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TECHNICAL REPORT ARLCB-TR-82037

THERMAL WARNING DEVICE PROGRAM

155mm M185 HOWITZER M109A1/A2/A3

JOHN E. BROWER

NOVEMBER 1982

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
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A Product Improvement Program was undertaken to provide a thermal warning device to measure the temperature of the M185 Howitzer tube forcing cone area from the tube outside diameter and provide a readout to the user at the breech end. This would warn the gun crew when a dangerous temperature level had been attained, as well as permit a higher rate of fire than current procedures allow.

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20. Abstract (Cont'd)

The plan was to adapt the thermal warning device from the 155mm M198 Howitzer to the 155mm M109A1/A2/A3 Howitzer. The major problem required developing a method to attach the temperature sensor to a cannon tube which recoils through concentric recoil bearings without reducing the fatigue life of the cannon. After a suitable attachment method had been developed and successfully tested, the program was terminated by ARRCOM because of funding priorities.

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INTRODUCTION

On 6 January 1975, Product Improvement Proposal (PIP) Number 1-79-05-2006 entitled "155mm M109A1 Thermal Warning Device" was submitted to ARMCOM (ARRCOM). The proposal received TRADOC concurrence per letter dated 3 December 1976 (CPT Gunn), was approved by ARMCOM and received initial funding on 1 April 1979 in accordance with standard PIP procedures.

The objective of the program was to provide a thermal warning device to determine the temperature of the M185 Howitzer tube forcing cone area and provide a readout to the user at the breech end. The program would adapt the mercury bulb Thermal Warning Device (TWD) designed for the 155mm M198 Howitzer with as few changes as possible. The TWD is intended to eliminate guesswork and inefficient cannon usage by actually measuring the tube temperature and visually warning the gun crew when a dangerous temperature level has been attained. Prior to submittal of this proposal during the Service Test of the M109A1, a cook-off occurred where the M119 propelling charge spontaneously ignited while the cannoneer was loading the primer resulting in injury to the cannoneer. Two similar incidents occurred during the Engineering Test. It was anticipated that the cook-off hazard would become more dangerous with the new XM203 propelling charge because it produces more heat and contains M30 propellant which is the most susceptible propellant to cook-off. Also, the XM203 is the longest propelling charge used in this weapon. It therefore extends furthest forward into the chamber where temperatures are higher. Knowledge of the forcing cone temperature would greatly reduce this hazard.

Since the M109A1/A2/A3 did not have a TWD, a conservative rate of fire was placed upon the weapon:

Charge 1-7	1 rd/min
Charge 8	1 rd/min for 60 min and 1 rd/3 min thereafter

When firing any combination of Charge 8 and lower charges, Charge 8 rates of fire apply. These rates are based on extreme conditions, are overly restrictive and difficult to follow. An equally poor method of determining a "hot" gun tube was defined as a tube that causes water placed just forward of the gas check seat to boil or steam off, or when the prescribed firing rate has been exceeded. With the TWD, more accurate temperature information would permit less restrictive rates of fire than the current procedures allowed resulting in increased availability of the weapon. Also, the TWD determines the temperature in the forcing cone area where the projectile contacts the gun tube. This is the area of concern and is about 40° warmer here than at the gas check seat. It is therefore possible for a gun crew to fire what is defined as a "cold" tube by the present method and follow cold tube misfire procedures when actually the tube is 79° (212°-173°+40°) beyond the melting point for high explosive filler (173°F) at the forcing cone.

PROCEDURE

All development work had been accomplished during the M198 Howitzer program. It only remained to apply the M198 TWD to the M185 Howitzer. The following is a list of design constraints which had been prepared for the TWD:

1. Weight: 10 lbs maximum

2. Size: Small enough to be mounted on the recoiling parts of any cannon currently being developed.

3. Physical Location:

a. Sensor: The sensor will be held against the exterior of the cannon tube. The actual location and manner of attachment will vary for each cannon model. These must be determined on an individual basis by the responsible design engineer based on applicable cannon/mount/ammunition criteria.

b. Indicator: The indicator must be located in a conspicuous position near the rear of the cannon where it can be easily seen by the crew.

4. Power Source: No power source will be considered available to operate the device except the thermal energy source.

5. Indication:

a. Range: -40°F to 800°F capability for the basic design.

b. Type: Fixed arcuate scale with rotating indicator which points to progressively higher temperatures as it rotates clockwise. Continuous monitoring of temperature with no "on-off" switch.

c. Legibility:

(1) The scale shall consist of black lines, letters, and numbers on a white background.

(2) Standard color coding is to be used to define specific regions in which the same warning instructions apply. (See Section 13).

(3) The crew must be able to read the device at a distance of three feet without standing in line with the recoiling parts.

(4) Night readings may be assisted by a small external light source such as a flashlight.

6. Operation Environment:

a. Ambient Temperature: -65°F to 145°F

b. Relative Humidity: 0 to 100%

c. Barometric Pressure: Any encountered in a world situation.

d. Precipitation: Any encountered in a world situation including rain, sleet, hail, snow, etc.

e. 375 g's recoil force accompanied by severe random vibration.

f. Field conditions of dust, dirt, mud, fresh and salt water, etc.

