Generally, one of the first functions of the fire chief at the scene of a fire is to get the current disrupted so electricity is not a hazard.

Impact tests are important, but not to the point where a helmet must withstand a great weight with not consideration given to a person's neck. It would seem that it is better to test the helmet for "deflection" of either the falling object or the wearer's head, keeping in mind a brim is needed for the channeling of water.

I believe "change" is good if it benefits, but to "change" for the sake of changing can be disasterous. Let's look at what we have; perhaps those who designed the helmets used good logic and materials and if changes must be made, they can be minimal.

We shall notify those in the fire service in Michigan of your requests and urge them to assist you.

Sincerely,

Mr. Nicholas Calvano
National Bureau of Standards
A 225 Polymer Building
Washington, D.C. 20234

Dear Mr. Calvano,

I hope the following comments and observations will be of some use in your investigation of fire helmet performance.

We have available a wide variety of fire helmets, primarily as teaching aids in our protective equipment class, but also for use by our instructors. Most of our experiences have been with the following helmets:

, are the most common helmets in this area, due in great part to their low initial cost. The major problems with this type appear to be light weight, melting, and shattering.

The helmet is easily dislodged from the wearer's head, particularly during response to fires where wind will lift the helmet.

The suspension will not always keep the helmet on during routine firefighting activities, particularly while wearing breathing apparatus.

The helmet will melt or soften when exposed to high heat levels encountered in some fire situations.

One local department has had this type shatter when dropped, although this did not occur during routine use.

appears to offer the best level of protection, perhaps for this reason and the radical design as far as fire helmets are concerned, it has had a good deal of use.

Wearers complain of the weight of the helmet, it is the heaviest of those in our inventory. This weight does impart a feeling of security.

My personal feelings are that a fire helmet should offer protection from top and side impacts; provide ear and neck protection from radiant heat, steam and embers; provide face protection from flying objects (embers, plaster chips, etc.); and be compatible with breathing apparatus (i.e. fit over face piece and no brim interferance with B/A back pack tanks.)

Best of luck on your project.

Sincerely,

APPENDIX 3. Model Performance Criteria

1. Model Performance Requirements

1.1 Impact Attenuation

When tested in accordance with paragraph 2.1, all helmets tested shall meet the requirements below:

Impact Location	Maximum Acceleration	
	g_n*	(m/s^2)
Top	150	1472
Front	400	3924
Side	400	3924
Back	400	3924

Accelerations above 200 g_n shall not <u>exceed</u> three milliseconds in duration; accelerations above 150 g_n shall not exceed five milliseconds.

1.2 Penetration Resistance

There shall be no demonstrable electrical contact between the penetration test striker and the headform when the helmet is tested for penetration resistance as described in paragraph 2.2.

1.3 Chin Strap/Retention System

The static strength of the chin strap/retention system shall be tested in accordance with paragraph 2.3 without any break occurring and without any resulting slip or stretch of more than 25 mm (1.0 in). The width of the chin strap shall be at least 12 mm (1/2 in).

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*g_n is the standard acceleration of free fall and is defined as 9.80665 meters per second per second.

1.4 Ear Flaps

Ear flaps shall extend at least 25 mm (1 in) in front of the coronal plane and at least 60 mm (2.4 in) below the basic plane. (See fig. 2)

Ear flaps shall resist ignition when tested in accordance with paragraph 2.4.

1.5 Configuration

The helmet shall be designed to divert falling liquids away from the face and neck.

The helmet shall have no slits, holes or other openings above the reference plane. (See fig. 2) No part of the helmet shall extend more than 15 cm (5.9 in) from the mid-sagittal plane (see fig. 1) nor more than 20 cm (7.9 in) from the coronal plane. (See fig. 2) Distances are measured perpendicular to the planes.

1.6 Flame Resistance

Helmet shells shall resist ignition when tested in accordance with paragraph 2.4.

1.7 Heat Resistance

When tested in accordance with paragraph 2.5:

a) there shall be no visible distortion of the helmet suspension/retention system, chin strap, or ear flaps

b) no part of the helmet shell shall touch the headform

c) any shell distortion in the back of the headform shall not extend more than 8 cm (3.1 in) below the basic plane, and

d) any shell distortion in the front and sides of the headform shall not extend more than 4 cm (1.6 in) below the reference plane.

1.8 Electrical Insulation

Electrical leakage shall not exceed 3 milliamperes when the helmet is tested as described in paragraph 2.6.

1.9 Visibility and Reflectivity

1. For maximum visibility the helmet should be a light color such as white, yellow, light orange, light red, etc. For this document maximum visibility is defined as Munsell Value 7/(43.06%) for CIE source "C" (6774K) or lighter when tested in accordance with "Standard Method of Specifying Color by the Munsell System" or ASTM E308-66, "Standard Recommended Practice for Spectro-photometry and Description of Color in CIE 1931 System."
2. The helmet shall have retro-reflective markings on each of four locations: front, back, right side and left side. The area covered in each location shall be at least 40 cm^2 (6.2 in^2). When tested as described in paragraph 2.7, the retro-reflective material shall meet the requirements given in the table below:

	Minimum Candlepower per Foot Candle per sq. ft.		
Observation Angle	Entrance Angle (degrees)		
	-4	+30	+50
0.2	70	30	3.5
0.5	30	15	3.0

2. Associated Test Methods

2.1 Impact Attenuation Test

Four helmets (for large purchases, suitable quality control procedures and sampling plans should be arranged. Mil Std. 105 "Sampling Procedures and Tables for Inspection by Attributes" is recommended as a guide) are required for the environmental conditioning as described in paragraph 2.1.2. A schematic diagram of an impact attenuation test set-up is shown in figure 3.

2.1.1 Test Equipment

2.1.1.1 Test Headform

The test headform, which is size 7 1/4, shall conform to the dimensions in figures 2 and 4. It shall exhibit no resonance frequencies below 3000 Hz; it may be made of any low resonance magnesium alloy such as magnesium K-1A.

2.1.1.2 Drop Assembly

The drop assembly consists of the test headform, the accelerometer, and the supporting crossarm assembly and shall have a total mass of 5.2 ± 0.2 kg (11.4 ± 0.4 lb). The center of mass of the assembly shall lie within a cone of 10 degrees included angle about the vertical, with apex at the point of impact.

