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EXPERIMENTAL PROGRAM
FOR
INDUSTRIAL HEAD PROTECTIVE DEVICES
(PHASE II)

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FORWARD

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ABSTRACT

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This report presents the findings of a project designed to demonstrate that a head protective device could be developed for the American worker which would provide greater head protection than is presently available.

A prototype maximum duty industrial helmet was fabricated. Performance evaluation began with laboratory testing and was later expanded to include actual field testing by volunteers in high head injury risk industrial environments. Based upon the results obtained during test, standards for a class of heavy duty industrial helmets were developed. These are presented as appendix B of the report.

The report describes helmet test equipment and how it is used to evaluate the prototype helmet in relation to the developed recommended standard.

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1.0 INTRODUCTION

1.1 Background and Scope

Industrial head protection research previously performed by NIOSH (Phase I in the Development of Criteria for Industrial and Firefighters' Head Protective Devices) [1]* indicated that a need existed to provide the American worker with improved head protective devices. Three classes of helmets were recommended: Class 1 - Maximum Duty, Class 2 - Medium Duty, and Class 3 - Light Duty.

In this project, one of the three helmet classes, the Class 1 - Maximum Duty, was selected for prototype development, test, and evaluation. This report presents the findings of the development effort and proposes a recommended standard for the maximum duty, Class I, helmet.

The development effort was characterized by varying the helmet design to ensure acceptance by the industrial worker as well as to improve physical performance.

In the final phases of a field test of the developed prototype, an industrial accident occurred in which one wearer was severely struck with a heavy beam on the side of his head. The prototype helmet offered excellent protection. The worker was uninjured and no lost time on the job resulted.

The purpose of this study was to demonstrate that an improved helmet may be produced within available technology and that the helmet may be optimized to acceptably balance physical performance and wearability. The failure of presently available helmets to meet the proposed criteria predicated the need for NIOSH to develop a prototype helmet and to conduct research which would: (1) serve as justification for the viability of a proposed standard for Class 1 industrial helmets and (2) provide guidelines for helmet manufacturers in methods they may use to develop marketable helmets which would meet the proposed standard.

The helmets developed proved to have an acceptable level of performance. There was, however, an initial reluctance of people to wear the helmet. The prototype is larger, heavier, and styled differently from most currently available industrial helmets.

It is recommended that readers acquaint themselves with the referenced report on the Phase I criteria development project. This report provides greater insight into the industrial head injury problem.

*Numbers in brackets indicate references in section 7.0

1.2 Criteria for Development

Discussed below is background information leading to the formulation of this program. Outlined are the industrial environment, the performance of present industrial helmets, criteria for developing improved helmets, and the need for developing a prototype improved helmet.

1.2.1 The Industrial Head Injury Environment

The study of head injury in the industrial environment concerns itself with analyzing the causes and circumstances of industrial accidents which produce scalp, skull, and brain injuries.

Brain injuries which may result in permanent or long term physical disability, or death, are of primary concern. Scalp injuries and controllable skull fracture, though important, are not as significant to the study as are injuries to the brain.

Studies of accidents have shown that certain types of accidents correspond closely with the severity of injury.

The three most severe accident types are:

- (1) Falls to a different level - This type of accident is the most severe contributor to death or permanent brain injury. Such accidents as falling from roofs, ladders, scaffolds, or down stairs fit into this category. This accident is characterized by relatively high head impact velocities, the impact medium is often the ground or other flat surface. The impact energies involved follow no discrete pattern. The worker may be seen to have fallen from a one foot step stool or from the roof of a ten story building. A key factor of this accident type is that injuries are likely to occur anywhere on the head surface.
- (2) Struck by falling objects - This is the most frequent type of industrial head injury accident, though normally not as severe as the fall to different level accident. This accident is characterized by the fact that virtually any and every type of object which exists in an unsecured fashion at some level above the worker is a potential injury source. As such, the energies involved in this accident are also not well defined. The geometry of the impacting object is also highly variable, anything from a very blunt to a very sharp object may cause the injury. What is defined is that the falling object is likely to strike the worker on the top of his head.

1.2.1 The Industrial Head Injury Environment - (Continued)

- (3) Falls to same level - This accident type has an incidence similar to falls from different levels and a severity potential approximating the struck by falling object accident. The accident is produced from the slip-and-fall and trip-and-fall type of occurrence. The impact surface is normally a flat floor and the impact velocity of the head and resultant energy may be defined. These impacts, however, are most likely to occur at areas of the head other than at the top.

In general, the conditions of the workplace fairly well define the potential for each of these accidents.

A high head injury risk industry may be defined as one in which the conditions conducive to falls to different levels prevail and in which the hazards of being struck by falling objects and falling to the same level may also exist.

In like manner, a medium head injury risk industry is one in which the worker is likely to be struck by falling objects and where the fall to same level hazard may exist. The likelihood of falling to different levels would not be great in the medium risk industry. Following the same pattern, the light head injury risk industry would be one in which the fall to same level hazard would be the most severe.

1.2.2 Presently Available Industrial Head Protection

Helmets for the American worker are defined by governmental regulation. If the worker is to wear an industrial helmet at his workplace, it must meet the requirements of the ANSI Z89 standards for either general industrial or electrical workers use. The construction of the helmet produced under these standards is tightly controlled.

The major design feature of these helmets is that they offer impact protection to the direct top of the head only. As can be seen from the preceding discussion, this top-of-head impact situation is only one of many possibilities which exist in the accident environment.

The presently available helmets are constructed of a hard outer shell and a suspension system inside the helmet in which straps attached to the helmet shell extend over the top of the head providing clearance between the top of the head and the hard outer shell. The energy of an impact to the top of the helmet is controlled through deflection of the outer shell and in stretching of the suspension straps. These helmets must also be capable of warding off penetrating objects, they must not absorb water, they must not be flammable, and some of them must provide electrical insulation qualities.

The present helmet does, however, have two primary beneficial qualities. First, it is extremely light weight, easily cleaned and serviced. Second, it has been accepted well in the workplace. This second quality

1.2.2 Presently Available Industrial Head Protection - (Continued)

is perhaps the most important because getting the worker to wear the helmet is the first step in providing head protection.

1.2.3 Criteria for Improved Industrial Head Protection

The approach which has been taken under these head protection studies has been to provide a helmet to the worker which is compatible with the degree of risk in the workplace.

The aforementioned analysis of the industrial accident environment described three hazard or risk levels. It is therefore recommended that head protective devices be available to correspond to these three levels, that is, a maximum duty, medium duty, and light duty helmet.

The criteria for each of these helmets is:

- (1) Maximum Duty Helmet. The maximum duty helmet must be designed to protect from the most severe accident type, the fall to different level.

The helmet must also be able to protect from falling objects. Inherently it will protect from the fall on same level accident.

Because the potential energy levels of the two primary hazards are not definable, the helmet must offer the best available protection within the state of the art while being comfortable to wear. These factors are normally not complimentary. The impact protective and comfort features of the maximum duty helmet must both be compromised to a certain extent to obtain maximum optimization. The major goal in impact protection is to offer a high level of protection to both the top of the head and to areas away from the apex of the crown.

The helmet's ability to resist penetrating objects must also be the best available within comfort constraints.

The electrical, flammability, and water absorption requirements of the presently available helmets are considered satisfactory.

- (2) Medium Duty Helmet. The medium duty helmet should provide the maximum possible protection from falling objects. It should also provide protection from falls to same levels. This again requires a helmet with impact protection at areas other than at the direct top of the head. The top of the head should, however, be offered a higher level of protection than the lateral locations.

1.2.3 Criteria for Improved Industrial Head Protection - (Continued)

Penetration resistance should be proportionally incorporated. The other factors of electrical, flammability, and water absorption must be addressed as well.

- (3) Light Duty Helmet. The light duty helmet should offer impact protection from falls to the same level, should be resistant to sharp surfaces, and should offer the other benefits of electrical protection, flammability resistance, and low water absorption.

In addition to the above qualities, it is important that all classes of helmets be easily cleaned, inspected and maintained.

1.2.4 Requirements of the Phase II Study

Analysis of all currently available helmets showed that although many had some of the qualities desired, there was no one helmet which could meet each of the performance criteria of the maximum duty helmet.

An example is a helmet manufactured by Noel Daly Ltd. of New Zealand. Though most of the attributes of the maximum duty helmet are present, it is tested at its' top with a flat impact surface only. The data previously discussed, however, showed that falling objects infrequently strike with only a flat surface and, therefore, this helmet in its present configuration would not be an acceptable choice for the maximum duty helmet.

It was decided that a project be undertaken to develop a prototype maximum duty helmet. This study would establish the baseline performance required from such a helmet and culminate in a proposed standard for the helmet. The primary emphasis of the study would be to balance both performance and comfort into a viable concept.

1.3 Project Outline

The project was segmented into five tasks beginning with preparation of a detailed project plan and culmination in preparation of this final report.

By design, the project did not consider basic research into, and categorization of, possible helmet component materials, but rather integrated existing methods and materials into a prototype helmet.

Following approval of the initial design by the NIOSH Project Officer, the prototype construction was begun. At each stage of development, tests were conducted to assess the helmet's physical performance.

Prior to beginning production, a survey was performed to determine the acceptability of the helmet by industrial workers. This resulted in a redesign of the helmet exterior to improve its aesthetics.

1.3 Project Outline - (Continued)

Sixty final prototypes were constructed. Twenty helmets underwent in-house laboratory tests to demonstrate performance, twenty helmets were delivered to NIOSH for their internal research purposes, and the remaining twenty were field tested by volunteers to assess comfort and usage.

In addition to the helmet development, helmet test equipment was prepared for and delivered to NIOSH as part of the contract. An operation manual and design drawings for the equipment were delivered separately from this report.

All developed fabrication tools such as molds and patterns have been delivered to NIOSH and are available for inspection.

The efforts performed have resulted in proposed standards for maximum duty industrial helmets. These are presented in appendix B of this report.

2.0 PROTOTYPE HELMET DEVELOPMENT

2.1 Summary of Development

The target performance requirements were developed in reference [1]. These may be summarized as follows: (see appendix B for definitions)

- (1) Impact Attenuation. When mounted on an instrumented test headform and dropped a distance of 72 inches onto a rigid anvil the Head Injury Criterion must not be exceeded. Impacts to the apex of the helmet are to be conducted on a hemispherical anvil and all other impacts above the test line onto a flat anvil.
- (2) Penetration Resistance. When a 2.2 pound plumb bob with a 30 degree included angle is dropped from a height of 118.1 inches, the bob must not penetrate the helmet and contact the test headform. The maximum depth of penetration must also not exceed 0.375 inch.
- (3) Retention System Test. The helmet must be equipped with a chin strap capable of withstanding a pull force of 100 pounds and not elongate more than 1 inch while under this load.
- (4) Electrical Insulation. The helmet must be able to withstand a potential of 30,000 volts AC across the shell and should exhibit no more than 9 milliamps leakage current at 20,000 volts AC.
- (5) Flammability. No part of the shell of the helmet can burn at a rate greater than 3 inches per minute.
- (6) Water Absorption. When subjected to a 24 hour water bath the helmet must not absorb more than 5% water by weight.
- (7) Weight. The helmet must weigh no more than 18 ounces.

In addition, the helmet must have been adjustable to a variety of head sizes, must have been easily cleaned, and must have been manufactured of materials compatible with the user.

These were the ultimate goals of the prototype development effort.

2.1 Summary of Development - (Continued)

The prototype helmet was developed in three basic stages: initial assessment prototype, evaluation prototype, and final prototype. The numbers of helmets produced were as follows:

<u>Visual Examination and Initial Assessment</u>		8
<u>Evaluation and Pre-Production</u>	Model I	22
	Model II Type A	4
	Type B	4
	Type C	4
	Type D	4
	Variable outer shell thickness	4
<u>Final Prototype</u>	Model III	60
	Total	<u>110</u>

In section 3 of this report the tests performed on each of these samples are presented and discussed.

2.2 Selection of Materials and Manufacturing Processes

The helmets were to have been constructed of materials currently available and known to be suitable for use in protective helmets. Where at all possible, off-the-shelf components were to be incorporated in an effort to reduce manufacturing costs.

For those components which could not be purchased, the manufacturing processes used were to be suitable for small production runs and modifications. Permanent costly tooling was to have been avoided.

2.3 The Initial Assessment Prototype

Shortly after project initiation, sketches of the helmet exterior were reviewed by the NIOSH Project Officer. One of these was selected (see appendix A, enclosure 1) for prototype development.

In an effort to meet the performance requirements previously specified and in keeping with the material and manufacturing process constraints, the following helmet configuration was specified:

INITIAL ASSESSMENT PROTOTYPE

<u>Helmet Component</u>	<u>Description</u>
Shell	Molded polycarbonate thermoplastic 0.090 inch thickness
Liner	Molded expanded polystyrene 1.250 inch thick, 2.0 lbs./ft. ³ density

2.3 The Initial Assessment Prototype - (Continued)

Liner Cover	Polyurethane film, 0.015 inch thick
Headband	Medium density polyethylene, 0.050 inch thick
Crown Strap	1-1/4 inch nylon webbing, per MIL-W-4088, Type 3
Suspension and Strap Bracket	Polycarbonate, 1/8 inch thick
Chin Strap	1-1/4 inch nylon webbing, per MIL-W-4088, Type 3
Strap Fastener	1 inch velcro tabs, # 80 closure, 3 inches long

Preparations were made to have the outer shell thermoformed from clear polycarbonate sheet stock. Pattern drawings were made for the outer shell (appendix A, enclosure 2). A pattern maker then fabricated a wooden casting pattern from the drawings (appendix A, enclosure 3) from which an aluminum thermoforming mold was to be cast.

The thermoforming process selected was a drape forming method whereby the plastic sheet is heated and then pre-stretched by positive air pressure. The material is then draped over the male mold. Vacuum is then applied at the base of the male mold completing the forming process. This process is depicted in appendix A, enclosure 4.

For the purpose of visual examination and contour approval the first helmet shells were fabricated directly from the wooden casting pattern. The energy absorbing, nonresilient, expanded polystyrene foam liner selected was an off-the-shelf unit manufactured by a leading motorcycle helmet company. The headbands employed were procured from an industrial helmet manufacturer. Crown straps were manufactured by Dayton T. Brown, Inc. Difficulty was experienced in forming and adhering the polyurethane film liner cover and as such this was not included in the visual examination samples. These samples are shown in appendix A, enclosure 5.

The review and approval of the examination prototype resulted in a decision to fabricate an inner shell to totally enclose the energy absorbing liner.

2.3 The Initial Assessment Prototype - (Continued)

To circumvent the need to generate drawings and a wooden pattern for the inner shell, a thermoforming pattern was manufactured directly from the contours of the outer shell/liner combination by casting in carbolon epoxy resin. Carbolon is used for building temporary thermoforming molds and patterns. The carbolon pattern and resultant inner shell are depicted in enclosures 6 and 7 of appendix A.

2.4 Evaluation and Pre-Production Prototypes

Fabrication of evaluation and pre-production prototypes was segmented into the development of two models of helmets. The development of these helmets is detailed below.

2.4.1 Evaluation Prototype - Model I. The fabrication of Model I evaluation prototypes involved the use of all tooling developed for the visual examination helmet. A permanent aluminum thermoforming mold (appendix A, enclosure 8) was cast using the wooden thermoforming pattern previously described.

A preliminary group of helmets was assembled and checked for fit. It was found that the energy absorbing liner/inner shell combination used allowed insufficient room inside the helmet for the desired size range adjustment. A second inner shell mold was fabricated to allow the suspension mounting points to be recessed. The casting mold, thermoforming mold and resultant inner shell are shown in appendix A, enclosures 9, 10, and 11.

Manufacturers were canvassed for the availability of an energy absorbing liner conforming to the contours of the outer/inner shell. None were found readily available. This required that a liner be manufactured. The costs of having expanded polystyrene foam liners manufactured was prohibitive and a decision was made to fabricate energy absorbing liners in-house using a chemical mixture for polyurethane foam. The technique has been used in other helmet designs and the procedures and materials used are specified in a Naval Technical Manual for aviator helmets [2]. The setup for molding the liners and the resultant molded liners are shown in appendix A, enclosures 12 and 13.

The suspension mounts on the inner shell were prepared to accept a standard off-the-shelf industrial helmet suspension system (appendix A, enclosure 14).

Each of the component parts of the Model I prototype is shown in enclosure 15 of appendix A, the completed helmet is shown in enclosure 16. Twenty-two Model I helmets were fabricated for test and evaluation.

2.4.1 Evaluation Prototype - Model I - (Continued)

The specifications for the Model I Evaluation Prototype are as follows:

EVALUATION PROTOTYPE - MODEL I

Shell: Material - Polycarbonate, GE Lexan
Manufacturing Process - Vacuum Formed on Carbolon
Thickness - Nominally 0.090 inch outer and 0.020
inch inner
Color - clear

Liner: Material - Polyurethane Foam
Thickness - Nominally 1 inch

Suspension: MSA Stazon Part Number 454231

Chin Strap: 3/4 inch black nylon tape with 3 inch velcro sewn to
each strap attached to helmet with steel rivets

Total Assembly Weight: 1.50 to 1.70 pounds

Prior to performing physically destructive tests, samples of the Model I helmets were shown to prospective field test subjects. A meeting was held at the Philadelphia Navy Yard between their employees who normally wear industrial helmets, their management, and members of the project staff. The purpose of the visit was to discuss the prospects for having volunteers from the Navy Yard act as test subjects in a field test and to obtain objective comment on the helmet.

Most prospective wearers were displeased with the aesthetics of the helmet, the shape of the outer shell being of greatest concern. The helmet weight was greater than desired and some voiced objection to this.

The NIOSH Project Officer decided that a complete redesign to improve aesthetics was warranted and should be incorporated into the development of a Model II helmet.

2.4.2 Evaluation Prototype - Model II. The redesign for styling change required new tooling for both the outer and inner shells. A sketch of the redesigned outer shell, outer shell thermoforming pattern, thermoformed outer shell, inner shell thermoforming pattern, and thermoformed inner shell are shown in enclosures 17, 18, 19, 20, and 21 respectively of appendix A.

In order to properly address performance deficiencies in water absorption, electrical breakdown, impact performance, and weight, four types of Model II helmets were fabricated, tested, and evaluated. The most promising variation was to have been selected for the final prototype.

The specifications for the four Model II variations are as follows:

2.4.2 Evaluation Prototype - Model II - (Continued)

SPECIFICATION FOR - MODEL II, TYPE A

Helmet Number: II-1, II-2, II-3, II-4

Shell: Material - Polycarbonate
Manufacturing Process - Vacuum Formed on Carbolon
Thickness - Nominally 0.080 inch outer and 0.020
inch inner
Color - clear shell painted yellow on inner surface

Liner: Material - Polyurethane Foam (Partial)
Thickness - Nominally 1 inch

Suspension: MSA Stazon Part Number 454231 (Modified)
6 Metal Fasteners - 2 Plastic Fasteners

Chin Strap: 3/4 inch black nylon tape with 3 inch velcro sewn
to each strap. Attached to helmet with plastic rivets

Total Assembly Weight: 1.40 to 1.44 pounds

SPECIFICATION FOR - MODEL II, TYPE B

Helmet Number: II-5, II-6, II-7, II-8

Shell: Material - Polycarbonate
Manufacturing Process - Vacuum Formed on Carbolon
Thickness - Nominally 0.080 inch outer and 0.020
inch inner
Color - clear shell painted white on inner surface

Liner: Material - Polyurethane Foam (Partial)
Thickness - Nominally 1 inch

Suspension: MSA Stazon Part Number 454231 (Modified)
8 Plastic Fasteners

Chin Strap: 3/4 inch black nylon tape with 3 inch velcro sewn
to each strap. Attached to helmet with plastic rivets

Total Assembly Weight: 1.43 to 1.46 pounds

2.4.2 Evaluation Prototype - Model II - (Continued)

SPECIFICATIONS FOR - MODEL II, TYPE C

Helmet Number: II-9, II-10, II-11, II-12

Shell: Material - Polycarbonate
Manufacturing Process - Vacuum Formed on Carbolon
Inner Shell - Partial
Thickness - Nominally 0.080 inch outer and 0.020
inch inner
Color - clear shell painted yellow on inner surface

Liner: Material - Polyurethane Foam (Partial)
Thickness - Nominally 1 inch

Suspension: MSA Stazon Part Number 454231 (Modified)
6 Metal Fasteners - 2 Plastic Fasteners

Chin Strap: 3/4 inch black nylon tape with 3 inch velcro sewn
to each strap. Attached to helmet with plastic rivets

Total Assembly Weight: 1.33 to 1.40 pounds

SPECIFICATIONS FOR - MODEL II, TYPE D

Helmet Number: II-13, II-14, II-15, II-16

Shell: Material - Polycarbonate
Manufacturing Process - Vacuum Formed on Carbolon
Thickness - Nominally 0.080 inch outer and 0.020
inch inner
Color - clear shell painted red on inner surface

Liner: Material - Polyurethane Foam (Full)
Thickness - Nominally 1 inch

Suspension: MSA Stazon Part Number 454231 (Modified)
6 Metal Fasteners - 2 Plastic Fasteners

Chin Strap: 3/4 inch black nylon tape with 3 inch velcro sewn
to each strap. Attached to helmet with plastic rivets

Total Assembly Weight: 1.63 to 1.70 pounds

2.4.2 Evaluation Prototype - Model II - (Continued)

Each of the 16 Model II helmets was tested and evaluated, the results are detailed in section 3 of this report. The Model II full liner configuration showed the most promising performance, however, excessive weight was still a problem. By direction of the NIOSH Project Officer the outer shell thickness of the Model II helmet was reduced thereby decreasing the helmet's overall weight. Four Model II helmets were then constructed each with a different outer shell thickness. These were nominally 0.030, 0.040, 0.045, and 0.063 inch.

2.5 Final Prototype Helmet - Model III. At the completion of the test and evaluation of the Model II prototype helmets, it was concluded that the 0.040 inch outer shell helmet showed the best performance to weight ratio. That outer shell thickness was selected for the final prototype, designated the Model III. Appendix A, enclosures 25 and 26, describe the Model III final prototype geometry and component parts. A full discussion of the laboratory tests performed is contained in section 3 of this report.

Section 4 of this report contains a presentation of the final prototype field test results. Included is a discussion as to why the field test was conducted and what was expected to be learned from such an experiment.

3.0 HELMET TESTING

Each of the helmets fabricated in this study, with the exception of 20 which were delivered to NIOSH for their experimentation, were tested and evaluated.

In the discussion which follows, each of the important tests performed in the evaluation, pre-production, and final prototype helmets is detailed. The field tests are discussed in section 4.0 of this report.

Presented on the following four pages is a helmet testing matrix which lists the evaluations performed on each of the 110 prototype helmets fabricated.

3.1 Model I Helmet Assembly

The component parts of the Model I prototype helmet are shown in appendix A, enclosure 15. The inner shell was made from clear polycarbonate sheet yielding a post-forming thickness of approximately 0.020 inches. Four metal posts were attached to this inner shell so that the helmets' suspension system could be installed. The inner shell was locally reinforced in the areas of the four metal posts with plastic washers. Appendix A, enclosure 14 shows a close up of this reinforced area. Onto this inner shell assembly was placed a pre-formed polyurethane foam liner.

Appendix A, enclosure 12 depicts the setup used to mold the polyurethane foam liners and appendix A, enclosure 13 shows a complete, foamed liner ready for installation onto a Model I inner shell assembly. Because of the inherent problems of working with liquid pourable foams, it was extremely difficult to maintain a high degree of physical consistency among all the liners poured.

The following is a list of variables which contributed to the liner inconsistency problem:

- fluid mixing ratio
- fluid mixing time
- temperature
- humidity
- fluid pouring time
- foam setting time

HELMET TESTING MATRIX

Helmet Sample Number	TYPE OF TEST (Z89=ANSI Z89.2 - 1971, PS=Proposed Standard)	Visual Exam.				
		Impact	Penetration	Chin Strap	Water Absorption	Insulation Resistance
		Flammability				
Initial Assessment						
I-1						
I-2	by NIOSH					
I-3	by NIOSH					
I-4	by DTB					
I-5	Note 1					
I-6	Note 2					
I-7	Note 3					
I-8	Note 4					
	Note 5					
Evaluation Helmet Model I						
I-9	Z89					
I-10	Z89					
I-11	Z89					
I-12	Z89					
I-13	PS					
I-14	PS					
I-15	PS					
I-16	PS					
I-17	PS					
I-18	Z89					
I-19	Z89					
I-20	Z89					
I-21	Z89					
I-22	PS					
I-23	PS					
I-24	PS					
I-25	Z89					
I-26	Z89					
I-27	Z89					
I-28	PS					
I-29	PS					
I-30	PS					

HELMET TESTING MATRIX
(Continued)

Helmet Sample Number	TYPE OF TEST (Z89=ANSI Z89.2 - 1971, PS=Proposed Standard)	Visual Exam.	Impact	Penetration	Chin Strap	Water Absorption	Insulation Resistance	Flammability
Evaluation Helmet -								
Model II								
II-1		PS	PS					
II-2		PS	PS					
II-3		PS	PS					
II-4		PS	PS		PS	PS	PS	
II-5		PS	PS					
II-6		PS	PS					
II-7		PS	PS					
II-8		PS	PS		PS	PS	PS	
II-9		PS	PS					
II-10		PS	PS					
II-11		PS	PS					
II-12		PS	PS		PS	PS	PS	
II-13		PS	PS					
II-14		PS	PS					
II-15		PS	PS					
II-16		PS	PS		PS	PS	PS	
II-0.030		PS	PS					
II-0.040		PS	PS					
II-0.045		PS	PS					
II-0.063		PS	PS					
Final Prototype -								
Model III								
III-1		Z89	Z89					Z89
III-2		Z89	Z89			Z89		Z89
III-3		Z89	Z89			Z89		Z89
III-4		Z89	Z89			Z89		Z89
III-5		Z89	Z89			Z89		Z89

HELMET TESTING MATRIX
(Continued)

Helmet Sample Number	TYPE OF TEST (Z89=ANSI Z89.2 - 1971, PS=Proposed Standard)						
	Visual Exam.	Impact	Penetration	Chin Strap	Water Absorption	Insulation Resistance	Flammability
Final Prototype - Model III							
III-6	Z89	Z89			Z89	Z89	Z89
III-7	PS	PS					
III-8	PS	PS					
III-9	PS	PS					
III-10	PS	PS					
III-11	PS	PS					
III-12	PS	PS					
III-13	PS		PS	PS		PS	
III-14	PS		PS	PS		PS	
III-15	PS		PS	PS		PS	
III-16		Note 6					
III-17		Note 7					
III-18		Note 8					
III-19	Note 9						
III-20	Note 10						
III-21	Field tested	at Sound Beach	F.D. Rescue				
III-22	Field tested	at Sound Beach	F.D. Rescue				
III-23	Field tested	at Sound Beach	F.D. Rescue				
III-24	Field tested	at Sound Beach	F.D. Rescue				
III-25	Field tested	at Sound Beach	F.D. Rescue				
III-26	Field tested	at Sound Beach	F.D. Rescue				
III-27	Field tested	at Strata Well	Corporation				
III-28	Field tested	at Strata Well	Corporation				
III-29	Field tested	at Strata Well	Corporation				
III-30	Field tested	at Strata Well	Corporation				
III-31	Field tested	at Elaine Construction	Corporation				
III-32	Field tested	at Elaine Construction	Corporation				
III-33	Field tested	at Elaine Construction	Corporation				
III-34	Field tested	at Elaine Construction	Corporation				
III-35	Field tested	at Elaine Construction	Corporation				
III-36	Field tested	at Alcap Electric	Corporation				

HELMET TESTING MATRIX
(Continued)

Helmet Sample Number	TYPE OF TEST (Z89=ANSI Z89.2 - 1971, PS=Proposed Standard)						
	Visual Exam.	Impact	Penetration	Chin Strap	Water Absorption	Insulation Resistance	Flammability
III-37		Field tested at Alcap Electric Corporation					
III-38		Field tested at Alcap Electric Corporation					
III-39		Field tested at Alcap Electric Corporation					
III-40		Field tested at Alcap Electric Corporation					
III-41							
through							
III-60		Delivered to NIOSH for experimentation					
Note 1:		This helmet was experimentally impacted at a 24 inch drop height					
Note 2:		This helmet was experimentally impacted at a 48 inch drop height					
Note 3:		This helmet was experimentally impacted at a 72 inch drop height					
Note 4:		This helmet was used for fitting experimental webbing systems					
Note 5:		This helmet was experimentally impacted to study shell deflection					
Note 6:		This helmet was experimentally impacted to study 80 g level					
Note 7:		This helmet was experimentally impacted to study 80 g level					
Note 8:		This helmet was experimentally impacted to study 80 g level					
Note 9:		This helmet was evaluated for thermal conductivity					
Note 10:		This helmet was used for subjective comfort evaluation					

3.1 Model I Helmet Assembly - (Continued)

In general the foam liners used in the Model I helmets were 1 inch thick and were free from excessively large voids.

The outer shell was made from clear polycarbonate of 0.090 inch thickness. This outer shell fit over the foam liner and was adhered to the inner shell at the rim by means of a solvent bonding compound. Black electrical tape served as an edge finish where the outer and inner shells met.

The total assembly was completed by installing the MSA Stazon suspension and attaching a chin strap to the helmet by use of two metal posts through the outer shell. Appendix A, enclosure 16 shows the completed Model I - evaluation prototype helmet assembly.

The final weight of this assembly ranged from 1.50 pounds to 1.70 pounds. The variation in the weight was due to the forming processes used on the outer shell, inner shells, and polyurethane liner. The shell thickness variation was affected by the amount of vacuum and the temperature used at the time of forming which dictates the flow characteristics of the plastic on the forming mold. Thus, uniform shell thickness is not possible by using a vacuum formed technique. The relative inconsistency of the shell thicknesses results in variation in weight from shell to shell.

3.1.1 Model I Helmet Assembly - Laboratory Tests Performed - ANSI Z89

Once the Model I helmet was assembled, an evaluation program to determine its performance capability was begun. Because the Model I helmet was different from other helmets currently available, a direct performance comparison was not possible.

To allow a relative measurement of the prototype's performance, the first performance assessment was made in terms of the ANSI Z89.2 criteria. Refer to the preceding helmet testing matrix for a tabular list of the test performed.

The first series of tests performed were the impact resistance and mechanical proof tests as specified by ANSI Z89.2 (1971). Briefly, the helmet is placed on a headform, after being conditioned to the proper temperature, and is impacted at the apex by a free falling steel ball weighing 8 pounds dropped from a height of 60 inches. A measurement of the force transmitted through the helmet is recorded along with whether or not the helmet suspension system bottomed out during the impact. The results of these tests are as follows:

<u>Condition</u>	<u>Sample</u>	<u>Force Transmitted (pounds)</u>
0°F	I-18	1419
	I-25	1495
	I-27	No Record

3.1.1 Model I Helmet Assembly - Laboratory Tests Performed - ANSI Z89 - (Continued)

<u>Condition</u>	<u>Sample</u>	<u>Force Transmitted (pounds)</u>
120°F	I-18	1288
	I-25	1326
	I-27	1212

It should be noted that each of these helmets failed to meet the mechanical proof test requirements of ANSI Z89. It should be remembered, however, that crown clearance perse does not exist in this prototype.

The Z89 test criteria states that no force greater than 1000 pounds be transmitted by any one helmet, an 850 pound maximum force is the allowable average, and that no helmet shall bottom out its suspension system. From the data it is seen that the Model I failed to pass the Z89 criteria.