7. Shelf Life: 5 years

8. Operational Life: 5 years or 7,500 EFC rounds. (Recalibration or repair may be performed as necessary during this period).

9. Accuracy: ±5°F at the critical temperatures determined for each cannon.

10. Response Time: 99% of the external tube temperature change within 20 seconds.

11. Simplicity: The device must be simple enough to use at unit level without specialized training.

12. Reliability: The device will perform its specified functions with 99.99% reliability.

13. Color Coding:

a. A three color standard color-code system will be used which will be interpretted in the same manner for each cannon.

b. Colors/Interpretations:

(1) Green: Completely safe. No possibility of cook-off. Cold tube misfire procedures apply.

(2) Yellow: Cook-off can occur five minutes or more after loading. Hot tube misfire procedures apply.

(3) Red: Cook-off can occur within five minutes after loading. Do not load or fire cannon except in combat emergency.

14. Operational Checks: Appropriate scale markings must be present so that the crew may compare the indicated temperature of a cold tube (before firing) with the ambient temperature.

15. Calibration:

a. Initial calibration will be performed during manufacturing at either of the two temperatures specified in Section 13. The device will be checked for stated accuracy over full scale per Section 9.

b. Subsequent recalibration may be performed as necessary at DS or higher echelon maintenance levels. Any convenient temperature may be used and a full scale accuracy check is not required.

16. Repair: The device may be repaired or refurbished as necessary at a DS or higher level of maintenance.

At this time (March 1974) the EDO Corporation, College Point, New York submitted a technical proposal for an electronic thermal warning device. The device was designed to utilize seven (7) battery operated ferrite temperature sensors to indicate seven discrete temperature values. It included a readout device whi could give either the safe time to fire or tube temperature in seven interval The device had not been built or tested. The cost estimate was $985. After h debate, this proposal was dropped for the already proven mechanical device wh cost only $388. The additional advantage of continuous output was considered a necessary feature.

The mechanical TWD which had been developed for the M198 Howitzer consisted of a mercury filled stainless steel "bulb" (3/8 inch diameter) and a stainless steel "capillary" (5/32 inch diameter) which connects the bulb to a mechanical temperature indicator. The bulb and capillary assembly is manufactured by the Partlow Corporation, New Hartford, New York. The column of mercury within the bulb and capillary is capped by a piston-in-cylinder assembly providing linear movement directly relative to the temperature change. The piston is linked to a temperature dial indicating the tube temperature in the vicinity of the mercury bulb. (See Figure 1). The mercury bulb and capillary are mounted to the outside surface of the cannon tube and the temperature dial is mounted on the breech ring where it is easily seen by the gun crew. (See Figure 2). When mounted, the center of the mercury bulb is located approximately 36 inches forward of the rear face of the tube. This is directly over the tube forcing cone and forward parts of the

