MIL-STD-1751 (USAF)
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MILITARY STANDARD

SAFETY AND PERFORMANCE TESTS
FOR
QUALIFICATION OF EXPLOSIVES

FSC 136P

DEPARTMENT OF DEFENSE
WASHINGTON DC 20301

Safty and Performance Tests for Qualification of Explosives.

MIL-STD-1751 (USAF)

1. This Military Standard is approved for use by AFLC CASO/LODS, Department of the Air Force, and is available for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: AFLC CASO/LCDS, FEDERAL CENTER BATTLE CREEK, MI 49016, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

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1. SCOPE

1. General. This standard establishes the testing methods for the qualification of primary, booster and main charge explosives. These tests, include mandatory testing for qualification and tests desined to provide background information on explosives intended for Air Force use.

1.2 Applicability. This standard is applicable to new or modified explosives intended for Air Force utilization. It is necessary that explosives qualifying under this document for specific applicaitons contain in their procurement specifications, sufficient tests, referenced to or described herein. This action will enhance the quality control standards governing the physical and chemical properties of the explosives shich this document, is designed to measure. When such trests are not included, the requirements of this document, at the discretion of the procuring activity, may be invoked, to demonstrate that the explosive as procured qualifies.

2. REFERENCED DOCUMENTS

2.1 Issues of documents. The following documents of the issue in effect on date of initiation for bids or request for proposal, form a part of this standard to the extent specified herein.

SPECIFICATIONS

FEDERAL

C-F-206 - Felt Sheert: Cloth, Felt, wool, Pressed.

MILITARY

MIL-T-339 - Tetryl (Trinitrophenylmethylnitramine)
MIL-P-387 - Pentaerythrite Tetranitrate (PETN)
MIL-L-757 - Lead Styphnate, Normal
MIL-L-3055 - Lead Azide

STANDARDS

MILITARY

MIL-STD-650 -Explosive: Sampling, Inspection and testing
MIL-STD-810 -Environmental Test Methods

DRAWINGS

BUREAU OF BUREAU OF NAVAL WEAPONS

2426912 -Explosive Properties Assembly
2426913 -Donor Assembly
2426914 -Acceptor Assembly
2426915 -Body

BUREAY OF ORDNANCE (Department of the Navy)

457454 -Plug Subassembly
6552246 -Spacer
959221 -Primer Cup
1386180 -Plug
1417758 -Insulator
1417759 -Charge Holder

PUBLICATIONS

US NAVAL ORDNANCE LABORATORY
(The Technical Cooperation Program-Manual of Sensitiveness Tests)

US/Explosive Shock/02 (AD824359)	-Explosive Shock Sensitiveness Test (Large Scale Gap)
US/Explosive Shock/04 (AD824359)	-Explosive Shock Sensitiveness Test (Standard Scale Gap)
US/Fragment Impact/02 (AD824359)	-.30 Caliber Bullet Sensitivity
US/Fragment Impact/03 (AD824359)	-Sensitiveness to Fragment Impact
US/Fragment Impact/04 (AD82435g)	-Sensitiveness to Fragment Impact
US/Friction/01 (AD824359)	-Friction Sensitiveness Test
US/Friction/02 (AD824359)	-Friction Sensitiveness Test
US/Friction/03 (AD824359)	-Friction Sensitiveness Test
US/Friction + Impact/01 (AD824359)	--Impact Test (Large Scale-Skid)
US/Impact/01 (AD824359)	-Impact Test (Laboratory Scale)
US/Impact/02 (AD824359)	-Impact Test (Laboratory Scale)
US/Impact/03 (AD824359)	-Impact Test (Laboratory Scale)
US/Impact/04 (AD824359)	-Impact Test (Laboratory Scale)
US/Impact/05 (AD824359)	-Impact Test (Laboratory Small Scale)
US/Impact/06 (AD82435g)	-Impact Test (Laboratory Large Scale)
US/Impact/07 (AD824359)	-Impact Test (Laboratory Scale)
US/Impact/08 (AD824359)	-Impact ‘Test (Laboratory Scale)
US/Impact/09 (AD824359)	-Impact Test (Large Scale)
US/Impact/10 (AD824359)	-Impact Test (Large Scale)
US/Impact/11 (AD824359)	-Impact Test (Large Scale)
US/Impact/12 (AD824359)	-Impact Test (Large Scale)
US/Impact/13 (AD824359)	-Impact Test (Large Scale-Spigot)
US/Impact/14 (AD8243599)	-Impact Test (Large Scale-SUSAN)
NAVORD OD 5823	-Sensitivity Test of Primers and Detonators using Test Set MK 135 MOD O (Primer) and Test Set MK 136 MOD O (Detonator)

DEFENSE DOCUMENTATION CENTER

NAVORD 6632 (AD312827)	-The Electrostatic Spark Sensitivity of Bulk Explosives and Metal/Oxidant Mixtures
NOLTR 65-124 (AD371262)	-The Electrostatic Spark Sensitivity of Various Organic Explosives and Metal/Oxidant Mixtures
NWC TP 4258 (AD872306)	-Thermal Analyses Studies on Candidate Solid JPL Propellants for Heat Sterilizable Motors

(Copies Of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publicaitons. The following documents form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C177	-Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate; Method of Test for
ASTM D621	-Deformation of Plastics under Load, Methods of Test For
ASTM D638	-Tensile Properties of Plastics, Method of Test for
ASTM D695	-Compressive Properties of Rigid Plastics, Method of Test for
ASTM D696	-Coefficient of Linear Thermal Expansion of Plastics, Method of Test for
ASTM D747	-Stiffness of Plastics by Means of a Cantilever Beam, Method of Test for
ASTM D759	-Conducting Physical Property Tests of Plastics at Subnormal and Supernormal Temperatures
ASTM D785	-Rockwell Hardness of Plastics and Electrical Insulating Materials, Method of Test for

ASTM D790	-Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, Standard Test Methods for
ASTM D864	-Coefficient of Cubical Thermal Expansion of Plastics, Method of Test for
ASTM D1525	-Vicat Softening Temperature of Plastics, Standard Test Method for
ASTM D1895	-Apparent Density, Bulk Factor, and Pourability of Plastic Materials, Standard Test Methods for
ASTM D1897	-Injection Molding Test Specimens of Thermoplastic Molding and Extrusion Materials, Standard Recommended Practice for
ASTM D2117	-Melting Point of Semicrystalline Polymers, Standard Test Method for
ASTM D2566	-Linear Shrinkage of Cured Thermosetting Casting Resins During Cure, During Cure, Standard Test Method for

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Streets Philadelphia, PA 19103.)

3. DEFINITIONS

3.1 Booster Explosive. As used herein, a "Booster Explosive" is defined as an explosive acceptable for fuze components whose detonation would normally be communicated to the main charge explosive of a fuzed weapon when the fuze is in both the armed and unarmed conditions. This shall include explosives used in leads, relays, detonating cord, boosters, and other components used on the warhead side of the interrupter.

3.2 Candidate Explosive. As used herein, the term “candidate explosive" is any explosive material being evaluated in accordance with this document.

3.3 Explosive (Material). As used herein, the term "Explosive" or "Explosive Material" implies not only a specific composition, but a specific particle size distribution, purity, and process of manufacture wiht ranges specified. Whenever changes in particle size, purity, process of manufacture, grade, class, or any other modificaiton is made, including the addition of material (such as a binder or lubricant), the explosive shall be considered a new composition. Under these circumstances a decision shall be rendered by the applicable ordnance systems group as to whether a complete interim qualification test program shall be rerun.

3.4 Main Charge Explosive. Main charge explosives are compounds or formulations such as Trinitrotoluene (TNT) or Composition B “ that are used as the final charge in any explosive application. These explosives, because of their insensitivity, ordinarily require initiation by a booster explosive. For this document explosives do not include pyrotechnics or propellants unless they are used as the principle energy source for destructive effects.

3.5 Primary Explosives. Primary explosives are sensitive formulations or compounds such as Lead Azide or Lead Styphnate that are used to initiate detonation in high explosives. They are sensitive to heat, impacts or friction and undergo rapid reaction upon initiation. These sensitive explosives are separated from the booster explosive by the interrupter of the fuze, exploders or safety and arming device. For the purposes of this section a primary explosive is a single explosive compound or a mixture that does not meet the requirements of one or more of the tests specified in 5.4.1, 5,4.2, 5,4.3, 5.4,5, 5.4,7, or 5.4.8.

3.6 Representative Sample. Sampling procedures may be varied to accommodate circumstances. However, shere feasible, part of each representative sample shall be drawn from each container and from various locations within each container. The sample shall bot be blended before use in tests.

3.7 Sub-sample. Each sample, withdrawn from various locations within an individual container, is defined as a su-sample.

3.8 Test. As used herein, the term "test" is the complete series of trials or replicates specified.

3.9 Trial. The term "trial" means the application of a stimulus to a single specimen of explosive$_s$

4. GENERAL REQUIREMENTS

4.1 Reclaimed Material. The use of reclaimed material shall be encouraged to the maximum extent possible without jeopardizing the intended end use of the item.

4.2 Basic, Primary Explosives. All primary explosives used in weapons must meet all of the Detailed Requirements giver. in Section 5. Each explosive material, as defined in 3.3, must meet these requirewments. In addition, gives tests to provide desirable background information.

4.2.1 New compositions. In addition to passing the tests described in the Detailed Requirements each compound or mixture proposed for use as a primary explosive shall be studied for the possibility of reactions with containers or contaminants, or phase transitions under anticipated conditions of use. Experiments shall be performed to determine the probability of such changes and their effect upon stability and sensitivity as determined by tests described in Section 5.

4.2.2 Explosives description and analysis. A description of what constitutes the explosive (including its composition analysis) shall be presented when applying for an interim qualification. The explosive shall be adequately defined and shall have met the requirements of this section.

4.2.3 Sub-samples. To the extent that it is practical and feasible, sub-samples shall be kept separate, and equal numbers of specimens for each test described under Detailed Requirements (Section 5) shall be drawn from each sub-sample of a candidate explosive.

4.3 Basic, booster explosives. All explosives used in fuzes in direct communication with main explosive charges shall have met all of the Detailed Requirements given in Section 5. Each explosive material, as defined in 3.3, shall meet those requirements .