Upon further investigation it was found that the mounting posts in the inner shell were not being supported by the inner shell in as rigid a manner as was anticipated. The plastic washers used to stiffen the inner shell locally in the area of the metal mounting posts were not sufficient. There was excessive deflection of the inner shell under load and as a result, the suspension system did not distribute the impact load into the entire helmet, but rather localized it.

To correct these deficiencies the following changes were incorporated into the Model II helmet configuration:

- . suspension mounting post length was increased to have it protrude into the liner.
- . two washers were cemented to the posts, one at the post end (lying within the liner) and one at the liner/inner shell interface.
- . the number of mounting posts were increased from four to eight for better load distribution.
- . the liner was poured directly over the inner shell and posts and allowed to adhere to same to increase the rigidity of the mountings.

The next test performed on the Model I helmet assembly was the water absorption test specified by ANSI Z89.2 (1971) where the helmet is submerged in a tank of water for 24 hours after having been correctly pre-conditioned. The results of this tests are as follows:

<u>Sample No.</u>	<u>% Increase in Weight (water absorbed)</u>
I-18	11.3%
I-25	36.7%
I-27	27.8%

3.1.1 Model I Helmet Assembly - Laboratory Tests Performed - ANSI Z89 - (Continued)

The Z89 test criteria states that on the average there shall not be more than a 1/2% increase in weight. From the data it is seen that the water absorbed greatly exceeded the requirement. A poor seal between the edges of the inner and outer shell was identified as the problem. Water, being trapped between the inner and outer shells, accounted for the increase in weight indicating that either the seal could be improved or drain ports could be installed. For hygienic reasons, improving the seal was selected as the method which would be used on the Model II helmets to correct the problem.

The insulation resistance test as specified by ANSI Z39.2 (1971) was next performed on the Model I helmet assembly. The helmet assembly, after being conditioned, is inverted and partially submerged in water. Water is placed on the inside of the helmet and an increasing voltage is applied across the inner and outer surfaces. The results of the test are as follows:

S/N I-18: Inner shell burned and broke down at 24,000 volts

S/N I-25: Helmet broke down at 27,500 volts

S/N I-27: Helmet broke down at 26,000 volts

The Z89.2 test criteria states that no electrical breakdown through the shell shall occur at 20,000 volts and that when the voltage is increased to 30,000 volts the leakage shall not be more than 9 milliamperes.

From the test data it is seen that the Model I helmets were able to partially meet the test criteria. All of the failures occurred near the helmets' edge with conduction through the suspension and the chin strap mounting posts.

The following corrections were indicated and would be incorporated into the Model II helmet.

- . the chin strap mounting post would be non-conductive and would pass through the inner shell only.
- . the water absorption between shells would be decreased.

The next test performed on the Model I helmet assembly was the penetration resistance test as specified by ANSI Z89.2 (1971). The helmet assembly, after being placed on a headform, is impacted at the apex with a 1 pound plumb bob, having a pointed tip with an included angle of 35 degrees, from a height of 10 feet. The results of the test are as follows:

3.1.1 Model I Helmet Assembly - Laboratory Tests Performed - ANSI Z89 - (Continued)

<u>Serial Number</u>	<u>Actual Penetration</u>
18	0.075 inch
25	0.100 inch
27	0.090 inch

The Z89.2 test criteria states that the helmet shall not be pierced more than 0.375 inch. All of the helmets successfully passed this test, and therefore no corrective action was indicated.

The next test performed on the Model I helmet assembly was the flammability test as specified by ANSI Z89.2 (1971). Three strips are cut from the helmet assembly at the thinnest areas. According to Z89.2, the strips shall burn at a rate of not greater than 3 inches per minute. The results of this test are as follows:

- S/N I-18 - Self extinguished in 6 seconds. There was no change in length due to burning.
- S/N I-25 - Self extinguished in 5 seconds. There was no change in length due to burning.

Due to the inherent self-extinguishing qualities of the plastic material chosen, there was no difficulty in successfully passing this test. It was decided that for all future experimentation under this study, the flammability test be omitted since it offered no new information about the overall performance of the helmet. This would be continued until a change of materials was incorporated into the helmet.

Upon completion of the Z89 tests, samples of the Model I evaluation prototype were subjected to a series of tests to determine if they met the proposed criteria. The helmet testing matrix lists each of the tests performed.

In appendix B, section 2.0 of this report, the methods of test are described in detail. In this discussion specific reference will be made to paragraphs in the test standard in appendix B. It should be noted that the criteria values in appendix B are different than those presented in section 2.0. The methods of test, however, are identical.

The Model I helmets were subjected to impact attenuation tests as specified in appendix B, section 2.6.

This test method is significantly different from the ANSI Z89. The impact is conducted by placing the test helmet on an instrumented headform and dropping the helmet/headform combination on to a rigid anvil. The apex is impacted on a hemispherical anvil, the lateral locations on a flat anvil. The procedure also requires testing at five head locations, not just at the apex. The failure criteria is no longer a maximum transmitted force, but rather a human head injury tolerance.

3.1.2 Model I Helmet Assembly - Laboratory Tests Performed - Proposed Standard --
(Continued)

Mathematically this can be expressed as:

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

Computed values in excess of 1000 shall be cause for failure. This criterion is known as the "Head Injury Criterion" and is abbreviated as HIC. See Appendix B, Section 2.6.4.1 for further definition.

The results of the impact tests are as follows:

<u>Condition</u>	<u>Impact Location</u>	<u>Sample No. I-</u>	<u>Max g</u>	<u>HIC</u>
Ambient	Apex	13	155	710
		22	125	603
		28	190	774
	Forehead	13	205	1297
		22	195	1359
		28	180	1242
	Rear	13	200	1447
		22	190	1261
		28	200	1349
	Left Side	13	190	1400
		22	175	1107
		28	175	1259
	Right Side	13	205	1528
		22	185	1317
		28	190	1348
Low Temp.	Apex	14	150	651
		23	145	659
		29	210	833
	Forehead	14	190	1340
		23	195	1265
		29	195	1433

3.1.2 Model I Helmet Assembly - Laboratory Tests Performed - Proposed Standard -
(Continued)

<u>Condition</u>	<u>Impact Location</u>	<u>Sample No. I-</u>	<u>Max g</u>	<u>HIC</u>
	Rear	14	205	1462
		23	180	1194
		29	180	1155
	Left Side	14	190	No Record
		23	175	1148
		29	185	1243
	Right Side	14	185	1302
		23	185	1176
		29	180	1260
High Temp.	Apex	15	120	568
		24	150	628
		30	145	717
	Forehead	15	160	1063
		24	170	1335
		30	185	1332
	Rear	15	175	1204
		24	165	1025
		30	175	1136
	Left Side	15	165	1119
		24	160	1028
		30	165	1065
	Right Side	15	185	1214
		24	160	1046
		30	180	1248

As can be seen from the data the helmet did not meet the criterion. The apex impact location, however, did provide HIC values of less than 1000.

The construction modifications already proposed as a result of the Z89 tests were considered sufficient to improve the lateral impact performance.

These performance tests provided baseline HIC values. As modifications were incorporated it could easily be determined whether or not they improved the performance level of the helmet.

The next series of tests performed were the penetration resistance tests as specified in appendix B, section 2.7. In this test, a 2.21 pound plumb bob was dropped a distance of 118.1 inches onto the outer surface of the helmet.

3.1.2 Model I Helmet Assembly - Laboratory Tests Performed - Proposed Standard -
(Continued)

The results of the penetration test are presented below. Note that in no case did the striker contact the test headform. The depth of penetration is measured as the distance along the side of the plumb bob. The maximum allowable depth under the proposed specification is 0.375 inch.

<u>Condition</u>	<u>Location</u>	<u>Sample No. I-</u>	<u>Depth (inches)</u>
Ambient	Apex	13	0.148
		22	0.145
		28	0.204
	Fore*	13	0.125
		22	0.154
		28	0.185
	Aft**	13	0.114
		22	0.140
		28	0.130
Low Temp.	Apex	14	0.105
		23	0.138
		29	0.150
	Fore	14	0.133
		23	0.138
		29	0.137
	Aft	14	0.138
		23	0.206
		29	0.153
High Temp.	Apex	15	0.256
		24	0.188
		30	0.265
	Fore	15	0.198
		24	0.166
		30	0.182
	Aft	15	0.198
		24	0.202
		30	0.223

* Fore = 2.5 inches forward of apex

** Aft = 2.5 inches rearward of apex

As can be seen from the data, the Model I helmet assembly still exhibited excellent penetration resistance. This data shows that the Model I helmets' penetration resistance was excellent at both high and low temperatures

3.1.2 Model I Helmet Assembly - Laboratory Tests Performed - Proposed Standard - (Continued)

and that the helmet can successfully resist a heavier object than is specified by ANSI Z89.

The next series of tests performed were the retention tests as specified in appendix B, section 2.11. In this test the helmet's chin strap was subjected to a 100 pound pull force. The maximum allowable elongation of the strap is 1 inch. The data obtained is as follows:

<u>Condition</u>	<u>Sample No. I-</u>	<u>Elongation (inches)</u>	<u>Remarks</u>
Ambient	13	-	Rivet hole tore < 100 lbs.
	22	-	Rivet hole tore < 100 lbs.
	28	0.72	Satisfactory
Low Temp.	14	-	Rivet hole tore < 100 lbs.
	23	0.78	Satisfactory
	29	0.84	Satisfactory
High Temp.	15	-	Rivet hole tore < 100 lbs.
	24	-	No test
	30	-	Rivet hole tore < 100 lbs.

The results of the retention test necessitated an improvement in the chin strap attachment to the helmet shell. Only a single layer of chin strap material was being used at the attachment post. The data strongly suggested that a double layer be used. In addition, from the results obtained during the electrical tests, an entirely new chin strap mounting location was necessary.

3.1.3 Model I Helmet Assembly - Test Result Summary

The following is a summary of the prototype helmet performance at the Model I stage of development.

ANSI Z89.2 (1971) Specification:

<u>Test</u>	<u>Satisfactory Results</u>	<u>Improvement Required</u>
Weight		X
Impact Resistance		X
Mechanical Proof		X
Water Absorption		X
Insulation Resistance		X
Penetration Resistance	X	
Flammability	X	

3.1.3 Model I Helmet Assembly - Test Result Summary - (Continued)

Appendix B Specification:

<u>Test</u>	<u>Satisfactory Results</u>	<u>Improvement Required</u>
Weight		X
Impact Resistance		X
Penetration Resistance	X	
Retention		X

3.2 Model II Helmet Assembly

Based on the performance of the Model I helmet assembly, four Model II helmet types were constructed. The Model II was reshaped to improve its aesthetic appeal. Other areas of great concern that were addressed were weight, impact performance, and insulation resistance. The first Model II helmet configuration was designated type A. A description of this Model II, type A helmet was presented in section 2.0.

This first configuration had a partial liner to reduce its weight, an 8 point suspension to better distribute the impact load, a thinner outer shell to reduce its weight, and a coat of epoxy paint on the inside of the outer shell to improve its insulation resistance. In addition, the chin strap attachment point was moved to the inside of the helmet. Appendix A, enclosure 22 shows the partial liner, prior to assembly and appendix A, enclosure 23 shows the new 8 point suspension system.

The next configuration was called type B. A description of this Model II type B helmet was presented in section 2.0. Type B and type A differ in that the type B has 8 plastic non-conductive posts to support its suspension and mount its chin strap.

The next configuration was called type C. A description of this Model II, type C helmet was presented in section 2.0. Type C is identical to type A in all respects except that the type C had a smaller partial foam liner thereby making it lighter.

The next configuration was called type D. A description of this Model II, type D helmet was presented in section 2.0. Type D is identical to the type A configuration in all respects except that the type D had a full liner (see appendix A, enclosure 24).

All of the metal fasteners used on Model II, types A, C, and D were insulated with several coats of varnish prior to final helmet assembly.

3.2.1 Model II Helmet Assembly - Laboratory Tests Performed

Each of the four types of Model II prototypes were tested to the proposed standard.

All impact tests were conducted at a 72 inch drop height with the apex impacting a hemispherical anvil and the lateral locations impacting a flat anvil.

3.2.1 Model II Helmet Assembly - Laboratory Tests Performed - (Continued)

The impact test results are shown below. Note that once a helmet exhibited structural damage as a result of impact (broken suspension mount, cracked shell, etc.) no further impacts were performed on that helmet. It should also be noted in the data that when the maximum g was above 500 the usable range of the peak indicator was exceeded. HIC values are, however, accurate.

<u>Condition</u>	<u>Impact Location</u>	<u>Model II Type</u>	<u>Sample No. II-</u>	<u>Max g</u>	<u>HIC</u>	<u>Structural Failure</u>	
Ambient	Apex	A	1	>500	3373	Yes	
		B	5	>500	4097		
		C	9	455	1905		
		D	13	105	534		
	Forehead	A	1	360	2271		
		B	5	285	1283		
		C	-	-	-		
		D	13	200	974		
	Left Side	A	1	>500	3071		
		B	5	>500	5857		
		C	-	-	-		
		D	13	150	1091		
	Right Side	A	1	120	606		
		B	5	475	6115		
		C	-	-	-		
		D	13	140	805		
	Rear	A	1	140	882		
		B	5	110	462		
		C	-	-	-		
		D	13	144	1062		
	High Temp.	Rear	A	2	120	673	
			B	6	120	606	
			C	10	>500	6461	
			D	14	170	1249	
Left Side		A	2	120	704	Yes	
		B	6	120	766		
		C	10	780	5122		
		D	14	130	920		
Right Side		A	2	145	631		
		B	6	195	558		
		C	-	-	-		
		D	14	170	1257		

3.2.1 Model II Helmet Assembly - Laboratory Tests Performed - (Continued)

<u>Condition</u>	<u>Impact Location</u>	<u>Model II Type</u>	<u>Sample No. II-</u>	<u>Max g</u>	<u>HIC</u>	<u>Structural Failure</u>
	Forehead	A	2	230	1011	
		B	6	240	1003	Yes
		C	-	-	-	
		D	14	140	865	
	Apex	A	2	>500	7420	
		B	6	-	-	
		C	10	-	-	
		D	14	110	532	
Low Temp.	Left Side	A	3	>500	5239	Yes
		B	7	>500	5906	Yes
		C	11	>500	5124	
		D	15	130	865	Yes
	Forehead	A	-	-	-	
		B	-	-	-	
		C	11	290	1486	
		D	-	-	-	
	Rear	A	-	-	-	
		B	-	-	-	
		C	11	300	703	Yes
		D	-	-	-	
	Right Side	A	-	-	-	
		B	-	-	-	
		C	-	-	-	
		D	-	-	-	
	Apex	A	-	-	-	
		B	-	-	-	
		C	-	-	-	
		D	-	-	-	

3.2.1 Model II Helmet Assembly - Laboratory Tests Performed - (Continued)

A water absorption test was conducted, the results of which were:

<u>Model II Type</u>	<u>Sample No. II--</u>	<u>Percent Increase in Weight</u>
A	4	14.3
B	8	32.9
C	12	8.3
D	16	6.1

The helmets were then tested for insulation resistance. The results were as follows:

<u>Model II Type</u>	<u>Sample No. II--</u>	<u>Pass</u>	<u>Remarks</u>
A	4	Yes	8 milliamps max
B	8	Yes	7 milliamps max
C	12	No	Burned through at 27,000 volts
D	16	Yes	6.5 milliamps max

The last test of this series was the retention system (chin strap) test. Note that the penetration test was not performed because the helmet modifications were assumed not to affect the previously found acceptable performance.

The results of the retention system tests were:

<u>Model II Type</u>	<u>Sample No. II--</u>	<u>Elongation (inches)</u>	<u>Remarks</u>
A	4	-	Rivet sheared at 100 lbs. after 48 seconds
B	8	1.48	Excessive elongation
C	12	-	Rivet sheared at 96 lbs.
D	16	0.63	Acceptable elongation

3.2.2 Model II Helmet Assembly - Modification and Evaluation

Of the four Model II types tested, the type D performed best. The modifications incorporated improved impact attenuation and eliminated the insulation resistance and chin strap problems. The type D helmet, however, was the heaviest of the four, weighing between 1.63 and 1.70 pounds.

A major program decision was necessary. It was evident that in order to reduce the helmet weight it would be necessary to sacrifice all other performance parameters.

3.2.2 Model II Helmet Assembly - Modification and Evaluation - (Continued)

A decision was made to experiment with four prototypes, similarly constructed to the type D, but with varying outer shell thicknesses. The final prototype, or Model III would be selected as that experimental model which gave the best performance while staying within the 18 ounce maximum target weight.

Four nominal outer shell thicknesses were chosen. These were 0.030, 0.040, 0.045, and 0.063 inch requiring sheet stock of 0.060, 0.080, 0.090, and 0.125 respectively.

Again, the helmets incorporated full polyurethane foam liners, an inner shell 0.020 inches thick, MSA headband, two crown straps, and eight suspension mounts, six metal and two plastic.

The overall weight of the four assemblies were (18 ounce target weight):

<u>Assembly Nominal Outer Shell Thickness (inches)</u>	<u>Total Weight (ounces)</u>
0.030	15.69
0.040	18.36
0.045	17.85
0.063	19.86

It is seen from this data that the helmet with the 0.045 inch thick shell weighed less than the helmet with the 0.040 inch thick shell. This apparent contradiction is due to variation in shell weight due to the forming process and variation in liner weight due to the density control problems previously discussed.

Impact tests in accordance with the proposed specification were then conducted. The results of which are tabulated below.

Because only comparative performance differences were of importance only maximum accelerations (g) were recorded. No HIC values were calculated.

<u>Impact Location</u>	<u>Sample Nominal Outer Shell Thickness (inches)</u>	<u>Max g</u>
Apex	0.030	180
	0.040	190
	0.045	170
	0.063	210
Forehead	0.030	145
	0.040	145
	0.045	160
	0.063	125

3.2.2 Model II Helmet Assembly - Modification and Evaluation - (Continued)

<u>Impact Location</u>	<u>Sample Nominal Outer Shell Thickness (inches)</u>	<u>Max g</u>
Rear	0.030	120
	0.040	125 (structural failure)
	0.045	200 (structural failure)
	0.063	155
Right Side	0.030	235 (structural failure)
	0.040	-
	0.045	-
	0.063	110
Left Side	0.030	-
	0.040	-
	0.045	-
	0.063	110

The helmets were then tested to determine their resistance to penetration. In addition to the 2.2 pound striker specified in the proposed standard a 1 pound striker having the same geometry was also used. The results were as follows:

<u>Nominal Outer Shell Thickness</u>	<u>1 Kilogram (2.2 lbs.) Striker</u>	<u>1 Pound Striker</u>
0.030 inch	Fail	Fail
0.040 inch	Fail	Pass
0.045 inch	Fail	Pass
0.063 inch	Fail	Pass

The pass or fail criteria is based on headform contact.

Based upon the above test data the 0.040 outer shell thickness was chosen for the final prototype, designated Model III.

3.3 Model III Helmet Assembly

Based on the performance of the Model I and Model II helmets, a Model III helmet evolved. Its shape was the same as that of the Model II. The inner and outer shell were made from clear polycarbonate nominally 0.020 and 0.040 inch thick respectively. The shells cover a full pourable polyurethane foam liner which encapsulates aluminum suspension mounting posts which are attached to the inner shell. A 4 point suspension system was used as the 8 point suspension system proved to be inefficient for the amount of weight it contributed to the helmet assembly. The outer shell was coated on the inside with several coats of clear varnish so as to improve the electrical resistance performance of the helmet. All metal parts were electrically insulated with several coats of varnish. The outer shell was painted on the inside with an epoxy paint to again help

3.3 Model III Helmet Assembly - (Continued)

improve the helmets electrical resistance and to provide color. A full geometric description of the Model III helmet can be found in appendix A, enclosures 25 and 26.

In addition to the above changes, a new form of helmet edging was installed. Commercially available as "Trim-lok" edging material, this edging eliminated all rough edges and greatly improved aesthetics by providing a "finished" look to the helmet. This Trim-lok, however, added approximately 3.5 ounces to the assembly. Though this would increase the prototype weight, a more suitable edge finishing could be used in eventual helmet production.

3.3.1 Model III Helmet Assembly - Laboratory Tests Performed

Upon fabrication and assembly of 60 final Model III prototype helmets, 20 of the helmets were subjected to laboratory analysis to assess performance.

Six of these helmets were subjected to tests in accordance with ANSI Z89.2 (1971).

The drop ball impact was performed and the following results were obtained:

<u>Condition</u>	<u>Sample No. III-</u>	<u>Transmitted Force (pounds)</u>
Ambient	1	906
	2	909
High Temp.	3	990
	4	920
Low Temp.	5	984
	6	990

Though not within the 850 pound average required by the standard, the performance was considered acceptable considering that the maximum transmitted force was less than 1000 pounds.

The water absorption test produced the following results:

<u>Sample</u>	<u>% Water Absorbed</u>
III-2	15.4
III-4	11.8
III-6	13.5

The edge seal problem had persisted. In actual production the helmet seal could be improved. Drain ports however, would also be an acceptable method of circumventing excessive water retention.

3.3.1 Model III Helmet Assembly - Laboratory Tests Performed - (Continued)

The insulation resistance test was performed on three samples. Sample number III-2 reached 30,000 volts but burned through after 1 minute and 20 seconds at 20,000 volts. Sample number III-4 burned through at 26,000 volts. Sample number III-6 reached 30,000 volts, however, it burned through at 20,000 volts after 40 seconds. The primary reason for the decrease in electrical resistance was the helmet's reduced outer shell thickness.

Sample numbers III-2, 4, and 6 passed the Z89 penetration test.

Nine helmets were subjected to tests in accordance with the proposed specification.

The average helmet weight and standard deviation for 15 of the Model III helmets was:

Average = 19.47 ounces
 S.D. = \pm 0.54 ounce

Note that the Trim-lok edging contributed approximately 3.5 ounces to the total.

Water absorption tests on three samples produced the following results:

<u>Sample</u>	<u>% Water Absorbed</u>
III-13	9.0
III-14	11.3
III-15	6.7

Impact attenuation tests were conducted with the results as tabulated below.

<u>Condition</u>	<u>Location</u>	<u>Sample No. III-</u>	<u>Max g</u>	<u>HIC</u>	<u>Structural Failure</u>
Ambient	Apex	7	285	1037	
		8	190	746	
	Forehead	7	170	905	
		8	170	364	
	Left Side	7	140	793	
		8	150	900	
	Right Side	7	140	763	Yes
		8	130	807	
	Rear	7	-	-	
		8	175	906	

3.3.1 Model III Helmet Assembly - Laboratory Tests Performed - (Continued)

<u>Condition</u>	<u>Location</u>	<u>Sample No. III-</u>	<u>Max g</u>	<u>HIC</u>	<u>Structural Failure</u>	
Low Temp.	Apex	9	210	337		
		10	190	712		
	Forehead	9	205	1023	Yes	
		10	190	872	Yes	
	Left Side	9	-	-		
		10	-	-		
	Right Side	9	-	-		
		10	-	-		
	Rear	9	-	-		
		10	-	-		
	High Temp.	Apex	11	135	535	
			12	170	625	
Forehead		11	205	1009		
		12	205	1053	Yes	
Left Side		11	155	825		
		12	-	-		
Right Side		11	155	791	Yes	
		12	-	-		
Rear		11	-	-		
		12	-	-		

It should be noted that although structural failures occurred in the helmet during test, these would not necessarily cause the helmet to fail further tests and would not be cause for rejection. These structural failures were, however, considered potential variables in the evaluation of the prototype. Therefore, once a structural failure was encountered all further testing on that sample was ceased.

Analysis of the impact test data shows two major points. At the apex location the originally proposed maximum acceleration of 80 g was not attained. At all helmet locations a failure level of HIC less than 1000 should be attainable in a production helmet.

Three additional helmets were subjected to the insulation resistance test. Samples numbers III-13 and 15 passed the test with leakage currents of 1 and 0.5 milliamps respectively. Sample number III-14 burned through at 29,000 volts.

3.3.1 Model III Helmet Assembly - Laboratory Tests Performed - (Continued)

The data shows that the insulation resistance performance is attainable.

Sample numbers III-13, 14, and 15 were also subjected to the penetration resistance test. The results were:

<u>Location</u>	<u>Sample No. III</u>	<u>Depth</u>
Apex	13	0.418
	14	0.458
	15	0.607
Aft	13	0.443
	14	0.470
	15	0.516
Fore	13	0.475
	14	0.416
	15	0.570

Here the reduction in outer shell thickness had the greatest effect. It is noted, however, that in none of the above tests did the plumb bob (1 pound) contact the headform. This is considered significant as headform contact is the primary evaluation factor.

The final test performed in accordance with the proposed standard was the chin strap strength and elongation. The results were satisfactory and were as follows:

<u>Sample</u>	<u>Elongation (inches)</u>
III-13	0.70
III-14	0.70
III-15	0.60

3.3.2 Model III Helmet Assembly - Additional Investigation

The primary discrepancies between the performance of the final prototype and the originally proposed criteria were the apex impact and penetration performance.

The penetration requirement called for a 0.375 inch maximum depth of penetration as well as requiring that the penetrator not pierce through the helmet and contract the headform. This latter requirement is considered the one which should be retained in the proposed standard.

The apex impact requirement of 80 g maximum at a 72 inch drop onto a hemispherical anvil. The prototype was not able to attain this level.

3.3.2 Model III Helmet Assembly - Additional Investigation - (Continued)

Three helmets were subjected to lower test levels. The results were:

<u>Sample</u>	<u>Drop Height (inches)</u>	<u>Max g</u>	<u>HIC</u>
16	36	60	141
17	42	60	169
18	48	80	232

It was shown that if the required drop height was to be reduced from 72 to 48 inches the prototype would be able to maintain the 80 g level. It is considered more important, however, for the helmet to withstand high energy impacts. Therefore since the HIC was shown to be less than 1000 at the 72 inch drop height it is proposed that the HIC be maintained as the failure criterion.

4.0 FIELD TRIAL EVALUATION

The laboratory tests of the final prototype, Model III helmets, demonstrated that it offered a higher level of head protection than did any other helmet available and was suitable for high head injury risk industrial environments. What was not known was how well the helmet fit and how comfortable it was to different individuals. A field test was devised, using 20 final prototype helmets, to evaluate these human factors.

The criteria established to evaluate human factors was not intended to yield final quantitative answers. The post-wearing questionnaire used asked subjective questions in order to establish qualitative trends. In appendix A, enclosure 27 is presented a copy of the questionnaire. The participants were questioned as to how they felt about the looks, fit, comfort level, and overall "feel" of the prototype helmet.

Once these criteria were established the participants were selected. A major objective was to locate volunteers who were local to our test facility. This would simplify distribution, collection, and monitoring of the helmets during the test period. Volunteers who would normally have to wear industrial helmets on their job were sought. This would establish a common baseline among all the test participants. By requesting that the participants volunteer for the test, their motivations for wanting to participate in the test program were genuine and similar.

Using the aforementioned guidelines many possible groups were canvassed. After a short time it became clear that within project time constraints it would not be possible to place all of the 20 with one group. Instead, several smaller groups would be selected. The following is a list of the organizations selected along with the number of final prototypes worn:

<u>Organization</u>	<u>Number of Helmets</u>
1) Sound Beach Fire Dept. Rescue Squad	6
2) Strata Well Corporation	4
3) Elaine Construction Corporation	5
4) Alcap Electric Corporation	5

Once these groups were selected, guidelines were described to the participants. All of the helmets were distributed on the same day with instructions on how to properly adjust the headband size so as to obtain a comfortable fit. Each participant was instructed to wear the test helmet for six weeks during their normal work shifts. The helmets were to receive no special treatment but rather they be treated the same

4.0 FIELD TRIAL EVALUATION - (Continued)

way as any other head protective device. It was explained to each volunteer that at the end of the testing period a questionnaire would be distributed with the intent of gathering data about the comfort and fit of the helmet throughout the test.

Each of the volunteers received a copy of instructions and guidelines for conducting the test and at the time of helmet distribution each agreed that they would comply with the guidelines.

Each participant was also made aware that the project staff might make unannounced visits to the wearers' work site to verify that the helmets were being worn. Two groups, Elaine Construction and Alcap Electric, were visited during the test time and each was complying with the test guidelines. All of the helmets were collected at the end of the field test and returned to the laboratory.

At the end of the test the questionnaires were collected. Their responses are summarized below:

Question #1: I have worn protective headgear for:

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	First time	-
2	One year	-
3	One-five years	-
4	One-five years	-
5	Five-ten years	-
6	One-five years	-
7	Ten years or more	-
8	Ten years or more	-
9	Ten years or more	-
10	Ten years or more	-
11	First time	-
12	One-five years	-
13	First time	-
14	One-five years	-
15	Ten years or more	-
16	One-five years	-
17	Ten years or more	-
18	One-five years	-
19	Five-ten years	-
20	Ten years or more	-

4.0 FIELD TRIAL EVALUATION - (Continued)

Question #2: My favorite colors are:

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	Red, green, blue	-
2	Orange, yellow, blue	-
3	Orange, blue	-
4	Yellow	-
5	Yellow	-
6	Red, blue	-
7	Blue	-
8	Green	-
9	Blue	-
10	Blue	-
11	Red, yellow, blue	-
12	Red	-
13	Red	-
14	Yellow	-
15	Orange	-
16	Green, blue	-
17	No response	White
18	No response	White
19	Yellow	-
20	Orange, yellow	-

Question #3: The colors I like least are:

1	Yellow, Violet	-
2	Violet	-
3	Yellow, green	-
4	Orange	-
5	Orange, blue, violet	-
6	Orange, yellow	-
7	Violet	-
8	Violet	-
9	Red, orange, violet	-
10	Red, orange, violet	-
11	Red, orange, violet	-
12	No response	-
13	No response	-
14	Green	-
15	Blue	-
16	Orange, violet	-
17	Violet	-
18	Green	-
19	Orange	-
20	Red, green, blue, violet	-

4.0 FIELD TRIAL EVALUATION - (Continued)

Question #4: Did you like the looks of the helmet?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	Yes	-
2	No	Look like German helmets
3	No	-
4	Yes	-
5	No	Too much history to the design
6	No	Looked like a motorcycle helmet
7	Yes	-
8	No	Too big
9	No	Bigger than average helmet
10	No	Not very attractive
11	No	Too bulky
12	No	-
13	No	-
14	Yes	-
15	No	Looks like a Nazi helmet
16	No	Looks like a World War II German helmet
17	No	-
18	No	-
19	No	-
20	Yes	-

Question #5: Were you embarrassed to wear the helmet?

1	No	-
2	No	Most helmets look wierd
3	No	-
4	No	-
5	No	-
6	Yes	Looked like a motorcycle helmet
7	No	-
8	No	Too bulky, looks like German helmet
9	Yes	Looked like a German war helmet
10	No	-
11	No	-
12	No	-
13	No	-
14	No	-
15	Yes	-
16	Yes	Took much verbal abuse
17	No	-
18	Yes	-
19	Yes	-
20	No	-

4.0 FIELD TRIAL EVALUATION - (Continued)

Question #6: Would you select to wear this helmet instead of some other helmet?

If No, which helmet would you rather wear?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	No	My fire helmet
2	No	My fire helmet
3	Yes	Less cumbersome than other helmets
4	No	Doesn't look protective
5	No	No further response
6	No	No further response
7	No	Too bulky
8	No	A smaller one
9	No	A smaller one without a chin strap
10	No	Standard helmet
11	Yes	-
12	No	No further response
13	No	No further response
14	Yes	-
15	Yes	-
16	No	A more conventional design
17	No	No further response
18	No	A more standard helmet
19	No	No further response
20	No response	-

Question #7: Was the helmet easy to clean?