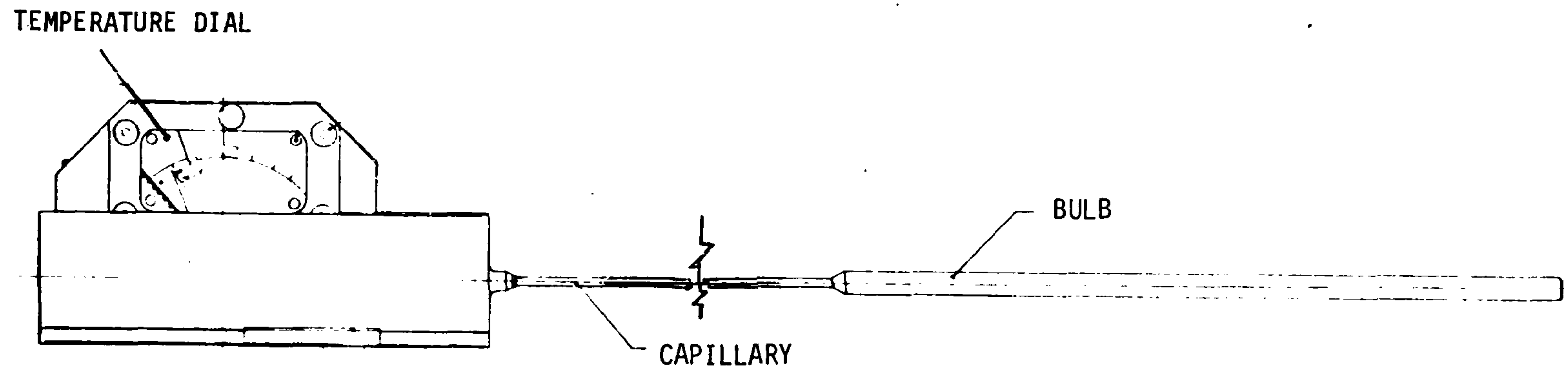

Figure 1 THERMAL WARNING DEVICE

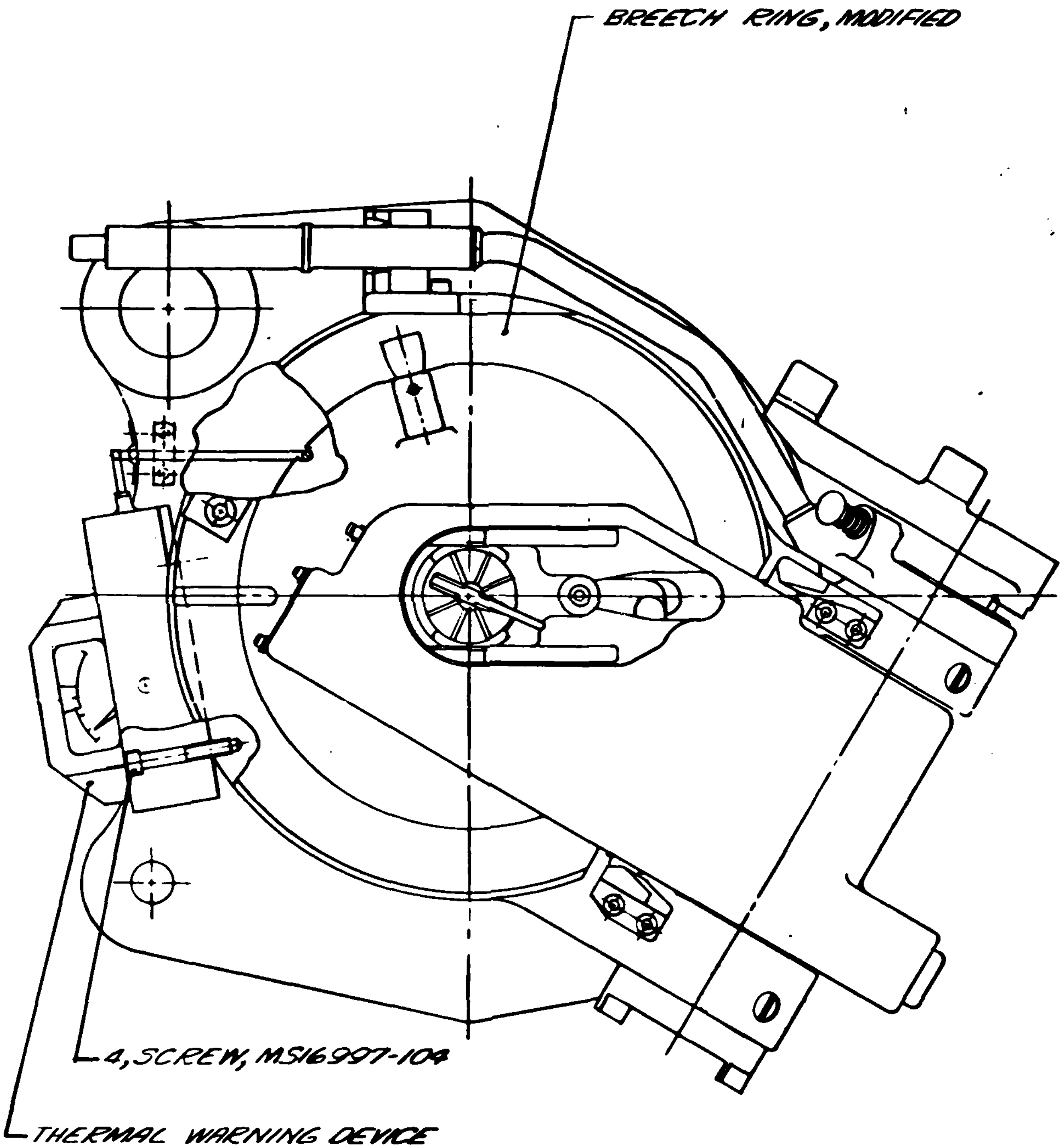

Figure 2 PROPCSED MOUNTING OF TEMPERATURE DIAL

zone 8 propelling charge. Since the mercury bulb is mounted to the outside surface of the cannon but the meaningful tube temperature is that of the bore, consideration is made for the difference between inside and outside tube surface temperatures. Using close to worst case conditions (propelling charges at 145°F, 10 mph wind velocity and -10°F ambient temperature), computer simulations were generated to predict inside tube surface temperature. From this, a TWD temperature reading was calculated below which cook-offs would probably occur only 0.5% of the time (350°F).[1]

The TWD temperature dial is divided into three color zones; green indicating a "cold" tube (0° to 170°F), yellow indicating a "warm" tube (170° to 350°F), and red indicating a "hot" tube (above 350°F). Each color zone has specific misfire procedures. If the outdoor temperature is expected to reach 100°F during the day, special hot weather misfire procedures apply. 300°F is the "hot" tube cut-off TWD reading during hot weather. This makes provision for the ammunition at a higher temperature prior to loading the weapon.

The installation of a TWD in the M185 Howitzer cannon tube requires the machining of a slot in the cannon tube outside surface to embed the mercury bulb and capillary below the outside surface. This is necessary for the M185 Howitzer because this cannon is mounted and recoils through concentric recoil bearings. The M198 Howitzer is mounted in a recoil mechanism which supports the cannon breech end on rails, leaving the top of the tube exposed. This allows external mounting of the TWD bulb and capillary. No slots are necessary for the TWD in the M198 Howitzer.