4.3.1 Compatibility. In addition to passing the tests prescribed in the Detailed Requirements, each compound or mixture proposed for use as a booster explosive shall be investigated for compatibility with potential containers or with other materials of expected contact. The presence of moisture as it affects these compatibilities shall be determined. A statement concerning compatibility shall be forwarded with the request for interim qualification, see 5.6.6.

4.3.2 Explosive description and analysis. A description of what constitutes the explosive (including its composition analysis) shall be presented when applying for an interim qualification. The explosive shall be adequately defined and shall have met the requirements of this sections

4.3.3 Sub-samples. To the extent that it is practical and feasible, sub-samples shall be kept separate, and equal numbers of specimens for each test described under Detailed Requirements shall be drawn from each sub-sample of a candidate explosive.

4.3.4 Granular explosive. For each test described under Detailed Requirements a procedure is described for the preparation of specimens from granular explosives. These procedures are applicable to pure crystalline explosives and granular explosive mixtures, including plastic bonded explosives; which are normally formed by pressing at temperatures below the melting point of the binder and at which the binder does not undergo a chemical change (such as curing) as part of the fabrication process.

4.3.4.1 Cast, molded, extruded, and injected explosives and PBX compositions not suitable for granular explosives. For each test described or referenced in the Detailed Requirements, the dimensions of the specimen required for each trial are given either in the test or a referenced drawing where necesary. Where the dimensions of a specimen to be used in a specific test are compatible with fabrication procedures for which the icandidate explosive is intended, such procedures shall be used in specimen preparation. Where intended fabrication procedures are only feasible for charges very much larger than the specimens specified herein, these procedures shall be used to form billets of the candidate explosive from which test specimens can then be machined. Speciments for each test described or referenced shall be made from material taken at each of several locations with respect to the principal dimensions of the billets form shich they are machined, and should be 95% of theoretical maximum density (TMD) or above unless a known application requires a lower value.

4.3.4.2 Other sampling requirements. When billets are machined, the uncontaminated chips, shavings, or dust resulting can be saved and used as specimens in tests such as the vacuum stability test and the electrostatic sensitivity test in which the tests are perormed on loose powders and hot wire ignition test 5.4.5 in which a finely divided powder is used. In general, except as noted in the Detailed Requirements, materials to be used in these tests shall be used in the "as received" state except for drying. However, explosives which have thermosetting or other binders which undergo chemical changes in the process of "curing" should be cured before testing. In tests where loose powders

are used, particle size shall be reduced to the point where all material passes through a U.S. Standard No. 12 screen. Such screening shall not result in separation or loss of material too coarse to pass the screen.

4.3.4.3 Density of speciment changes. If the loading pressures specified in the tests described in 5.4.1 through 5.4.8 produce densities that are substantially different from the densities at which the material will be used, additional testing under these "used" density conditions may be required.

4.4 Baxic, main charge explosives. All explosives used in main explosive charges shall have met all of the Detailed Requirements given in Section 5, each explosive material as defined in 3.3, shall meet those requirements.

4.4.1 New compositions. In addition to passing the tests prescribed in the Detailed Requirements, each compound or mixture proposed for use as a main charge explosive shall-be studied for the possibility of reactions with containers or contaminants or phase transitions under anticipated conditions of use. Experiments shall be performed to determine the probability of such changes and their effect upon sensitivity as determined by tests described in Section 5.

4.4.2 Exposive description and analysis. A description of what constitutes the explosive (including its composition analysis) shall be presented when applying for an interim qualification. The explosive shall be adequately defined and shall have met the requirements of this standard preparation, mixing and processing of the high explosives, and if applicable, synthesis thereof, shall be described in detail.

4.4.3 Sub-samples. To the extent that it is practical and feasible, sub-samples shall be kept separate, and equal numbers of specimens for each test described under Detailed Requirements shall be drawn from each sub-sample of a candidate explosive.

4.4.4 Granular explosives. For each test described under Detailed Requirements, a procedure is described for the preparation of specimens from granular explosives. These procedures are applicable to pure crystalline explosives and granular explosive mixtures, including plastic bonded explosives, which are normally formed by pressing at temperatures below the melting point of the binder and at which the binder does not undergo a chemical change (such as curing) as part of the fabrication process.

4.4.5 Cast, molded and exrtuded explosives. For each of the tests described in the Detailed Requirements, the dimensions of the specimen required for each trial are given either in the test or a referenced drawing where necessary. Where the dimensions of a specimen to be used in a specific test are compatible with fabrication procedures for which the candidate explosive is intended, such procedures shall be used in specimen preparation. Where intended fabrication procedures are only feasible for charges very much larger than the specimens specified herein, these procedures shall be used to form billets of the candidate explosive from which test specimens can then be machined. Specimens for each test described shall be made from material taken at each of several locations with respect to the principal dimensions of the billets from which they are machined. All explosives should be dried before testing.

5. DETAILED REQUIREMENTS

5.1 General specimen requirements. Test specimens, of each candidate explosive shall be of the same state, physically and chemically, as the candidate explosive is when it is used for it's intended purpose. This criteria shall prevail as far as practical and compatible with the test procedures. Where, within the latitude of the requirements as given, it is necessary to exercise judgement regarding specimen preparation, this objective shall form the basis of such judgement.

5.2 Qualification requirements of primary explosives.

5.2.1 Vacuum Thermal Stability and Chemical Decomposition Test. Refer to Test Method 1.

5.2.2 Impact Sensitivity Test. A dry representative sample of a candidate primary explosive shall be subjected to an impact sensitivity test as described in Test Method 2. A suitable alternate method is US/Impact/05 of The Technical Cooperation Program. The results shall be compared with the results for normal lead styphnate, MIL-L-757 and dextrinated lead azide MIL-L-3055, obtained at approximately the same time and using the same apparatus and procedures.

5.2.2.1 Sample preparation. Granular primary explosives shall be tested in the loose, as prepared condition, after drying to constant weight at 65° Celsius (C) [149° Fahrenheit (F)]. Primary compositions with binders and solvents or with curing binders shall be dried, then ground in a ball mill using a dispersing fluid in which none of the ingredients including the binder are soluble, and finally heated to constant weight at 65°C (149°F).

5.2.2.2 Test procedure. Place a 35 ± 1 milligrams (mg)[O.00123 ± 0.00004 ounces (oz)] sample of the candidate primary explosive on the rough side of a piece of No. 05 sandpaper which is supported on the steel anvil shown in Figure 1. Place the hardened steel striker, Figure 2 over the sample of explosive resting on the sandpaper and anvil. Drop a 2.5 kilogram (kg) [5.13 pound(lb)] steel weight from a height of 50 centimeters (cm) [19.685 inch(in)] in a frictionless guided drop so that it impacts the striker centrally. Note whether the response of the explosive is positive (explosion, burning, or other evidence of reaction) or negative. If the response is positive, reduce the height of the next drop by 50% if negative, increase the height by 100% and proceed until a region is found where a 50 trial Bruceton test can be run.

5.2.2.3 Qualification criterion. There is no fixed passing qualification criterion for this test. The test results shall be reported along with those for normal lead styphnate and dextrinated lead azide. (A normal range for these compounds shall have been obtained at the time of testing the explosive to be qualified.)

5.2.3 Electrostatic Sensitivity Test. A dry repres3entative sample of a candidate primary explosive shall be subjected to an electrostatic sensitivity test using the apparatus described in NAVORD Report 6632 (AD 312827) and NOLTR 65-124 (AD 371262) and using the procedure described in NOLTR 65-124. The test shall be run for both electrodes of metal and for the base electrode of conductive rubber. The results shall be compared with those for normal lead styphnate, MIL-L-757 and dextrinated lead azide, MIL-L-3055.

5.2.3.1 Sample preparation. Granular primary explosive shall be tested in the loose, as prepared condition after drying to constant weight at 65°C (149°F). Primary compositions with binders and solvents or with curing binders shall be dried, then ground in a ball mill using a dispersing fluid in which none of the ingredients including the binder are soluble, and finally heated to constant weight at 65°C (149°F).

5.2.3.2 Test procedure. Place approximately 15 mg (0.00053 02) of the explosive in the phenolic holder and position on the base electrode. Rotate the charge/discharge knob-to charge the capacitor to the full 7,500 volt apparatus limit and hold in position until the voltmeter shows that the potential is reached. Rotate the charge/discharge knob to discharge the capacitor through the sample. Using only the voltage steps given below, repeat the procedure until, for each capacitor size, the highest voltage at the highest voltage at which twenty out of twenty samples do not fire is determined. The test shall be run for each capacitor size and for each electrode condition, i.e., base electrode metal and base electrode conductive rubber.

Voltage Steps	Capacitor Sizes
250	1 mfd
500	0.1 mfd
1,000	0.01 mfd
1,500	0.001 mfd
3,000	
4,500	
6,000	
7,500	

5.2.3.3 Definition of fire. For the purpose of 5.2.3.2 a fire shall be defined as any audible report or noise that can be distinguished from the noise of the spark and/or any visible smoke or flame emitted from the sample.

5.2.3.4 Qualification criterion. There is no qualification criterion for htis test. The test results shall be reported along with those for normal lead styphnate and dextrinated lead azide obtained using the same apparatus and procedure and run at the same time.

5.2.3.5 Special requirements.

5.2.3.4.1 Relative humidity. The test must be run with ambient relative humidity not exceeding 40%. Humidity shall be determind by wet and dry bulb hydrometry or by instruments of equal or better accuracy and precision.

5.2.3.5.2 Electrode replacement. The upper (needle) electrode shall be replaced after it has been used in ten trials, after any trial in which a fire is obtained, whenever tests of a new explosive are started, or when any other condition dictates, whichever circumstance occurs first.

5.2.4 Compatibility with materials of construction.

5.2.4.1 Discussion. Primary explosives may be categorized on the basis of their reaction products into gassy materials and "gasless" materials. Each of the two categories may be further subdivided:

Gassy Materials	Examples
a. Single Compounds	Lead Styphnate, lead azide
b. Mixtures	NOL 130, NOL 60$_5$ FA 878

"Gasless" Materials	Examples
a. Single Compounds	Silver acetylide
b. Mixtures	Zirconium/potassium perchlorate, A-1A

In general. the gassy materials are used in detonating systems; the gasless materials in delay trains, explosive switches, igniters, and some 1 amp/1 watt no fire devices.