1	Yes	-
2	N/A	-
3	Yes	-
4	Yes	-
5	Yes	-
6	Yes	-
7	Yes	-
8	Yes	-
9	Yes	-
10	No response	-
11	Yes	-
12	Yes	-
13	Yes	-
14	No response	Never cleaned it
15	Yes	-
16	Yes	-
17	Yes	-
18	N/A	-
19	N/A	-
20	N/A	Not necessary

4.0 FIELD TRIAL EVALUATION - (Continued)

Question #8: Was the helmet easy to disinfect?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	Yes	-
2	N/A	-
3	Yes	-
4	Yes	-
5	Yes	-
6	N/A	-
7	No response	-
8	Yes	-
9	No response	I've never disinfected a helmet
10	No response	-
11	Yes	-
12	Yes	-
13	Yes	-
14	Yes	-
15	Yes	-
16	N/A	-
17	N/A	-
18	N/A	-
19	N/A	-
20	N/A	Not necessary

Question #9: Was the helmet durable?

1	Yes	-
2	Yes	-
3	Yes	-
4	Yes	-
5	No	-
6	Yes	-
7	No	Edging kept coming off
8	Yes	-
9	Yes	-
10	Yes	-
11	Yes	-
12	No	-
13	No	-
14	No	-
15	Yes	-
16	No	Edging kept coming off
17	Yes	-
18	No	Edging kept coming off
19	No	-
20	Yes	-

4.0 FIELD TRAIL EVALUATION - (Continued)

Question #10: Did any part of the helmet break after repeated use?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	No	-
2	No	-
3	No	-
4	No	-
5	No	-
6	No	-
7	Yes	Edging
8	No	-
9	No	-
10	Yes	Edging
11	No	-
12	Yes	Edging
13	Yes	Edging
14	Yes	Edging
15	Yes	-
16	No	-
17	Yes	Edging
18	No	-
19	Yes	-
20	Yes	Edging

Question #11: Was the helmet comfortable to wear?

1	No	Chin strap was uncomfortable
2	No	Head pins dig into head
3	No	Tight around temples
4	Yes	-
5	No	Chin strap uncomfortable
6	No	Tight around the ears
7	No response	-
8	No	-
9	Yes	-
10	Yes	-
11	No	-
12	No	-
13	No	-
14	Yes	-
15	Yes	-
16	Yes	-
17	Yes	-
18	Yes	Stays on head, light in weight
19	Yes	-
20	Yes	-

4.0 FIELD TRAIL EVALUATION - (Continued)

Question #12: How many hours per day on an average did you wear the helmet?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	One hour or less	-
2	One hour or less	-
3	One hour or less	-
4	One hour or less	-
5	One hour or less	-
6	One hour or less	-
7	Five to eight hours	-
8	More than eight hours	-
9	Five to eight hours	-
10	Five to eight hours	-
11	One hour or less	-
12	Two to four hours	-
13	Two to four hours	-
14	Five to eight hours	-
15	One hour or less	-
16	Two to four hours	-
17	Two to four hours	-
18	Five to eight hours	-
19	Two to four hours	-
20	Five to eight hours	-

Question #13: The helmet was _____ to wear.

1	Cool	-
2	Cool	-
3	Cool	-
4	Warm	Chin strap very uncomfortable
5	Cool	-
6	Cool	-
7	Warm	-
8	Hot	-
9	Warm	No warmer than any other helmet
10	Cool	-
11	Hot	Band was hot on forehead
12	Warm	-
13	Warm	-
14	Warm	-
15	Hot	-
16	Cool	-
17	Cool	-
18	Cool	-
19	Cool	-
20	Cool	-

4.0 FIELD TRAIL EVALUATION - (Continued)

Question #14: The helmet was _____ to wear.

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	Light	-
2	Light	-
3	Light	-
4	Light	-
5	Light	-
6	Light	-
7	Light	-
8	Heavy	-
9	Light	-
10	Light	-
11	Light	-
12	Heavy	-
13	Heavy	-
14	Light	-
15	Light	-
16	Light	-
17	Light	-
18	Light	-
19	Light	-
20	Light	-

Question #15: How would you compare the weight of this helmet with other helmets you have worn?

1	Lighter than others	-
2	Lighter than others	-
3	Lighter than others	-
4	Lighter than others	-
5	Heavier than others	-
6	Lighter than others	-
7	Lighter than others	-
8	Heavier than others	-
9	Heavier than others	-
10	Same as others	-
11	Heavier than others	-
12	Heavier than others	-
13	Heavier than others	-
14	Same as others	-
15	Lighter than others	-
16	Same as others	-
17	Lighter than others	-
18	Same as others	-
19	Same as others	-
20	Lighter than others	-

4.0 FIELD TRAIL EVALUATION - (Continued)

Question #16: Did the helmet interfere with your vision?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	No	-
2	No	-
3	Yes	Helmet hit my glasses
4	No	-
5	No	-
6	No	-
7	No	-
8	No	-
9	No	-
10	No	-
11	No	-
12	Yes	-
13	No	-
14	No	-
15	No	-
16	Yes	Upward vision is affected
17	No	-
18	No	-
19	No	-
20	No	-

Question #17: Did the helmet interfere with your hearing?

1	No	-
2	No	-
3	No	-
4	No	-
5	No	-
6	No	-
7	Yes	Did not fit right
8	No	-
9	No	-
10	No	-
11	No	-
12	No	-
13	No	-
14	No	-
15	No	-
16	No	-
17	No	-
18	No	-
19	No	-
20	No	-

4.0 FIELD TRAIL EVALUATION - (Continued)

Question #18: Did the helmet interfere with your movements?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	No	-
2	Yes	Couldn't speak with chin strap on
3	Yes	A little cumbersome
4	No	-
5	Yes	Talking
6	No	-
7	Yes	A little bulky
8	No	-
9	No	-
10	No	-
11	Yes	Not designed for framing
12	Yes	-
13	No	-
14	No	-
15	No	-
16	Yes	-
17	No	-
18	No	-
19	No	-
20	No	-

Question #19: Did the helmet fit well?

1	Yes	-
2	Yes	Except for head pins and chin straps
3	No	-
4	Yes	-
5	Yes	-
6	No	Couldn't get a comfortable adjustment
7	No	Back strap needs to be made more rigid
8	Yes	Don't like the chin strap
9	Yes	Don't like chin strap
10	Yes	-
11	Yes	-
12	Yes	-
13	Yes	-
14	Yes	-
15	No	-
16	Yes	-
17	Yes	-
18	Yes	-
19	Yes	-
20	No	Suspension kept coming off

4.0 FIELD TRAIL EVALUATION - (Continued)

Question #20: Did the helmet protect you from an impact with a blunt object?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	My helmet did not receive such an impact	-
2	" " " " " " " " "	-
3	" " " " " " " " "	-
4	" " " " " " " " "	-
5	" " " " " " " " "	-
6	" " " " " " " " "	-
7	" " " " " " " " "	-
8	" " " " " " " " "	-
9	" " " " " " " " "	-
10	" " " " " " " " "	-
11	" " " " " " " " "	-
12	" " " " " " " " "	-
13	" " " " " " " " "	-
14	" " " " " " " " "	-
15*	Yes	-
16	My helmet did not receive such an impact	-
17	" " " " " " " " "	-
18	" " " " " " " " "	-
19	" " " " " " " " "	-
20	" " " " " " " " "	-

*Details of impact are on page 60.

Question #20A: Did you sustain any injury?

1	N/A	-
2	N/A	-
3	No	-
4	No	-
5	No	-
6	N/A	-
7	No	-
8	No	-
9	No	-
10	No	-
11	N/A	-
12	No	-
13	No	-
14	No	-
15	No	-
16	No	-
17	No	-
18	N/A	-
19	N/A	-
20	No	-

4.0 FIELD TRAIL EVALUATION - (Continued)

Question #20B: Was the helmet damaged in anyway?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	No	-
2	No	-
3	No	-
4	No	-
5	No	-
6	N/A	-
7	No	-
8	No	-
9	No	-
10	No	-
11	N/A	-
12	No	-
13	No	-
14	No	-
15	Yes	-
16	No	-
17	No	-
18	N/A	-
19	N/A	-
20	No	-

Question #21: Did the helmet protect you from an impact with a sharp object?

1	My helmet did not receive such an impact	-
2	" " " " " " " " " "	-
3	Yes	Protected me from broken glass in a car windshield
4	My helmet did not receive such an impact	-
5	" " " " " " " " " "	-
6	" " " " " " " " " "	-
7	" " " " " " " " " "	-
8	" " " " " " " " " "	-
9	" " " " " " " " " "	-
10	" " " " " " " " " "	-
11	" " " " " " " " " "	-
12	" " " " " " " " " "	-
13	" " " " " " " " " "	-
14	" " " " " " " " " "	-
15	" " " " " " " " " "	-
16	Yes	-
17	My helmet did not receive such an impact	-
18	" " " " " " " " " "	-
19	" " " " " " " " " "	-
20	" " " " " " " " " "	-

4.0 FIELD TRAIL EVALUATION - (Continued)

Question #21A: Did you sustain any injury?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	N/A	-
2	N/A	-
3	No	-
4	No	-
5	No	-
6	N/A	-
7	No	-
8	No	-
9	No	-
10	N/A	-
11	N/A	-
12	No	-
13	No	-
14	No	-
15	No	-
16	No	-
17	No	-
18	N/A	-
19	N/A	-
20	No	-

Question #21B: Was the helmet damaged in any way?

1	No	-
2	No	-
3	No	-
4	No	-
5	No	-
6	N/A	-
7	No	-
8	No	-
9	No	-
10	No	-
11	N/A	-
12	No	-
13	No	-
14	No	-
15	No	-
16	No	-
17	No	-
18	N/A	-
19	N/A	-
20	No	-

4.0 FIELD TRAIL EVALUATION - (Continued)

Question #22: Did the helmet protect you from an electrical shock?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	My helmet did not receive one	-
2	" " " " " "	-
3	" " " " " "	-
4	" " " " " "	-
5	" " " " " "	-
6	" " " " " "	-
7	" " " " " "	-
8	" " " " " "	-
9	" " " " " "	-
10	" " " " " "	-
11	" " " " " "	-
12	" " " " " "	-
13	" " " " " "	-
14	" " " " " "	-
15	" " " " " "	-
16	" " " " " "	-
17	" " " " " "	-
18	" " " " " "	-
19	" " " " " "	-
20	" " " " " "	-

Question #22A: Did you sustain any injury

1	No	-
2	N/A	-
3	No	-
4	No	-
5	No	-
6	N/A	-
7	No	-
8	No	-
9	No	-
10	N/A	-
11	N/A	-
12	No	-
13	No	-
14	No	-
15	No	-
16	No	-
17	No	-
18	N/A	-
19	N/A	-
20	No	-

4.0 FIELD TRIAL EVALUATION - (Continued)

Question #22B: Was the helmet damaged in any way?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	No	-
2	No	-
3	No	-
4	No	-
5	No	-
6	N/A	-
7	No	-
8	No	-
9	No	-
10	No	-
11	N/A	-
12	No	-
13	No	-
14	No	-
15	No	-
16	No	-
17	No	-
18	N/A	-
19	N/A	-
20	No	-

Question #23: Based on the helmet's overall performance did you feel safe while wearing the helmet?

1	No	-
2	Yes	It felt snug
3	Yes	-
4	Yes	-
5	No	Not enough protection
6	Yes	-
7	Yes	-
8	Yes	-
9	Yes	-
10	Yes	Very
11	Yes	-
12	Yes	-
13	Yes	-
14	Yes	-
15	Yes	-
16	Yes	-
17	No response	-
18	Yes	-
19	Yes	-
20	Yes	-

4.0 FIELD TRIAL EVALUATION - (Continued)

Question #24: The things I like most about this helmet are:

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	Was light, comfortable to wear	-
2	Color, weight	-
3	It was cool, light, color	-
4	No response	-
5	No response	-
6	No response	-
7	Light weight	-
8	None	-
9	No response	-
10	Look and color	-
11	No response	-
12	No response	-
13	No response	-
14	No response	-
15	Ear protection, construction	-
16	Snug fit, stays on head solid	-
17	No response	-
18	No preference	-
19	No response	-
20	No response	-

Question #25: The things I liked least about this helmet are:

1	Inside was small, chin strap uncomfortable	-
2	Chin strap	-
3	Uncomfortable	-
4	Chin strap	-
5	Design, chin strap	-
6	Fit was uncomfortable	-
7	Back strap	-
8	Chin strap and color	-
9	Shape, color, chin strap	-
10	Looks and color	-
11	No response	-
12	No response	-
13	No response	-
14	No response	-
15	Way it sat on head	-
16	Odd shape	-
17	No response	-
18	Its overall size, too bulky	-
19	Style and color	-
20	No response	-

4.0 FIELD TRIAL EVALUATION - (Continued)

Question #26: I felt the overall size of the helmet was _____ other helmets:

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	Smaller than	-
2	Larger than	-
3	Smaller than	-
4	Comparable to	-
5	Larger than	-
6	Smaller than	-
7	Larger than	-
8	Larger than	-
9	Larger than	-
10	Larger than	-
11	Larger than	-
12	Larger than	-
13	Larger than	-
14	Larger than	-
15	Larger than	-
16	Larger than	-
17	Larger than	-
18	Larger than	-
19	Larger than	-
20	Larger than	-

Question #27: Did you become fatigued while wearing the helmet?

1	N/A	-
2	No	-
3	No	-
4	No	-
5	No	-
6	No	-
7	No	-
8	No	-
9	No	-
10	No	-
11	Yes	-
12	Yes	-
13	Yes	-
14	No	-
15	No	-
16	Yes	-
17	No	-
18	No	-
19	No	-
20	No response	-

4.0 FIELD TRIAL EVALUATION - (Continued)

Question #28: Did you develop headaches while wearing the helmet?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	No	-
2	Yes	From pins
3	No	-
4	No	-
5	No	-
6	No	-
7	No	-
8	No	-
9	No	-
10	No	-
11	No	-
12	No	-
13	No	-
14	No	-
15	No	-
16	No	-
17	No	-
18	No	-
19	No	-
20	No	-

Question #29: Did the helmet feel balanced on the head?

1	Yes	-
2	Yes	-
3	Yes	-
4	Yes	-
5	No	-
6	Yes	-
7	No	Backstrap need to be more rigid
8	Yes	-
9	Yes	-
10	No	A bit wobbly
11	Yes	-
12	No	-
13	No	-
14	Yes	-
15	Yes	-
16	Yes	-
17	Yes	-
18	Yes	-
19	Yes	-
20	Yes	-

4.0 FIELD TRIAL EVALUATION - (Continued)

Question #30: Did the helmet affect your sense of balance?

<u>Helmet Number</u>	<u>Individuals' Responses</u>	<u>Comments</u>
1	No	-
2	No	-
3	No	-
4	No	-
5	No	-
6	No	-
7	No	-
8	No	-
9	No	-
10	Yes	-
11	No	-
12	No	-
13	No	-
14	No	-
15	No	-
16	No	-
17	No	-
18	No	-
19	No	-
20	No	-

4.0 FIELD TRIAL EVALUATION - (Continued)

From the comments received, it can be concluded that most of the participants questioned were pleased with the comfort and fit of the prototype helmet. This is not to say that the helmet was unanimously accepted without flaw. There were constructive criticisms made that warrant additional investigation. Some of the participants felt that the inside shell cavity within which the suspension was attached was too small. Others felt that the chin strap was uncomfortable and actually limited their ability to speak. Some felt that the metal posts on the inner shell served as an irritant. Others recommended that the edging around the helmet be redesigned or eliminated. It kept coming off the helmet.

What can be inferred from these comments is that with some further refinements in the helmets design, a more acceptable helmet design can be achieved.

In addition to information gained from the field test questionnaires, an on the job accident affecting one of the participants demonstrated that the helmet actually does protect from a serious impact.

During the field test one volunteer (test helmet number 15) was severely struck on the left side of his helmet while performing his normal work routine. The volunteer was a carpenter working on the ground level at a residential dwelling construction site. A 12 foot wooden beam, 2 inches by 8 inches, was upset and slid from a level approximately 10 feet above the carpenter. It struck his head on the left side. The impact caused damage to the helmet. Appendix A, enclosure 31 shows the damage done to the helmet. The volunteer, however, suffered no injury and required no medical assistance. Furthermore, he was able to continue to work immediately after the impact occurred.

The volunteer would have sustained a good deal of injury if he had been wearing a currently available industrial helmet. The impact was a side impact, and this is where the prototype helmet offers improvement over present industrial helmets used in the United States.

Even though this one occurrence is not conclusive evidence of the merits of this prototype helmet, it is a strong indication of the level of performance that may be obtained with this design. This occurrence also serves to correlate actual, in-use, performance with laboratory data.

5.0 TEST EQUIPMENT

As part of this program, helmet test equipment was prepared for and delivered to NIOSH. The following discussion serves to amplify the procedures and methods presented in the Testing Standard of appendix B.

5.1 Impact Test Equipment

- 5.1.1 Description and Installation. Impulse loads are imparted to the test helmet by means of a drop test machine consisting of a headform and drop assembly utilizing frictionless linear bearings guided by a vertical roundway. See appendix A, enclosure 28.

Installation of the monorail impact test assembly is relatively straightforward; however, there are a few points which must be given strict attention in order to realize the full potential of the system.

First, a suitable massive (2 400 pounds) base must be prepared upon which the monorail and impact anvils are installed. Once installed the monorail must be aligned to within a maximum deviation of 0.5 degree from true vertical.

Next, the drop assembly should be installed on the monorail. Care should be taken in the final adjustment of the two set screws associated with each linear bearing cartridge. The larger of the two is intended to provide crimping force about the roundway. It must be noted that overtightening either of these screws will result in excessive bearing-to-roundway friction and loss of system energy at impact.

The final point which should be observed during installation of the drop assembly is adjustment of the outrigger bearings. Initial alignment should center the drop assembly on the monorail (i.e., in a plane normal to the plane of the monorail mounting plate). While maintaining the position of the drop assembly, adjust one of the outrigger bearings for a clearance of 0.003 inch. The other bearing should be in a firm contact with the monorail mounting plate.

The headform and accelerometer may now be installed and test drops performed to confirm proper operation of the system. It is necessary that a velocity measurement be used as the initial indicator of system performance.

- 5.1.2 Impact Equipment. To perform a test, the position of the pneumatic release cylinder is adjusted to achieve the desired drop height. The drop assembly is then raised until its detent tab can be engaged by the cylinder shaft. The drop assembly is released by operating the pneumatic selector valve, causing the cylinder shaft to retract.

Operation, calibration, and servicing information for the instrumentation system (accelerometer, shock amplifier and pulse amplifier) is provided by manufacturers of these devices.

5.2 Penetration Test Equipment

- 5.2.1 Description of Installation. The penetration test apparatus consists of a vertical 'free-fall' guide tube, an electrically conductive headform with a suitably massive base palte, a hardened steel penetration striker, a hoisting mechanism, and a control console. See appendix A enclosure 29.

The installation procedure involves providing adequate structural supports for the guide tube. Care should be taken during final alignment to ensure that the guide tube is vertical to within 0.5 degree (maximum deviation).

- 5.2.2 Penetration Equipment Operation. The system is utilized as follows. The appropriate weight penetration striker is affixed to the hoisting mechanism by energizing the electromagnet. The striker is then hoisted a short distance into the guide tube. The helmet to be tested is placed on the conducting headform and positioned so as to locate the desired impact site directly beneath the open end of the guide tube. The striker should be in physical contact with the helmet when the counter is zeroed. The helmet surface thus becomes the zero reference point for drop height measurement. With the test helmet in position, the striker is raised to the desired drop height (as indicated by the digital counter, measuring in tenths of an inch, located on the guide tube table). The continuity of the circuit should now be checked. Once functional readiness has been verified, the penetration striker is released from a signal in the control console. Contact between the striker and headform (i.e., a failure) will be indicated by a light on the control console and an audible alarm.

It is suggested that frequent checks of the drop height measuring system be made to ensure its continued accuracy. In addition it is recommended that the hoisting mechanism be operated at relatively moderate rates to prevent possible slippage between the hoisting cable and counter drive shaft which would result in erroneous drop height measurements.

5.3 Retention Test Equipment

- 5.3.1 Description of Installation. The retention test equipment is designed for use in conjunction with an Instron tensile test machine. The headform and its support structure are attached to the moveable crosshead of the testing machine. The chin block assembly is suspended from the test machine load cell by a rod which passes through the crosshead. As the crosshead is moved downward, load is applied to the helmet retention system. See appendix A, enclosure 30.

- 5.3.2 Retention Equipment Operation. The helmet to be tested is placed on the headform and the chin strap is threaded through the chin block rollers. The load is applied, as previously mentioned, by lowering the test machine crosshead and is recorded on the testing machine's strip chart.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The basic conclusion of this study is that a maximum duty industrial helmet is feasible. A recommended standard governing such a device is presented as appendix B of this report.

The essence of the originally proposed standards [4] have been retained, however, many of the performance levels have been adjusted as a result of this study to ensure that they are attainable.

Specifically, the apex impact failure criterion was reduced from 30 g to an HIC of less than or equal to 1000 while the impact velocity remained the same. The penetration failure criterion of a post-test reinsertion depth of 0.375 inch has been omitted while the no headform contact criterion has been retained. All other parameters including the recommended maximum allowable weight of 18 ounces have been retained.

Subtle changes have been incorporated into the testing standard to bring this document in line with current practice.

Some important conclusions and recommendation of this study are:

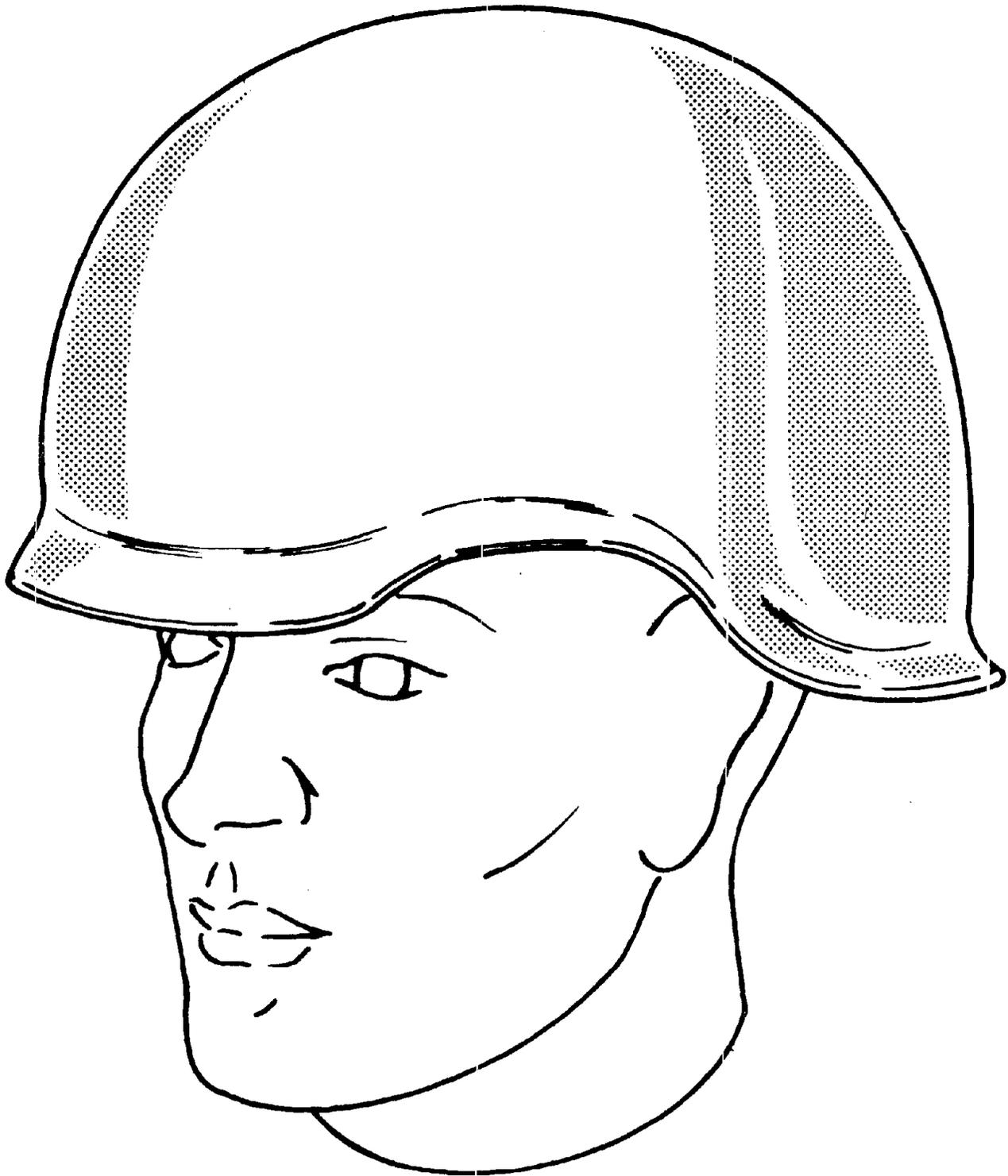
- (1) It is concluded that a helmet may be produced within available technology which will greatly reduce the chance of a serious head injury in industrial accidents.
- (2) The primary difficulty in introducing a maximum duty helmet into the workplace will be worker apathy, not cost or technical considerations.
- (3) It is recommended that similar prototype developmental programs be conducted to prove the viability of the medium duty and light duty helmet.
- (4) The damage done to the field trial helmet which withstood an impact on the wearer's head should be replicated in the laboratory to assess the prototype's performance in human terms.
- (5) Further field testing of the prototype maximum duty helmet, with modifications, should be conducted to quantitatively assess worker acceptance.
- (6) In accordance with our contract a sampling technique for quality assurance inspections of the proposed class of helmet was to have been established. During the conduct of this effort, however, insufficient data were generated to draw statistical conclusions. It is anticipated that NIOSH will conduct sufficient tests to develop such a sampling plan. It is recommended that initial helmet qualification tests be performed in accordance with the test matrix of appendix B, section 2.4 indicating seven tests and four helmet conditions. It is further recommended that, in order to reduce test complexity, only the ambient and water immersed helmets be tested for production sampling.

7.0 REFERENCES

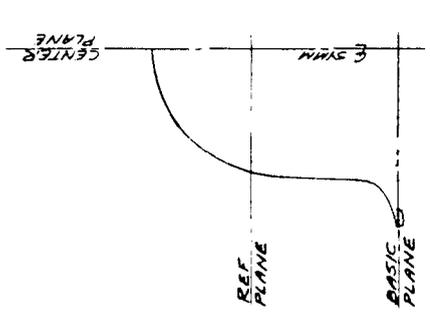
1. Dayton T. Brown, Inc., "Phase I in the Development of Criteria for Industrial and Firefighters Head Protective Devices", HEW Publication Number (NIOSH) 75-125, U.S. Department of Health, Education, and Welfare, National Institute for Occupational Safety and Health
2. Rapid Action Change Number 4, Manual, Aviation - Crew Systems, Aircrew Personal Protective Equipment, Naval Air Systems Command, NAVAIR 13-1-6.7, 5 June 1975
3. "Safety Requirements for Industrial Protection Helmets for Electrical Workers, Class B", American National Standards Institute, Z89.2-1971
4. Development of Standards for Industrial and Firefighters' Head Protective Devices", Dayton T. Brown, Inc., Report DTB06R73-1273, 13 August 1973