[1] Vottis, P.M., and Hasenbein, R.G., DRDAR-LCB-DA DF dated 23 August 1979, subject: Thermal Warning Device (TWD) for the M198 155mm Howitzer, ARRADCOM, Benet Weapons Laboratory, Watervliet, NY.

A design requirement is the machining of the slot into the M185 Howitzer tube must not reduce the fatigue life of the tube. It was necessary to design a slot with a cross section which did not produce a stress concentrator greater than that created by the recoil keyway. The fatigue life of the production tube is determined by cracks forming at the fillets of the keyway and progressing inward toward the bore. The first prototype slot design was of circular cross section for the mercury bulb (.395 inch depth) and semi-circular cross section for the capillary (.290 inch depth). The bulb and capillary were held in place with epoxy, which was filled into the slot after the bulb and capillary were installed. This prototype was tested at Aberdeen Proving Ground as a "piggy-back" to the Product Improvement Validation RAM M109/M203 test in November 1979. The prototype quickly proved to be unsuccessful since the epoxy is brittle and unable to accommodate the tube dilation imposed by the firing pressure and temperature. The epoxy chipped and broke away in some areas. Additionally, when the tube was returned to Benet Weapons Laboratory for in-house fatigue testing, it failed prematurely at the TWD slot after 2427 cycles @ 56000 psi (M203 charge pressures).

These failures required the complete redesign of not only the slot but also the method of securing the bulb and capillary within the slot. To reduce the stress concentration created by the mercury bulb slot, it was reduced in depth by .040 inch (10%) and increased in width. The cross-section of the capillary slot was also redesigned to be similar to that of the bulb slot but proportionally smaller. (See Figure 3). The principle behind this design change was recommended by the Research Branch, Benet Weapons Laboratory (BWL). Reducing the depth of the slot required a reduction in the diameter of the mercury bulb. The next smaller size standard bulb (5/16 inch diameter) replaced the original bulb.