2.1.1.3 Test Anvil

The test anvil shall be steel and have a flat striking surface. The anvil shall be firmly mounted on a steel plate 250 X 250 X 25 mm (10 X 10 X 1 in) minimum, backed with a solid mass of at least 140 kg (309 lb).

2.1.1.4 Acceleration Measurement System

An accelerometer is used to measure the acceleration imparted to the helmeted headform upon striking the anvil and should be able to withstand shocks up to 2000 g_n. The acceleration data channel, including all instrumentation which may alter the frequency content of the test data and all recording and analysis procedures, shall comply with SAE Recommended Practice J211b requirements for channel class 1000. The time duration of acceleration shall be measured to within ± 0.1 millisecond.

2.1.1.5 Reference Anvil

The reference anvil is substituted for the test anvil to check the acceleration measurement system. When the bare headform is dropped from an appropriate height, it shall produce a peak acceleration of 400 g_n ± 20 g_n and accelerations above 200 g_n of at least one millisecond duration. The reference anvil may be of any material which will reproducibly yield these results. A reference anvil found to be suitable is a one-inch Open Blue Modular Elastomer Programmer available from MTS Systems Corp., P.O. Box 24012, Minneapolis, Minn. 55424.

2.1.2 Conditioning for Testing

2.1.2.1 Room Temperature

Condition one helmet at a temperature of 20 - 28 C (68 - 82 F) for at least 4 hours. Test as in paragraph 2.1.3.

2.1.2.2 Radiant Heat

Condition a second helmet by exposing the helmet area to be impacted to an infra-red lamp. The area to be impacted is defined as the circle with 6 cm (2 3/8 in) radius with its center at the impact point of the helmet. Mount the helmet on the test headform in the appropriate drop position and raise the drop assembly to the prescribed drop height. Measure the radiant flux by temporarily removing the helmet from the headform and placing a radiometer in the impact area. Adjust the distance of the heat source until a constant radiant flux of 0.6 Watts per square centimeter is achieved. Remove the radiometer, reposition the helmet on the headform, and subject the impact area to the radiant flux for three minutes.

The heat source should be mounted so that it can be easily swung away to allow helmet impact immediately after the application of heat. Test according to paragraph 2.1.3. If the helmet is not impacted within 10 seconds after removal of the heat source, reapply the heat load for an additional 3 minutes.

2.1.2.3 Water

Condition a third helmet by immersing it in water at a temperature of 25 ± 5 C (77 ± 9 F) for not less than 4 hours nor more than 24 hours. Test according to paragraph 2.1.3 within 10 minutes after removal from the water.

2.1.2.4 Low Temperature

Condition a fourth helmet by exposing it to a temperature of -15 + 0 -2 C (5 + 0 -4 F) for not less than 4 hours. Test according to paragraph 2.1.3. If the test is not completed within one minute after removal from the cold temperature environment, recondition the helmet 10 minutes for each minute out of the chamber.

2.1.3 Test Procedure

Mount the accelerometer at the center of mass of the drop assembly with the sensitive axis aligned to within 5 degrees of the true vertical when the headform is in the impact position.

Prior to testing, allow all electronic equipment to warm up for 30 minutes or until stability is achieved. Throughout calibration and testing, the ambient temperature shall be 20 - 28 C (68 - 82 F) and the relative humidity 30 to 70 percent.

Check all instrumentation before and after each continuous sequence of tests by impacting a bare instrumented headform on the reference anvil. Record a minimum of three such impacts before and after a test sequency and make them part of the test record. Should the acceleration-time history not meet the required tolerance (2.1.1.5) prior to testing, adjust the equipment as necessary. Should the post-test average differ from the pretest average by more than 40 g_n, discard the entire test series.

Position the helmet squarely on the headform and secure it to the headform-crossarm assembly by its chin strap or other means which will not interfere with the test, so as to maintain this position during guided fall.

Adjust the drop height so that the velocity at impact is 6.0 ± 0.2 meters per second (19.6 ± 0.7 ft/sec).

Impact each helmet once at each of the four sites described below:

Drop Site	Impact Area
Top	No more than 75 mm (3 in) from the point described by the intersection of the helmet shell, the mid-sagittal plane and the coronal plane (see fig. 2).
Side	No more than 75 mm (3 in) from the line described by the intersection of the coronal plane and the helmet surface, above the reference plane and below the top impact area.
Front	At least 25 mm (1.0 in) above the reference plane, below the top impact area and in front of the side impact area.
Back	Above the reference plane, below the top impact area and to the rear of the side impact area.

The mass of the test helmet is not included in calculating the impact energy.

2.2 Penetration Resistance Test

Two of the helmets used in the impact attenuation test may be used for this test.

A diagram of the penetration resistance test set-up is shown in figure 5.

2.2.1 Test Equipment

2.2.1.1 Test Headform

The test headform, which is size 7 1/4, shall conform to the dimensions in figures 2 and 4. Above the reference plane, it shall have an electrically conductive surface which is electrically connected to the contact indicator (2.2.1.3).

2.2.1.2 Penetration Striker

The penetration striker shall have a mass of 1.0 kg + 25 g - 0.0 g (2.2 lb + 0.05 lb - 0.0 lb). The point of the striker shall be a cone with an included angle of 60 ± 0.5 degrees, a height of 38 mm (1.5 in) and a tip radius of 0.5 ± 0.1 mm (0.020 ± 0.004 in). The hardness of the striking tip shall be Rockwell scale - C 60, minimum. The penetration striker shall be electrically connected to the contact indicator (2.2.1.3).

2.2.1.3 Contact Indicator

The contact indicator shall indicate when electrical contact of 1 millisecond duration or longer has been made between the penetration striker and the conductive surface of the test headform.

2.2.2 Conditioning for Testing

2.2.2.1 Room Temperature

Condition one helmet at a temperature of 20 - 28 C (68 - 82 F) for at least 4 hours.

2.2.2.2 High Temperature

Condition one helmet in a circulating air oven controlled at 100 + 3 C (212 ± 5 F) for not less than 4 hours nor more than 24 hours.