Testing for the gassy materials usually is not difficult. The vacuum thermal stabiltiy test can be run on the compound or mix-

ture. It should be noted, however, that running the test on individual ingredients of a mixture can be misleading if results are improperly interpreted. For example, NOL 130 and NOL 60 compositions are thermally stable, but tetracene, a constituent of both mixes, is itself not thermally stable.

The "gasless" materials pose quite a problem. It is likely that a performance test will be necessary for them. A single performance test may not suffice because different compositions may be compounded for quite different uses, i.e., stb action or hot wire action. Testing for some other property may not be applicable.

5.2.4.2 Gassy materials. Mix proposed explosive and material and subject to the 100°C(212°F) Vacuum Thermal Stability Test given in Test Method 1.

5.2.4.3 Gasless materials. Mix proposed explosive and material, subject to 100°C (212°F) for 48 hours and conduct appropriate chemical analysis and performance tests.

5.3 Desirable background information. In addition to mandatory requirements, background information should be reported on a new primaty explosive priot to use. This type of information includes the following:

5.3.1 Detonation velocity. Assemble the test equipment as shown in Figures 3 and 4. Press the primary explosive so that it reaches a uniform density of 90-95% theoretical maximum density (TMD). Conduct five identical tests and record the detonation veloxity in meters/second and the measured density.

5.3.2 Density. Use any standard method of determining density on three samples pressed at 137895.14 ± 3447.38 kilopascal (k Pa) [20,000 + 500 pound force per square inch (lbf/in^2]. A density versus loading curve in the 68947.57 to 344737.85k Pa (10,000 to 50,000 lbf/in^2) range would be useful.

5.3.3 Priming ability.

5.3.3.1 Loose explosives. Load 200 mg (0,00705 oz) of cyclotrimethylenetrinitramine (RDX) in the base of the cup as shown in Figure 5 and press to 68947.57 kPa (10,000 lbf/in^2) Place 100 mg (0.003527 oz) of the proposed priming composition loosely on top., Position safety fuze as shown in Figure 5 on top of primary composition; use sufficient fuze 120 sec/0.9144m (120 sec/yd) to a safe position. Light the safety fuze with a match and remain in a safe position until after explosion.

Measure the depth of the dent in the steel plate. For dents greater than 0.076 cm (0.030 inch), reduce the primary charge by 15mg (0.00053 oz) and repeat test. If it is less than 0.076 cm (0.030 inch), increase the primary charge by 25mg (0.00053 oz) and repeat test. Repeat this procedure increasing or decreasing each succeeding primary charge by 15mg (0.00053 oz) until a legitimate 30 trial Bruceton run is obtained. Calculate the 50% priming charge weight and standard deviation.

5.3.3.2 Pressed explosives. Repeat the procedure of 5.3.3.1 using the same primary composition pressed to 68947.57 kPa (10,000 lbf/in^2) in all cases.

5.3.4 Dent output. Make five test items as described in paragraph 5.3.3, replaceing all explosive charges (both RDX and primary) with 300 mg (0.01058 oz) of the primary explosive only, pressed at 68947.57 kPa (10,000 lbf/in^2). Initiate with safety fuze and measure dent depth in steel plate. Calculate and record the average of 5 tests.

5.3.5 Dead pressing susceptibility. Repeat 5.3,4 increasing the pressure loading as follows: 5 at 137895,14 kPa (20,000 lbf/in^2), 5 at 206842.71 kPa (30,000 lbf/tn^2), 5 at 275790.28 kPa (40,000 lbf/in^2), etc., until the dent value falls by at least 50% or 689475.7 kPa (100,000 lbf/in^2) is reached, whichever occurs first.

5.3.6 Volubility in water. Use any American Society for Testing and Materials (ASTM) method to determine solubility in water.

5.3.7 Hot wire initiability. Bridge 60 P-12 plugs (Drawing 1386180) with a 0.0005 Nichrome wire. Attach a charge holder with a 0.254 cm (0.1 inch} diameter charge hole (Drawing 1417759) and insulator (Drawing 1417758, and press in 20 mg (0,00071 oz) of the primary explosive at 34473.79 kPa (5,000 lbf/in^2). Fire 30 plugs in a continuous constant current Bruceton test (current applied for 10 seconds in arithmetic steps of 10 mA current constant to + 2%) and 30 in a capacitor discharge Bruceton test using a 0.1 mfd capacitor and 0.03 log unit voltage steps: Repeat using 60 plugs with 0.0254 millimetem (mm) (O.OO1 inch) diameter Nichrome wire. Record the number of detonations for each test condition and calculate the means and standard deviations.

5.3.8 Stab initiability. Load 50 Mk 102 Mod 1 primer cups (Drawing 959221) with the primary explosive pressed at 137895.14 kPa (20,000 lbf/in^2) Determine sensitivity using a 0.057 kilogram (2-ounce) ball, the Bruceton method, and the Mk 136 test set see OD 5823. Repeat with explosive loaded at 551580.56 kPa (80,000 psi).

5.3.9 Differential thermal analysis (DTA). Run standard DTA. using heating rates of 10°C/minute (18° F/min)and 25°C/minute (45°F/min.). Report the curves obtained showing temperatures s all exotherms and endotherm together with sample size and identification.

5.3.10 Cook-off temperature. Using a standard melting, point bar, determine the lowest temperature at which approximately 5 mg (0.00018 oz) samples of the primary explosive flash-off in 10 seconds.

5.4 Qualification requirements of booster explosives.

5.4.1 Small Gap Test (SSGT). A representative sample of the candidate booster explosive shall be subjected to the standardized SSGT as described herein.

5.4.1.1 Loading and calibration of donor assemblies. Twenty-fove donor assemblies shall be prepared in accordance with Figure 6 (Drawing 2426913). Five of these donors shall be selected at random, assembled in the test fixture shown in Figure 7, and fired against the block by initiation of the detonation with a 50 volts DC (minimum) 20 amperes (minimum) power supply. To be acceptable for use in the sensitivity test, the average depth of dent produced in the block by the five representative donors must be between 1.524 and 1.651 mm (60 and 65 mils) and the standard deviation must not exceed 0.3016 mm {4.0 mils). Each block shall be used only once and the measurement of the indentation depth shall be made in accordance with 5.4.2.6.

5.4.1.2 Preparation of acceptor specimens (granular explosives). The explosive shall be loaded in eight equal weight increments at 110316.11 ± 6894.8 kPa (16,000 ± 1,000 lbf/in^2). The first trial loading shall be with increment weights in milligrams of 90 times the theoretical specific gravity of the explosive. The acceptor body Figure 8 shall be weighed before and after loading. If all eight increments fit in the acceptor body with room to spare, measure the remaining unloaded column height and adjust the weight of each increment to meet the tolerance shown in Figure 8 (Drawing 2426914). Load another test body to assure that the drawing tolerance has been met. When the adjustment is satisfactory, load the acceptor bodies to form a total of 20 acceptors meeting the tolerance shown in Figure 8. The acceptors shall be weighed before and after loading and each individual charge density determined and accurately reported to three decimal places. If in loading the first test body all eight increments do not fit into the acceptor body, adjust the individual increment weight based on the actual weight of explosive contained in the

body and proceed to adjust and load until 20 acceptors meeting the tolerance shown in Figure 8 are obtained. Acceptors shall be weighed before and after loading, and each individual charge density determined and accurately reported to three decimal places.

5.4.1.3 Preparation of acceptor specimens (cast, molded, extruded, and injected explosives). The acceptor specimens of cast, molded, extruded, injected, and PBX-type explosives not suitably prepared under 5.4.2.2 shall be prepared in accordance with 4.3.4.1. Where mechanical properties of the explosive make it possible, rods shall be made $5.1054^{+0.0000}_{-0.0127}$ mm $\left(0.201^{+0.0000}_{0.0005}\text{ inch}\right)$ in diameter by $38.608^{+0.000}_{-0.254}$ mm $\left(1.520^{+0.000}_{-0.010}\text{ inches}\right)$ long.

Materials which are too fragile to be conveniently made into specimens this long, may be made into shorter pellets which can be stacked end to end to result in a composite specimen of these dimensions. (For extrudable non-curing materials the explosive may be extruded directly into the acceptor and trimmed flush on each end of the acceptor body.) Each speciment shall be inserted in a body as shown in Figure 9 (Drawing 2426915) after which the specimen shall be trimmed to a length, such that it is flush with the body at both ends, by a method appropriate to the specific material being tested. Before insertion into the body, each acceptor specimen shall be accurately weighed and its diameter and length accurately measured. These measurements shall be used to calculate accurately to three decimal places the charge density for each acceptor. These densities shall be reported as an adjunct of this test.

5.4.1.4 Small scale gap test assemblies. Twenty explosive properties assemblies shall be prepared in accordance with (Drawing 24269312)(except a Mk 86 Mod O Detonator may be used instead of a Mk 70 MOd O Detonator) from a random selection of the acceptable donors prepared in accordance with 5.4.1.1 and the acceptors prepared in accordance with 5.4.1.2 or 5.4.1.3. The concentricity of the acceptor to the dent block shall be within 6.35 mm (0.250 inch) and the concentricity of the external surfaces of the donor, attenuator, and acceptor shall be within 0.127 mm (0.005 inch).

5.4.1.5 Test procedure. Twenty assemblies shall be fired using 4.0 deci-bang attenuators see Test Method 3. The dents produced in the witness blocks shall be measured in accordance with paragraph 3.5.1.6.

5.4.1.6 Measurement of indentation depth. Depth of indentation made in the block by the explosion of the donor or acceptor as applicable, shall be measured with a dial indicator capable of measuring 0.0254 mm (0.001 inch) units and accurate to 0.0127 mm (0.0005 inch) or better. The point of the dial indicator probe shall have an approximate 0.5235 radians (rad) (30 degree) included angle and the end of the point shall have a radius of 0.635 ± 0.0508 (0.025 ± 0.002 inch). Before measuring the depth of indentation in the block, remove any foreign material, such as deposits, from the dent. Zero the indicator with the point of the probe in the deepest part of the dent. Take the readings at four points near the periphery of the block. These points shall be approximately 3.175 mm (0.125 inch) away from the periphery and 1.5705 rad (90 degrees) apart.