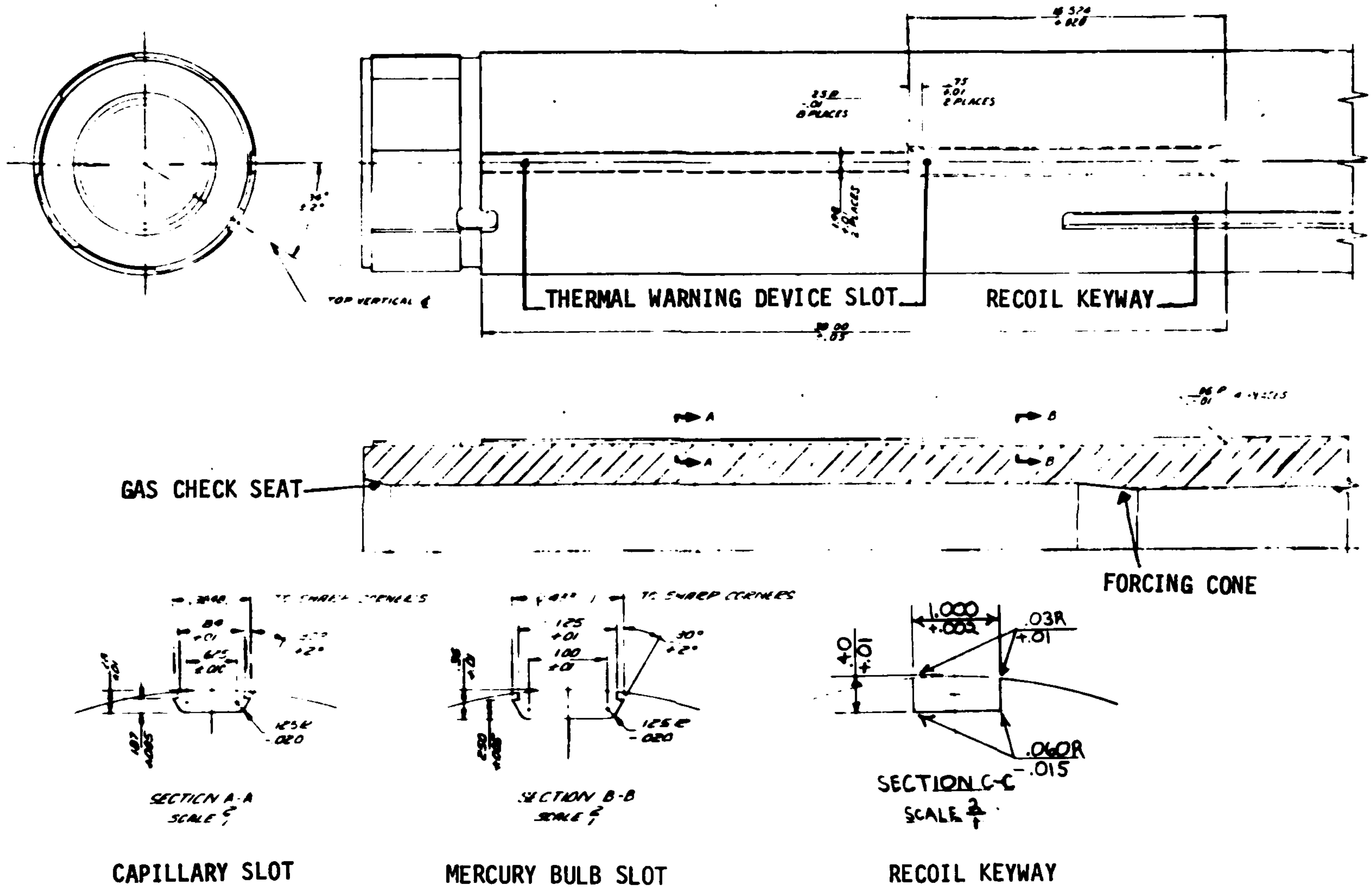

Figure 3 M185 HOWITZER TUBE BREECH END WITH THERMAL WARNING DEVICE SLOT

As an alternate means of securing the bulb and capillary, the use of a soft metal of low melting point such as lead to replace epoxy was considered but found to be unacceptable because of a phenomenon called "liquid metal embrittlement". During manufacture, a cannon tube is autofrettaged to increase fatigue life. This process creates high residual tensile stresses in the outer diameter of the tube. If one of the metals which cause embrittlement (lead, mercury, gallium, antimony and indium) contact the tube when they are in a liquid phase, the tube will become brittle and may crack. Trace amounts of such metals are sufficient to cause embrittlement.

Also considered were heat transfer cements such as Thermon T-85 Heat Transfer Cement (Thermon Manufacturing Company, San Marcos, Texas) but were not acceptable because, similarly to epoxy, become too brittle.

A mechanical means of securing the bulb and capillary was then investigated. Spring retainers were designed for both the bulb and capillary to fit into the slot over the bulb and capillary holding them against the gun tube. (See Figure 4). Annealed SAE 1075 spring steel of .020 inch thickness was used for the spring retainers and heat treated to Rc 35-40 after shaping. Axial movement of the bulb, capillary and spring retainers was prevented in both recoil and counterrecoil by the manner in which they were mounted within the slot and secured to the cannon.

To prevent movement between the bulb or capillary and the retainers, two methods were tested. The first was to solder the bulb and capillary to the retainers with high strength silver bearing solder (7% silver, 93% tin). Lead solder was not used due to its lower strength and possible liquid metal embrittlement to the cannon tube. The second method was the use of a filler material similar to the failed epoxy but substantially more resilient. General Electric Room Temperature Vulcanizing Silicone Rubber Cement (RTV 60) was selected because of its high melting point and ability to withstand 300% elongation.