2.2.3 Test Procedure

Place the conditioned, complete helmet on the rigidly mounted test headform and secure it by its chin strap or by other means which will not interfere with the test. Adjust the helmet in the same manner as a person would adjust it to his head. Drop the penetration striker in guided free fall onto the outer surface of the helmet anywhere above the ference plane and at least 75 mm (3.0 in) from the center of a previous impact site or penetration site. Drop the striker from a height of 2.50 + 0.01 -0 meters (98.5 + 0.5 - 0 in) as measured from the striker point to the point of impact on the outer surface of the helmet. Apply a minimum of two penetration blows at different locations to each of the two helmets. The long axis of the striker should be perpendicular to the plane tangent to the impact area. If the test is not completed within 3 minutes after high temperature conditioning, recondition and repeat.

2.3 Chin Strap/Retention System Test

The same test helmets used in the impact attenuation test may be used for this test. A diagram of the test set-up is shown in figure 6.

2.3.1 Test Headform

The test headform shall be size 7 1/4 and capable of supporting the helmet when a load of 890 newtons (200 pounds force) is applied to the retention system.

2.3.2 Conditioning for Testing

2.3.2.1 Room Temperature

Condition one helmet at a temperature of 20 - 28 C (68 - 82 F) for at least 4 hours.

2.3.2.2 High Temperature

Condition a second helmet by exposing it in a circulating air oven to a temperature of 100 ± 3 C (212 ± 5 F) for not less than 1 hour nor more than 3 hours.

2.3.3 Test Procedure

Place the conditioned, complete helmet on the rigidly mounted test headform and fasten the chin strap to the loading device, as shown in figure 6. Adjust the helmet on the headform so that the points of attachment of the chin strap to the helmet will be subjected to the same stress as the chin strap. Support the helmet so that it will not move during the application of the test loads.

Apply the test loads perpendicular to the basic plane of the headform and symmetrically with respect to the helmet retention system.

Statically load the chin strap system with 100 newtons (22 pounds force) for at least 30 seconds but no more than 1 minute and then measure the maximum distance between the chin strap and the apex of the helmet. Do not remove the load.

Apply an additional 550 newtons (124 pounds force) for at least 3 minutes and again measure the maximum distance between the chin strap and the apex of the helmet.

Record any break in the chin strap/retention system. Record any slip or stretch as the difference between the two distance measurements.

If the test is not completed within 5 minutes after high temperature conditioning, recondition and repeat.

2.4 Flame Resistance Test

2.4.1 Shell

Place the helmet in front of a radiant heat source such as the type described in ASTM E162 so that the basic plane of the helmet is parallel to the radiant heat source. Position the helmet so that the crown receives a radiant flux of 0.6 w/cm^2. After 60 seconds exposure to the radiant flux, and without removing the helmet from the heat source, place the cone tip of a methane flame against the helmet crown so that the cone makes an angle of 45 with the plane tangent to the crown (see figure 7). After 15 seconds remove the flame and observe whether the helmet shell resists ignition, (No visible flame or afterglow 5 seconds after removal of methane flame.) If part of the shell is constructed of a different material than the crown, test each material in an equivalent manner.

2.4.2 Ear Flaps

The flame resistance test for ear flaps is the same as 2.4.1 with the following exceptions:

1. The mid-sagittal plane of the helmet is parallel to the heat source.
2. The ear flap receives a radiant heat flux of 0.6 w/cm^2.
3. The cone of the flame is applied at an angle of 45 degrees with the ear flap.

2.5 Heat Resistance Test

Mount the helmet with ear flaps down on an epoxy headform conforming to the dimensions in figures 2 and 4, and fasten the chin strap securely. Place the headform, with helmet attached, into a circulating air oven which has been preheated to 250 ± 3 C (482 ± 5 F). After three minutes remove the helmet and headform and measure the shell distortion, relative to the basic and reference planes, at the front, sides and back of the helmet. Then remove the helmet from the headform and examine the chin strap, ear flaps, and retention system for distortion.

2.6 Electrical Insulation Test

Support the helmet in an inverted position with a wire frame and place it in a vessel containing tap water (see fig. 8). Submerge the helmet until the water is within 13 mm (1/2 in) of the reference plane. Fill the inside of the helmet to within 13 mm (1/2 in) of the reference plane with tap water. Attach one terminal of a suitable* transformer to the wire frame. The second terminal is connected to an electrode and immersed in the water in the helmet. Starting at zero, apply a 60 hertz, alternating current voltage and increase it to 2200 volts root mean square. Maintain the voltage at 2200 ± 2% for 3 minutes. Caution should be exercised in conducting this test because of the high voltages required.

2.7 Visibility Test - Reflectivity

The retroreflective material shall be tested in accordance with Federal Specification LS-300B paragraph 4.3.7 (available from: Federal Supply Services, General Services Administration, Washington, D.C. 20407).

3. Glossary of Terms

3.1 Basic Plane

The plane through the centers of the external ear openings and the lower edges of the eye sockets (see figure 1).

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*The transformer should have an output voltage which is essentially sinusoidal with a crest factor of 1.41 ± 0.07 (crest factor = peak voltage/true rms voltage).

3.2 Coronal Plane

The plane, perpendicular to the basic and mid-sagittal planes, which passes through the centers of the external ear openings as modeled on a headform (see figures 1 and 2).

3.3 Edging

The edge, rim, or rim trim around a helmet.

3.4 Headform

A test device which conforms to the configuration of the human head (see figures 2 and 4).

3.5 Mid-Sagittal Plane

The plane, perpendicular to the basic and coronal planes, which symmetrically bisects the head (see figure 1).

3.6 Reference Plane

The plane 60 ± 1 mm (2.36 ± 0.04 in)* above and parallel to the basic plane.

3.7 Retention System

The complete assembly by which the helmet is retained in position on the head.

3.8 Retro-Reflective Material

A material which reflects and returns a relatively high proportion of light in a direction close to the direction from which it came.

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*Measures in parentheses are approximate.

4. Model Product Labeling

Each helmet shall be durably and legibly labelled in a manner such that the label can be easily read without removing padding or any other permanent part. The label shall be affixed so that it is not easily removable and shall retain its integrity throughout the Associated Test Methods (Section 2). Each label shall include the following information:

a) name or designation of manufacturer

b) model designation

c) size and weight*

d) month and year of manufacture (uncoded)

e) lot number

f) recommended cleaning agents, paints, etc., which can be applied to the helmet without damage

g) helmets which can be damaged by cleaning with common solvents shall include a warning that some common solvents may damage the shell

h) helmets with compressible linings shall include a warning that after a severe blow the helmet may no longer protect the head and should be replaced or repaired by the manufacturer.