APPENDIX A

Enclosures

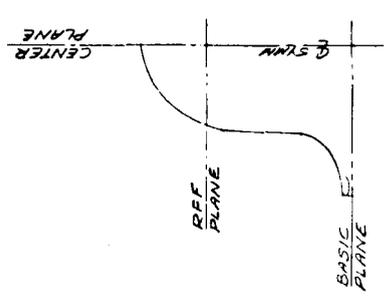


APPENDIX A, ENCLOSURE 1
ARTISTS CONCEPTION OF INITIAL PROTOTYPE HELMET

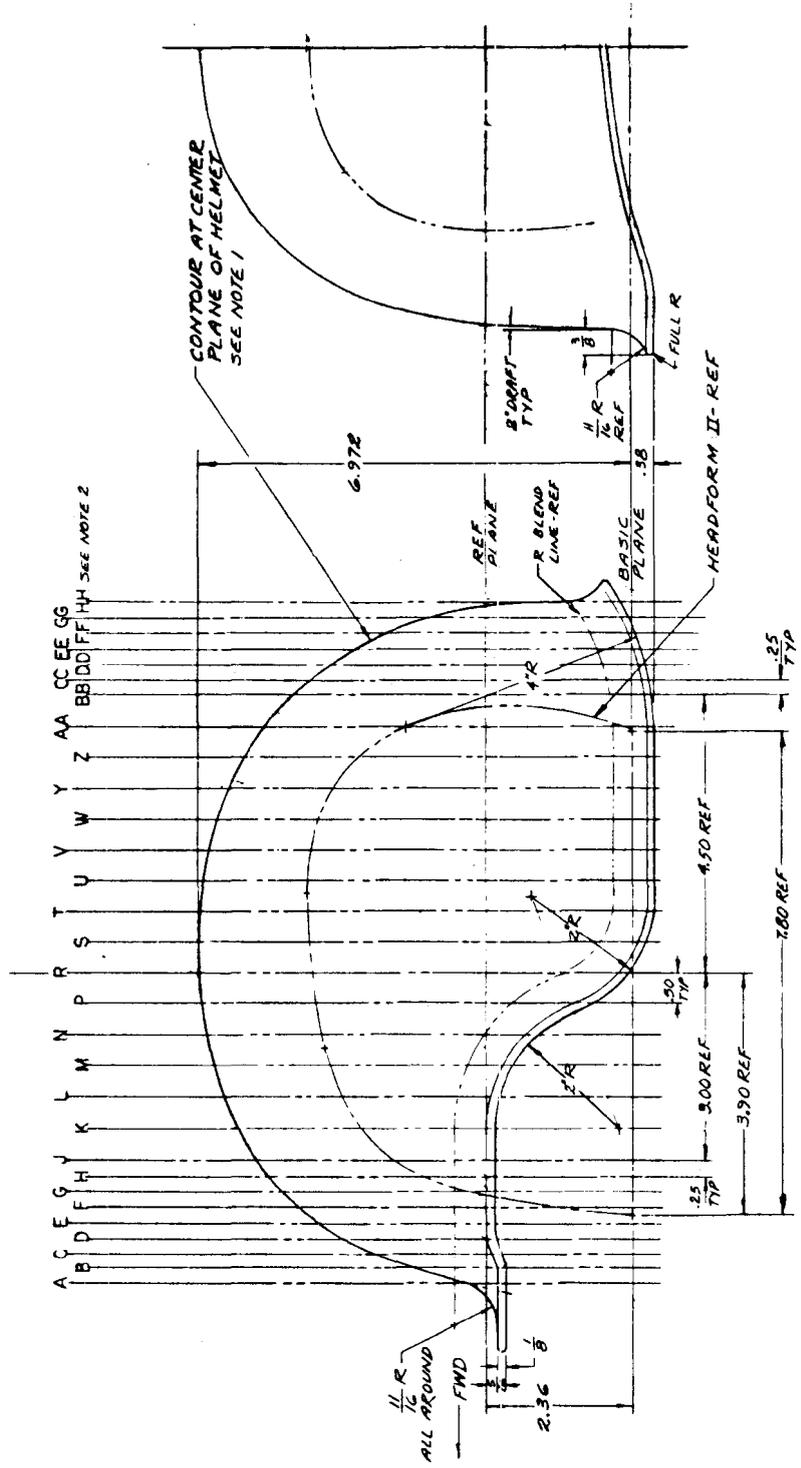


CONTOUR AT FF

VIEW A
SEE 3/12

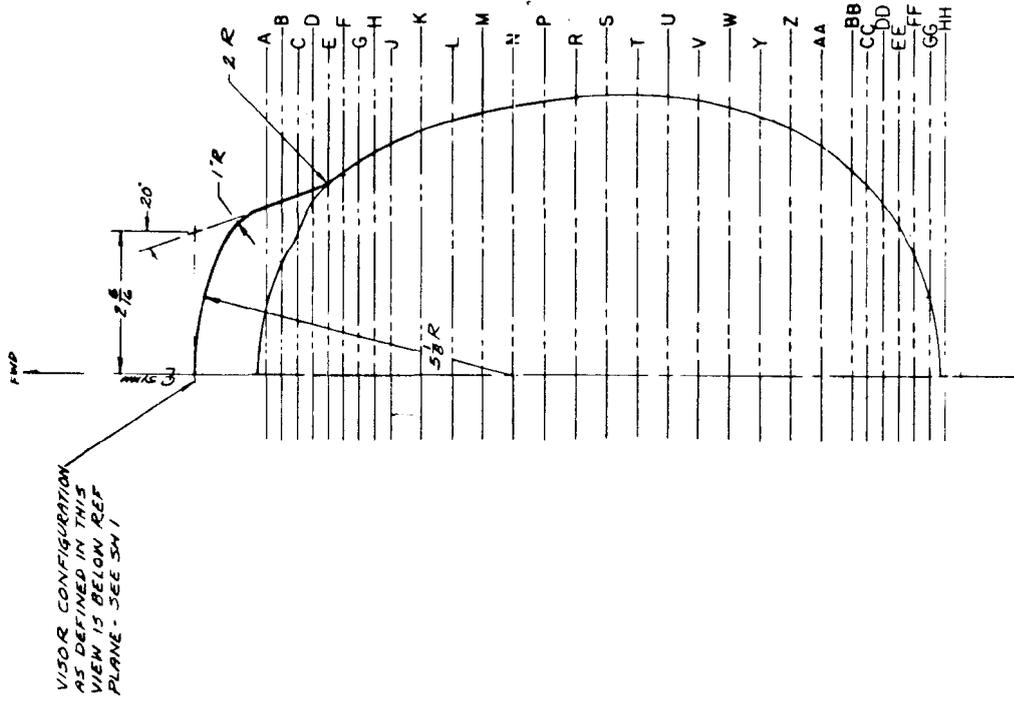


CONTOUR AT GG

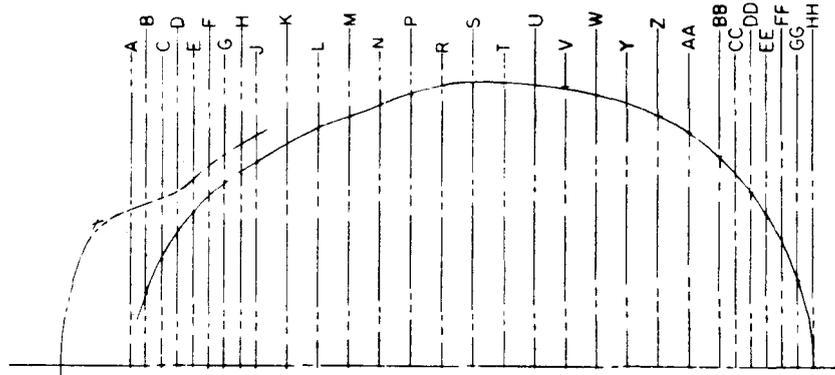


- NOTE:
1. CENTER PLANE IS MIDSAGITTAL PLANE
 2. CONTOUR HH NOT DEPICTED
 3. MATL: POLY CARBONATE (GF LEXAN 161 OR MOBAY M 50)
 4. BASIC WALL THK: .030 ± .003

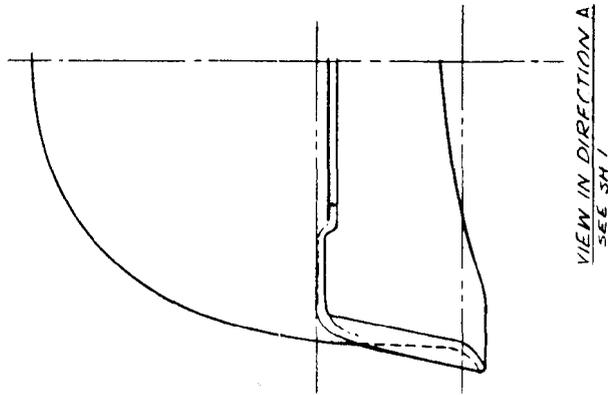
APPENDIX A, ENCLOSURE 2, PAGE 1 OF 2
PATTERN DRAWINGS FOR PROTOTYPE OUTER SHELL



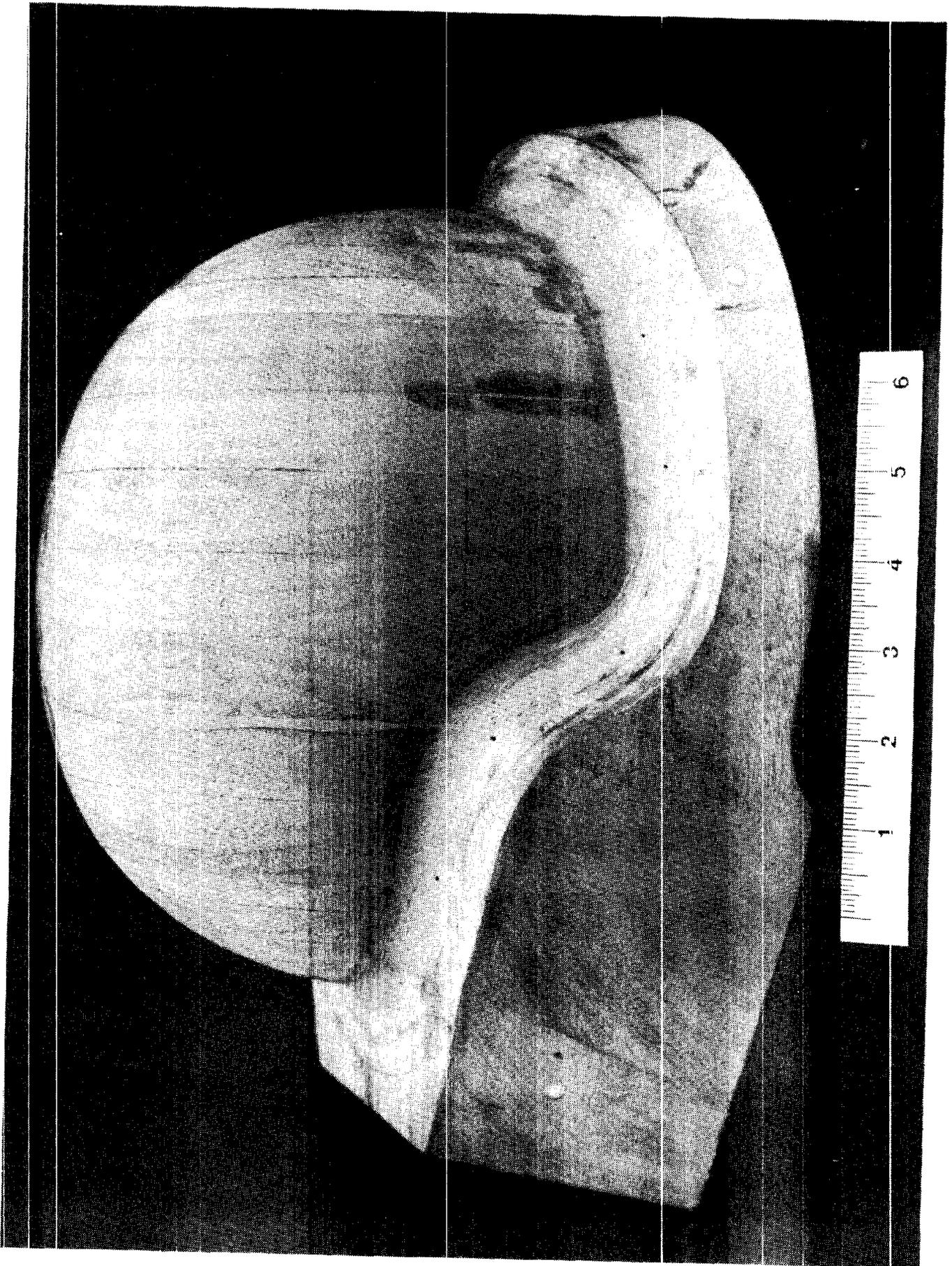
CONTOUR AT REF PLANE
SEE SH 1



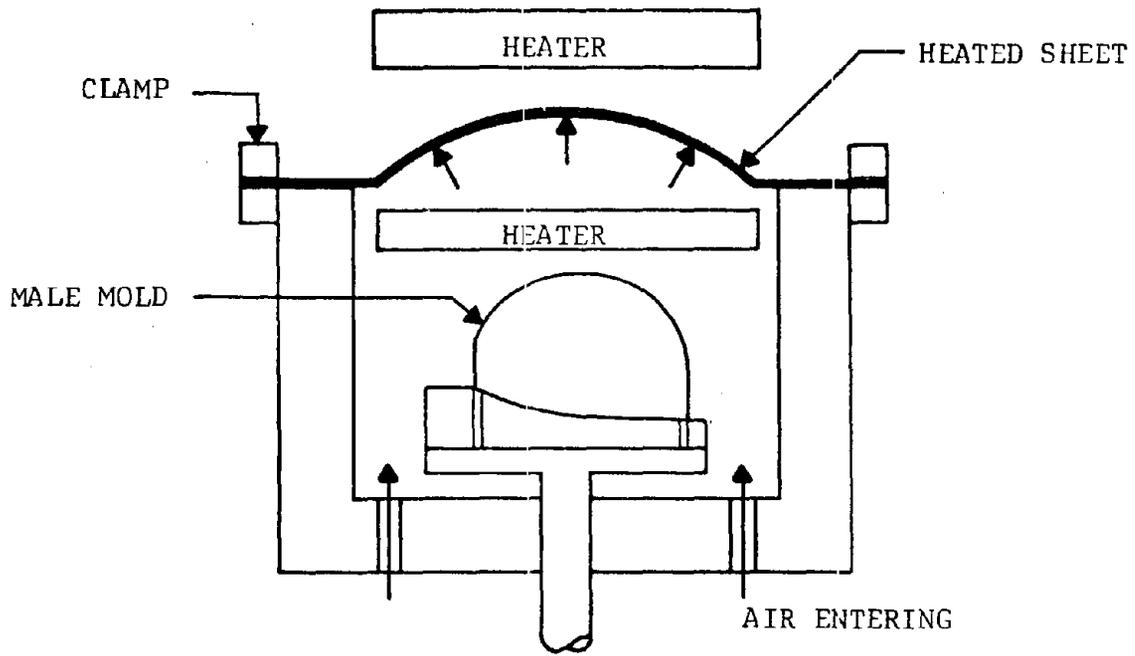
CONTOUR AT RADIUS BLEND LINE
SEE SH 1



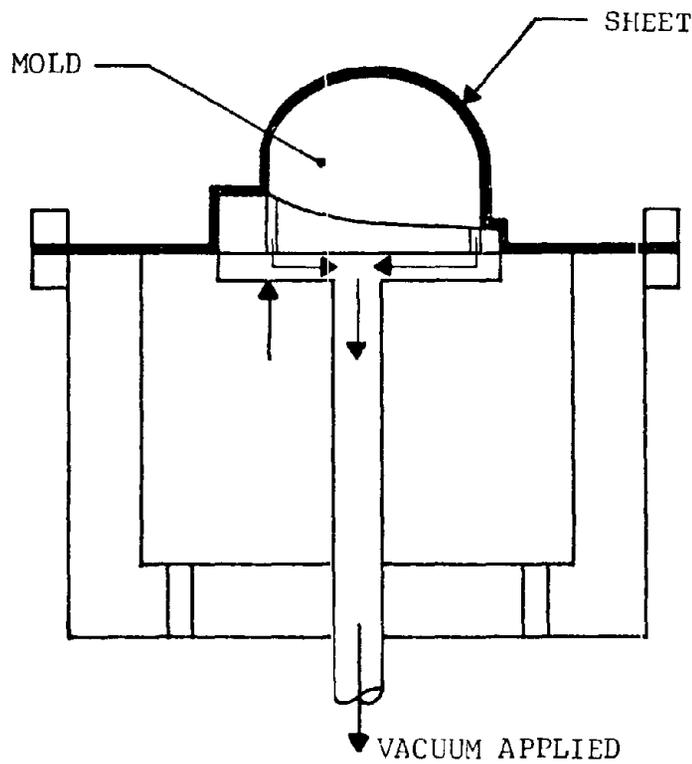
APPENDIX A, ENCLOSURE 2, PAGE 2 OF 2
PATTERN DRAWINGS FOR PROTOTYPE OUTER SHELL



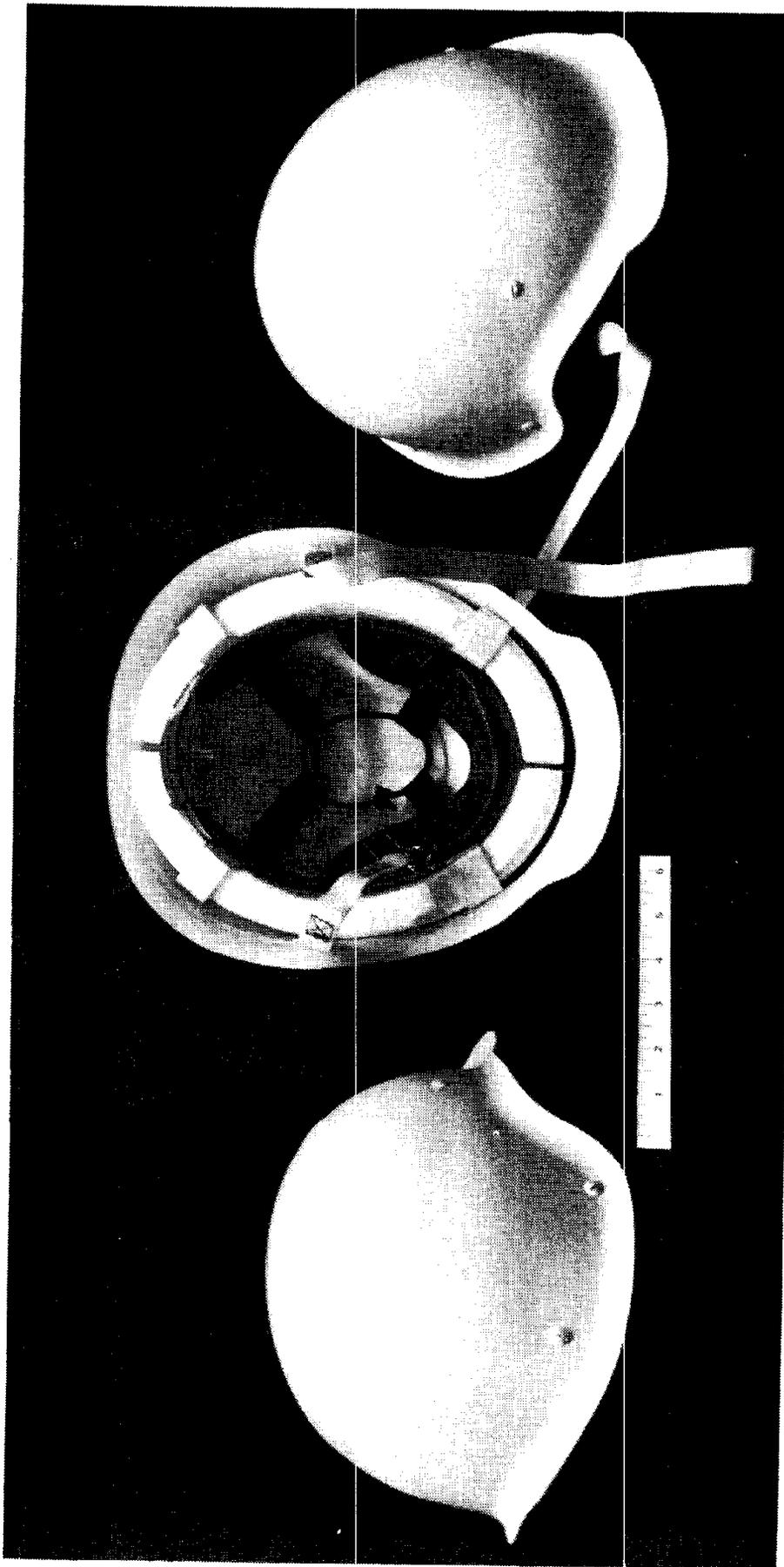
APPENDIX A, ENCLOSURE 3
WOODEN CASTING PATTERN FOR INITIAL PROTOTYPE OUTER SHELL



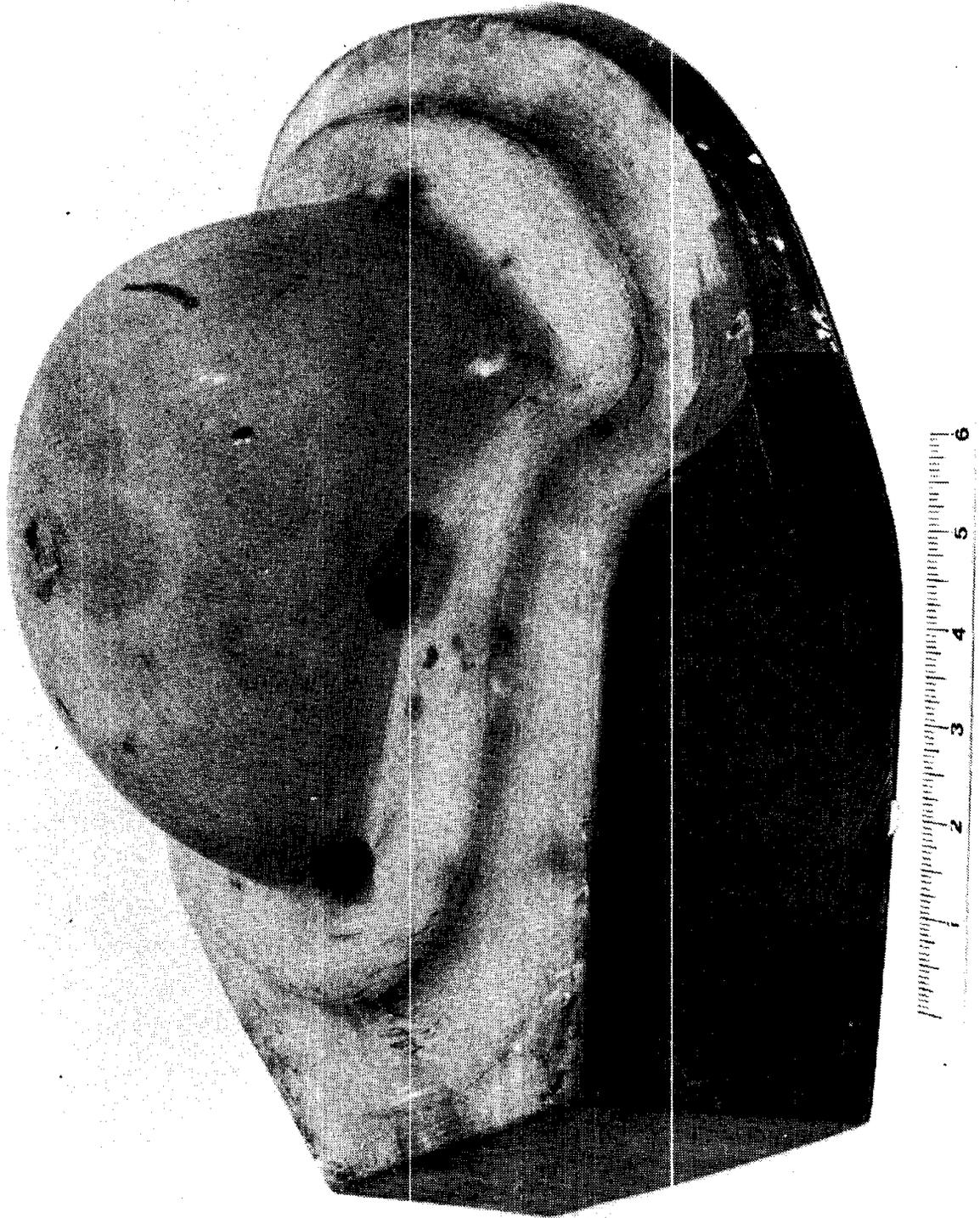
POSITIVE PRESSURE APPLIED UNDER
HEATED SHEET FOR PRE-STRETCHING



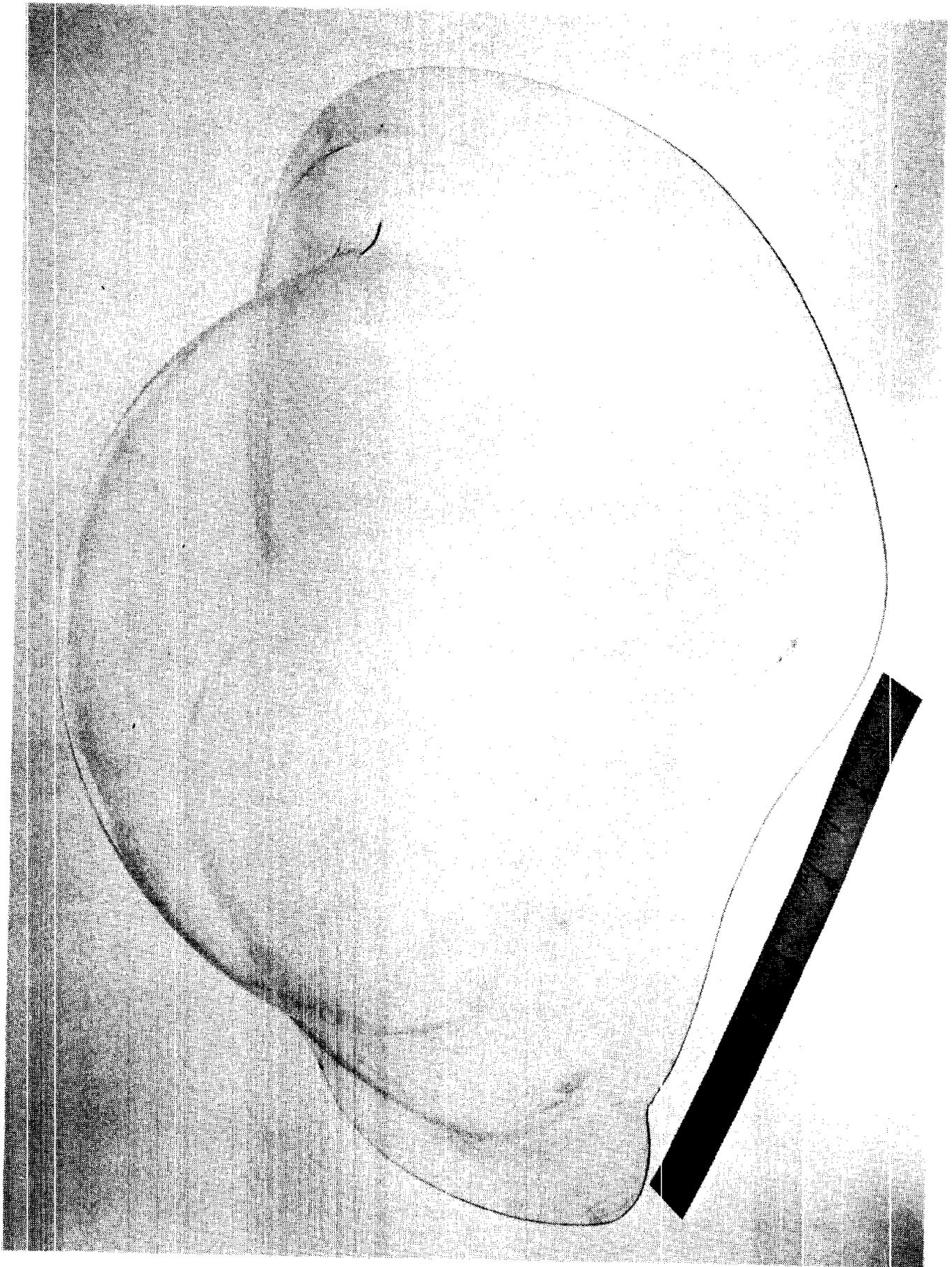
HEATER REMOVED, MOLD RAISED
AND VACUUM APPLIED



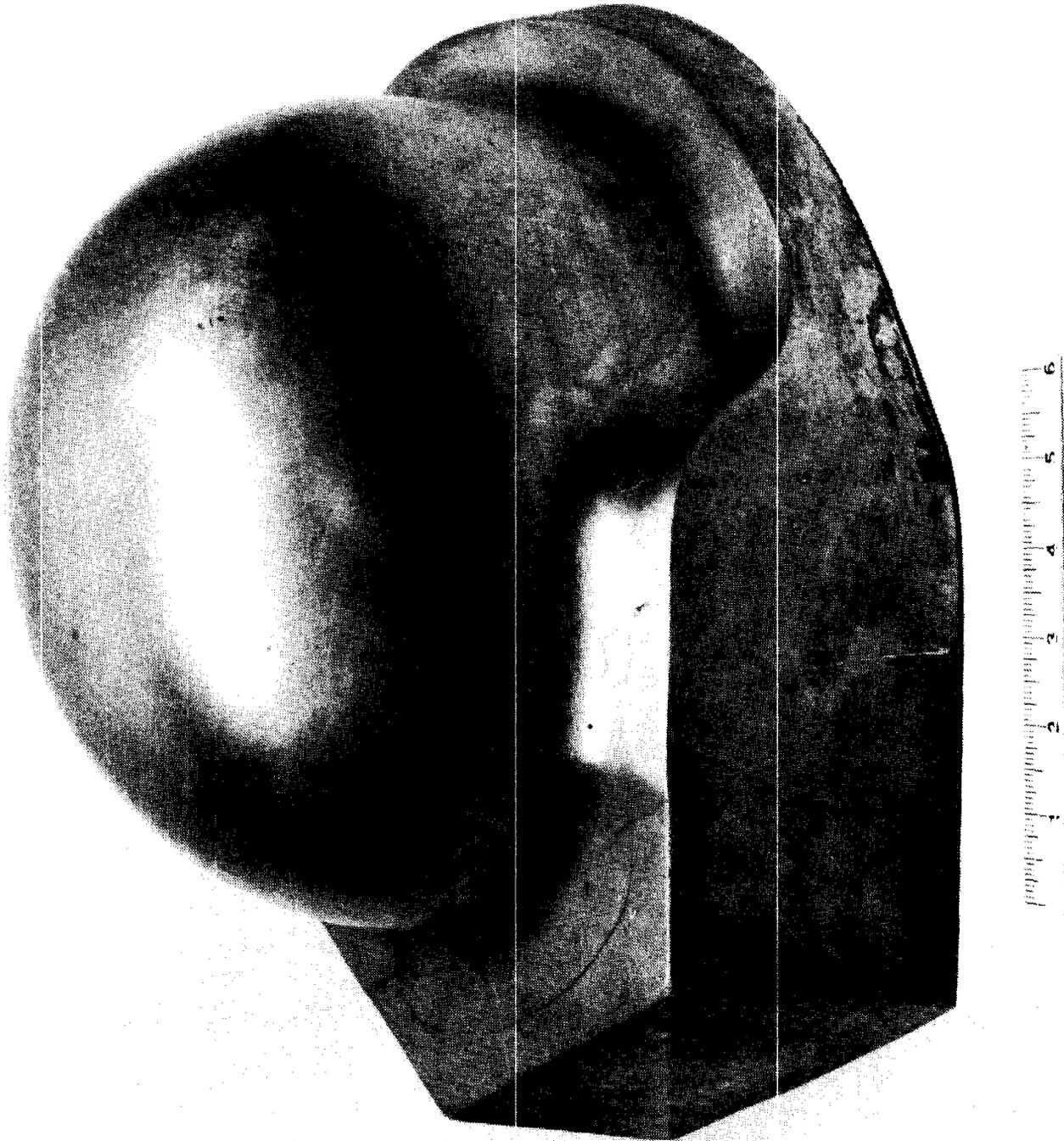
APPENDIX A, ENCLOSURE 5
VISUAL EXAMINATION PROTOTYPE HELMETS