5.4.1.7 Qualification criterion. The candidate explosive shall be reported to have passed the Small Scale Gap Test if there are no explosions in 20 and only 20 trials. Any reaction causing a dent of 0.0508 mm (0.002 inch) or more shall be considered an explosion.

5.4.2 Impact sensitivity (Small Scale Drop-Weight Test). A representative sample of a candidate explosive shall be subjected to an impact sensitivity test using ERL Type 12 tools as described in Test Method 2.

5.4.2.1 Specimen preparation (granular materials). Granular materials, as defined in 4.3.4 shall be used as received. The specimen size shall be approximately 35 ± 1 milligrams.

5.4.2.2 Speciment preparation (casts molded extruded, and injected explosives. Samples of casts molded, extruded and injected explosives shall be prepared in accordance with 4.3.4.1. Each specimen shall be a pellet not less than 6.35 mm (0.25 inch) $^{+0.000}_{-0.254}$ mm ($^{+0.000}_{-0.010}$ inch) thick. When testing non-curing explosives, this size pellet should be formed directly on a piece of sandpaper as described in 5.4.2.3.

5.4.2.3 Test procedure. Place a specimen of the candidate explosive prepared in accordance with 5.4.2.1 or 5.4.2.2 (taken from the sample prepared in 5.4.1.2) on the rough side of a piece of No. 05 sandpaper which is supported on the steel anvil shown in Figure 1. Place the hardened steel striker shown in Figure 2 over the sample of explosives resting on the sandpaper anvil. Drop a 2.5 kilogram steel weight from a height of 12 centimeters in a frictionless guided drop so that it impacts the striker centrally.

5.4.2.4 Qualification criterion. The candidate explosive shall be reported to have passed the impact sensitivity test if there are no explosions, burning, smoke-or other positive evidence of reaction in 20 of only 20 trials.

5.4.3 Impact vulnerability (Flying Plate Test).

5.4.3.1 Expeimental conditions. Impact vulnerability tests for this requirement shall be performed using the arrangement shown in Figure 10 and the following experimental conditions.

5.4.3.1.1 Speciment dimensions. The specimen used for each trial in an impact vulnerability test shall consist of one cylindrical pellet 2.223 cm (0.875 inch) in diameter and 2.54 cm (1.00 inch) long, loaded directly into an aluminum tube 2.540 cm OD X 210 cm ID (1.00 inch OD X 0.870 inch ID).

5.4.3.1.2 Specimen preparation {granular explosives). The pellets shall be parepared by pressing at 110316.11 + 6894.76 kPa (16,000 ± 1,000 pounds per square inch). PBX compositions shall be pressed at pressures sufficient to obtain 95% Or greater Of TMD.

5.4.3.1.3 Speciment preparation (cast molded, extruded and injected explosives). Specimens of cast, molded, extruded, and injected explosives shall be prepared in accordance with 4.3.4.1 (Extrudable non-curing explosives may be extruded directly into the aluminum tube.) Each specimen shall be a pellet $2.1971^{+0.0000}_{-0.0127}$ cm ($0.865^{+0.000}_{-0.0005}$ inch) in diameter and $2.5400^{+0.0000}_{-0.0127}$ cm $1.000^{+0.000}_{-0.005}$ inch) long. The specimen shall be inserted in the aluminum tube as shown in Figure 10. The density of the specimen charges shall be determined and reported accurately to three decimal places.

5.4.3.1.4 Driving plate. The driving plate used in the impact vulnerability tests for this requirement shall be AISI E6150 steel, heat treated to a hardness of 28-31 Rockwell C. The driving plate shall have a diameter of $5.08^{+0.0000}_{-0.0127}$ cm ($2.000^{+0.000}_{-0.005}$ inches) and a thickness of $1.905^{+0.0000}_{-0.0127}$ cm ($0.750^{+0.000}_{-0.005}$ inch).

5.4.3.1.5 Propulsion change. The propulsion charge shall be sufficient to propel the driving plate at a velocity of

+7.62 +25
121.92 -0.00 meter per second (m/s) (400 -00 feet per second). In the arrangement shown in Figure 10, with an explosive column 5.08 cm (2 inches) in diameter by 20.32 cm (8 inches) long, low bulk density nitroguanidine loaded at 0.685 gm/cc (0.02475 lbs/in3)(70.5 gm = 1,100 grains in each 5.08 cm (2-inch) increment) should give the desired result, but the veloxity shall-be measured in a preliminary experiments. The plate velocity shall be determined by an electronic time interval measurement system which will provide an accuracy of at least 2% over the measured interval. The propulsion charge shall be adjusted until five consecutive shots give velocities within the specified range. The propulsion charge density which gives this result shall be used in the test of the 20 charges of each candidate explosive.

5.4.3.2 Impact vulnerability qualification criteria. A candidate explosive shall have passed the impact vulnerability test if there are no explosions in 20 of only 20 trials.

5.4.3.2.1 Criterion of an explosion. For purposes of this specifications any reaction which causes detectable damage to the witness plate shall be considered an explosion.

5.4.4 Vacuum Thermal Stability and Chemical Decomposition Test. Refer to ‘Test Method 1.

5.4.5 Hot Wire Ignition. A representative sample of a candidate explosive shall be subjected to the hot wire ignition test as detailed below.

5.4.5.1 Explosive material. The explosive material particle size for this test must be small compared to the diameter of the ignition wire. Therefore, only explosive passing through a 325 meshg screen shall be used. (Except for extrudable non-curing explosives which shall be extruded directly into the charge holder and onto the bridgewire.) If a minimum of 90% of the explosive as submitted does not pass through a 325 mesh screen, a representative sample shall be taken and milled. Milling should be conducted under a noncombustible wetting agent that will neither appreciably dissolve nor react with the explosive. The milling shall be accomplished using stainless steel balls. Milling shall be continued until at least 98% of the sample passes through the 325 mesh sieve. Only that portion passing the 325 mesh sieve shall be used for the test. If it is not feasible to pass the material through a 325 mesh sieve, then pass the material through as fine a sieve as is possible. The explosive shall be dried to constant weight at 55°C (131°F) before being loaded in accordance with 5.4.5.2.

5.4.5.2 Loading procedure. Bridge 40 plug assemblies (Drawing 457454) with a 0.00508 cm (2-mil) diameter tungsten wire flush with the plug surface Figure 11. Firmly attach the spacer (Drawing 652246) to the bridged plug assembly. Twenty bridged plug subassemblies each shall be loaded with the dry explosive prepared as in 5.4.5.1 by pressing the explosive flush (± 0.010 inch) with the spacer at pressures of 27579.028 and 103421.36 kPa (4,000 and 15,000 lbf/in^2) respectively

5.4.5.3 Firing procedure. Each loaded unit shall be tested with an ohmmeter prior to firing to determine that the tungsten bridge wire is intact. The test unit shall then be placed explosive side down on a aluminum witness plate Figure 12 and fired in a safety chamber. Firing voltage shall be supplied by a fully charged 12 volt lead-acid automotive storage battery of at least 45 ampere hours capacity. The battery shall be connected to the test unit-by a plunger type mercury relay (Macke electrical devices or equivalent) through appropriate wiring and safety interlocks. The total circuit resistance including the relay, wiring, and interlocks, but not the battery or test unit, shall not exceed 0.4 ohm. Testing shall continue until all 40 samples (only 20 samples are necessary for extrudable non-curing explosives since they are extruded not pressed into the charge holder) are tested, unless an individual test sample does not meet the requirement of 5.4.5.4.

5.4.5.4 Qualificaiton criterion. The candidate explosive shall be reported to have passed the hot wire ignition test. if none of the 40 samples show any evidence of reaction in the fork of visible, audible, or measurable external damage to the test explosive, the test unit, or the witness plate. The tungsten wire shall, however, have been burned out as determined by an ohmmeter test.

5.4.6 Thermal detonability (Bon-Fire Test).

5.4.6.1 Test arrangement. Each trial shall be arranged as shown in Figure 13.

5.4.6.2 Specimens.

5.4.6.2.1 Speciment preparation (granular explosives). The small column of explosive shall be pressed directly into the hole provialed at 68947.57 kPa (10,000 lbf/in^2). The length of the loaded increment shall not exceed its diameter. The large diameter components of the specimen may be either a pellet 2.3622

+0.0000 +0.000 +0.0000
-0.0127 cm (0.930 -0.005 inch) in diameter by 2.5400 -0.0254 cm
+0.000
(1.000 -0.020 inch) long pressed at 68947,57 kPa (10,000 lbf/in^2) or it may be pressed directly into a 2.54 cm (1.00 inch) length of steel tubing 2.38cm (0.937 inches) in diameter by 24 gage wall.

5.4.6.2.2 Dpeciment preparation (cast, molded, extruded, and injected explosives). Specimens of cast, molded, extruded or injected explosives shall be prepared in accordance with 4.3.4.1 (Extrudable noncuring materials by be extruded directly into the hole.) The specimens shall be of dimensions indicated in Figure 13.

5.4.6.3 Test procidure. Each trial shall be arranged as shown in Figure 13 bombproof shelter or firing chamber adequate for protection against the effects of detonation of a charge of the size shown. After personnel have retreated to a protected position, or the firing chamber has been closed, the thermite mixture shall be ignited. Personnel shall not approach the charge nor shall the firing chamber (if used) be opened until 1 hour after the ignition of the thermite.

5.4.6.4 Qualification criterion. The candidate explosive shall be reported to have passed the thermal detonability test and to be acceptable as a booster explosive as defined in 3.1 if there are no explosions in 20 of only 20 trials.

5.4.6.5 Criterion for explosion. For the purpose of this document, any reaction shich causes detedtable damage to the witness plate, of results in an enlargement of the inside diameter of drilled threaded rod 0.0508 cm (0.020 inch) or greater, or both, shall be considered an explosion.

5.4.7 Electrostatic sensitivity test. A representative sample of the candidate explosive shall be subjected to the electrostatic sensitivity test described in Test Method 4.

5.4.8 Friction sensitivity test. A repnesentative sample of the candidate explosive shall be subjected to the friction sensitivity test as described in the following manner.

5.4.8.1 Experimental conditions and procedures. Each trial shall be performed using the arrangement as shown in Figure 14 through 18 and the following experimental conditions. An acceptable alternate method would be US/Friction/01 thru 03.