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*Weight refers to the helmet, without accessories, as offered for sale.

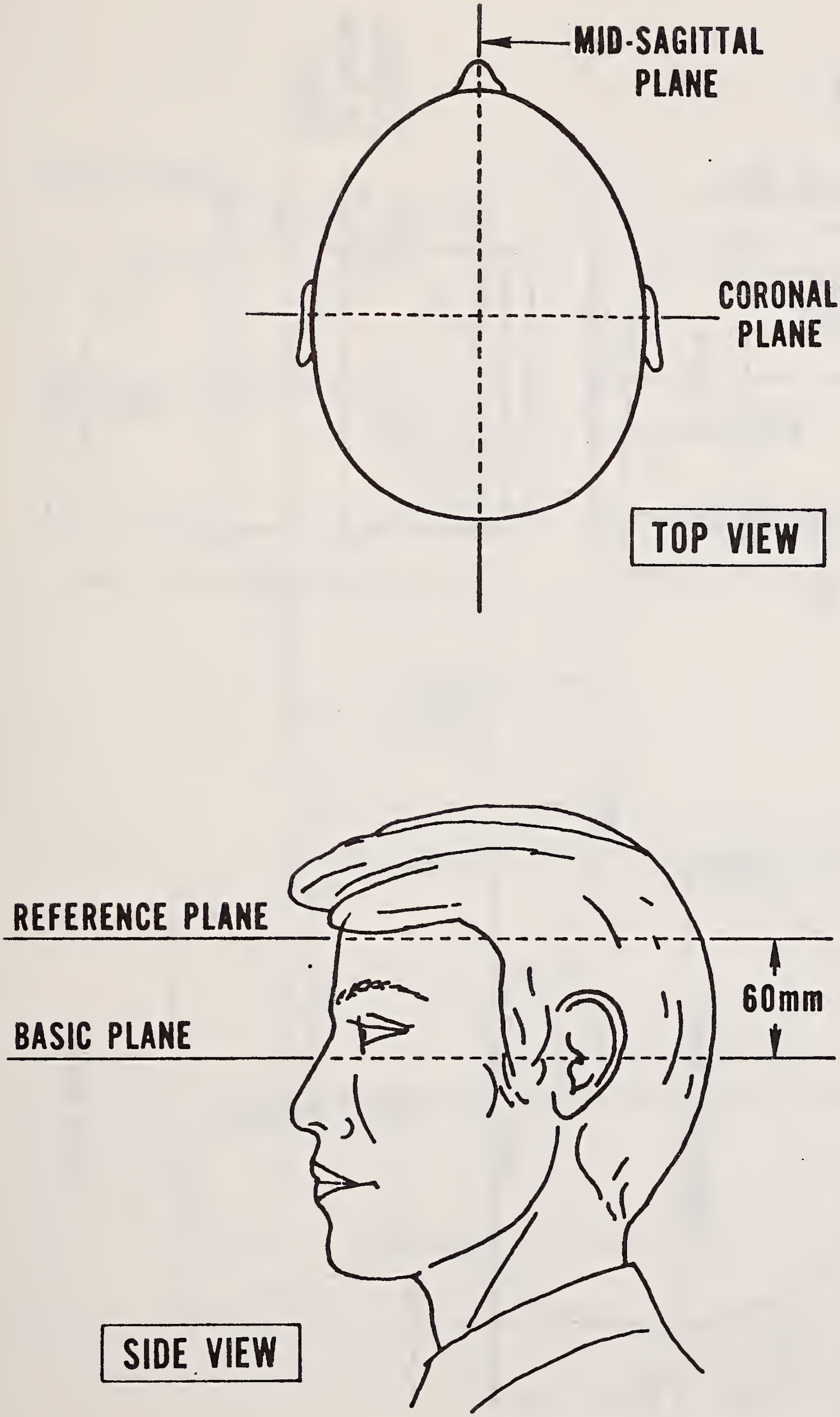


Figure 1. Locations of basic, coronal, mid-sagittal and reference planes.