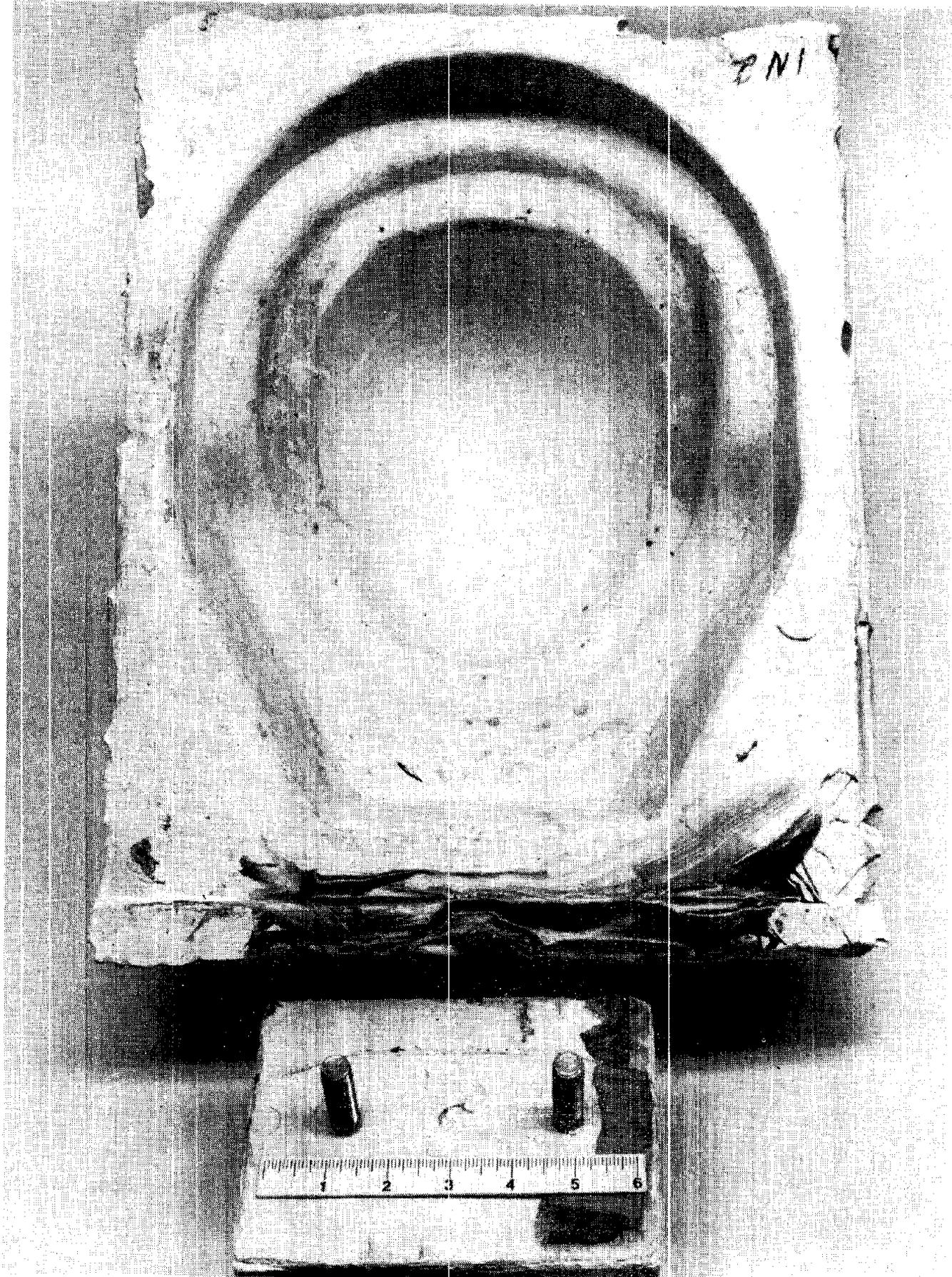
APPENDIX A, ENCLOSURE 6
CARBOLON THERMOFORMING MOLD FOR INITIAL INNER SHELL



APPENDIX A, ENCLOSURE 7
THERMOFORMED INITIAL INNER SHELL



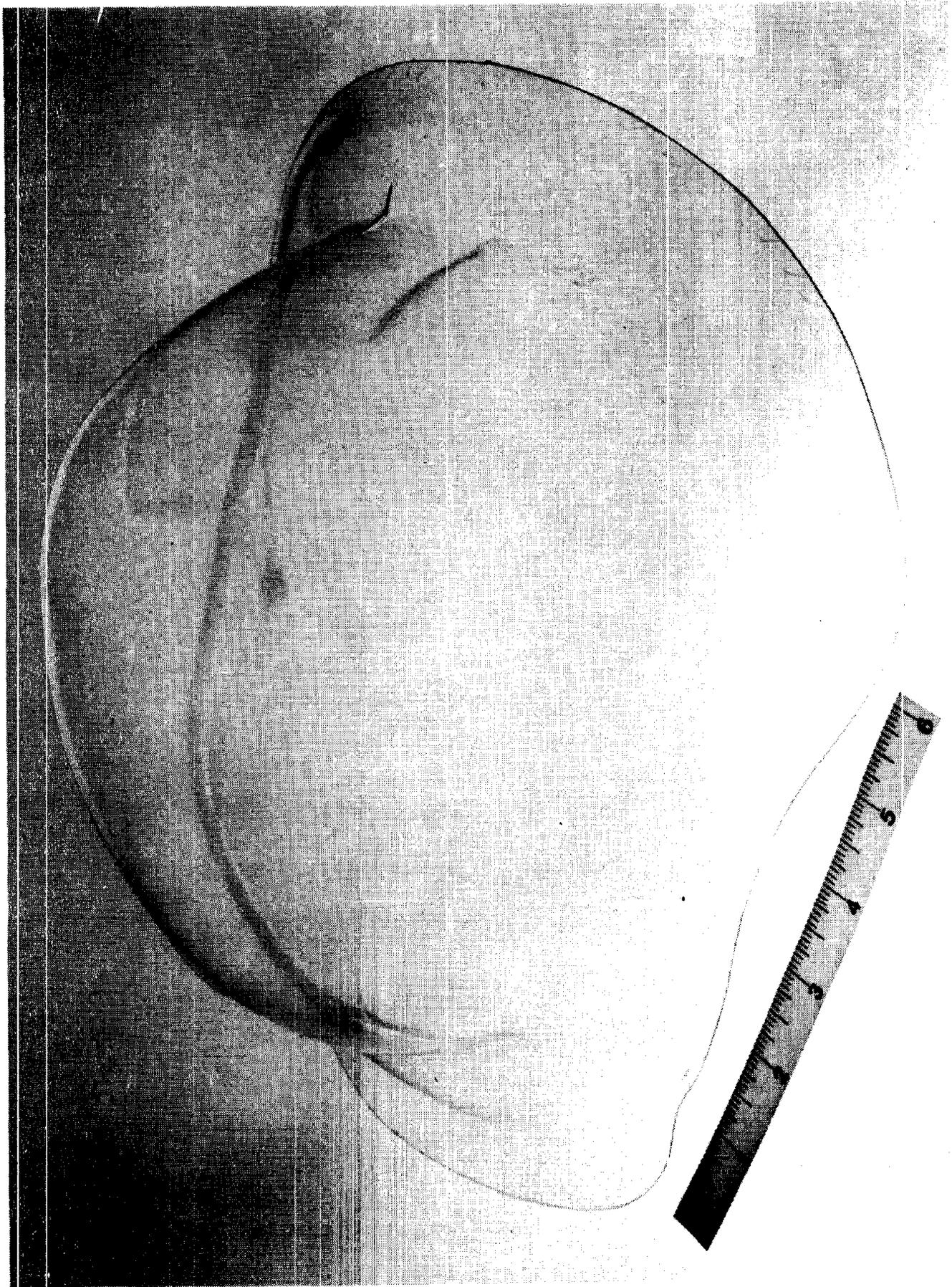
APPENDIX A, ENCLOSURE 8
ALUMINUM THERMOFORMING MOLD FOR MODEL I EVALUATION PROTOTYPE



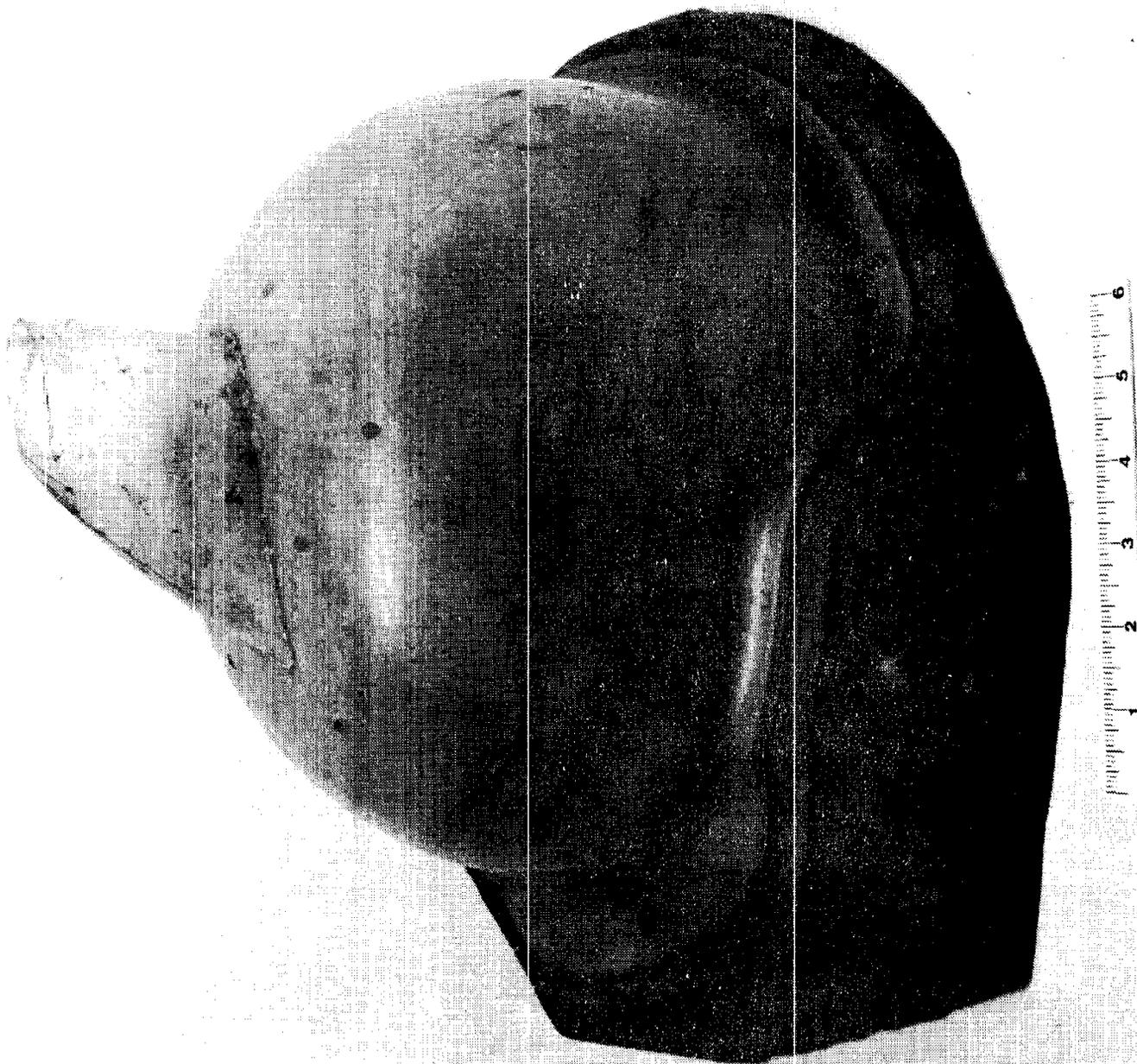
APPENDIX A, ENCLOSURE 9
SETUP FOR CASTING CARBOLON THERMOFORMING MOLDS



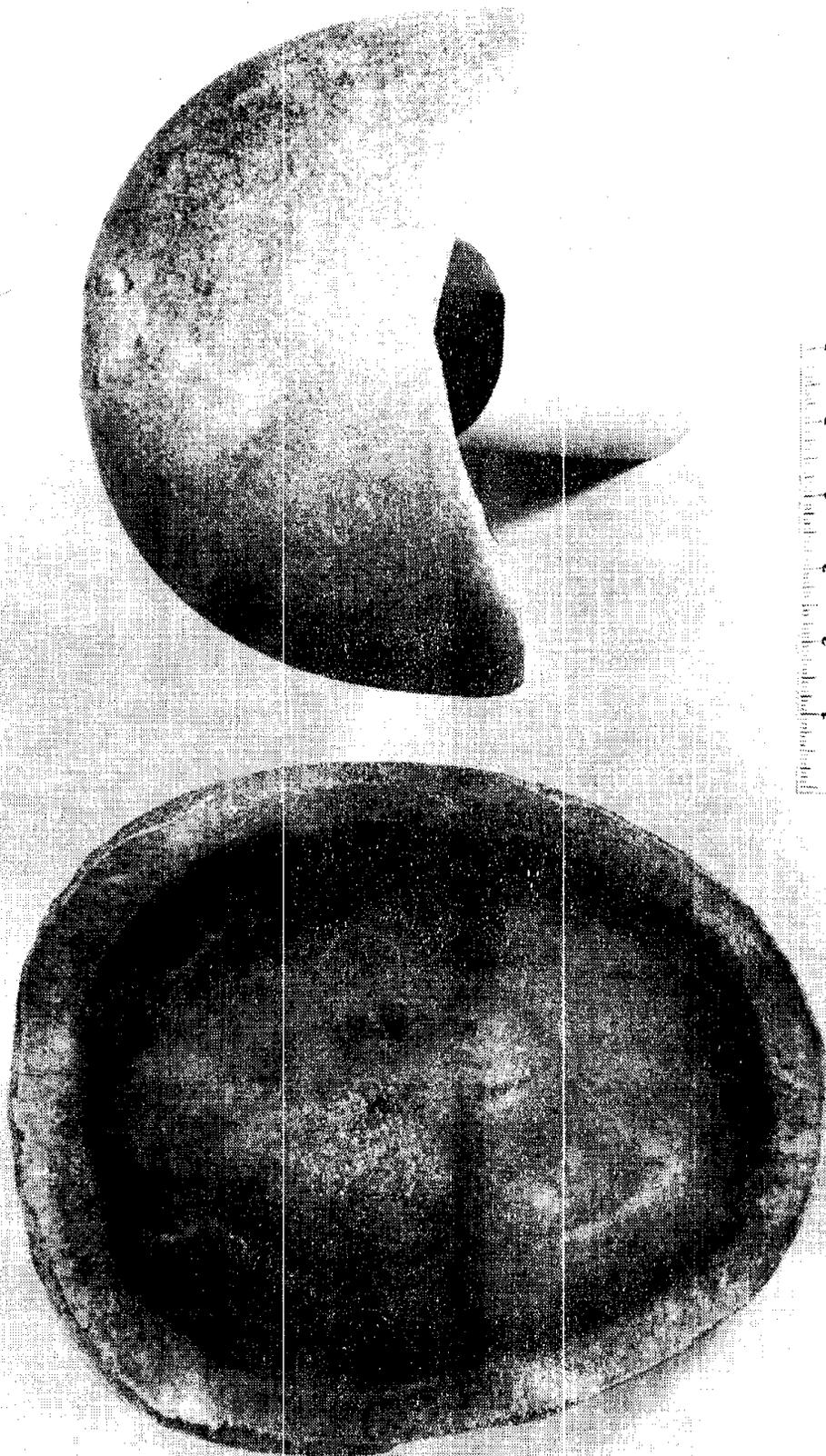
APPENDIX A, ENCLOSURE 10
CARBOLON THERMOFORMING HOLD FOR MODEL I INNER SHELL



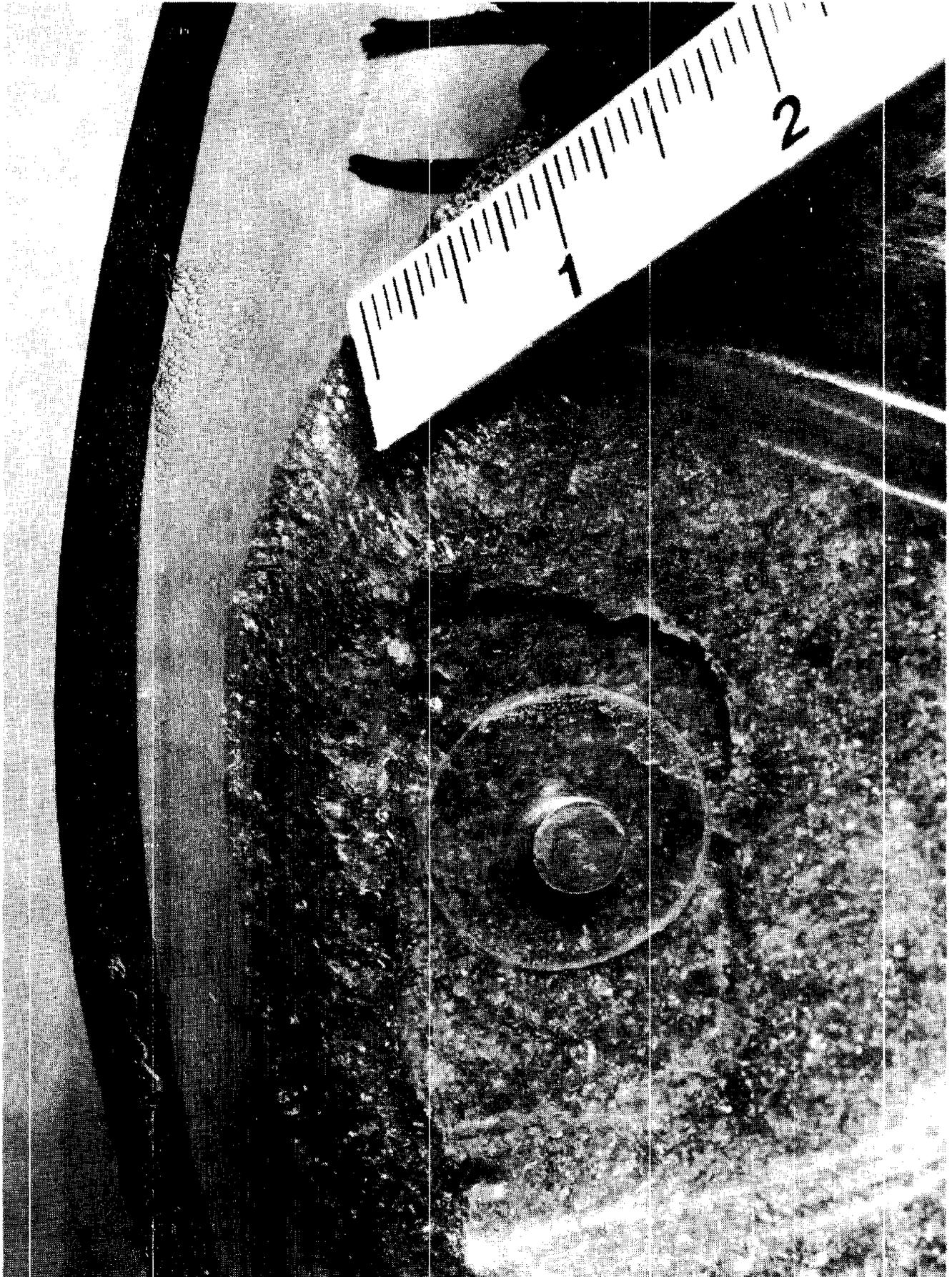
APPENDIX A, ENCLOSURE 11
THERMOFORMED INNER SHELL FOR MODEL I



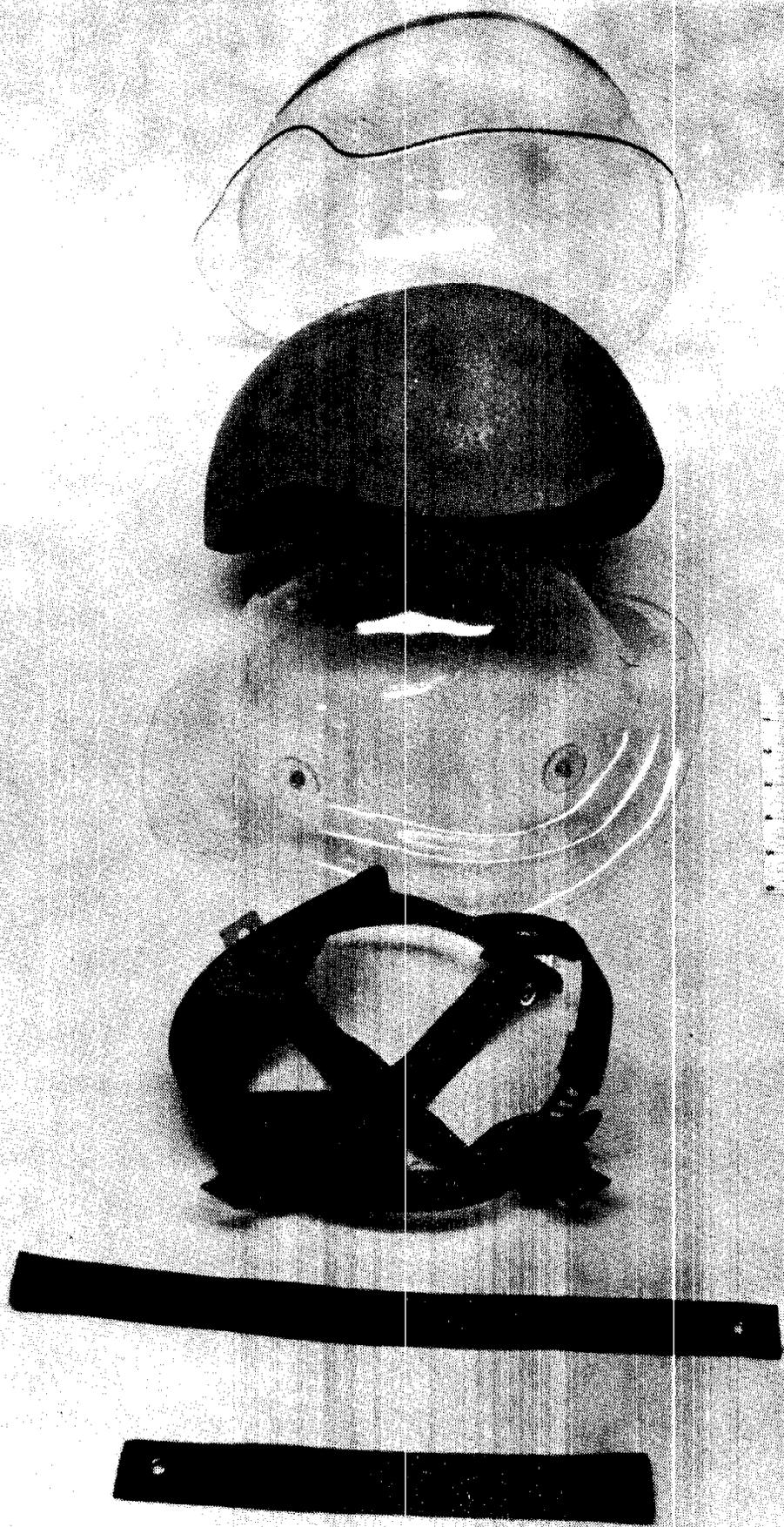
APPENDIX A, ENCLOSURE 12
SETUP FOR MOLDING POLYURETHANE LINERS FOR MODEL I



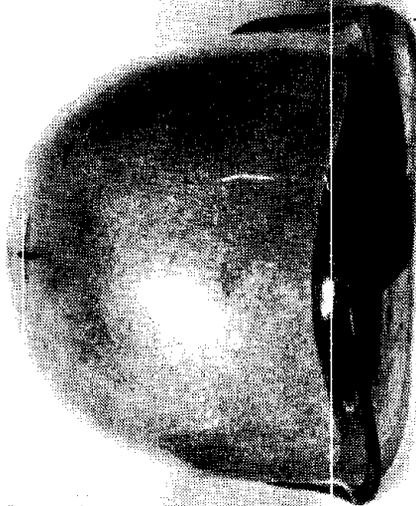
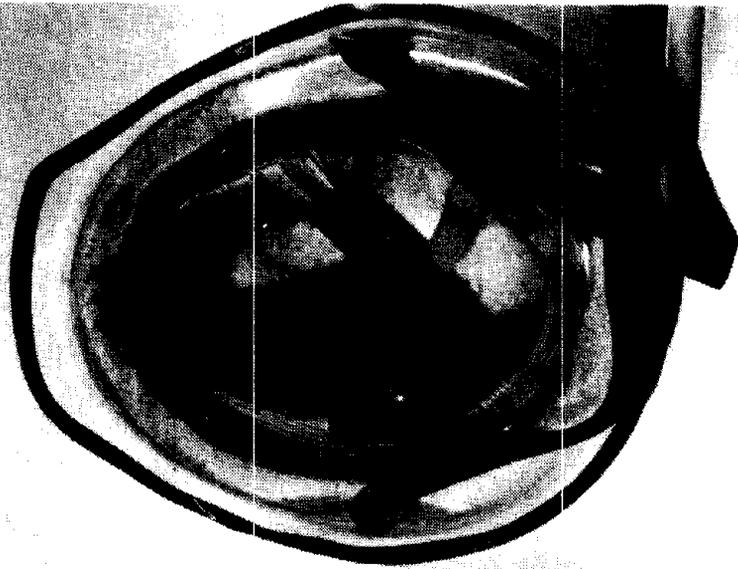
APPENDIX A, ENCLOSURE 13
FOAMED POLYURETHANE ENERGY ABSORBING LINER



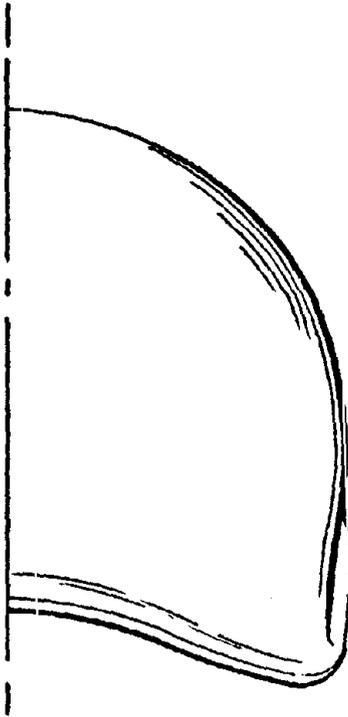
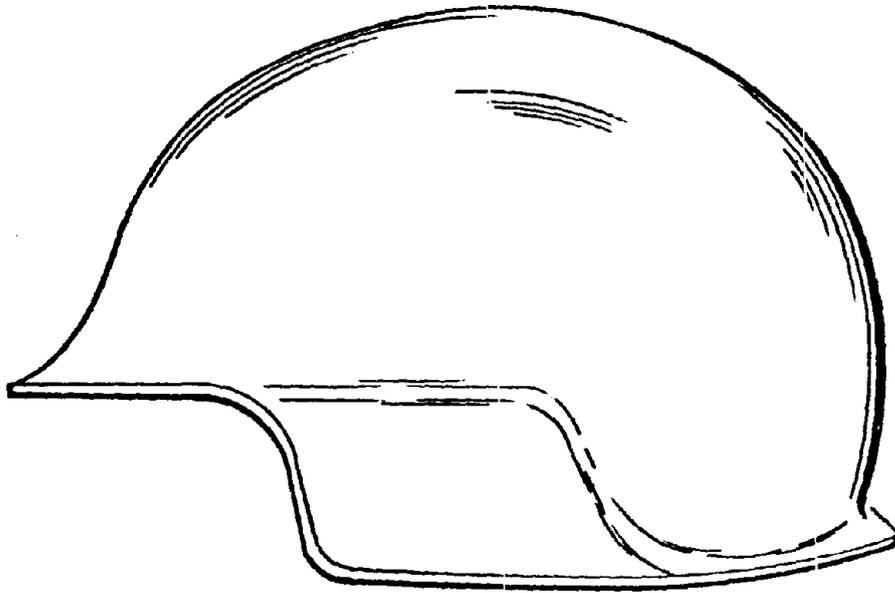
APPENDIX A, ENCLOSURE 14
SUSPENSION MOUNT ON INNER SHELL OF MODEL I



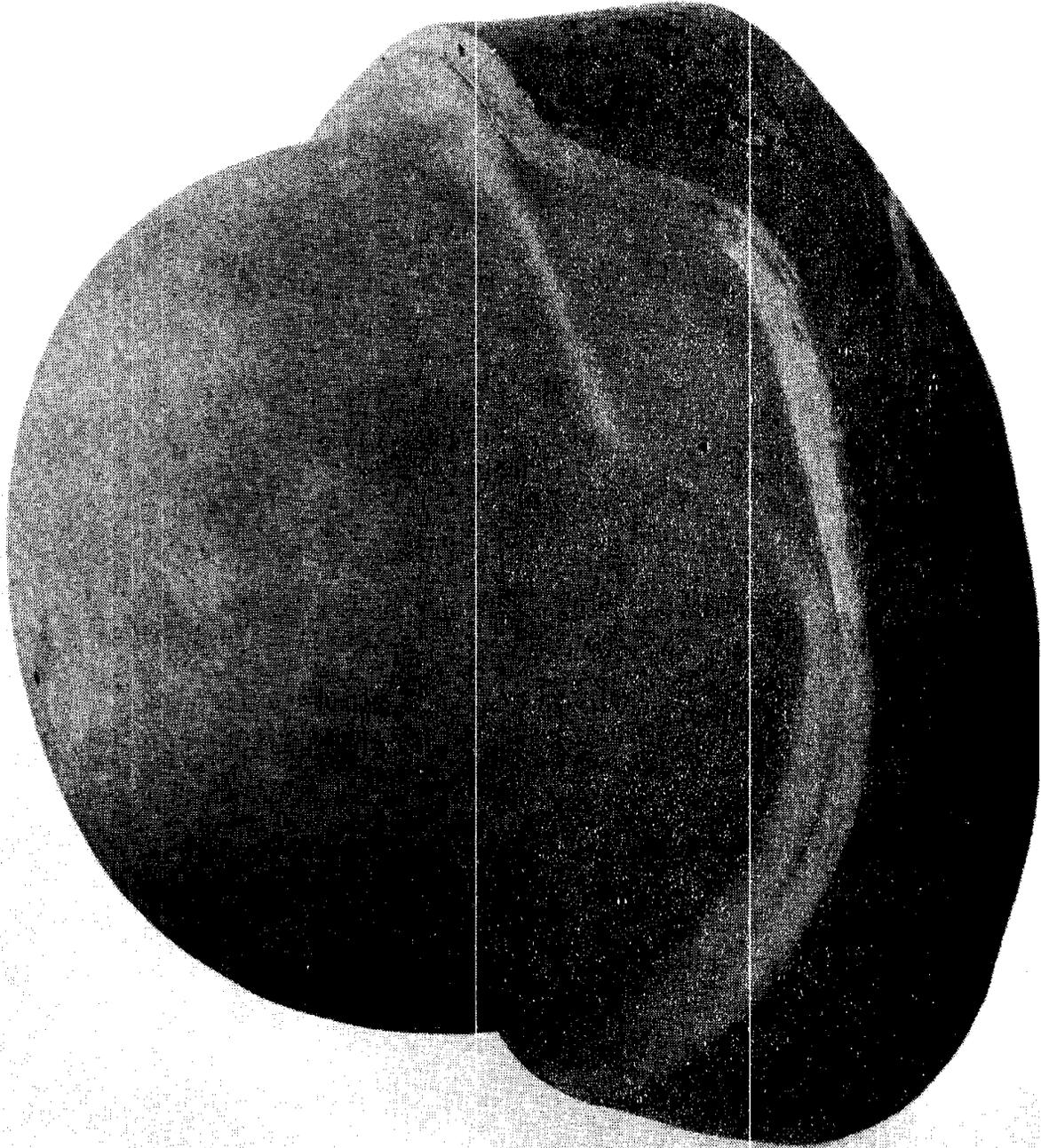
APPENDIX A, ENCLOSURE 15
MODEL I EVALUATION PROTOTYPE COMPONENT PARTS



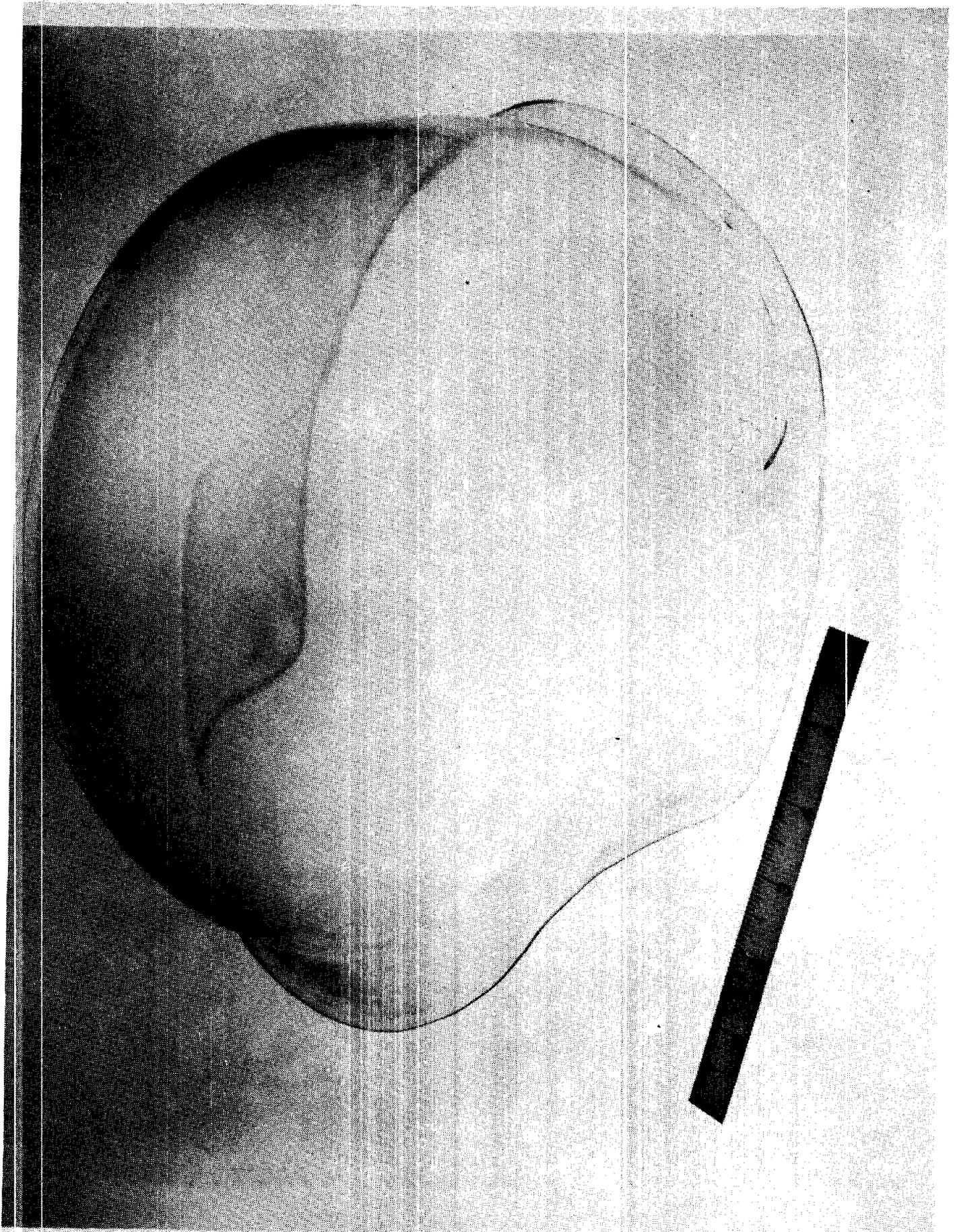
APPENDIX A, ENCLOSURE 16
MODEL I EVALUATION PROTOTYPE HELMETS