5.4.8.1.1 Speciment preparation (cast, molded, extruded, and injected explosives). The method of preparation of test samples shall depend upon the properties of the explosive and the intended procedure to be used in fabrication for use as a booster explosive. Pellets of the test explosive shall be fabricated to the configuration as shown in Figure 16 in accordance with 4.3.4.1.

5.4.8.1.2 Speciment preparation (granular explosives). Four tenths of a gram of the test explosive shall be pressed into the specimen holder at 137895.14 kPa (20,000 lbf/in) [a dead load of 997.92 kg (2,200 pounds)] to the configuration shown in Figure 14. Note - since some explosives are subject to segregation with respect to particle size or components of mixtures, care should be exercised to insure that, in the course of a test, the material actually used constitutes a representative sample, with respect to both particle size distribution and composition.

5.4.8.1.3 Abrasive strip preparation. The abrasive strip shall consist of spring steel strip 0.254 mm (0.010 inch) thick by 50.8 mm (2.000 inches} wide by 457.2 mm (18.0 inches) long, hardened and tempered to a hardness of Rockwell C48/51 (Rockwell 30 N 66.5/69.5) and roughened as follows: On one side, over an area including the entire width and from one end to a point not less than 6.5 inches from the end. The roughening is accomplished by means of a belt sander using a cloth belt with resin bonded, 60 grit silicon carbide abrasive (Carborundum, Locking, Type 865F, or equivalent). While sanding, the long axis of the stainless steel strip shall be perpendicular to the motion of the sanding belt. The sanding shall continue until all temper color has been removed from the area defined above and the apparent texture of this area is uniform. Fresh sanding belts, which have not been used for other operations, shall be used and not more than five spring steel straps shall be roughened with the same belt. The roughness shall be such as to have an average deviation of not less than 1.27 micrometers (µm) nor more than 2.286 pm (50 nor more than 90 microinches), as measured by means of a profilometer, from the mean surface.

5.4.8.1.4 Procedure for each trial. The procedure for each trial shall be as follows (see Figure 15).

5.4.8.1.4.1 Witness block. Locate witness block with the help of spacer block, as shown in Figure 15, so that witness block is approximately centered with center line of specimen support bushing.

5.4.8.2.4.2 Coating of abrasive strip. Coat back (opposite side to that roughened) of spring steel abrasive strip with a two to one mixture of S.A.E. 30W engine oil and flake graphite (Dixon Crucible Co. No. 635 or equivalent). Roughened surface shall be kept clean.

5.4.8.1.4.3 Installation of abrasive strip. Install spring steel abrasive strip as shown in Figure 15, with roughened surface facing specimen support bushing, and bend end of spring steel strip (opposite end to that roughened) around heel of jerk lever. Clamp as shown in Figure 15.

5.4.8.1.4.4 Insertion of specimen. Insert specimen in specimen holder assembly. (see Figures 14 and15). Insert specimen holder assembly with specimen in-place in support bushing and apply normal force of 759.78 ± 11.34 kg (1,675 ± 25 pounds) tO ram Of specimen holder. (Either hydraulic pressure or dead weight may be used to apply and maintain the normal force. It may be advant-ageous, particularly with dead weights, to use a lever system or other force multiplying mechanism).

5.4.8.1.4.5 Boom Box. The "boom box" shall be closed, the safety bar (shich restrains the edndulum) removed, the handle of the pendulum adjusted so thea tits center of gravity is 45.72 ± 1.27 cm (18 + 0.5 inches) above its low equilibrium point (at shich it strikes the jerk leverI, and the pendulum released. If the apparatus is performing normally, the spring steel abrasive strip will be jerked entirely free from the boom box (except for pieces which may be broken or torn from the strip as the result of an explosion).

5.4.8.1.4.6 Removal of specimen. The pendulum Shall be returned to its top position, the safety bar replaced the boom box opened, the normal force3 removed, and the specimen holder removed from the support busing. (When an explosion has expanded the specimen holder, it is usually necessary to remove the witness block and remove-the specimen holder through the hole in the witness block support.)

5.4.8.2 Qualificaiton criterion. The candidate explosive shall be reported to have passed the friction sensitivity test if there are no explosions in 20 of only 20 trials.

5.4.8.2.1 Criterion of explosion. For purposes of qualification any reaction which results in an expansion of 0.127 mm (0.005 inch) or more of hte specimen holder or produces a dent more than 0.0508 mm (0.002 inch) deep in the witness block, or both, shall be considered an explosion.

5.4. 8.3 Other requirements. The test shall not be considered to be valid nor shall the results be reported as part of the qualification data for the explosive under test unless the following conditions have been met.

5.4.8.3.1 Relative humidity. The relative humidity shall not exceed 80% as measured by a wet and dry bulb thermometer or instrument of similar' reliability.

5.4.8.3.2 Periodic apparatus check. The apparatus shall be checked subsequent to or concurrent with each series of qualifying tests, by subjecting a sample of tetryl, MIL-T-00339 and a sample of PETN, (pentaerythritol tetranitrate) per MIL-P-387 to the friction sensitivity test. Data obtained subsequent to a check test shall not be officially reported or used in the qualification of any candidate booster explosive until another apparatus check test has been performed. (Check test trials may be interspersed among qualification test trials in a random or systematic order so that data can be developed concurrently.) The procedure and condiditions shall be as outlined above. The apparatus shall be considered to be performing satisfactorily if the PETN fails and the tetryl passes in accordance with the criterion outlined in 5.4.8.2 and 5.4.8.3. If either the PETN passes or the tetryl fails, a detailed examination and calibration of the apptaratus shall be made to detect any change in test conditions and all data obtained since the last satisfactory check test discarded.

5.4.9 Detonation Velocity Test. Dentonation Belocity Tests will be conducted in accordance with 5.7.2.

5.5 Qualificaiton requirements of main charge explosives.

5.5.1 Impact sensitivity.

5.5.2.1 Acceptable procedures. A dry representative sample of a candidate main charge explosive shall be subjected to an impact sensitivity test as described in Test Method 2. Suitable alternate procedures can be accomplished in accordance with US/Impact 01 thru 14 of the Technical Cooperation Program. TNT (set pt 80.2°C (176.36°F) or Better] Composition B (Grade II), and RDX are suggested calibration standards.

5.5.1.2 Qualification criteria. Although the impact sensitivity test does not always correlate very well quantitatively and sometimes qualitatively with larger scale tests, a 50% sensitivity number less than that of RDX for a formulated explosive should usually rule it out for consideration. This test is to be used only for a guideline; the passing criteria are not mandatory.

A sensitivity number equal to or greater than that of Composition B wcuild indicate a likely candidate for larger scale sensitivity tests.Standard explosive values should be reported together with the test explosive value determined using the same procedures. The physical form, state, and size (including whether powder or pellet) should be reported.

5.5.2 Large Scale Gap Sensitivity Test. The large scale gap test or shock sensitivity test indicates the sensitivity of a material to shock and therefore yields useful information relating to boostering requirements safety from sympathetic detonation while in storage, and vulnerability to air-blast weapons.

5.5.2.1 Acceptable procedures. Refer to Test Method 5. Acceptable alternates are US/Explosive Shock/02 and 04.

5.5.2.2 Qualification criteria. For use as a main charge explosive, the gap shall be no greater at the 50% probability point than the 50% value for tetryl [at 1.57 ± 0.03 g/cc 98.0151 ± 1.8729 lb/ft^3)]. Gaps smaller than those from Composition B are preferred. The explosive must be compared using the same gap test procedure. The preparation and the processing method for the explosive shall be disclosed. The small scale gap test may give useful information when the material is limited in quantity. However, before the exsplosive is considered as a serious candidate for a weapon, the supply must be sufficient for large scale tests.

5.5.3 Friction Sensitivity Test. Friction sensitivity tests are made to determine relative sampling during processing.

5.5.3.1 Acceptable procedures. Refer to Test Method 6. Acceptable alternates are US/Friction/01 through 03.

5.5.3.2 Qualification criteria. Using the procedure described in Test Method 6, the following criteria shall be adhered toto. 20/20 no fires with 1112.1 newton (N) (250 pound force) using the ABL, or equivalents sliding friction machine with 90 degrees pendulum drop angle and 2,4384 m/s (8 ft/sec) initial slider velocity shall be sufficient criteria for passing.

5.5.3.3 Other requirements. The test shall not be considered to be valid nor shall the results be reported as part of the qualification data for the explosive under test unless the following conditions are met.

5.5.3.3.1 Relative humidity. The relative humidity shall not exceed 40% as measured by a wet and dry bulb thermometer or instrument of similar reliability.

5.5.3.3.2 Periodic apparatus check. The apparatus shall be checked subsequent to or concurrent with each series of qualifying tests, by subjecting a sample of PETN (Pentaerythritol tetranitrate) per MIL-P-387 and a sample of tetryl, MIL-T-00339, to a 50% value determination on the friction sensitivity test. Data obtained subsequent to a check test shall not be officially reported or used in the qualification of any candidate explosive until another apparatus check test has-been performed. (Check test trials may be interspersed among qualification test trials in a random or systematic order so that th e data can be developed concurrently.)

5.5.4 Electrostatic sensitivity Test. Electrostatic sensitivity tests are made to ensure relative safety from the discharge of charged objects or bodies including humans.

5.5.4.1 Acceptable procedure. Refer to Test Method 4.

5.5.4.2 Criteria for electrostatic sensitivity. There shall be at least 20 consecutive tests of which no fires should occur at the 0.25 joule level under the foregoing test.

5.5.5 Vacuum Thermal Stability and Chemical Decomposition Test. Refer to Test Method 1.

5.5.5.1 Acceptable procedures. When an explosive is to be used at a higher temperature values at higher temperatures are necessary so that proper extrapolation can be made.

5.5.5.2 Qualification criteria. To be sufficiently stable for military storage and use, the VTS value must not be larger than 2.0 ml/g/48 hours (0.004 pints/0.03527 oz/48 hours) when a 5 gram (0.17635 ounce) sample is used and the test conducted according to 5.5.5.1.1 When the products of decomposition are not known, as in the use of new explosive ingredients it must first be determined whether gas evolution is sufficient criterion.