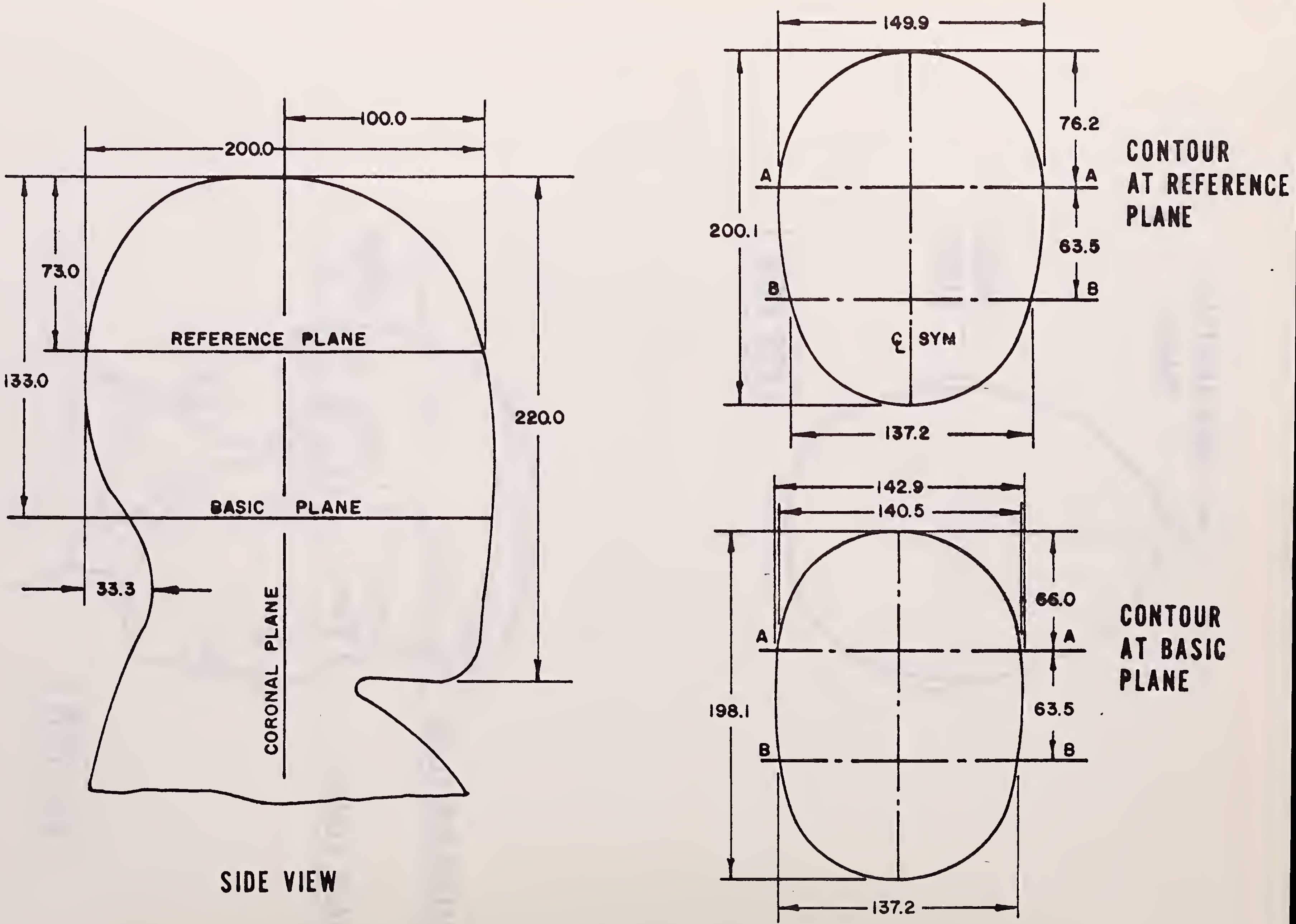


Figure 2. Headform, heat resistance test, dimensions in mm

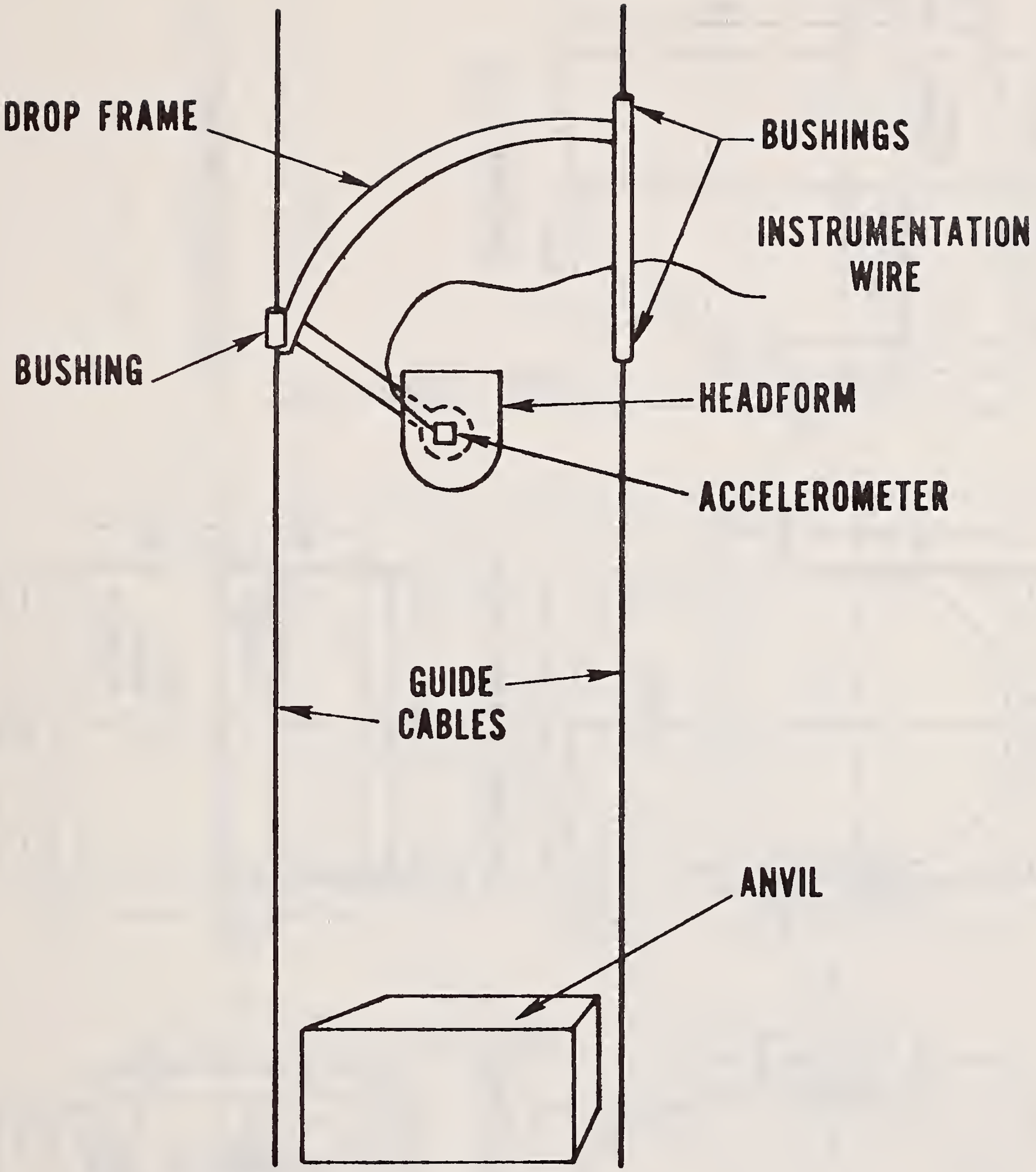
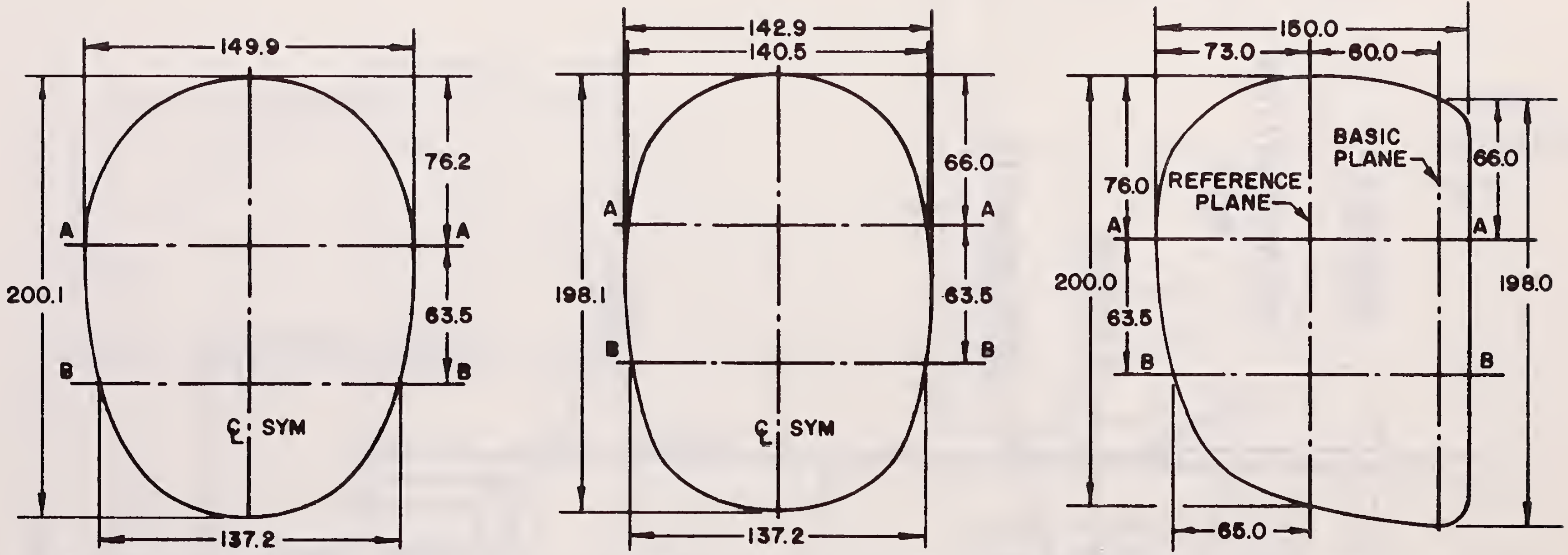