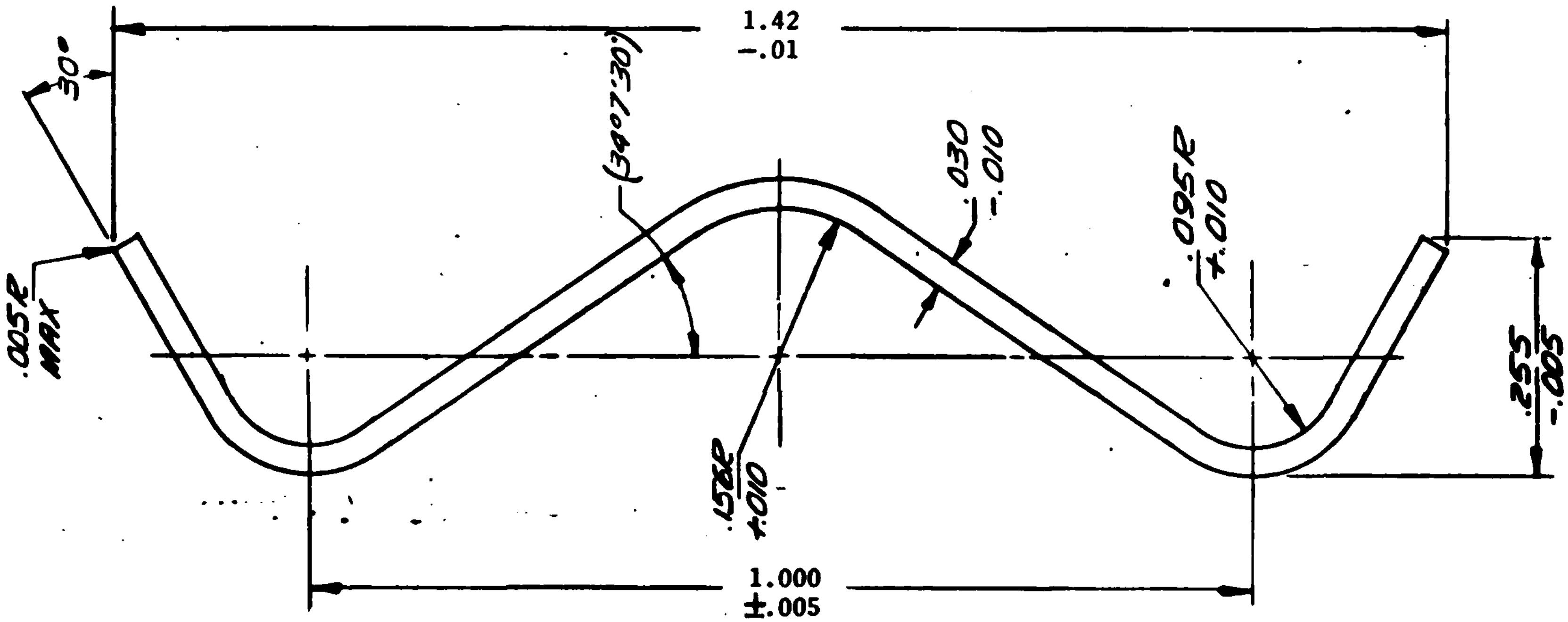

Figure 4   SPRING RETAINER FOR MERCURY BULB

During this time frame (May 1980) the Product Improvement Program to establish compatibility of the M203 propelling charge with the 155mm M109A2/3 Self Propelled Howitzer was not accepted for type classification. This was due to unfavorable results following a 4000 round test program to assess RAM-D characteristics of the weapon and blast and over pressure impact[2]. The M119 zone 8 propelling charge then became the maximum charge for this weapon. All subsequent testing regarding the TWD was conducted with the M119 charge. When the M203 propelling charge was not approved for use in the M109A1/A2/A3 Howitzer, the justification for adoption of the TWD was diminished.

The new design was tested in-house at Benet Lab as both a "C specimen" test to determine the affect on tube fatigue life and a "Drop" test simulating cannon recoil to test the method of physical attachment of the hardware.

The "C specimen" tests a section of the cannon tube two inches thick with a small opening machined completely through the specimen and directly opposite the stress concentrator being tested. (See Figure 5). The specimen is externally loaded to produce stresses which closely approximate the service stresses at any point in the specimen. Actual tube failures and simulation test results have agreed closely indicating these experiments are a good measure of actual tube behavior[3]. The results of this test indicated the life with the thermal device slot is a factor of 1.4 greater than the life with the keyway. It was concluded

[2]Merritt, MG, CG; ATSF-CD-MW teletype, 12 May 80, Ft. Sill, OK.

[3]Kapp, J.A. and Underwood, J.H., "An Interim Report of the Simulation Tests to Determine the Keyway Fatigue Life of the M185 Tube", ARRADCOM, Benet Weapons Laboratory, Watervliet, NY.