5.5.6 Growth and, exudation characteristics. When explosives contain liquids as impurities they often undergo irreversible dimensional changes when subjected to many temperature cycles between -53.88 and 71.11°C (-65 and +160°F). In explosives containing TNT, the dinitrotoluenes form low-melting liquid eutectics that cause problems. Mononltrotolunes added as anti-cracking agents give large irreversible growth in TNT explosives. Another cause for irreversible dimensional change is the solid-solid polymorphic transition such as occurs with ammonium nitrate.

5.5.6.1 Growth and exudation characteristics acceptable procedures. Acceptable procedures for solids include any cylindrical sample at least 1.27 cm (0.5 inch.) diameter by 1.27 cm (0.5 inch) high, temperature cycled between -53.88 and 71.11°C (-65 and 160°F) for 30 cycles or more. If no exudation nor excessive growth is noted on triplicate samples, and additional test should be made for exudation by placing two cyli8nders together inside a sealed can. These should be held together by steel parallel face plates and clamped together to an initial pressure of 413.68542 kPa (60 psi). Teh sealed unit is subjected to 30 cycles from ambient to 71.11°C (160°F), maintaining each temperaure long enough for the entire sample to reach the temperature of the oven. It is then observed for exudation) any exudate is removed and weighed.

5.5.6.2 Qualification criteria. Irreversible "growth" and exudation both cause problems in ordnance items. Irreversible dimensional change could ruin a carefully designed warhead by distorting the geometry of a lens system, by damaging the fuze wells or by causing leakage into detonator areas. The irreversible change after 30 cycles should not be more than 1.0 volume percent as measured by calipers and calculated, or determined by density change. Exudation should be less than 0.1% by weight.

5.5.7 Self Heating Tests. A series of laboratory tests will be run to determine the relative safety of material for self-heating under varied conditions. This should include thermal decomposition studies and selected physical property analysis on the candidate explosive Then, shen possible, kinetic or procedural kinetic parameters (frequency factors and activation energies), thermal diffusivity, heat capacity and heat of reaction will be determined so that for slabs, spheres, or cylindrical configurations, the critical temperature (heat balance) and time to explosion can be predicted starting from any ambient or standard condition.

5.5.7.1 Acceptable tests. Refer to Test Method 7. An acceptable alternate is NWC TP 4258 (AD 872306).

5.5.7.2 Criteria for acceptance. Self-heating should not cause deflagration nor be detectable [<0.55°C(<1°F)] in any size or shape of explosive used in bombs or warheads from ambient temperature conditions up to 71.11°C (160°F}. The calcuated critical temperature or the time to explosion for a given mass and geometry of explosive should not be less than 82.22°C (180°F) or 500 days at this temperature. The maximum size to be considered for normal use will be 907.2 kg (2,000 pounds). Whenever an Whenever an explosive is to be used in larger quantities in any one warhead

or bomb, self-heating and calculations for critical temperature and time to explosion must be considered for that size for any explosive.

5.5.8 Detonation velocity. Refer to Test Method 8.

5.6 Bacground information. The following tests are desirable for backgroun information. Some of these tests may be required for interim qualification.

5.6.1 Bullet impact sensitivity.

5.5.1.1 Acceptable procedures. Refer to Test Method 9. The sample containers with flat ends may give less variation of results. US/Fragment Impact/02 through 04 are considered satisfactory alternates.

5.6.1.2 Advisory statement. Those explosives that do not detonate, deflagrate or burn would be considered highly desirable; those burning out not detonating would still be generally satisfactory, those detonating would be used only in applications where detonation from projectile impact is unlikely because of protection, high altitude or other considerations.

5.6.2 SUSAN Sensitivity Test. This is a test developed to evaluate impact sensitivity of main charge explosives.

5.6.2.1 Acceptble procedures. Refer to Test Method 10.

5.6.2.2 Advisory statement. To be acceptable the explosive. should indicate a sensitivity significantly lower than that of PBX 9404 in the form and density normally used for these tests. This test is not adequate in its present form for some slurry and other explosives.

5.6.3 Vibration Test. Vibration tests will be conducted to provide some indication of the ability of the new explosives to withstand a dynamic environment without serious degradation or deterioration of the explosive due to powdering, physical property changes, structural failure of the explosive, etc.

5.6.3.1 Acceptable procedure.

5.6.3.1.1 Test samples. Test samples shall be made by using predicted liner material and explosive manufacture processes to make a sample in the test container shown in Figure 19. Three Three samples of a given type and manufacture shall be submitted for testing.

5.6.3.1.2 Vibration test environment. The samples shall be subjected to a vibration environment of:

0.508 cm (0.2 inches) double amplitude (DA) from 5 to 14 Hz (cycle per second)
2 g vector from 14 to 26 Hz
0.1524 cm (0.06 inches) Double Amplitude (DA) from 26 to 57 Hz
10 g vector from 57 to 500 Hz

Sweep time from 5 to 500 Hz shall be 7 minutes 30 seconds for the resonat search. Resonant dwells of 30 minutes shall be conducted at the four lowest resonant frequencies. If four resonant frequencies are not present, the total time of 2 hours shall be completed by cycling from 5 to 500 to 5 Hz in 15 minute cyucles.. Tests shall be conducted in longitudinal and one transverse direction only. Total test time shall be 4 hours and 15 minutes.

5.6.3.1.3 Test instrumentation. Accelerometers for control and response vibration measurement and thermocouples for temperature measurement shall be installed as shown in Figure 19.

5.6.3.1.4 Test temperature. Tests shall be conducted at $-40\ ^{+2.3}_{-2.2}$ °C (-40 ± 4°F0 57.2 ± 2.2°C (135 ± 4°F) and $25\ ^{+2.7}_{+2.8}$ ° C (77 ± 5°F).

The three samples (one at each temperature) shall be subjected to the testl Minimum temperature pre-conditioning time shall be 8 hours temperature shall be maintained during the tests.

5.6.3.1.5 Failure criteia. A catastrophic failure (detonation or burn) shall be investigated to determine mode of failure. If the failure is due solely to the explosives it would be considered unusable. Slight deterioration on powdering shall not be considered unusable. Slight deterioration or powdering shall not be considered a failure. Other failure criteria shall be determined by the particular explosive chatacteristics relative to the series of tests being conducted.

5.6.4 Skid Tests. A combination of friction and impact is a frequent cause of accidents where large pieces can be dropped a few feet.

5.6.4.1 Acceptable procedure. Refer to Test Method 11. A suitable alternate method is US/Friction + Impact/01 of the Technical Cooperation Program.

5.6.4.2 Advixory statement. Although this is listed under background information, if conducted, a value of less than 1.524

meters (m) (5 feet} in Test 02 giving high order detonations should disqualify an explosive. Similarly in Test 01 a 50% height of less than 2.743 m (9 feet) should be cause for rejection.

5.6.5 High temperature exposure. The nature of this test will depend upon the expected use of the explosive. If it is expected to be used at higher than normal storage temperatures (e.g., flight at high Mach No.), the upper temperature requirement must be determined.

5.6.5.1 Acceptable procedures.

5.6.5.1.1 Procedure. The procedure of Test 501 of MIL-STD-810 shall be used except that the specimen rather than being a warhead will be a test vehicle. A 10.16 cm (4-inch) diameter by 15.24 cm (6-inch) long pipe with caps on both ends will be used. Three of these will be filled with 10.16 cm (4 inches) of explosive being careful to keep explosive out of threads. The weight and height should be determined accurately. Post test examination shall be made for irreversible growth, cracking, exudation, and any migration of explosive ingredients.

5.6.5.1.2 Supplementary test. A supplementary test shall be to include three sets of two specimens 2.54 cm (1 inch) diameter and 2.54 cm (1-inch) high, clamped together at a pressure of 413.685 kPa (60 psi). These specimens shall undergo the sample test cycle and examination for exudation. Instead of being exposed to humidity, these specimens should be placed in sealed containers so that any exudate will not be lost. Samples shall be measured and weighed accurately; and weight loss, irreversible dimensional changes, and percent of exudate determined.

5.6.5.3.3 Alternate procedure. An alternate procedure for determining exudation under temperature cycling exposure is the procedure used for determining exudation of a PBX during cycling to 148.8°C (300°F).

5.6.5.1.3.1 Casting of explosive to be tested. The explosive to be tested is cast into 5.08 cm (2 inch.) diameter by 4.1275 cm

same inside dimensions, each with a cover with outside threads which can be screwed into the aluminum cup to make contact with the top of the explosive.

5.6.5.1.3.2 Cup dimensions. The cup dimensions are approximately as shown in Figure 20. Half of the covers have 0.3175 cm (0.125 inch) diameter holes in the center.

5.6.5.1.3.3 Temperature cycles. The charges in the containers and also the base charges are cycled to a temperature of 148.8°C (300°F), held at this temperature for 1 hours and then cooled to ambient.

5.6.5.1.3.4 Weight and dimensional changes. After 10 cycles, weight and dimensional changes of all samples are measured to check for possible losses and exudate.

5.6.5.2 Advixory statement. Greater than 1% weight loss for any reason (other than loss of water; or irreversible dimensional change usually should be cause for rejection. Greater than 0.1% exudation (other than water is also cause for rejection. Crumb- Crumbling under the temperature-humidity cycling is also grounds for rejection. If exudation and growth are not excessive and other properties are not changed excessively (see prescribed MIL-STD-810 Test 501), the explosives are considered to have passed this test series.

5.6.5 Compatibility with standard materials. Explosives are used in proximity with various materials; it is important that the explosive not react with steel, brass, copper, aluminum, zinc, magnesium, lead, stainless steel, and malleable iron.

5.6.6.1 Acceptable procedure. Reactivity test given in MIL-STD-6.50 under 504.1.

5.6.6.2 Advisory criteria for compatibility from reactivity tests. The mixture should show no enhancement in gas evoultuion as described in MIL-STD-650.

5.6.7 Physical stability. The explosie should maintain its intgergrity thoughout the normal usage temperature range -53.8 to 71.1°C (-65 to 160°F). That is, it should neither be segregated by standing (or from being vibrated) at anelevted temperature nor be changed in physical phase such that a large volume expansion occurs.

5.6.7 Acceptable procidure. Exudation and irreversible kimensional change were covered under 5.5.6 and 5.6.5. To observe whether segregation occurs, analysis of sections of the explosive must be made when the material has been partially liquid at any time.