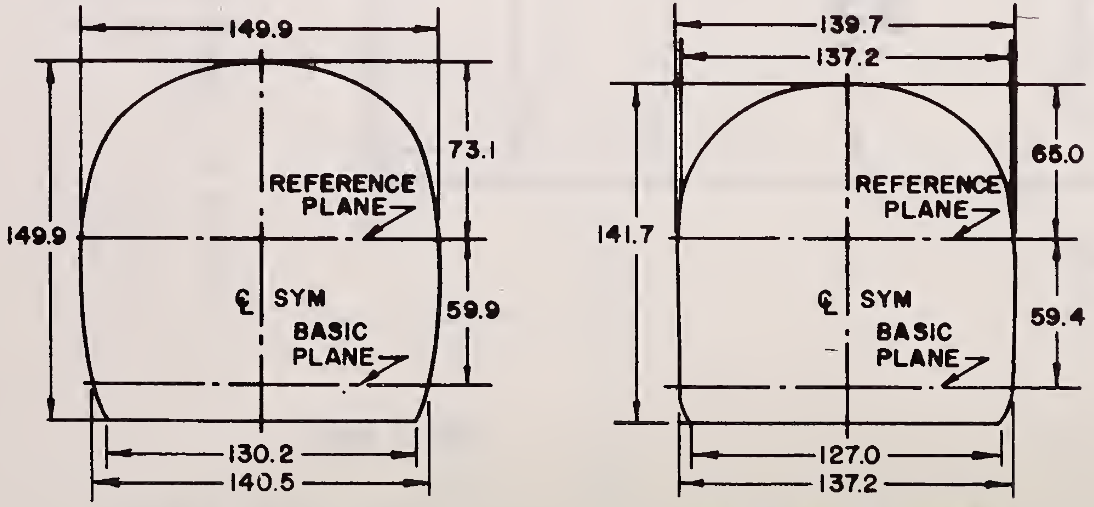
Figure 3. Impact attenuation test setup.