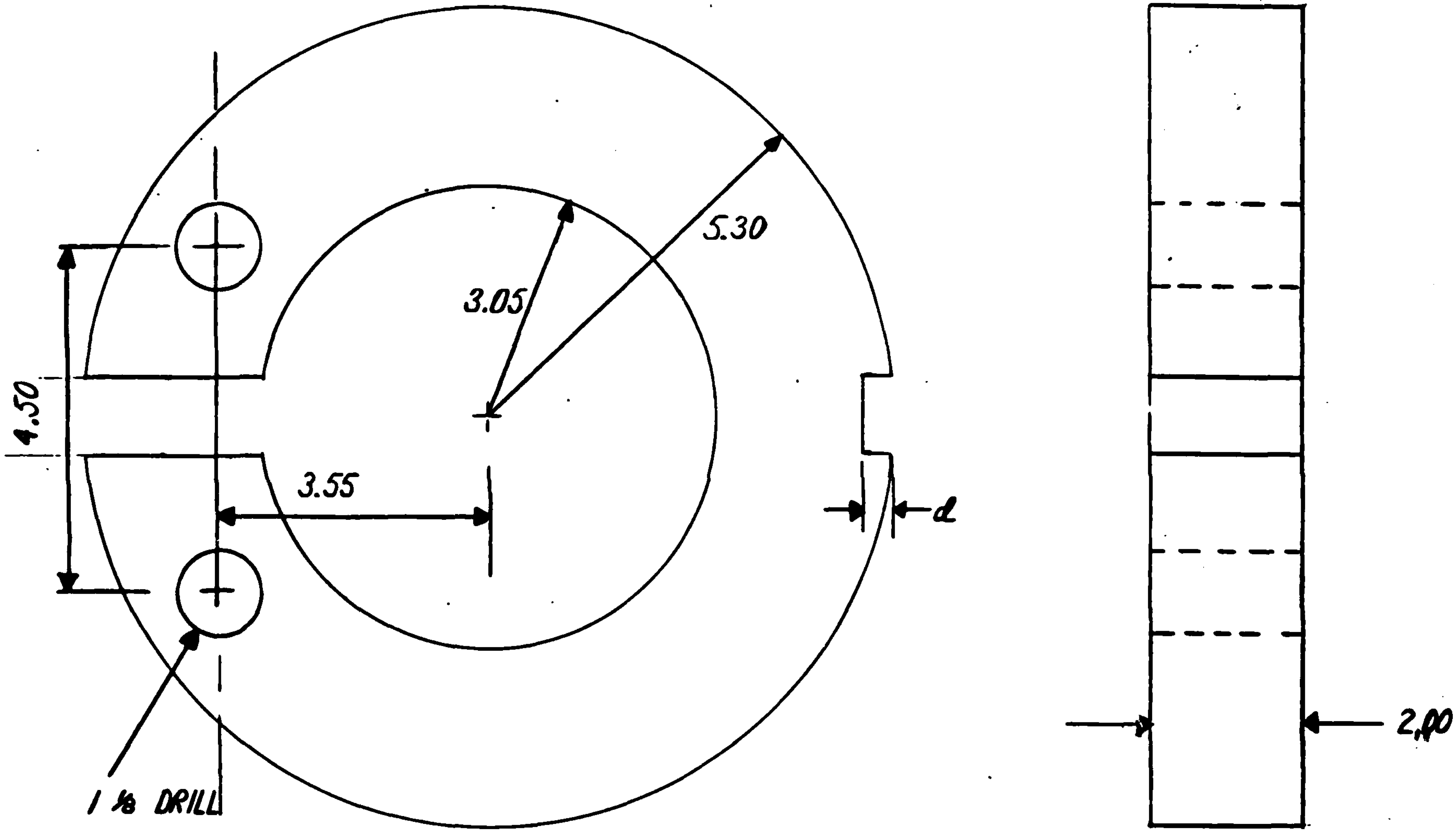

Figure 5 C SPECIMEN

that the stress concentration effect of the thermal device slot is less than that of the existing recoil keyway and the addition of the thermal device slot to the tube would have no large effect on the life of the tube[4].

The "Drop" test simulates cannon recoil using a standard Vari-Pulse Machine. A section of gun tube approximately three feet in length is taken from a cannon in the area of the TWD slot. The TWD is installed in the slot and the tube section mounted in the Vari-Pulse Machine. The inertial load of firing is simulated in the axial direction at both 250g and 300g (maximum for the M185 Howitzer) by raising the tube section to a pre-determined height. The section is then dropped upon a cushioned foundation which absorbs the inertial shock and measures it electronically. For this test, the TWD was cycled 300 times at 250g and 200 times at 300g and was conducted for both methods of securing the bulb and capillary to the retainers; solder and RTV60. The specimen was examined at regular intervals for TWD slippage or damage. No slipping or damage was detected during the test and both the solder and RTV60 performed successfully.

A TECOM evaluation of the TWD was conducted at Aberdeen Proving Ground between 9 January and 17 February 1981. The objectives of the TECOM test were to determine:

a. The dynamic response to heat input of the 155mm M185 Howitzer TWD.

b. TWD system integrity, adequacy of installation and safety through endurance firing.

c. Which of the two fastening methods is more effective.

d. The effects of accidental crimping on the accuracy of the TWD and any impact on safety.

[4]Underwood, J.H. and Brown, B.B., DRDAR-LCB-RM DF dated 10 Jul 80, subj: Fatigue Life Simulation Tests for Thermal Device Notch in M185 Tube, ARRADCOM, Benet Weapons Laboratory, Watervliet, NY.

The test involved firing 300 M119 zone 8 propelling charges with M107 projectiles. Both methods of securing the bulb and capillary to the retainers were tested for endurance. After all test firing was completed, a crimp safety check of the TWD was made in the physical test laboratory.

Prior to each method of installation to compare TWD readings with actual readings, six iron constantan thermocouples were installed in three equally spaced locations on either side of the mercury bulb temperature sensor to measure the axial temperature profile. During the course of installation and testing, some thermocouples were lost. These losses were anticipated and was the reasoning for placing the thermocouples on both sides of the temperature sensor. A manual temperature probe was also used to measure the chamber temperature at the origin of rifling.

Four firing phases were conducted. For each method of installation, 100 rounds were fired in one day, the cannon allowed to cool overnight, then fired 50 rounds the following day.

No problems with TWD system integrity or interference were noted in either method of installation. There were no safety problems and the TWD performed successfully. Correlation between the TWD and thermocouples was good. However, installing the TWD with the RTV 60 silicone rubber was awkward, messy and lengthy. The solder method proved superior due to quicker and easier TWD installation. Neither method caused any problems in mating the tube to the breech ring. TECOM therefore recommended the solder installation technique be adopted for the M109A1/A2/A3 Howitzer TWD.

One TWD was deliberately crimped at the capillary to observe adverse affects, if any. The TWD was placed in an oil bath and calibration checks run before and after crimping. No differences in temperature readings resulted[5].

Shortly after the successful completion of the TECOM test, the TWD program was subjected to the newly instituted "Independent Design Review" (IDR). The IDR is an ARRADCOM Large Caliber Weapon Systems Laboratory (LCWSL) Standing Operating Procedure (SOP No. 15-2 dated 26 Jan 81). The intention is to review the technical areas of all Large Caliber programs for design and interface considerations prior to submission of the program to the CCB for a fielding decision.

The IDR process involves the creation of a team of technology area experts selected from the Large Caliber community and headed by a chairperson proposed by the Applied Science Division, LCWSL. At the initial IDR meeting, the developer briefs the review team and makes available any information requested. Included are a physical and operational description, drawings and specifications, analysis, test data and results. Also reviewed were designs regarding heat transfer, impact on cannon, impact on system, producibility, ILS, reliability, maintainability, training, manuals, misfire procedures and safety.