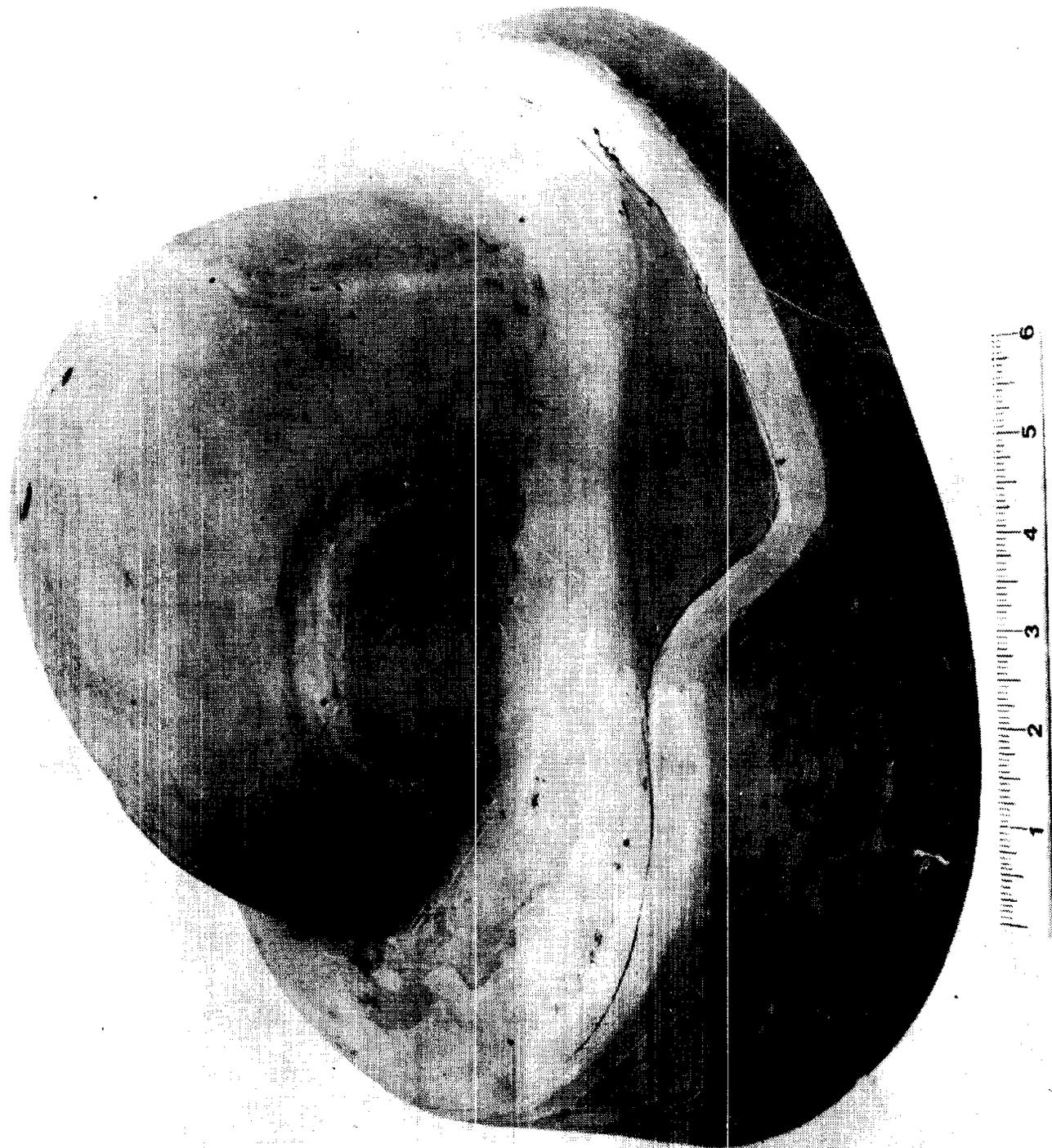
APPENDIX A, ENCLOSURE 17
SKETCH OF REDESIGNED OUTER SHELL FOR MODEL II



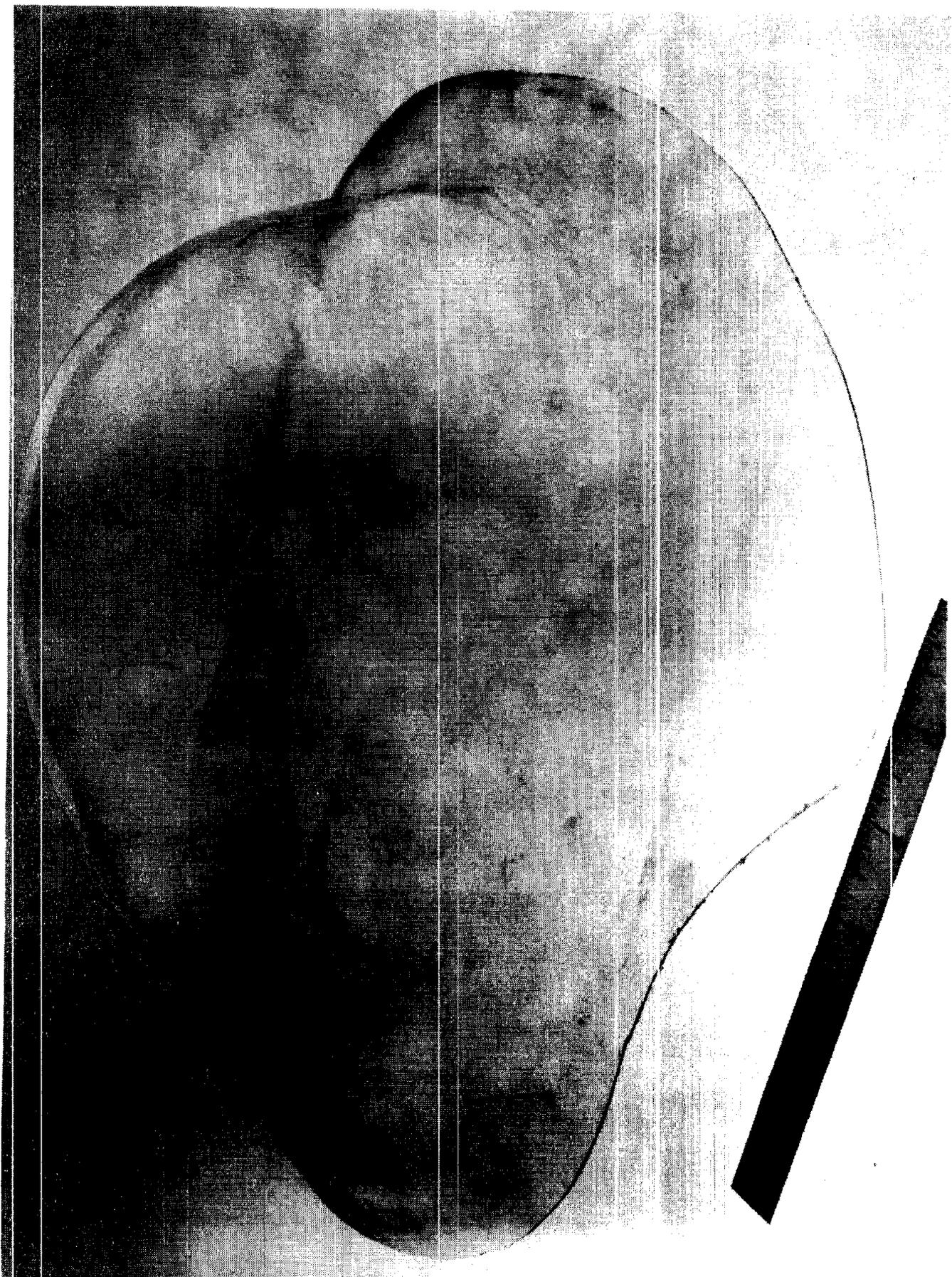
APPENDIX A, ENCLOSURE 18
THERMOFORMING MOLD FOR MODEL II OUTER SHELL



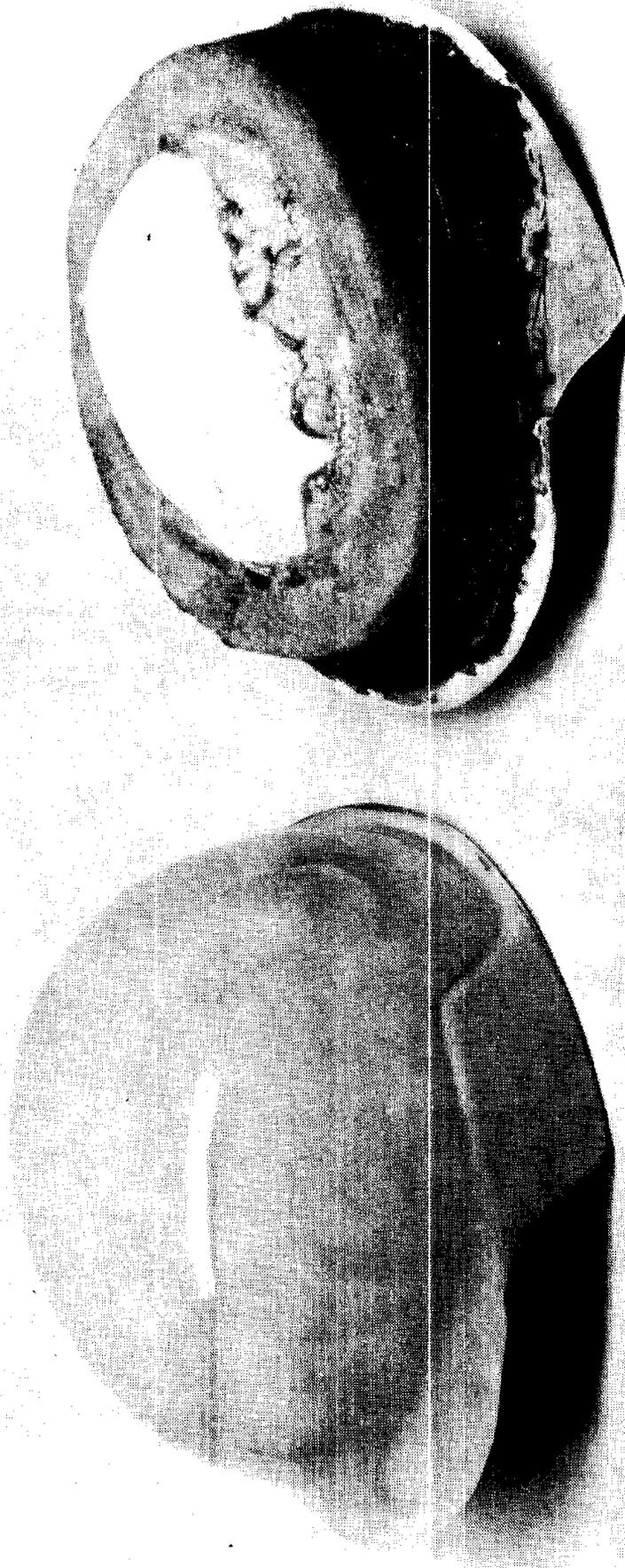
APPENDIX A, ENCLOSURE 19
THERMOFORMED OUTER SHELL FOR MODEL II



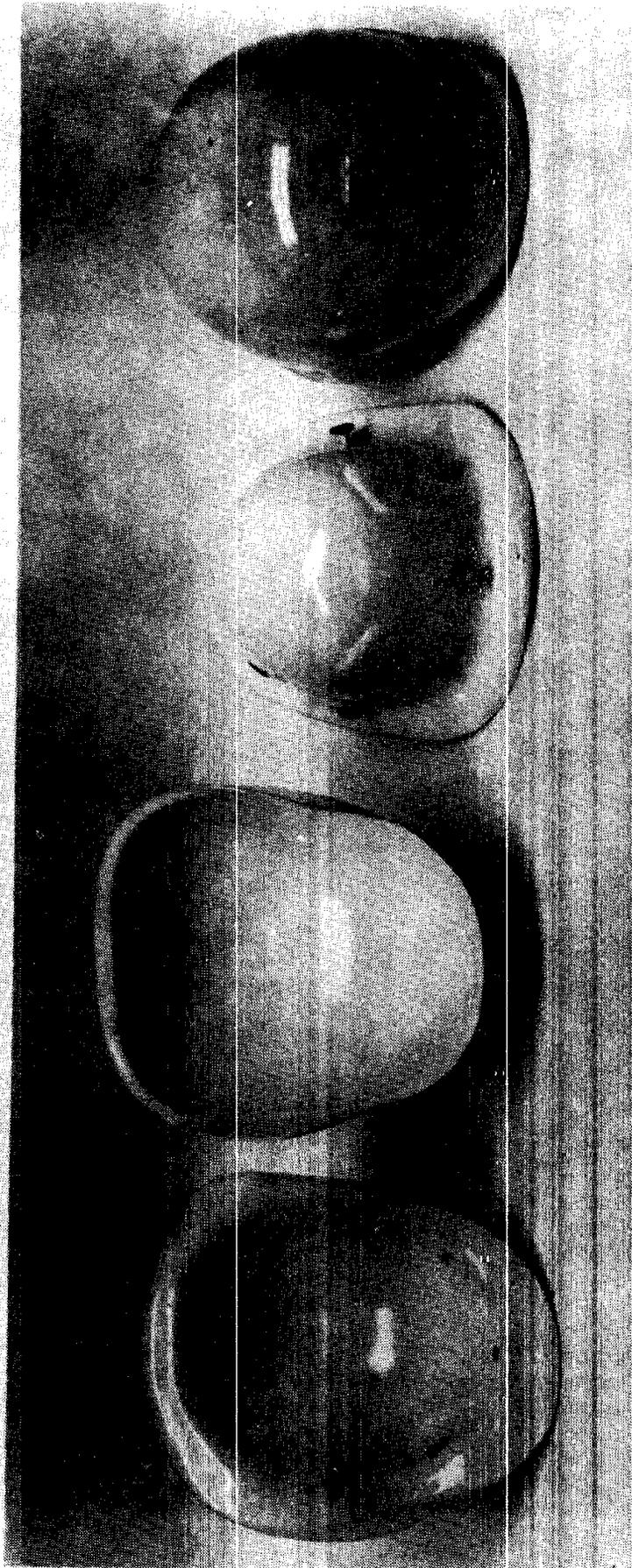
APPENDIX A, ENCLOSURE 20
THERMOFORMING MOLD FOR MODEL II INNER SHELL



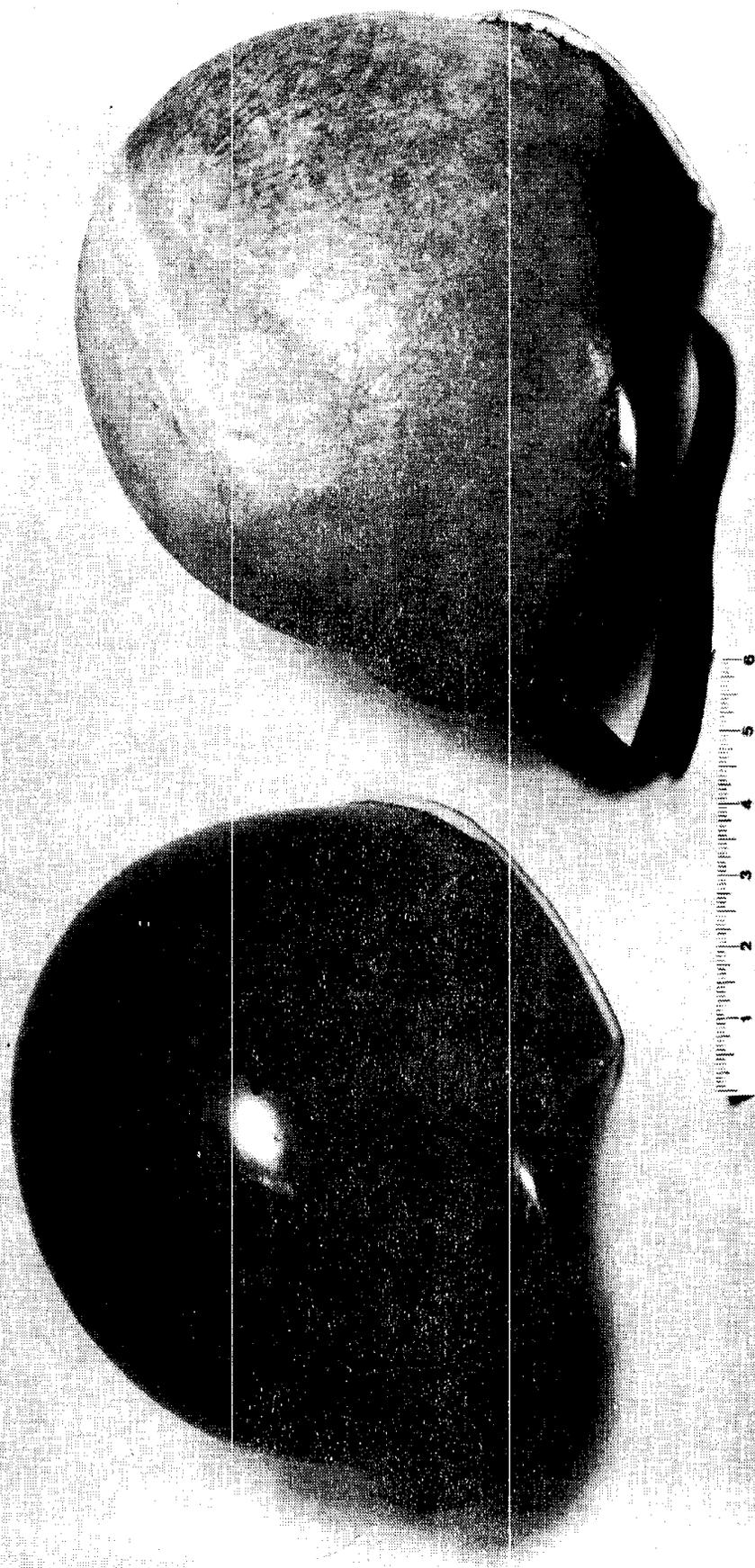
APPENDIX A, ENCLOSURE 21
THERMOFORMED INNER SHELL FOR MODEL II



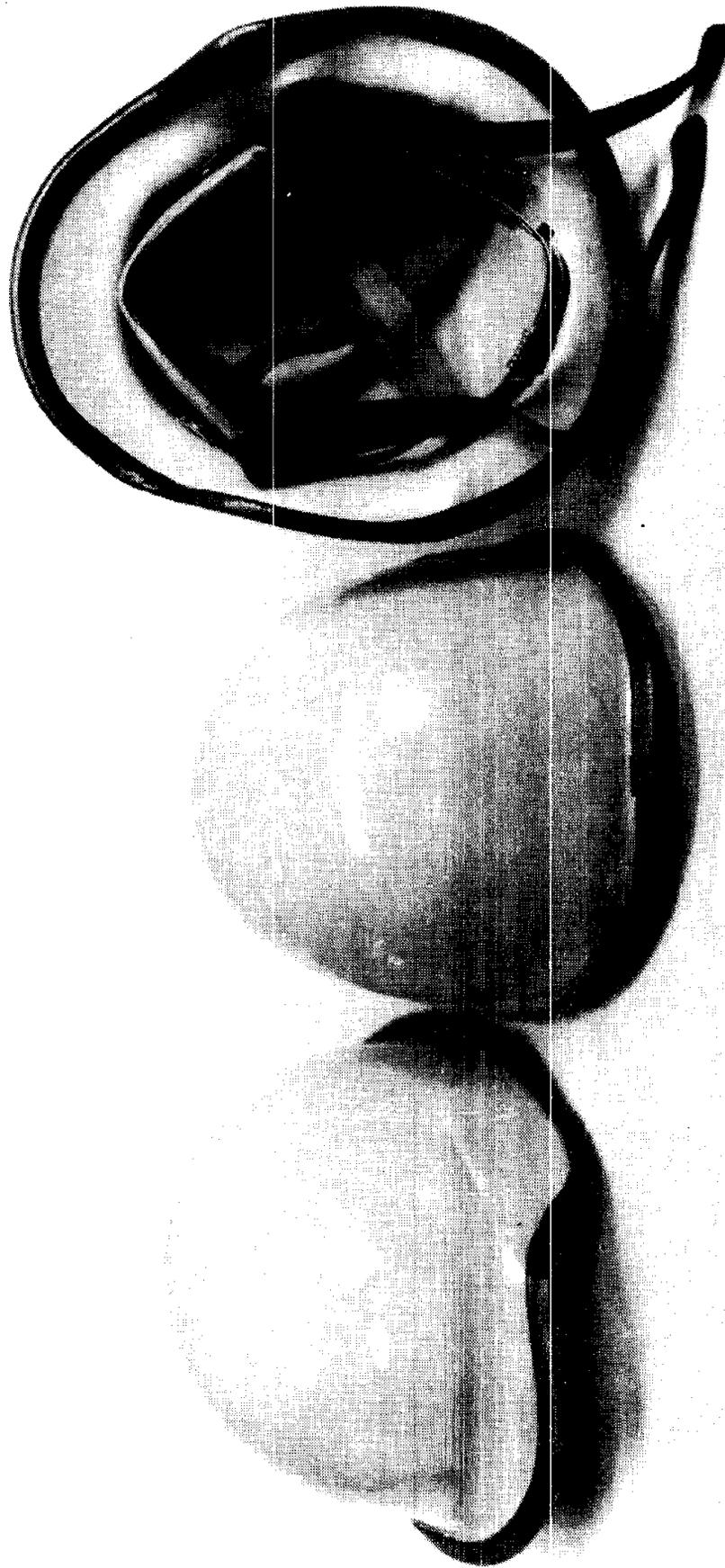
APPENDIX A, ENCLOSURE 22
MODEL II WITH PARTIAL LINER



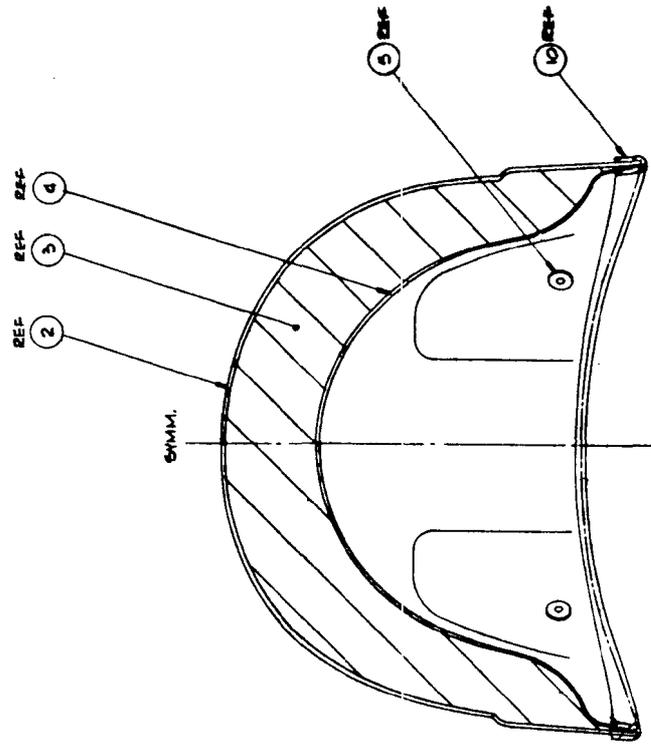
APPENDIX A, ENCLOSURE 23
MODEL II EIGHT POINT SUSPENSION MOUNTING



APPENDIX A, ENCLOSURE 24
MODEL II WITH FULL LINER

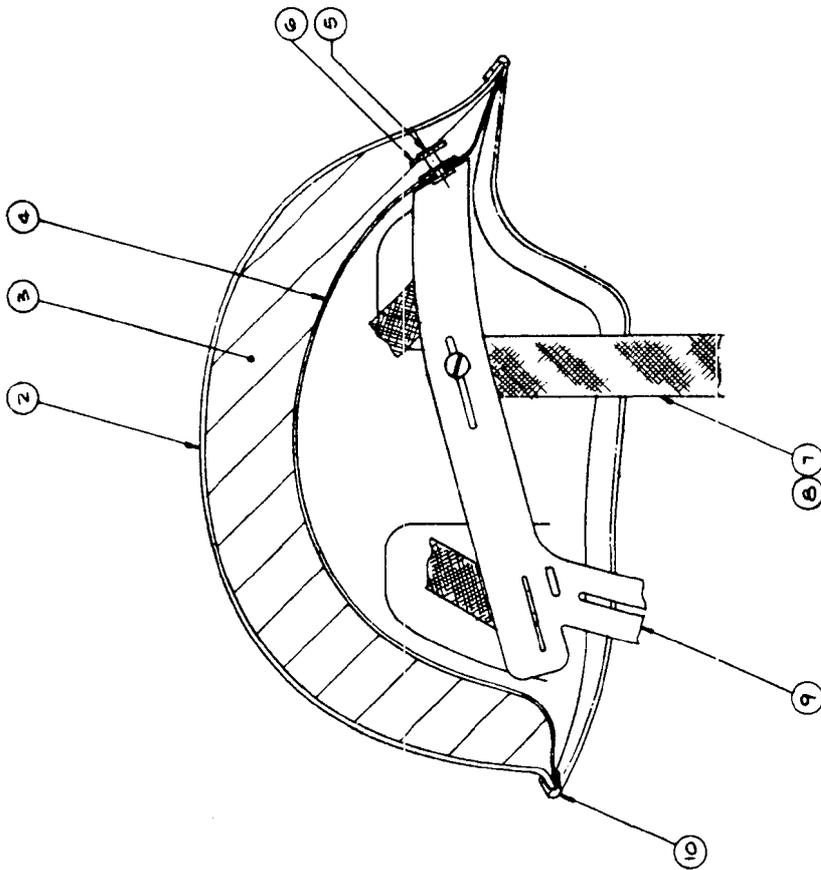


APPENDIX A, ENCLOSURE 25
MODEL III FINAL PROTOTYPE HELMET



NOTE - HELMET SUSPENSION OMITTED FROM SECTION FOR CLARITY

SECTION B-B



SECTION C-C

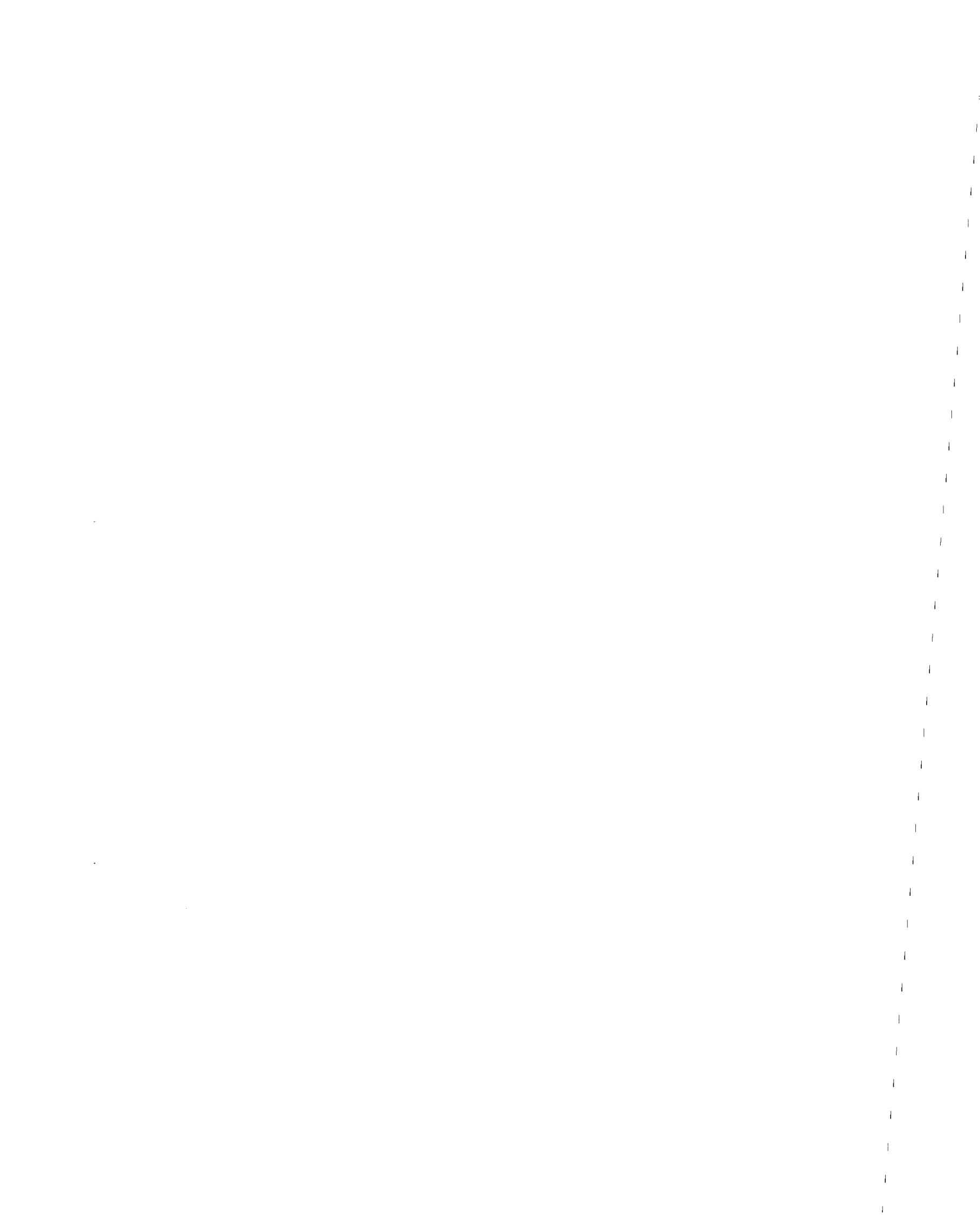
APPENDIX A, ENCLOSURE 26, PAGE 2 OF 2
 MODEL III FINAL PROTOTYPE HELMET DRAWINGS

HEAD PROTECTION RESEARCH PROGRAM FOR THE
FEDERAL GOVERNMENT

QUESTIONNAIRE

TEST HELMET NUMBER _____

Appendix A - Enclosure 27
Helmet Field Trail Questionnaire



Introduction:

The new helmet that you have been wearing has been developed for high risk industrial environments by the National Institute for Occupational Safety and Health (United States Department of Health, Education and Welfare). Like any new device the human factors of comfort and fit must be evaluated in addition to physical performance.