CONTOUR AT REFERENCE PLANE

CONTOUR AT BASIC PLANE

CONTOUR AT ℄



CONTOUR AT PLANE A-A

CONTOUR AT PLANE B-B

FIGURE 4

TEST HEADFORM SIZE 7¼

Dimensions in mm

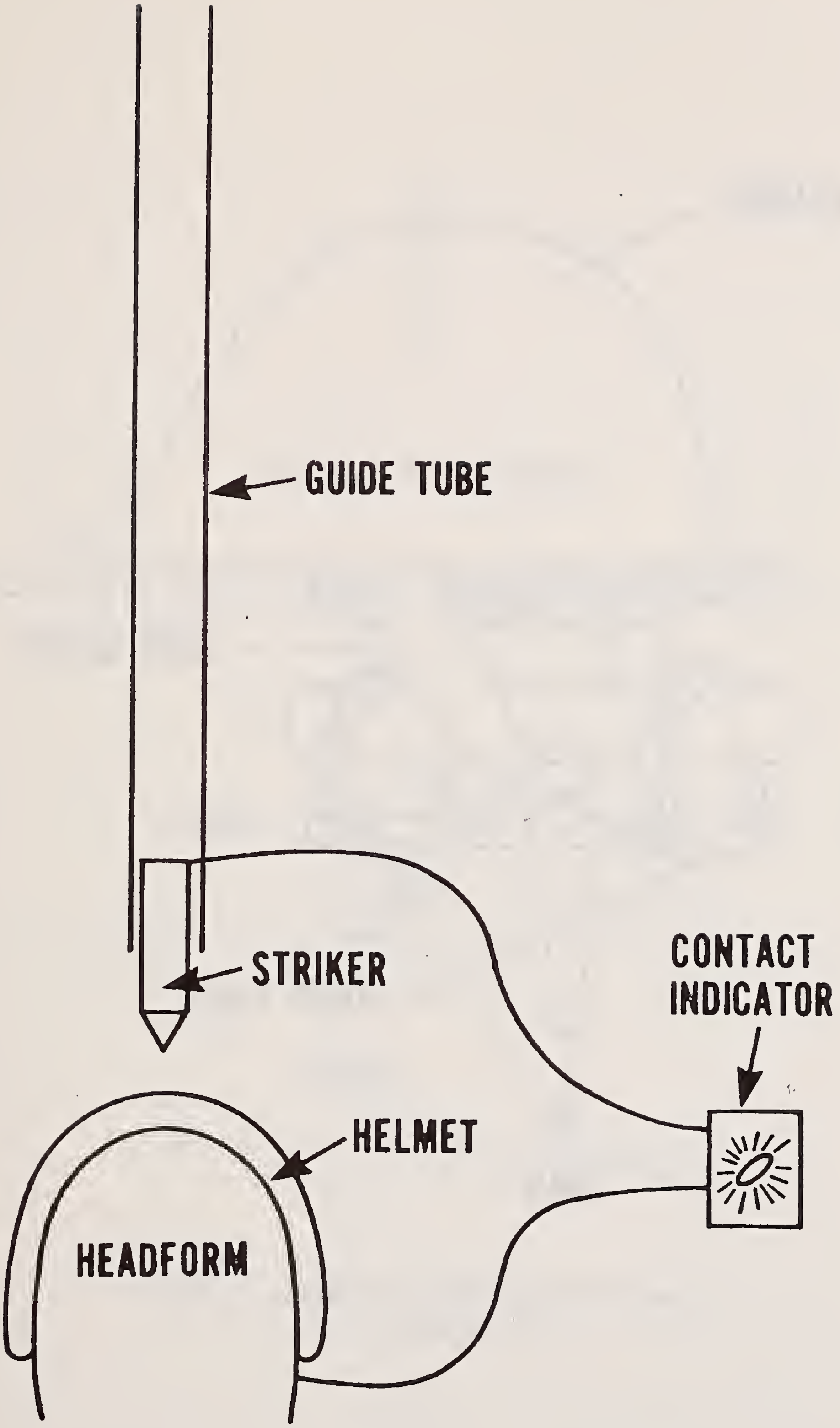


Figure 5. Penetration resistance test setup.

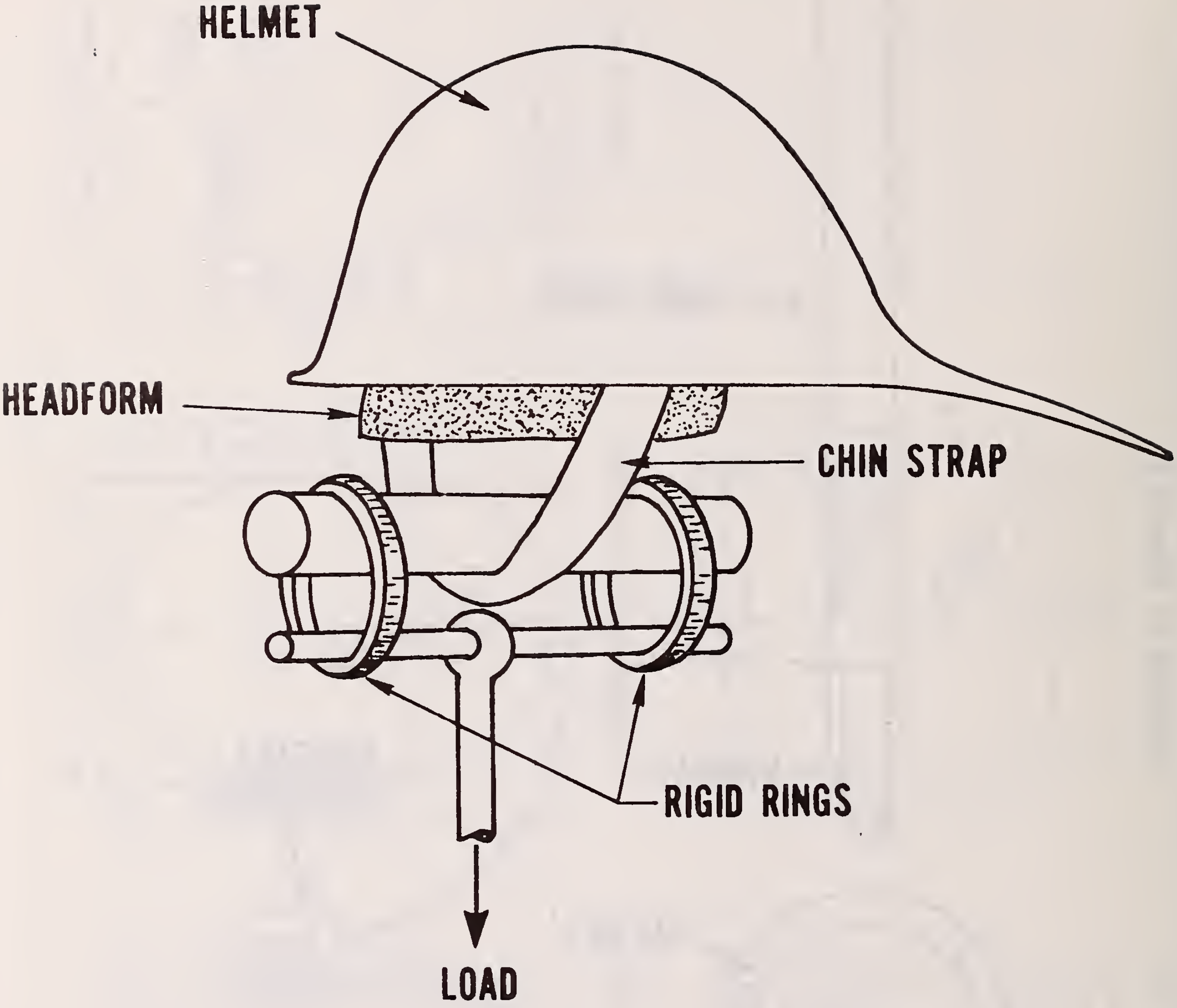


Figure 6. Chin strap/retention system test setup.