5.6.7.2 Criteria for acceptance. A composition spread of more than 4% of one ingredient from top to bottom of an explosive charge (not specifically designed that way for an application) should be considered excessive.

5.6.8 Physical properties.

5.6.8.1 Melting point. This is a simple determination and any method where a suitable calibration standard is used in the range of the melting point of the compound or mixture involved is considered suitable.

5.6.8.1.1 Procedures. The acceptable procedure is "Melting Point of Semi-Crystalline Polymers", ASTM D2117 or acceptable alternate.

5.6.8.1.2 Criteria for melting point. For a conventional solid explosives there should be no. melting of ingredients below 60°C (140°F). The preferred solid explosives melting point would be above 72°C (161°F).

5.6.8.2 Softening point.

5.6.8.2.1 Acceptable procedure. ASTM D1525. The softening point can be used where non-crystalline or non-melting components are present.

5.6.8.2.2 Criteria for softening point. No softening of a material should occur below 60° (140°C).

5.6.9 Physical properties at various temperatures. Within the temperature range of normal use [unless otherwise specified -53.8 to 71.1°C {-65 to +160°F)], the material should not undergo undesirable changes in properties. A phase change that caused the material to undergo liquifaction would be unsuitable if a design incorporating the use of an explosive did not allow for use of liquids. If physical strength such as compressive and tensile are made use of in subsequent applications, a large degradation of strength on heating could lead to a design failure. A solid polymorphic transition could also lead to undesirable properties.

5.6.9.1 Acceptable procedures. ASTM procedures are acceptable test methods. Compressive and tensile strength and modulus of elasticity are often useful measurements (see 5.6.11 through 5.6.20).

5.6.9.2 Advisory statement. Unless certain properties are called for in applications considered, this need not be considered for acceptance, however gross reduction in physical, tensile, and compression strength should be cause to question the use of the explosive. A 100% or more reduction in modulus might indicate a phase change with attendant possible exudation.

5.6.10 Coefficient of thermal expansion.

5.6.10.1 Acceptnce procidures. Coefficient of linear thermal expansion-of plastics ASTM D696 and Coefficient of Cubical Thermal Expansion of Plastics ASTM D864.

5.6.11 Thermal conductivity.

5.6.11.1 Acceptable procedures. Test for thermal conductivity of materials by means of the guarded hot plate ASTM C177.

5.6.12 Flexural strength.

5.6.12.1 Acceptable procedures. Flexural Properties of plastics ASTM D790.

5.6.13 Modulus.

5.6.13.1 Acceptable procedure. Included under compressive properties in ASTM D 695.

5.6.14 Hardness.

5.6.14.1 Acceptable procedure. Rockwell Hardness of Plastics and Electrical Insulatory Materials ASTM D785.

5.6.15 Compressive Strength.

5.6.15.1 Acceptable procedure. ASTM D695. This document includes compressive stress, compressive strength, compressive strength at failure, compressive deformation, compressive strain, compressive yield point, yield strength, modulus of elasticity and crushing load.

5.6.16 Tensile strength.

5.6.16.1 Acceptable procedures ASTM D638. This includes tensile strength, percent elongation, rate of stressing, and elastic modulus.

5.6.17 Impact resistance.

5.6.17.1 Acceptable procedure. Impact Resistance of Plastics at Subnormal and Supernormal Temperatures ASTM D 759.

5.6.18 Stiffness.

5.6.18.1 Acceptable procedure. Stiffness of Plastics by means of a Cantilever Beam, ASTM D 747.

5.6.19 Deformation under load.

5. 6.19.1 Acceptable Procedure. Deformation of Plastics Under Load, ASTM D621. This is a useful test to aid in determining flow properties and compressibility.

5.6.20 Bulk density. It is important to know the bulk density of an explosive both for a solid warhead or bomb explosive and for explosive powders that are to be pressed.

5.6.20.3. Acceptable procedure. Place approximately 50 gramss (weighed tonearest 0.1 gram) of the sample material from the composite sample into a 100 ml cylinder (graduated in 1 ml increments). Compact the material by allowing the cylinder to fall freely from a height of 2,54 cm (1 inch) onto a 0.635 cm (0.250 inch) thick felt pad meeting requirements of Federal Specification C-F-206, Type I, Class 16R3. After the sample material has been compacted 50 times, read the volume of material in the cylinder to the nearest ml.

Bulk density: gin/ml

where

W= weight of sample in grams

V= volume compacted material in ml.

5.6.20.2 Alternative procedure. Another acceptable procedure is Apparent Density, Bulk Factor and Pourability of Plastic Materials ASTM D 1895.

5.6.21 Shrinkage on cure.

5.6.21.1 Acceptable procedure. Lineare Shrinkage of Thermnosetting Casting Systems During Cure. ASTM D 2566.

5.6.22 Flow and injection moldability.

5.6.22.1 Acceptable procedure. Injection Molding of Specimens of Thermoplastic Molding and Extrusion Materials, ASTM D1897,

5.6.23 Adiabatic Sensitivity Test.

5.6.23.1 Acceptable procedure. Refer to Test Method 12.

5.6.24 Thermal Detonability Test. The explosive detonability test measures the type of fragmentation produced under controlled conditions. From this it oan be determined whether a detonation or merely a deflagration has occurred. The test forms an inter-correlation to the existing enveloping flame test where the time-temperature history of both tests are in the same region.

5.6.24.1 Acceptable test. Refer to Test Method 13.

5.6.24.2 Criteria for acceptance. Those explosives that do not detonate in this test but burn slowly without transformation to detonation would be considered highly desirable. Those that only deflagrate rapidly but do not detonate under the test may be acceptable.

5.6.25 Composition analysis. A composition analysis procedure should be available before the explosive is considered for weapon application. Each procedure will have to be determined according to the ingredients and their properties and the methods necessary for their separation and determination.

5.6.24.1 Acceptable procedure. Any procedure that gives ingred-ient analysis sufficiently close for practical evaluation (usually from ± 0.1 to ± 0.2 of the true value) will be satisfactory This varies according to the type of composition and actual ingredients.

5.6.26 Wedge Test-for shock initiation sensitivity. The wedge test procides quantitative information about the build-up to detonation of an HE when subjected to long duration planar shocks. Specifically, it is used to measure the delay till detonation, in terms of both time and distance, as a function of input pres-sure. It also provides information concerning the nature of the build-up and about events occurring behind the shock front; both of these are important in studying fuel-oxidizer systems. The usefulness of the sensitivity data obtained includes: general background information for comparing explosives; and feasibility studies for specific proposed applications.

5.6.26.1 Acceptable procedure. Refer to Test Method 14.

5.6.25.2 Advisor statement. It is suggested that the wedge test be employed as a standard source of background information on sensitivity and performance because of its-ability to provide numerical initiation data, expressed in physically meaningful terms; such data are directly relevant to weapon design. Firing three or four shots at a suitable choice of pressures would pro-

vide a wide-range initiation profile for an explosive. A comprehensive catalog of such profiles would facilitate technical decisions for varying boosters and main charges in a weapon. Firing series at high and low temperatures could substantially reduce the number of full scale shots required in environmental testing. The usefulness of the wedge test is not limited to the design stage. It has been proven capable of detecting rather small sensitivity shifts during thermal aging studies and should also be of value in stockpile surveillance.

5.6.27 Gas Chromatographic Reactivity Test.

5.6.27.1 Purpose. The gas chromatographic reactivity tests are used to determine the chemical reactivity of high explosives with other materials. This test is performed by heating for a predetermined time samples of the explosives, the material of interset, and a 50/50 mixture of the explosive and the material. The gas volumes liberated from each sample are determined by gas chromatograpy. A measure of the reactivity is obtained when the types and volumes of gas liberated from the mixture are compared with the types and volumes of gases liberated from the individual components.

5.6.24.2 Equipment.

1. A grinder or cutting device capable of grinding or cutting materials such as plastics elastomers, foams, rubber-materials foams , rubber-materials etc., between and 300 mesh.
2. Analytical balance.
3. Drying oven.
4. Screens, 300, 100, and 40 mesh.
5. A vacuum system with pressure indicator capable of evacuation down to approximately 0.133322 Pa (1 millitorr).
6. Sample holders which consist of an inlet and outlet valve, a crucible (stainless steel or glass), and spacers to reduce the internal volume of the sample holder.
7. Oil bath for heating the sample holders capable of 1.20 ± 1°C.
8. A gas chromatographic system capable of separating N_2, CO, NO, CO^2, N^20. The system shall have an inlet system for the sample hol ers and a means for calibrating the chromatography.
9. Pure and dry gas standards of N_2, CO, NO, $C0_2$, and N_20.

5.6.27.3 Procedure. The following procedure shall be used to determine the chemical reactivity of explosives with other materials:

5.5.27.3.1 Calibration. To analyze any gaseous mixture, calibration curves of peak area versus volume must be established for N_2, CO, NO, $C0_2$, N_20.

5.6.2.7.3.2 Sample hodlers. All sample holders, stainless steel or glass crucibles, and spacers shall be thoroughly cleaned and free of solvents prior to use.

5.6.27.3.3 Sample preparation.

1. shall be ground without "smearing out" on loss of the binder. A 0.250 ± 0.010 gram sample shall he weighed into the crucible for the control run.
2. A 0.250 ± 0.010 gram sample of the material of interest shall be weighed into the crucible for the control run.
3. A mixture of 0.250 ± 0.010 gram of the explosive and 0.250 ± 0.010 gram of the material of interest shall be weighed into a crucible. The contents shall be stirred until the components are thoroughly mixed.
4. Each crucible shall be placed into a sample holder followed by a spacer.
5. All the air shall be removed from the sample holder with a vacuum system. After the sample holder has been evacuated it shall be filled with helium.

6. The sampler holder shall then be held within ± 1°C at the specified temperature for 22 ± 0.5 hours. Each sample holder shall then be analyzed on the chromatograph.

5.6.27.4 Calculations.

5.5.27.4.1 Gas chromatograph calibaration. The gas chromatograph is calibrated by injecting a given volume (V_s) of standard gas at temperature (T_s) and pressure (P_s). The volume of gas corrected to Standard Temperature and Pressure (STP) is given by

$$V_0 = V_s \frac{P_s}{P_0} \cdot \frac{T_0}{T_s}$$

and the calibration constant K is given by

$$K = V_0/A$$

where A is the area of the gas chromatographic peak.