Instructions:

The following questions will be used to gather important data about the helmets. All of your observations, reactions and comments are important. All responses will be kept anonymous and confidential. Circle, underline, fill in or pass comment on all 30 questions. If a question does not apply or if any event did not happen, write the letters N/A next to the question.

AGE: _____ HEIGHT: _____ WEIGHT: _____ MALE _____ FEMALE _____

YOUR HAT SIZE: (IF KNOWN) _____ THE HELMET WAS WORN FOR _____ DAYS.

1. I have worn protective head gear for:

- (a) First Time
- (b) Less than One Year
- (c) One Year
- (d) One - Five Years
- (e) Five Years
- (f) Five - Ten Years
- (g) Ten Years or More

2. My favorite colors are:

Red, Orange, Yellow, Green, Blue, Violet

3. The colors I like least are:

Red, Orange, Yellow, Green, Blue, Violet

4. Did you like the looks of the helmet?

- (a) Yes
- (b) No

Comments _____

5. Were you embarrassed to wear the helmet?

- (a) Yes
- (b) No

Comments _____

6. Would you select to wear this helmet instead of some other helmet?

- (a) Yes
- (b) No

If No, which helmet would you rather wear? _____

7. Was the helmet easy to clean?

- (a) Yes
- (b) No

Comments _____

8. Was the helmet easy to disinfect?

- (a) Yes
- (b) No

Comments _____

9. Was the helmet durable?

- (a) Yes
- (b) No

Comments _____

10. Did any part of the helmet break after repeated use?

- (a) Yes
- (b) No

If yes, explain _____

11. Was the helmet comfortable to wear?

- (a) Yes
- (b) No

Comments _____

12. How many hours per day on an average did you wear the helmet?

- (a) One Hour or Less
- (b) Two to Four Hours
- (c) Five to Eight Hours
- (d) More than Eight Hours

13. The helmet was _____ to wear?

- (a) Cool
- (b) Warm
- (c) Hot

Comments _____

14. The helmet was _____ to wear.

- (a) Light
- (b) Heavy

Comments _____

15. How would you compare the weight of this helmet with other helmets you have worn?

- (a) The same as others.
- (b) Heavier than others.
- (c) Lighter than others.

Comments _____

16. Did the helmet interfere with your vision?

- (a) Yes
- (b) No

If yes, explain _____

17. Did the helmet interfere with your hearing?

- (a) Yes
- (b) No

If yes, explain _____

18. Did the helmet interfere with your movements?

- (a) Yes
- (b) No

Comments _____

19. Did the helmet fit well?

- (a) Yes
- (b) No

Comments _____

20. Did the helmet protect you from an impact with a blunt object?

- (a) My helmet did not receive such an impact
- (b) Yes
- (c) No

Comments _____

A. Did you sustain any injury?

- (a) Yes
- (b) No

Comments _____

B. Was the helmet damaged in any way?

- (a) Yes
- (b) No

Comments _____

21. Did the helmet protect you from an impact with a sharp object?

- (a) My helmet did not receive such an impact.
- (b) Yes
- (c) No

Comments _____

A. Did you sustain any injury?

- (a) Yes
- (b) No

Comments _____

B. Was the helmet damaged in any way?

- (a) Yes
- (b) No

Comments _____

22. Did the helmet protect you from an electrical shock?

- (a) My helmet did not receive one.
- (b) Yes
- (c) No

Comments _____

A. Did you sustain any injury?

- (a) Yes
- (b) No

Comments _____

B. Was the helmet damaged in any way?

- (a) Yes
- (b) No

Comments _____

23. Based on the helmet's overall performance did you feel safe while wearing the helmet?

- (a) Yes
- (b) No

Comments _____

24. The things I like most about this helmet are:

25. The things I liked least about this helmet are:

26. I felt the overall size of the helmet was:

- (a) Comparable to other helmets.
- (b) Smaller than other helmets.
- (c) Larger than other helmets.

27. Did you become fatigued while wearing the helmet?

- (a) Yes
- (b) No

Comments _____

28. Did you develop headaches while wearing the helmet?

- (a) Yes
- (b) No

Comments _____

29. Did the helmet feel balanced on the head?

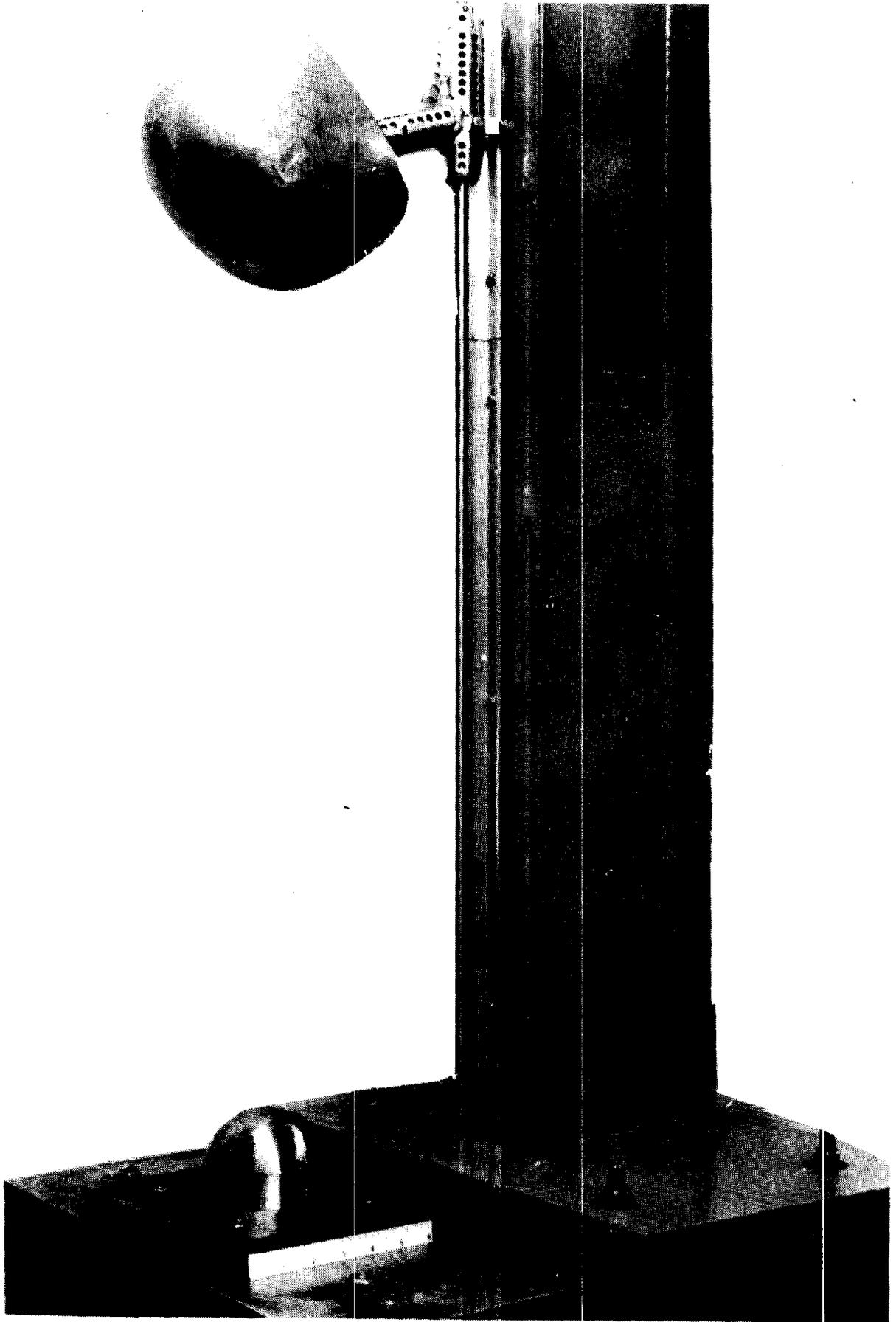
- (a) Yes
- (b) No

Comments _____

30. Did the helmet affect your sense of balance?

- (a) Yes
- (b) No

Comments _____

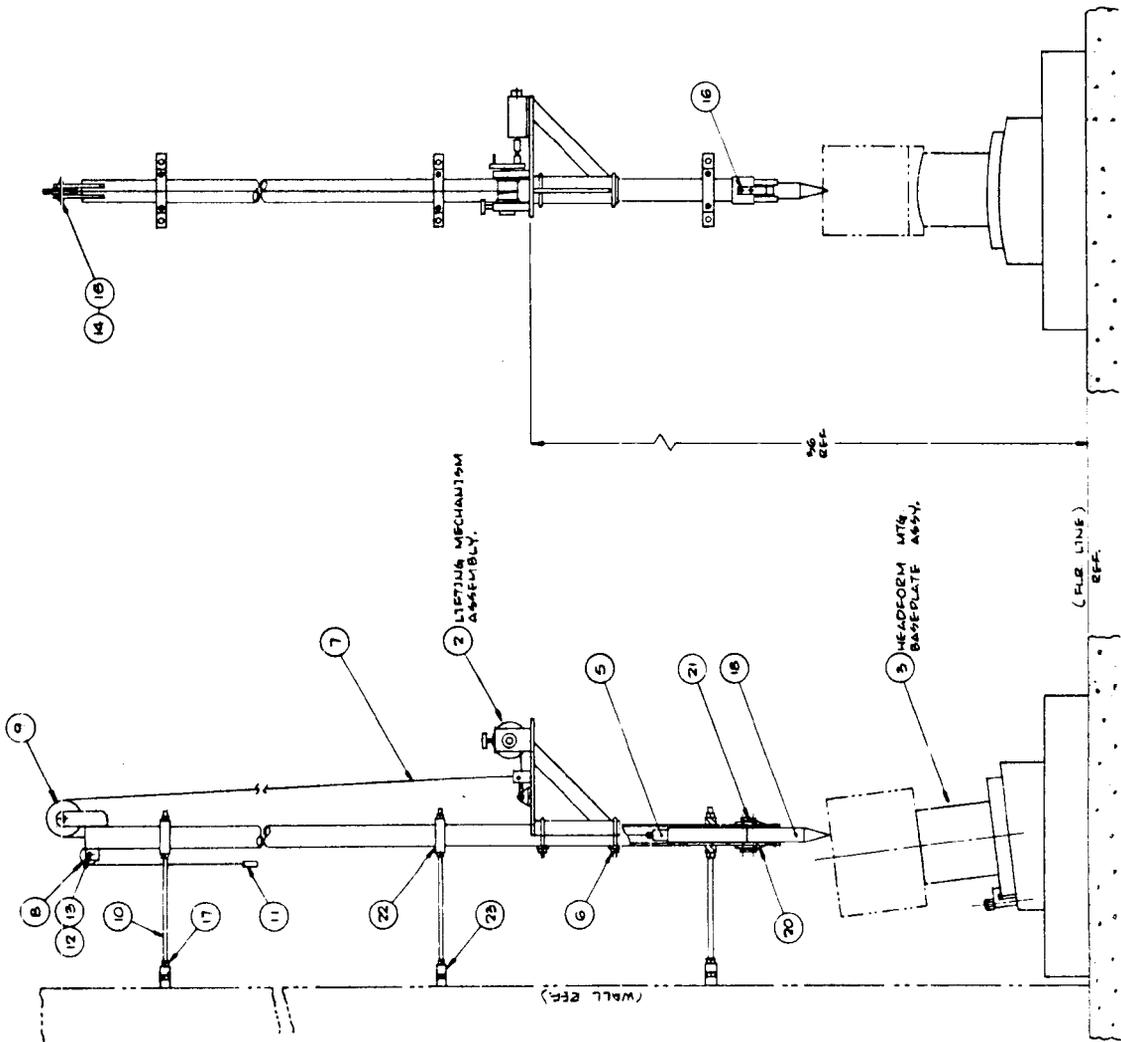


APPENDIX A, ENCLOSURE 28
MONORAIL IMPACT TEST ASSEMBLY - OBLIQUE VIEW

NO.	PART NO.	DESCRIPTION	MAT'L.	QTY.	UNIT
1	LB597	PENETRATION FIXT. ASSY.		1	
2		LIFTING MECHANISM ASSY.		1	
3		HEADFORM MTG. BASE ASSY.		1	
4		JACK ASSEMBLY		1	
5	5C98K14	ELECTROMAGNET		1	
6	6048T69	U-BOLT, W/UT. PLATE	STEEL	1	
7	7850T24	MISCO STAND W/IFF ROPE	STAIN. SL.	1	
8	8168T11	DALL BEARING SHEAVE	STEEL	1	
9	9A1210T24	PULLEY (CAT NO 9046)	NORWICA	1	
10		THREADED ROD (UT TO NUT)	STEEL	1	
11		COUNTERWEIGHT	STEEL	1	
12		60C HD CAP SCREW	STEEL	1	
13		HEX NUT	STEEL	1	
14		60C HD CAP SCREW	STEEL	1	
15		HEX NUT	STEEL	1	
16		SCREW, RD HEAD	STEEL	1	
17		HEX NUT	STEEL	1	
18		THREADED ROD	STEEL	1	
19		PENETRATION SPLITTER	AL. 7075	1	
20		ELECTRICAL CONTACT	AL. 6061	1	
21		ELECT. CONTACT CLAMP	AL. 7075	1	
22		GUIDE TUBE MTG. BRKT.	AL. 7075	1	
23		WALL BRACKET	AL. 7075	1	
24		STEEPLE GUIDE TUBE	AL. 6061	1	
25		PULLEY BRACKET	AL. 6061	1	
26		SLEEVE	AL. 6061	1	
27		ROUND	CE. 47L	1	
28		TUBE	AL. 6061	1	
29		RECT. PLAT	AL. 7075	1	
30		PLATE	AL. 6061	1	
31		RECT. PLAT	AL. 7075	1	
32		RECT. PLAT	AL. 6061	1	
33		RECT. PLAT	AL. 7075	1	
34		ROUND BAR	AL. 7075	1	
35		PULLEY	ALUM.	1	

MAT'L LIST COUNT ON SHIT. 2

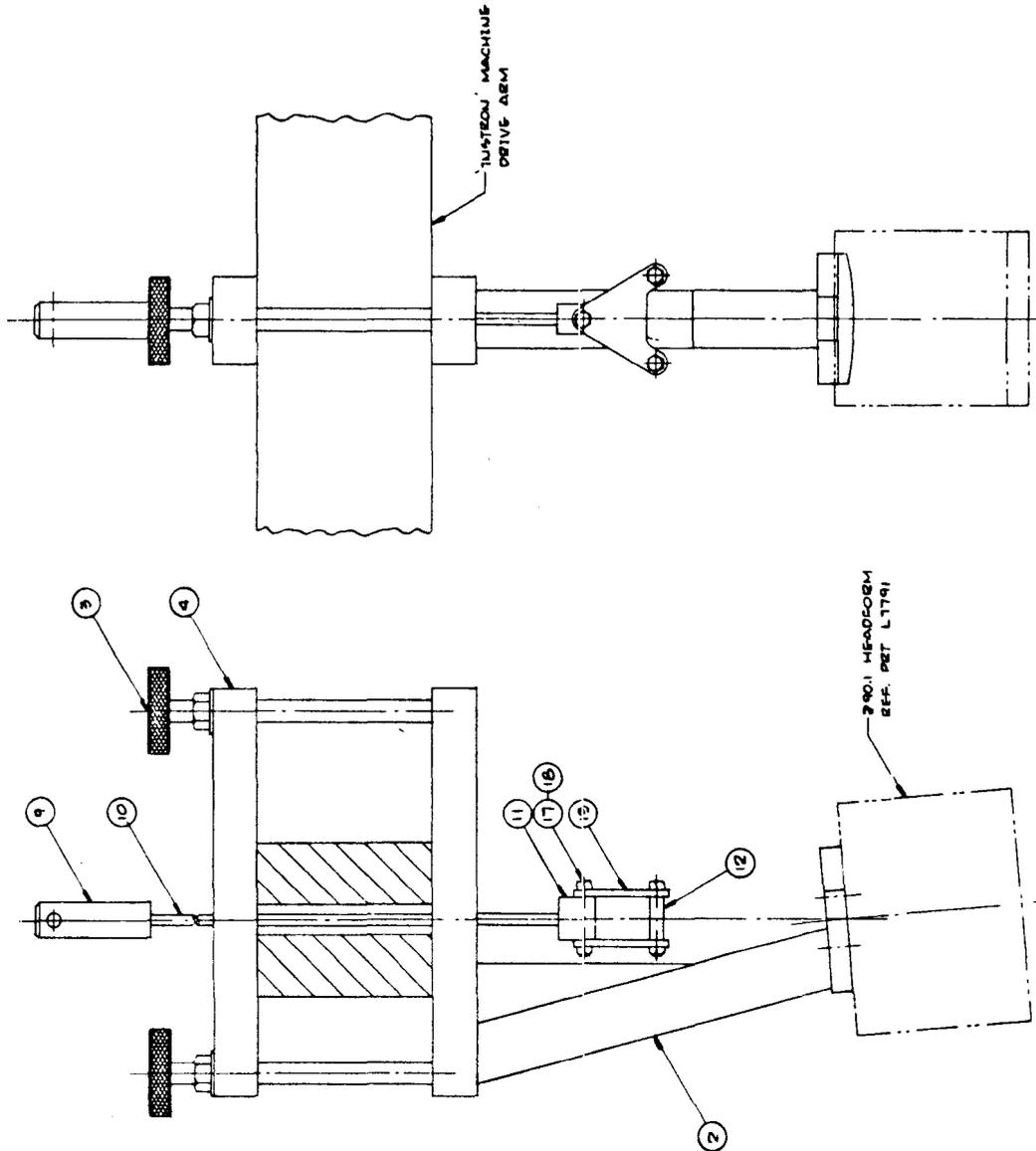
- NOTES -
- INSTALLATION NOTE
 - GUIDE TUBE TO BE MOUNTED PERPENDICULAR TO FLR LINE.
 - MOUNTING BRACKETS ARE TO BE EQUALLY SPACED ON GUIDE TUBE.
 - SEE SHIT. 7 FOR CONTROL PANEL & ELECTRICAL SCHEMATIC DIAGRAM & PARTS LIST.



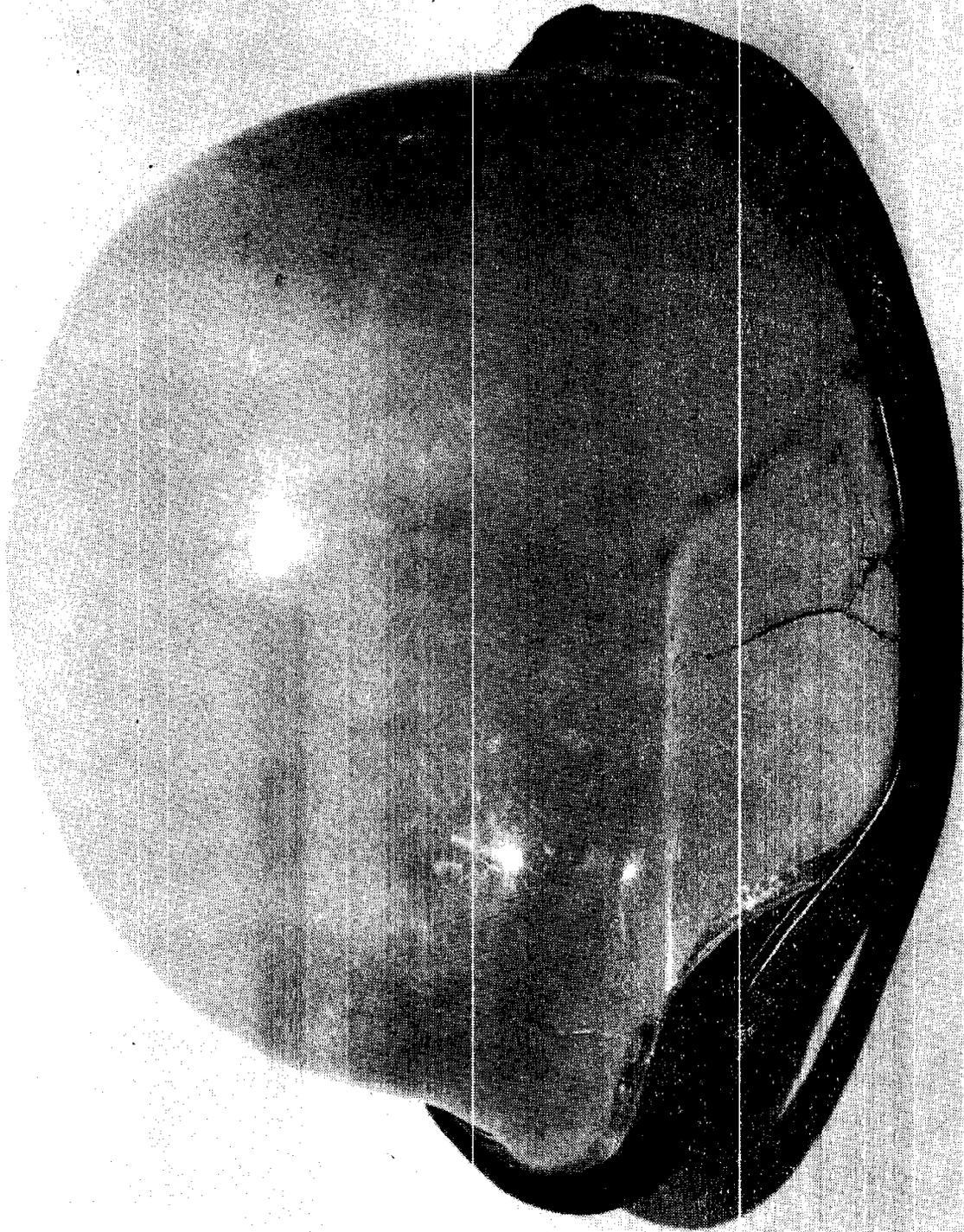
APPENDIX A, ENCLOSURE 29
PENETRATION TEST FIXTURE ASSEMBLY

ITEM NO	PART NO	DESCRIPTION	MAT'L	QTY	SIZE
1	RETENTION TEST FIXT ASSEMBLY			1	
2	MAIN SUPPORT ASSEMBLY			1	
3	KNURLED KNOB			2	
4	RECT. ALUM. BAR		6061-T6	1	1 1/2 x 5 x 18 LG
5	RECT. ALUM. BAR		6061-T6	1	1 1/2 x 5 x 18 LG
6	ALUM. BAR		6061-T6	2	2 x 2 x 17 1/2 LG
7	ALUM. BAR		6061-T6	2	2 x 2 x 17 9/16 LG
8	ALUM. FLAT		6061-T6	1	1/8 x 4 1/2 x 5 1/4 LG
9	C. F. STEEL ROD		57L	1	1/4 DIA x 4 1/4 LG
10	C. F. STEEL ROD		57L	1	1/4 DIA x 22 LG
11	C. F. STEEL FLAT		57L	1	1 x 1 1/2 x 1 1/2 LG
12	HOLLOW STL. TUBE		57L	2	.500 OD .308 ID x 1 1/2 LG
13	C. F. STEEL FLAT		57L	2	1/4 x 3/8 x 3 1/4 LG
14	C. F. STEEL FLAT		57L	2	5/8 x 1/2 x 2 1/4 LG
15	C. F. STEEL ROD		57L	2	3/4 x 10 1/2 LG
16	HEX NUT		57L	2	3/8 - 10 UNC
17	HEX HD. BOLT		57L	2	3/8 - 10 UNC x 2 1/2 LG
18	HEX NUT		57L	2	3/8 - 10 UNC

- NOTES
1. REMOVE BURRS & BREAK SHARP EDGES.
 2. ALL STEEL PARTS ARE TO BE SOLVENT CLEANED & ZINC PLATED .0008 TO .0010 THICK.
 3. HEADFORM IS TO BE BOLTED IN PLACE USING 3 - SOCKET HEAD CAP SCREWS 3/8-10UNC x 1 1/2 LG.



APPENDIX A, ENCLOSURE 30
RETENTION TEST FIXTURE ASSEMBLY



APPENDIX A, ENCLOSURE 31
SIDE VIEW - DAMAGED FIELD TEST HELMET

APPENDIX B
RECOMMENDED STANDARD FOR CLASS I INDUSTRIAL
HEAD PROTECTIVE DEVICES

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1.0 PERFORMANCE STANDARD FOR INDUSTRIAL HEAD PROTECTIVE DEVICES

1.1 Scope and Purpose

This performance standard lists the attributes and levels of performance for industrial head protective devices. This standard is designed to be suitable for use as a basis of an industrial head protective device testing and certification program.

1.2 Definitions

Industrial Protective Headgear - A device designed to prevent or reduce head injury resulting from industrial accidents.

Shell - The outermost and/or innermost part of a protective headgear, less energy absorption devices, accessories and mountings.

Peak - An integral part of the shell of the headgear extending forward over the eyes only.

Brim - An integral part of the shell of the headgear extending around the entire circumference of the headgear.

Protective Padding - A material designed to attenuate the force of an impact.

Suspension - A complete assembly that positions and maintains the headgear on the head.

Headband - That part of the suspension which encircles the head.

Crown Straps - That part of the suspension which passes over the head.

Chin Strap - An adjustable strap, fitting under the chin to secure the helmet to the head.

Bitragion - Inion arc - An arc extending through the upper edges of the ear hole and over the small bump often found at the rearmost part of the head.

Nape Strap - An adjustable strap which is located at approximately the Bitragion - Inion arc, used to aid in helmet retention.

Sweatband - That part of the headband, either integral or attached to, which comes in contact with the wearer's forehead.

Basic Plane - The basic plane is a plane through the centers of the right and left external ear openings and the lower edge of the eye sockets as modeled on a reference headform or test headform.

1.2 Definitions - (Continued)

Reference Headform - A reference headform is a measuring device corresponding to the dimensions of a standard headform in all areas above the basic plane.

Test Headform - A test headform is a test device corresponding to the dimensions of a standard headform in all areas above the basic plane.

Reference Plane - A plane, above and parallel to the basic plane shall be located on each headform.

Mid-sagittal Plane - The mid-sagittal plane is an anterior - posterior plane passing through the vertex of the headform, perpendicular to the basic plane which geometrically bisects the headform.

Helmet Positioning Index - The helmet positioning index is the distance in inches from the basic plane of a standard headform to the lowest point at the front of the headgear along the mid-sagittal plane.

Apex - The apex of a headgear is a point on the upper sagittal plane, equidistant from the anterior and posterior portions of the reference plane.

Apex Area - The apex area is the area described by all points on the upper surface of the headgear within the arc distance of 1.5 inches (3.8 cm) from the apex.

Head Injury Criterion - The Head Injury Criterion requires that the resultant acceleration at the center of gravity of the head during an impact shall be such that when the average acceleration (expressed in g's) during any time interval is raised to the 2.5 power and multiplied by the length of the interval in seconds, the product shall not exceed 1000. (The Head Injury Criterion is that as defined by Federal Motor Vehicle Safety Number 208*).

1.3 Classes of Protection

Industrial head protective devices shall be categorized in the following classes:

CLASS 1 - Maximum Duty Industrial Protective Headgear

CLASS 2 - Medium Duty Industrial Protective Headgear

CLASS 3 - Light Duty Industrial Protective Headgear

1.4 General Requirements

1.4.1 Materials

1.4.1.1 Shell materials shall be durable and shall withstand any temperature in the ranges as stated in section 1.5.8 of this standard.

- 1.4.1.2 Shell materials shall not be significantly affected by ultraviolet radiation.
- 1.4.1.3 All materials coming in contact with the head shall not be a type which may cause skin irritation or disease and shall be unaffected by perspiration, body oils or normal hair preparations.
- 1.4.1.4 All edges of the headgear shall be smoothed and there shall be no rigid internal projections which may cause injury to the wearer in the event of an impact.
- 1.4.1.5 Any materials used in the fabrication of industrial protective headgear shall be resistant to ordinary household soap and water, mild detergents and cleaners recommended by the manufacturer.

1.4.2 Protective Headgear Assembly

- 1.4.2.1 All industrial protective headgear shall consist essentially of: (a) a hard, smooth outer shell, (b) an internal means of attenuating the force of an impact which may consist of protective padding, a suspension, or both, and (c) a retention system, capable of retaining the headgear in position on the head. Provision shall be made for ventilation between the suspension and the shell.
- 1.4.2.2 Extent of Protection. Industrial headgear shall meet the physical performance requirements of this standard in all areas of the head above the reference plane as modeled on a standard headform.

At all times, a minimum of 120° peripheral vision to each side of the mid-sagittal plane must be maintained.

The ability of the headgear to meet the minimum requirements of this standard shall not be a function of wearer adjustment.
- 1.4.2.3 Shell. The shell of the protective headgear shall have a smooth external surface with no reinforcing ridges or rigid external projections greater than 3/16 inch (5 mm) in height in the area above the reference plane. The shell shall have no holes or air gaps and shall be of nominally uniform thickness in the area above the reference plane.
- 1.4.2.4 Peaks. Each headgear shall have a peak, a minimum of 1 inch (2.5 cm) and a maximum of 2 inches (5 cm) in width and shall cover the eyes by extending a minimum of 2 inches (5 cm) to each side of the mid-sagittal plane.
- 1.4.2.5 Brims. If it is found desirable to incorporate a full brim around the circumference of the headgear for the purpose of deflecting water, such brims shall cover the eyes by meeting the minimum dimensions of the peak in the front part of the head. Brims on CLASS 1, headgear shall be no greater than 2 inches (5 cm) in width.

1.4.2.5 Brims - (Continued)

NOTE: Industrial headgear incorporating integral eye and face protection or those designed to be used in conjunction with a one-piece protective suit shall not be required to meet the requirements of paragraphs 1.4.2.4 and 1.4.2.5.

- 1.4.2.6 Force Attenuating Medium. Impact force attenuation may be accomplished by the use of protective padding materials or by means of a suspension. Protective padding shall be moisture and perspiration resistant, exposed areas shall be easily cleanable and if cements are used to secure the shell, such cement shall be resistant to expected environmental exposures. A suspension used for the purpose of impact force attenuation should have straps at least 3/4 inch (1.9 cm) in width and should have an area of not less than 12 square inches (77 cm²) in contact with a standard test headform. The suspension shall be securely attached to the shell.
- 1.4.2.7 Headband (If provided). That part of the headband in contact with the wearer's head shall be a minimum of 1 inch (2.5 cm) in width. Headbands shall be adjustable in 1/8 size increments (See Table 1). The size range and adjustment shall be marked on the headband in a permanently legible manner. At maximum headband adjustment, ventilation clearance shall be retained around the headband.
- 1.4.2.8 Sweatbands (If provided). Sweatbands shall cover at least the forehead part of the head by extending a minimum of 2 inches to either side of the mid-sagittal plane and shall be either removable or integral with the headband.
- 1.4.2.9 Retention System. The retention system shall consist of a chin strap, a nape strap may also be provided. Chin straps shall be a minimum of 3/4 inch (1.9 cm) in width, and shall be adjustable. Nape straps shall extend around the occipital region of the head at approximately the location of the Bitragion - Inion arc. The nape strap shall be adjustable to the head size range provided by the headgear and shall be a minimum of 3/4 inch (1.9 cm) in width.