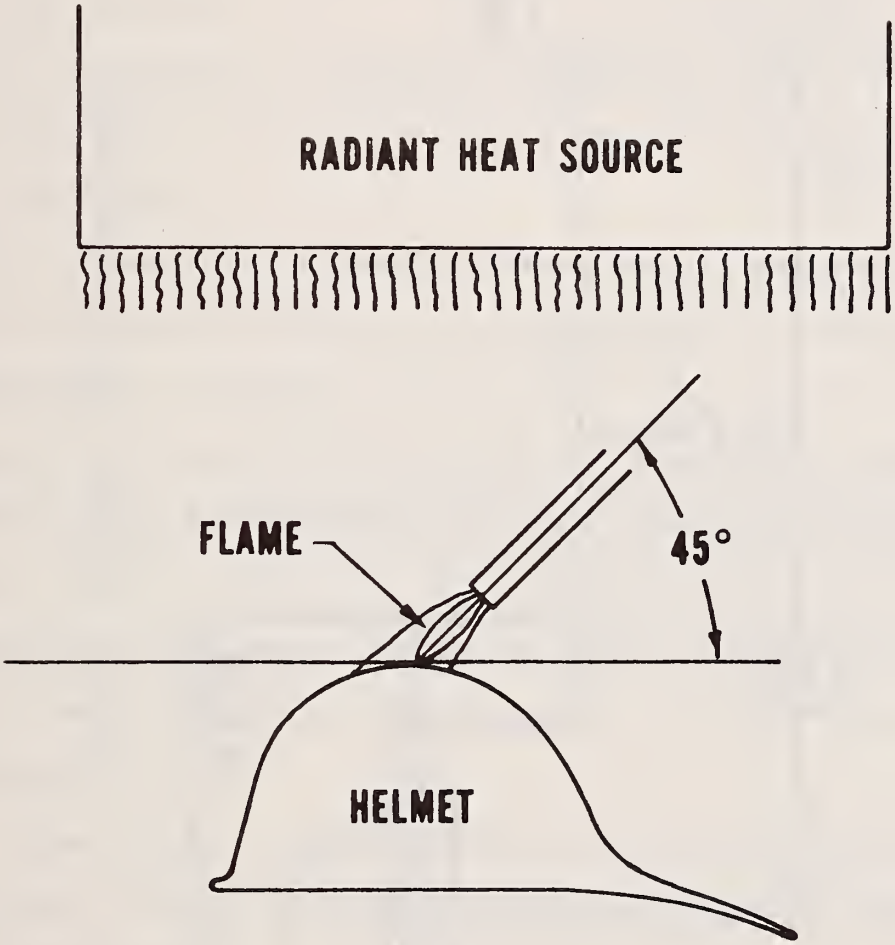


Figure 7. Flame resistance test setup.

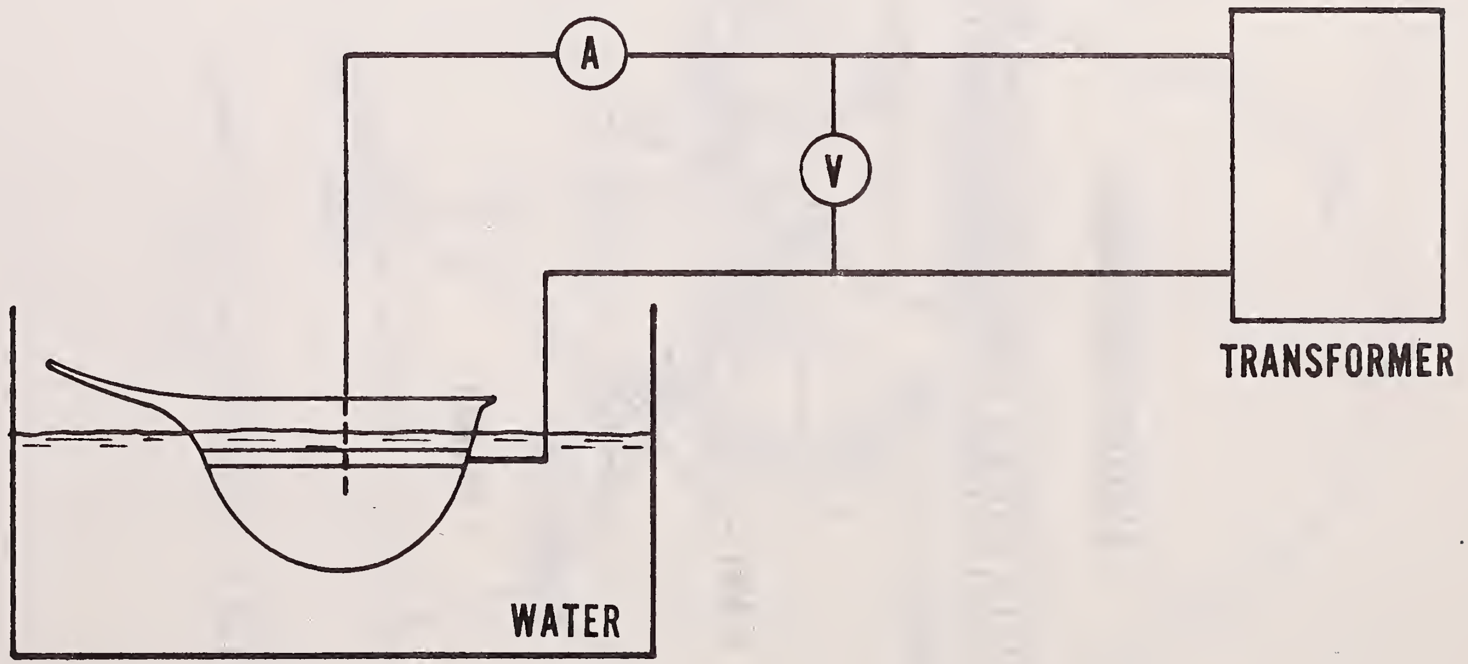


Figure 8. Electrical insulation test setup.

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The report describes the development of performance criteria for firefighters' helmets. Biomedical and physiological considerations are discussed. Fire helmet constructions and test methods for impact attenuation, penetration resistance, heat resistance and flammability are described. Results of tests on various types of fire helmets are presented. A proposed standard for fire helmets is included.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name, separated by semicolons)*

Fire helmet; head injury; head protection; heat resistance; helmet; impact; penetration resistance; test methods

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