From the above topics, the IDR team created 38 questions from 23 concerns which required formal detailed written responses. The responses provided to the IDR team were satisfactory and the final meeting and presentation to the Director of Large Caliber Weapon Systems Laboratory was successfully completed. The total cost of the IDR to the project was $7866 expended by the IDR team plus three months engineering time and funding.

[5]Taylor, H.J., "Final Report - Product Improvement Proposal (PIP) for 155mm M185 Howitzer Thermal Warning Device (PIP 1-79-05-2006)", TECOM Project No. 2-WE-205-185-098, Test Agency Report No. APG-MT-5509, US Army Aberdeen Proving Ground, Aberdeen, MD, March, 1981.

One important issue resulted from the IDR. This involved the effect on the breech ring from mounting the TWD temperature dial. A flat surface and four threaded holes are machined into the breech ring which could reduce the fatigue life. The developer agreed to investigate this issue.

Research of the TWD files revealed no studies on the fatigue effect of the four holes. Additionally, the PIP itself included no funds to perform a breech ring fatigue test. Correspondence with the Research Branch, BWL resulted in concern over the particular location of the bolt holes directly opposite the I.D. thread relief groove. This is the highest stressed region in this type of breech ring. A finite element analysis was not considered appropriate due to the physical complexity of the breech ring. Since there was no other suitable location on the breech ring to mount the temperature dial and the only alternative was to redesign the dial housing, further fatigue testing would be required before the TWD could be type classified on the M109A1/A2/A3 Howitzer.

To receive a "Safe Fatigue Life" for the modified breech ring, a six specimen test is required per TECOM agreement. The testing is conducted in-house by the Applied Mathematics and Mechanics Section, BWL. It involves pressure cycling a stub tube-breech ring-breech block combination in a manner simulating actual firing. The cost to perform this test was estimated at $281,000 plus additional funds for engineering support. The high cost is due to the hardware involved, i.e., three stub tubes are required for each breech ring at a cost of over $6,000 each plus the cost of breech rings and blocks. Also, the cost of the test operation itself is $17,000 per breech ring. A funding request was submitted to ARRCOM whose response was:

a. There are no PIP funds available for FY81 or FY82; earliest is FY83.

b. The user sees a need for the TWD in the M109A1/A2/A3 Howitzer but it is a low priority item and is not willing to pull funds from other programs.

Shortly thereafter, ARRCOM requested the developer to make a formal presentation, including funding requirements, to a Level II Configuration Control Board (CCB). Having accomplished this, the official CCB reply was a request for a written response, in more detail, regarding the same issues.

The CCB reply to the written response was a request for a second formal presentation to both a Level II and Level I CCB. This presentation would include all aspects of the program and focus on the breech ring problem and related costs.

A presentation was prepared which stressed the importance of a TWD and the dangers or hazardous situations which currently may occur on the M109A1 Howitzer but are prevented by the TWD on the M198 Howitzer if misfire procedures are properly followed. This argument, however, depended upon a high rate of fire (one round per minute) of adequate duration to raise the tube temperature to greater than 170°F. In normal training exercises this tube temperature is not achieved and during combat the TWD would have to be ignored regardless of the temperature reading. In view of this, plus the M203 propelling charge M109A1/A2/A3 incompatibility and the unavailability of immediate funds, the Level II CCB recommended to the Level I CCB that the TWD program be terminated. The user was contacted at the Ft. Sill Field Artillery School who agreed with the recommendation. The user also stated the TWD is no longer considered essential for the M109A1/A2/A3 Howitzer. A written confirmation was issued stating "...the potential increase to current capability and margin of safety is viewed as being less than the potential increases offered by other on-going actions to improve overall weapon RAM, survivability and combat capabilities. This is mandated by priority funding considerations of competing systems".[6] The PIP was then terminated by ARRCOM

[6] Baggott, C.P., ATSF-CD-MW Letter dated 19 Feb 82, subj: 155mm M109A1/A2/A3 SP Howitzer Thermal Warning Device, PIP 1-79-05-2006, USAFAS, Ft. Sill, OK.

Level I Configuration Control Board Directive of 28 Jan 82.

SUMMARY

The 155mm M109A1/A2/A3 Howitzer Thermal Warning Device Product Improvement Program was undertaken to provide accurate cannon tube temperature data to the gun crew. At the time the proposal was written, there appeared to be a genuine need for a Thermal Warning Device on this weapon. However, during the engineering phase, several events occurred reducing the justification for adoption. Additionally, unanticipated breech ring fatigue testing required funding which had not been provided for in the program. After all design problems had been resolved and the device was successfully tested by TECOM, the program was terminated by ARRCOM in January 1982.

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1. Vottis, P.M., and Hasenbein, R.G., DRDAR-LCB-DA DF dated 23 August 1979, subject: Thermal Warning Device (TWD) for the M198 Howitzer, ARRADCOM, Benet Weapons Laboratory, Watervliet, NY.

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5. Taylor, H.J., "Final Report - Product Improvement Proposal (PIP) for 155mm M185 Howitzer Thermal Warning Device (PIP 1-79-05-2006)", TECOM Project No. 2-WE-205-185-098, Test Agency Report No. APG-MT-5509, US Army Aberdeen Proving Ground, Aberdeen, MD, March 1981.

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