TABLE 1
RECOMMENDED NOMINAL HEADGEAR SIZES

<u>Headband Size</u>	<u>Circumferential Measurement</u>	
	<u>(Inches)</u>	<u>(cm)</u>
6 1/2	20 1/2	52.1
5 5/8	20 7/8	53.0
6 3/4	21 1/4	54.0
6 7/8	21 5/8	55.0
7	22	55.9
7 1/8	22 3/8	56.8
7 1/4	22 3/4	57.8
7 3/8	23 1/8	58.7
7 1/2	23 1/2	59.7
7 5/8	23 7/8	60.6
7 3/4	24 1/4	61.6
7 7/8	24 5/8	62.6
8	25	63.5

1.4.2.10 Accessories. Any optional devices fitted to the headgear shall not create a hazard to the wearer nor shall they decrease the protection afforded by the headgear.

1.4.2.11 Identification Markings. Each headgear conforming to the requirements of this standard shall have the following identification markings:

- (a) A seal on the outer surface of the shell designating the class of headgear. This identification marking shall be permanently molded as part of the headgear shell.
- (b) On the underside of the peak or brim, in the front of the headgear, in letters at least 3/32 inch (2.5 mm) high, the following information shall be permanently molded, stamped, branded, engraved or etched into the headgear shell: class of headgear (example: "Class 2 - Medium Duty"), manufacturer's name, model designation, month and year of manufacture (example: "June 74" or "6/76"), and recommended cleaning agent ("clean with . . .").

1.4.2.12 Warning Label. Permanently affixed on the inside of the headgear shall be a durable label containing the following warning in letters at least 1/16 inch (1.6 mm) high:

"This helmet must be properly adjusted and secured to the head in order to provide protection.

If this helmet has been struck a severe blow return the helmet to the manufacturer for competent inspection or destroy and replace the helmet."

1.4.2.13 Instructions. When sold, each headgear shall be supplied with instructions which shall:

- (a) Provide a procedure (which may include diagrams) explaining to the user, the proper method of fitting and adjusting the headgear to the head.
- (b) Provide direction for visually examining the headgear to determine the necessity of replacement and/or repair of the entire headgear or parts thereof in order to maintain minimum performance levels.
- (c) Provide direction for cleaning, disinfecting, maintaining and replacing parts of the headgear. Those parts of the headgear which require replacement for proper maintenance shall be able to be replaced without the use of special hand tools or power tools.
- (d) Provide direction to the user for placing his personal identification on the headgear in a permanent manner.
- (e) State the name and address of the manufacturer.

1.4.2.13 Instructions - (Continued)

These instructions shall be attached to the headgear at the time of sale and in such a manner such as not to cause damage to the headgear when removed by the user.

1.5 Performance Requirements

Industrial head protective devices shall meet the following physical performance requirements.

1.5.1 Impact Attenuation. When mounted on a test headform/drop arm assembly and dropped in a guided fall from a predetermined height on to a rigid steel anvil, the acceleration - time history of the impact, measured at the headform center of gravity of the headform shall be within the impact attenuation requirements of the headgear as follows:

1.5.1.1 CLASS 1 - Maximum Duty Headgear. When mounted on an impact test apparatus and dropped from a height of 72 inches (183 cm):

(a) Onto a hemispherically shaped anvil in the apex area, the Head Injury Criterion shall not be exceeded (HIC F 1000).

(b) Onto a flat anvil impacting at any point above the reference plane, the Head Injury Criterion shall not be exceeded (HIC F 1000).

1.5.2 Penetration Resistance. When mounted on a rigid test headform and struck by a penetration striker weighing 1 kilogram (2.2 pounds) having a point with an included angle of 30° and a tip radius of 0.019 inch and dropped in a guided fall onto the outer surface of the test headgear, the striker tip shall not contact the surface of the test headform during penetration. The penetration striker drop heights for the various classes of headgear shall be as follows:

1.5.2.1 CLASS 1 - Maximum Duty Headgear. The striker shall be dropped from a height of 118.1 inches (3 m) onto any point above the reference plane.

1.5.3 Electrical Test. When tested for dielectric strength all industrial and firefighter's headgear shall withstand 30,000 volts (root mean square), AC, 60 Hertz, and when 20,000 volts is applied for three minutes the leakage shall not exceed 9 milliamperes.

1.5.4 Flammability. When tested for flammability in accordance with ASTM 635, no portion of the shell of CLASS 1 headgear shall burn at a rate greater than 3 inches per minute (7.6 cm/min.).

1.5.5 Water Absorption. When industrial and firefighter's headgear are pre-conditioned in a water bath for a period of 24 hours, the headgear shall not absorb more than 5 percent water by weight.

- 1.5.6 Retention Test. When a force is applied to the fastened chin strap by means of a mechanical chin structure for a period of one minute, the chin strap deflection shall not exceed 1 inch (2.5 cm). The force applied to CLASS 1 chin straps shall be 100 pounds (449 newtons).
- 1.5.7 Weight. The maximum weight of industrial headgear shall be:
CLASS 1 - 18 ounces (510 gm)
- 1.5.8 Environmental Exposures. CLASS 1, headgear shall withstand an environment consisting of a temperature range from 14°F (-10°C) to 160°F (63°C) and water immersion at 77°F (25°C). No portion of the headgear shall become loosened or dislodged nor shall the headgear performance be degraded as a result of this exposure.

2.0 TESTING STANDARD FOR INDUSTRIAL HEAD PROTECTIVE DEVICES

2.1 Scope and Purpose. This standard describes the test methods, procedures and equipment for the testing of industrial head protective devices.

2.2 Samples

2.2.1 Condition and Attachments. For all testing, protective headgear shall be taken in the condition as offered for sale, and shall be accompanied by all attachments (other than eye, ear, respiratory, winter liners or other protective devices) normally sold with the protective headgear. All attachments necessary for compliance with the minimum levels of performance shall be installed on the helmet during testing.

2.2.2 Number of Samples. Four samples are required for testing. Each test sample, following preliminary preparation and exposure to respective environmental conditioning as described in paragraph 2.5 shall be subjected to all tests and visual observation set forth in Table 2.

These four samples shall be mechanically identical and shall comprise a test sample set. Failure of any one headgear of the set to conform to the minimum performance requirements set forth herein shall constitute a failure of the test sample set to comply with this standard.

2.3 Reference Marking

2.3.1 Headband circumference and other adjustable suspension components of the test headgear shall be adjusted using manufacturer's adjusting procedures and complete test headgear shall be placed on a reference headform.

2.3.2 The sample headgear shall be placed on a firmly seated reference headform having its basic and reference planes horizontal.

2.3.3 The headgear shall be centered laterally and positioned vertically in accordance with the manufacturer's positioning index.

2.3.4 A line on the outer surface of the headgear shall be drawn 1 inch (2.5 cm) above and parallel to the reference plane of the test headform. The line shall hereinafter be called the test line. The surface of the headgear shall no be scratched or otherwise damaged as a result of this marking.

2.4 Order of Testing

All headgear shall be identified, marked, conditioned and tested according to the schedule shown in table 2. Tests to be conducted in ascending numerical order for each sample.

T A B L E 2
ORDER OF TESTING

TEST	S A M P L E D E S I G N A T I O N			
	A	B	C	D
	AMBIENT CONDITION	LOW TEMPERATURE CONDITION	HIGH TEMPERATURE CONDITION	WATER IMMERSED CONDITION
Visual Examination and Weight	1	1	1	1
Water Absorption	N/R	N/R	N/R	2
Impact	2	2	2	3
Dielectric	N/R	N/R	N/R	4
Penetration	3	3	3	5
Retention	4	4	4	6
Flammability	5	5	5	N/R

NOTE: N/R = No test required for the sample.

2.5 Conditioning of Test Samples

2.5.1 Samples. (CLASS 1 - Headgear)

2.5.1.1 Sample A - Ambient Condition. Sample A shall be conditioned in the following environment:

- Temperature: 70 - 85°F (22-30°C)
- Relative Humidity: 30 - 70 percent

for a period of not less than 12 hours prior to testing.

2.5.1.2 Sample B - Low Temperature Condition. Sample B shall be conditioned in a temperature environment of 14°F (-10°C) \pm 3.6°F (2°C) for a period of not less than 12 hours nor more than 24 hours prior to testing.

2.5.1.3 High Temperature Condition.

2.5.1.3.1 Sample C - High Temperature Condition.

Sample C headgear shall be conditioned in a temperature environment of 122°F (50°C) \pm 3.6°F (2°C) for a period of not less than 12 hours nor more than 24 hours prior to testing.

2.5.1.4 Sample C - Water Immersed Condition. Sample C shall be completely submerged in a tank of sufficient capacity filled with tap water held at a temperature of 77°F (25°C) \pm 9°F (5°C) for a period of not less than 24 hours nor more than 36 hours.

2.5.2 Time of Conditioning. Prior to testing, the sample headgear shall have remained at the specified environmental conditions for the minimum periods as specified in paragraph 2.5.1.

Testing shall begin immediately after removal from the conditioning environment. During testing, the maximum time during which the headgear may be out of the conditioning environment shall not exceed three minutes. It must then be returned to the conditioning environment for a minimum of 15 minutes before being again withdrawn. This process must be continued until all of the tests on the headgear have been completed.

Cumulative conditioning time for any one sample shall not exceed the values as specified in paragraphs 2.5.1.1, 2.5.1.2, 2.5.1.3.1, and 2.5.1.4.

2.5.3 Conditions of Test. Ambient environmental conditions, as specified in paragraph 2.5.1.1, shall prevail throughout the period of testing.

2.6 Impact Attenuation Tests

2.6.1 Requirements. Impact attenuation shall be measured by determining imparted acceleration to any appropriately instrumented standard headform dropped in a guided fall vertical within 0.5 inch per 15 feet (13 mm per 460 cm) from a predetermined height upon a fixed rigid anvil base.

2.6.1.1 CLASS 1 - Maximum Duty Headgear. When mounted on an impact test apparatus and dropped from a height of 72 inches (183 cm):

- (a) On to a hemispherically shaped anvil impacting at the apex area, the computed value of the Head Injury Criterion shall not be exceeded.
- (b) On to a flat anvil impacting at any point above the test line, the computed value of the Head Injury Criterion shall not be exceeded.

2.6.2 Impact Test Apparatus. Test apparatus for impact attenuation should consist of headform and drop assembly utilizing frictionless linear vertical guides.

2.6.2.1 Headform.

2.6.2.1.1 Dimensions. Standard headforms shall be used in all tests.

2.6.2.1.2 Headform Center of Gravity. The center of gravity of the headform including the drop carriage shall lie within a cone with axis vertical and forming a 10 degree included angle with the apex of the angle at the point of impact.

2.6.2.1.3 Headform Weight. The combined weight of the drop carriage and instrumented headform shall be as follows:

<u>Headform Size</u>	<u>Weight</u>
I	8.9 + 0.2-0 pounds (5 + 0.091-0 kg)
II	11.0 + 0.2-0 pounds (5 + 0.091-0 kg)
III	13.4 + 0.2-0 pounds (5 + 0.091-0 kg)

The headform supporting assembly shall weigh not more than 20 percent of the total drop assembly weight.

2.6.2.1.4 Headform Material. Test headforms for impact testing are to be constructed of magnesium alloy (K-1A) or equivalent and shall exhibit no resonant frequencies below 3,000 Hz.

2.6.2.2 Anvils. The flat steel anvil shall have a 5 inch (127 mm) minimum diameter and the hemispherical steel anvil shall have a 1.9 inch (48 mm) radius.

Anvils shall be made of stainless steel (AISI 303) and have a surface roughness not in excess of 63 m in., RMS.

2.6.2.3 Back up of Anvil

The steel anvil shall be backed up with a concrete or steel mass of at least 300 pounds which shall be faced with a steel plate of 1 inch (2.5 cm) minimum thickness and 1 ft.2 (0.1 m²) minimum surface area.

2.6.2.4 Acceleration Measurement. Test headform acceleration shall be measured by means of a uniaxial piezoelectric accelerometer, appropriate signal conditioning equipment and an acceleration - time recording system. The acceleration data channel, including all instrumentation from and including the accelerometer up to and including any analysis and recording procedures that may alter the frequency content of the data, shall comply with SAE Recommended Practice J211a requirements for channel Class 1000.

2.6.2.4.1 Accuracy. The instrumentation system used to measure acceleration shall have an inaccuracy of less than + 7%, RMS, including reading error. Readings shall not be corrected for system accuracy. Acceleration samples for data analysis shall be sampled at a rate of 200 micro-seconds or shorter.

2.6.2.4.2 Acceleration Measurement System Components. The following items shall comprise the acceleration measurement system:

(a) Accelerometer. The accelerometer shall be mounted at the center of gravity of the test headform and supporting assembly with the sensitive axis aligned to within 5° of true vertical when the headform is in the impact position.

2.6.3 Impact Test Procedure.

2.6.3.1 Equipment Warm-Up. All equipment shall be turned on and allowed to warm up for at least 30 minutes, or until equilibrium is reached, whichever time is greater, prior to testing.

2.6.3.2 System Check. Prior to and following the impact testing of headgear a series of three pretest and three post test system check drops shall be conducted by dropping the headform/cross arm from a height of 48 inches (122 cm) on to an MEP* pad. For each system check impact, the headform shall be positioned such that the apex of the headform strikes the center of the MEP. The acceleration - time

* 1" Open Blue Modular Elastomer Programmer, MTS Systems, Inc., or equivalent.

2.6.3.2 System Check - (Continued)

history of each drop shall be recorded. Prior to the recorded pre-test and post test system check drops, a series of three unrecorded drops will be made on to the MEP. Therefore, there shall be a total of six pretest drops, the last three of which shall be recorded and six post test drops, the last three of which shall be recorded. The time between all system check drops shall be two minutes.

The MEP shall be securely attached to the anvil base to assure that it does not shift position prior to or during impact. The vertical centerlines of the accelerometer and the MEP shall be coincident.

2.6.3.3 Impact Velocity. The velocity of the headform/drop arm assembly shall be recorded for each impact test drop. No impact velocity shall deviate by more than 5% of the theoretical impact velocities.

2.6.3.4 Mounting of Samples. Prior to each test fix the headgear on the test headform in accordance with paragraphs 2.3.1, 2.3.2, and 2.3.3. Secure the helmet so it does not shift position prior to impact during testing. The chin strap of the headgear or adhesive tape may be used for this purpose. Chin strap or tape forces used to secure the headgear to the headform shall not distort the shape of the headgear.

2.6.3.5 Height of Drop. The drop height shall be as measured from the uppermost part of the anvil to the impact site on the headgear. A suitable measuring rod of 72 inches (183 cm) (± 0.1 inch; ± 2.5 mm) may be used for this purpose. The vertical centerline of the accelerometer shall be coincident with the vertical centerline of the anvil prior to impact.

2.6.3.6 Calibration Signal. Prior to each impact, no less than two short duration (approximately one second) calibration signals of 300 g magnitude shall be inserted into the system input (accelerometer output), and shall be recorded as a reference for data analysis.

2.6.3.7 Testing. Each headgear shall be dropped from the heights as stated in paragraph 2.6.1.

Each headgear shall be impacted at five locations above the test line. These shall include one impact in the apex area and four impacts at sites above the test line but not in the apex area. Impact sites shall be separated by a distance of not less than $1/5$ the outer circumference of the headgear at the test line.

2.6.3.8 Record. The acceleration-time histories of each impact shall be recorded.

2.6.3.9 System Check. If the average of the three pretest peak acceleration values differs from the average of the three post-test peak acceleration values by more than 10%, the impacts conducted on the headgear shall be invalid. Additional impact test samples required due to invalidated data may be submitted for impact tests after being exposed to the appropriate environmental conditions.

2.6.3.10 Breakage. If as a result of impact testing the sample headgear is rendered incapable of withstanding further testing, the headgear shall be considered as failing the impact test and such a failure shall be reported. It is permissible, however, to continue testing on samples which appear structurally weakened.

2.6.4 Impact Test Data.

2.6.4.1 Head Injury Criterion. Impacts above the reference of CLASS 1 headgear shall be evaluated by determining the average acceleration during any time interval of the impact, raising this average acceleration to the 2.5 power and multiplying it by the length of the interval in seconds, which may be expressed mathematically as:

$$\left[\frac{\int_{t1}^{t2} a dt}{t2 - t1} \right]^{2.5} (t2 - t1)$$

Where "a" is the headform acceleration, as determined from the reference calibration signal, expressed as a multiple of "g" (acceleration due to gravity) and t1 and t2 are two points in time during the impact. Acceleration data points used for the solution to the above formula shall be selected a maximum of every 200 microseconds during the pulse. Computed values of the above formula in excess of 1000 shall be cause for failure.

2.7 Penetration Resistance Test

2.7.1 Requirements. The penetration test shall be conducted by dropping a test striker on to a test headgear, the striker being dropped in a guided fall with its axis aligned vertically and in a direction perpendicular to the outer surface of the headgear.

2.7.1.1 CLASS 1 - Maximum Duty Headgear. The striker shall be dropped from a height of 118.1 inches (3 m) on to any point above the test line.

2.7.2 Penetration Apparatus.

2.7.2.1 Penetration Striker. The weight of the penetration test striker shall be 1.00 + 0.1, -0 pound (0.4536 Kg). The point of the striker shall have an included angle of 30 degrees + 0.5 degrees and a cone height of not less than 1.5 inches (38 mm). The hardness of a striking tip shall be a minimum of 60 Rockwell (Scale C). The striker tip shall have a radius of 0.019 + 001 inch (1 mm) and shall be electrically conductive.

2.7.2.2 Penetration Test Headform. Headforms used for penetration are to conform to standard headform dimensions and may be made of aluminum or magnesium. Prior to penetration testing, the headform shall be smooth. The surface of the test headform shall be electrically conductive. The headform shall be backed up with a concrete or steel mass of not less than 100 pounds.

- 2.7.2.3 Contact Sensor. The system shall be able to detect contact between the headform and striker of at least one millisecond duration.
- 2.7.3 Penetration Test Procedure.
- 2.7.3.1 Mounting of Samples. Prior to each test, fix the helmet on the test headform so that the test line is positioned in accordance with paragraph 2.3.2. Secure the helmet so that it does not shift position prior to penetration.
- 2.7.3.2 Testing. Each headgear shall be penetration tested in three locations above the test line. These shall include one penetration in the apex area and two penetrations at sites above the test line but not in the apex area. The penetration drop heights for the various classes of headgear shall be as stated in paragraph 2.7.1.
- 2.7.4 Penetration Test Data. Evidence of contact between the striker and the headform shall be reported as a failure.
- 2.8 Electrical Test
- 2.8.1 Requirements. When tested for electrical insulation, the headgear shall withstand 30,000 volts (RMS), AC, 60 Hz and when 20,000 volts is applied for three minutes the leakage shall not exceed 9 milliamperes.
- 2.8.2 Electrical Test Apparatus.
- (a) Vessel - A vessel, containing fresh tap water, of sufficient size to submerge an inverted helmet shell to within 1/2 inch of the test line.
 - (b) Frame - A frame for suspending the test specimen in the water.
 - (c) Power Supply - A source of 60-Hertz alternating current of 30,000 volts (Root Mean Square).
 - (d) Wiring - Wiring and terminals for application of voltage across the crown of the test specimen.
 - (e) Voltmeter - A voltmeter having a range of 0 - 30,000 volts (2% Full Scale Accuracy).
 - (f) Milliammeter - A milliammeter having a range of 0 - 75 ma (2% Full Scale Accuracy).
- 2.8.3 Electrical Test Procedure.

- 2.8.3.1 Preparation of Samples. Where it is evident that the sample helmets have a protective coating over the basic material, the exterior surface of the shell shall be abraded until the basic material is exposed using a No. 60 grit garnet paper.
- 2.8.3.2 Mounting of Samples. The inside of the helmet shell (without suspension or accessories), after having been submerged in fresh tap water for 24 hours and then surface dried, shall be filled with fresh tap water to within 1/2 inch of the junction of the brim with the crown, or whatever level is required to prevent flashover at the voltage tested. The shell shall then be submerged in the same type of water to the same level as the water on the inside of the shell. The voltmeter and milliammeter shall be attached to the circuit.
- 2.8.3.3 Procedure. The voltage shall be increased to 30,000 volts at the rate of 1000 volts per second. The voltage shall then be decreased to 20,000 volts at a rate of 1000 volts per second and shall be maintained at this level for three minutes. Leakage current shall then be recorded.

2.9 Water Absorption Test

- 2.9.1 Water Absorption Requirements. After conditioning in water for a period of 24 hours, the test headgear shall not have absorbed more than 5% water by weight.

2.9.2 Apparatus

- 2.9.2.1 Water Immersion Tank. A water immersion tank as specified in paragraph 2.5.1.4 shall be used.

- 2.9.2.2 Measurement. A suitable scale having an accuracy of ± 2 gm shall be used to weigh the conditioned and unconditioned headgear.

2.9.3 Procedure.

- 2.9.3.1 Preparation of Samples. Where it is evident that the sample helmets have a protective coating over the basic material, the exterior surface of the shell shall be abraded until the basic material is exposed using No. 60 grit garnet paper.

- 2.9.3.2 Conditioning. Prior to conditioning, the sample headgear shall be weighted.

The headgear shall be submerged in the water tank for a period of 24 hours. After removal, the headgear shall be freely suspended in the normal wearing position and allowed to drip dry for a maximum period of one hour.

- 2.9.3.3 Weighing. Immediately following the drying procedure, the headgear shall be weighed.

2.9.4 Water Absorption Test Data. The percentage increase in weight during immersion shall be calculated to the nearest 0.05 percent as follows:

$$\text{Increase in weight, percent} = \frac{(\text{wet weight} - \text{conditioned weight})}{\text{conditioned weight}} \times 100$$

A percent increase greater than 5% shall be cause for failure.

2.10 Flammability Test

2.10.1 Requirements. When tested in accordance with ASTM D635-1969, the shells of CLASS 1 headgear shall burn at a rate not greater than three inches per minute. The chin strap shall be tested in accordance with ASTM D568-1972.

2.10.2 Procedure. The procedure as set forth in ASTM D635-1969 and ASTM D568-1972 shall be followed except that three samples shall be cut from the shell and the chin strap.

2.10.3 Data. The burning rate or evidence of self-extinguishment shall be reported for each sample.

2.11 Retention System Test

When a force is applied to the fastened chin strap by means of a mechanical chin structure for a period of one minute, the chin strap deflection shall not exceed 1 inch (2.5 cm). The force applied to CLASS 1 chin straps shall be 100 pounds (45 kg).

2.11.1 Retention Test Apparatus.

2.11.1.1 Headform. A rigid headform conforming to the basic test headform dimensions shall be used.

2.11.1.2 Mechanical Chin Structure. The mechanical chin structure shall consist of two metal rollers 1/2 inch (12.5 mm) in diameter and centers three inches (75 mm) apart.

2.11.2 Retention Test Procedure. The headgear is mounted on the test headform and the chin strap is passed through the rollers and secured. An initial force of 10 pounds (44.5 newtons) is applied to the chin strap and the distance between the apex of the headgear and the rollers is measured. The force is then gradually increased to 100 pounds (445 newtons) and held steady for one minute after which a second measurement is recorded.

2.11.3 Retention Test Data. The distances from the apex of the headgear to the rollers at initial load and at maximum load are recorded and their difference is reported as the chin strap elongations. Elongations in excess of 1 inch (2.5 cm) are cause for failure.

2.12 Equipment Calibration

At the time of the test, all test equipment must have been calibrated with standards traceable to the National Bureau of Standards. (In accordance with ASTM D2865-71).

3.0 USER'S STANDARD FOR INDUSTRIAL HEAD PROTECTIVE DEVICES

3.1 Scope and Purpose

This standard is designed to describe how industrial head protective devices are to be properly selected, used and maintained.

3.2 Selection of Industrial Protective Headgear

3.2.1 Applications.

3.2.1.1 Classes. Industrial headgear governed by this standard are of the following class:

CLASS 1 - Maximum Duty Industrial Head Protective Devices

3.2.1.2 Occupational Hazards. The hazards in the working environment determine the type of head protective which should be worn in order to protect from possible accidental head injury.

Selection. The following chart (table 3) should serve as a guide in the selection of the proper head protective device to meet the needs of the worker. The workplace should be surveyed and where hazards are known to exist, the worker shall be issued the appropriate class of headgear.

Headgear which meet the requirements of this class may be identified by the circled numeral appearing on the forehead of the headgear. These are:

1 - CLASS 1 - Maximum Duty Headgear

The class of headgear may also be determined by inspection of the underside of the peak or brim where the following information exists:

- . class of headgear
- . manufacturer's name
- . model designation
- . date manufactured
- . recommended cleaning agent

T A B L E 3
SELECTION OF HEADGEAR

	<u>HAZARD</u>	<u>APPLICABLE CLASS</u>
<u>FALLS</u>	Worker falls to different level	1
	Worker falls on same level	1
<u>STRUCK BY OBJECTS</u>	Worker struck by falling objects	1
	Worker struck by flying objects of large mass	1
	Worker struck by flying objects of small mass	1
	Worker struck by moving objects of large mass	1
	Worker struck by moving objects of small mass	1
	Worker striking immovable objects	1
<u>STRUCK AGAINST OBJECTS</u>		

- 3.2.1.3 Cautions on Selection. A competent safety inspector should be consulted prior to selection. The safety inspector is referred to sections 1 and 2 of this standard for a quantitative description of the abilities and limitations of the helmet.

Headgear covered by this standard are intended for general industrial use. Applications requiring unique or specialized protection should be discussed with the head protective device manufacturer.

- 3.2.1.4 Electrical Protection. All headgear governed by this standard are made of high voltage electrically insulating materials and are suitable for limited protection from electrical shock.
- 3.2.1.5 Limitation of Protection. The method of selection of industrial and firefighter's headgear shall not be construed to mean that the specified class of headgear will protect the wearer from any and all head injury as a result of an accident of the type described. The performance requirements which have been described from the hazard classifications are intended to reflect optimized circumstances and have been limited by comfort factors and current protective helmet technology.

3.3 Use of Industrial and Firefighter's Protective Headgear

Industrial protective headgear are safety devices which must be properly adjusted and cared for in order to function as intended.

- 3.3.1 Cautions on Use. No headgear can protect from all foreseeable accidents. In order for the headgear to be effective, it must be securely fitted to the head.

Protective headgear are so constructed that the energy of a severe blow is absorbed through partial destruction of the headgear. Though the damage may not be visible to the eye, if it has been struck severely, return the headgear to the manufacturer for competent inspection or destroy and replace it.

The materials in the headgear may be adversely affected by certain chemicals or environmental conditions. The manufacturer should be consulted if severe chemical or environmental exposures are anticipated.

- 3.3.2 Fitting and adjusting. Industrial headgear should be adjusted by following the manufacturer's instructions accompanying each headgear at the time of purchase.
- 3.3.3 Chin Strap. The headgear is supplied with a chin strap for securing the helmet to the head. In order for the headgear to function, it must be securely in place at the time of an accident. This is particularly important when a considerable risk of falling is present.

- 3.3.4 Comfort. Industrial protective headgear are designed by the manufacturer for maximum wearer comfort. At no time should the wearer attempt to alter the structure of the headgear to improve comfort. If, in service, the headgear is found to be uncomfortable, the manufacturer should be consulted for replacement or modification of the headgear.

These recommendations apply to such practices as: drilling holes in the shell to increase ventilation which may result in structurally weakening the headgear and reducing electrical and hot liquid splash protection, or removing suspension straps which may cause complete or partial loss of impact protection. At no time should protuberances be flattened to reduce discomfort.

The industrial headgear is a compact unit of inter-relating protective components and is almost devoid of features which lend only cosmetic appeal. As such, it should be treated as a protective system. Alteration of any one component may greatly reduce the protection afforded by the headgear as a whole.

- 3.3.5 Personal Identification. The user shall follow the instructions explaining the method of personal identification set forth by the manufacturer in the instruction sheet supplied with each headgear.

At no time should the user scratch, burn or otherwise modify the headgear in order to place a personal identification marking on the headgear.

- 3.3.6 Decals and Stick-On Labels. The user should be cautioned that the adhesives used in decals and stick-on labels may adversely affect the materials in the headgear. If such marking is deemed necessary by the user, the manufacturer should be consulted prior to affixation of any such decal or label.

- 3.3.7 Painting. To avoid chemical attack, the user should avoid painting the headgear unless otherwise notified by the manufacturer.

- 3.3.8 Electrical Insulation. Industrial and firefighter's protective headgear, if properly used and maintained, will offer limited protection from electrical shock. It should be noted that the maximum voltage against which the headgear will protect the wearer will be a function of the characteristics of the electrical hazard and ambient environmental conditions. Therefore, the test voltages do not imply safe operating voltages and the local use of the headgear as an electrical insulator is beyond the scope of this standard.

3.4 Maintenance of Industrial and Firefighter's Headgear

- 3.4.1 Use of Instructions. Supplied with each headgear at the time of sale will be an instruction sheet from the manufacturer explaining the proper method of visually inspecting the headgear for damage and wear and the steps which must be taken to rectify these problems.

- 3.4.2 Timetable for Inspection. Each headgear should be inspected at least every six months. This period should be shortened depending upon the severity of use. There are, however, conditions which should receive immediate attention. These are:
- (a) Shell Breakage or Fracture: If the headgear shell shows signs of fracture, breakage, holes or deep scratches, the headgear should be replaced.
 - (b) Softened, Warped or Dented Shell: If the headgear shell becomes soft or if its shape becomes distorted, the headgear should be replaced or returned to the manufacturer for competent inspection.
 - (c) Broken, Frayed or Cut Suspension Straps, Chin Strap or Nape Strap:
If the suspension straps, chin strap, nape strap or any other strap used to fasten the headgear to the head is found to be broken, frayed or cut, these should be repaired or replaced immediately.
- 3.4.3 Cleaning. Following the manufacturer's recommended cleaning method (instruction sheet) and cleaning agent (underside of peak or brim) each headgear should be cleaned periodically. The length of time between cleanings will be determined by the environment in which the headgear is used. It should be noted that frequent cleaning will complement other forms of personal hygiene requirements in the work place.
- 3.4.4 Disinfection. When headgear are used by more than one employee, the headgear should be disinfected prior to being issued to another employee. The method of disinfection should follow the manufacturer's recommendations.
- 3.4.5 Throw-Away Date. Unless done so by the manufacturer, no throw-away date has been established for the headgear. The necessity of replacement will be determined by the type and severity of use of the headgear.
- 3.4.6 Abuse of Headgear. Abuse will shorten the effective service life of the headgear and may reduce the level of protection afforded by the headgear when worn. Obvious abuses such as: sitting on the headgear, carrying materials in the headgear, storage of the headgear in hostile environments (such as the rear window ledge of an automobile or loosely placed in the trunk of the auto), use of the headgear as a work rest, or throwing the headgear about, must be avoided.
- In order to perform properly, industrial safety headgear should be used with the same respect given to other safety equipment.
- 3.4.7 Electrical Insulation. Under conditions of use where hazards of electrical shock and burn are frequently encountered, periodic electrical tests of the headgear may be necessary to insure continued protective capability.