5.6.27.4.2 Gas volume formula. The volume of gas evolved from a sample (at STP) shall be determined by

$$V = K \cdot A$$

where K is the calibration constant for and A is the area of the gas chromatographic peak.

5.6.27.5 Interpretation of the data. The reactivity coefficient (R) for each gas and the total gas evolved shall be determined by

$$R = \frac{V_m}{V_E + V_I}$$

where V_m is the volume of gas evolved by the mixture, V_E is the volume of gas evolved by the explosives and V_I is the volume of gas evolved by the material of interest. Samples having an R value less than 1.5 are unreactive while those with an R greater than 1.5 but less than 3 are borderline reactive. Those with an R value greater than 3 are reactive.

5.7 Performance. Explosive performance is considered separately from essential tests and background information because some performance methods will be considered essential for some applications and others for different applications. The performance of an explosive in a given weapon is determined through a number of warhead tests such as fragmentation with recovery of fragments, damage to specific targets, and pressure measurements. In order to decide to which applications particular new explosives should be applied, it is necessary to determine values relating to particular modes of energy delivery (i.e., fragments, air-blast, shaped charge, etc.). Calculations and past experience serve as general guides toward synthesizing and formulating explosives with sufficient potential energy and release-rate-level to be undertaken for development. Calculations, while providing information for initial selection, must be backed up by actual performance data before selection is made to use the explosive in a given application. If the initial objective for an explosive is to increase energy of a fragmenting warhead, for example, tests which give results correlating well with fragmenting warheads are desired. Gurney values for explosives have been used to predict fragment accelerating capability in non-nuclear warheads. In nuclear warheads, hydrodynamic codes together with determined explosives parameters such as Chapman Jouget pressure, detonation temperature and others are used. Experimental methods that scale will are preferred for performance evaluation. Of all the means for predicting either fragment acceleration or metal movement for

nuclear of non-nuclear warheads, the cylinder expansion method is considered the best. best. A condensation (Table I) has been made of the performance evaluation methods that appear useful for explosives considering the applications for which this information is needed.

5.7.1 Determination of critical diameter. The critical diameter (d.) defines the threshold for propagation of steady-state conditions. Because it is a failure threshold, it is far more easily affected by small variations in the phusical properties of the change than is the value of the detonation velocity at larger diameters. Consequently, charge must be of good quality if reproducible results are to be obtained. Charge preparation recommendations of 5.7.2 should be used. As an explosive approaches its d_c, its shock sensitivity decreases rapidly. Hence, it is important to specify a powerful booster (e.g., CH-6, 9404) for these tests. Any irregularity of the charge such as continuous wires or metal probes are apt to perturb the threshold conditions. Hence, optical measurements with the smear camera are recommended. For steady detonation, the streak is straight; for a failing detonation the streak is curved, and may disappear altogether. In fact, some of the unreacted explosive may be recovered after the shot. It is not necessary to determine the instantaneous velocity of the detonation from the curved traces. The observation that the trace is definitely curved in the direction of decreasing velocity is sufficient to show that the test diameter is less than d_c. This avoids the necessity of differentiation of experimental data. It is important to have a sufficiently long charge because as d approaches d_c from below, the shock induced reaction may run for long distances at apparently constant velocity before failure can be seen.

TABLE I Performance Evaluateion of Explosives.

Application	Test method										
	Detonation velocity for ∞ diameter	Fragment velocity	Gurney constant	Fragment mass distribution	Pressure versus scaled distance	Impulse versus scaled distance	Cylinder expansion	Chapman Jouget pressure	Shaped charge penetration	W.D. (weight for same shock as 1-lb Pentolite)	M.B.E. (Mechanical Bubble Energy
Bombs	+	+	+	+	+	+	+	+	-	-	-
Shaped charge	+	-	-	-	-	-	+	+	+	-	-
Small caliber shells (to 40mm)	+	+	+	+	+	+	+	+	-	-	-
Large caliber shells	+	+	+	+	+	+	+	+	-	-	-
Torpedoes	+	-	-	-	-	-	-	-	-	+	+
Depth charge	+	-	-	-	-	-	-	-	-	+	+
Mines	+	-	-	-	-	-	-	-	-	+	+
Blast	+	-	-	-	+	+	-	-	-	-	-
Focussed blast	+	-	-	-	+	+	-	+	-	-	-
Continuous Rod W/H	+	+	+	+	+	+	+	+	-	-	-
Fragmenting W/H	+	+	+	+	+	+	+	+	-	-	-
Bomblets	+	+	+	+	-	-	-	-	-	-	-
Polygon charge	+	+	+	+	+	+	+	+	-	-	-
Destruct system	+	-	-	-	-	-	+	+	-	-	-

+ desirable.
- not needed.

The most direct method of determining d_c is to fire a series of different diameter charges and obtain the smear-camera record of each. For castable materials that can be easily prepared as conical charges, the record of the reaction initiated at the cone's base will show failure at some diameter of the cone. This measured d_c is always too small, because in a base initiated conical charge the detonation is overboostered as it progresses to smaller diameters. The use of a stepped cylinder, instead of a cone. avoids this problem but introduces others. The length at each diameter (each step) must be about 4 d or greater to allow the overboostering to fade out and a sufficient length of steady state propagation to measure detonation velocity (D). The camera cannot view an extremely long charge and still give a record that can yield an accurate value of D. Hence, the stepped cylinders, like the cone, is best suited for obtaining a preliminary and approximate value of d_c. d_c. It should be followed by more precise measurements on cylindrical charges. Another method depends on an approximate measurement Of total "output" and does not establish the existence of a steady-state detonation. It may, however, give a good estimate of d_c, and it can be applied to confined charges (as can also the probe method of measuring D). Up to this point only bare unconfined charges have been considered because the theory of confinement is not quantitative for practical problems it is, of course, possible to work with a scaled confinement, i.e., constant ratio of wall thickness/ internal diameter. The range in d_c over all explosives is very large. Common pressed HE have d_c of approximately 1 cm or less whereas voidless composite propellants may exhibit d_c of approximately several meters. For the materials with a very small d_c, ,it is sometimes easier to prepare a rectangular plate charge (or even a wedge) than to prepare a cylinder. In such cases, a critical height (instead of d_c) is measured and may be related to a corresponding d_c. For charges of very large d_c, strong confinement is sometimes used to reduce charge size.

5.7.2 Determination of infinite diameter detonation velocity. Detonation velocity (D) is the most easily measured of the detonation parameters. Its value is highly dependent on the loading density (ρ_c) of the charge and somewhat dependent on charge diameter and, for granular charges, on the initial particle size of the explosive. The hydrodynamic theory of detonation includes the density effect but not the diameter effect. Hence, it is the detonation velocity which would be observed in an infinite diameter cylindrical charge (D_i) that is necessary in any comparison of experimental results with the theory. The usual method of obtaining D_i is to fire a series of charges of different diameters

(d), and measure the corresponding D. A plot of D versus d generally shows D increasing with d and apparently approaching the value D_i asymptotically as d approaches limit of infinity. However, it is difficult to select D_i from such a curve, and it is more customary to plot D versus d^{-1} or D^{-2} versus d^{-1} in a range of values of d large enough to give a linear curve. D_i is then taken from the intercept at d^{-1} equal to 0 or d^{-2} equal to 0. The plot D versus d^{-1} is most commonly used and seems most successful in exhibiting linearity at large values of d. Because a number of charges must be used in determining the value of D_i for a single explosive in a given physical condition, charge preparation is a problem. For good results, all charges should be prepared from one uniform batch of the explosive. If the charges are pressed, isostatic pressing is recommended in preference to ram pressing. This method requires machining the pressings to make cylinders of the required dimensions. If the material is cast from a melt, conditions must be carefully controlled to insure that all charges have the same physical properties (e.g., the same density and the same crystal structure). Hence, charges of different diameters and length must be prepared under carefully controlled conditions in order to determine the true value of D_i. Diameters of the charges should be chosen so that the resulting data are most useful in the extrapolation to D_i. That is, if d^{-1} is chosen as the independent variable for plotting the results, the data points should be more or less equally spaced with respect to the d^{-1} axis. The booster explosive should have a shock impedance about 20-30% greater than that of the test explosive so that detonation is initiated reliably. Because of the mismatch of the explosives, the test charges must be long enough so that the effects of over bolstering will die out by the time the detonation reaches the portion of the charge where the detonation velocity is to be measured. That is, the measured D should be that for steady state detonation. The length of charge required for this is conveniently expressed in terms of the ratio of the length of the charge to its diameter, ℓ/d and is probably adequate when ℓ/d is greater than or equal to 2. If the explosive has a front of constant curvature this distance will also be sufficient for its establishment. If, on the other hand, the explosive has a front showing spherical expansion, an ℓ/d is greater than or equal to 9 should be attained for 1% accuracy. In such a case, use of a plane wave booster can reduce the required length of run before measurement. Detention velocity can be determined in any of several ways; the choice of a method probably depends more on the availability of equipment and well tested procedures than on any inherent advantage of a given method.

5.7.2.1 Electronic method. The electronic method is widely used; it depends on the closing of "switches" either by the conduction of hot gases between two electrodes, or the forcing together of two electrodes by the pressure induced by the detonation. Precision of the measurements depends on the number of switches or pins that are used on the charge, and on the precision of the equipment. Precautions which should be observed are discussed in Test Method 8.

5.7.2.2 Optical method. A commonly used optical method makes use of the streak or smear camera to record the instantaneous position of the detonation front. This method is also discussed by Taylor, who gives a picture of the "streak" for a typical explosive. Because the record gives the instantaneous location of the detonation fronts the slope of the streak is proportional to the velocity. Simple data reduction techniques can be used for the application discussed here. The traces are straight so that after digitizing, the data are fitted with a linear relation, the coefficient of the time being the velocity of the detonation. Again, this method can be made to give precise results if sufficient care is taken in preparing the charges and in arranging the experiment. A description of smear camera techniques is given in Test Method 15.

5.7.3 Fragmentation velocity.

5.7.3.1 Cylinder expansion. Refer to Test Method 16.

5.7.4 Gurney Constant. The Gurney constant a or 2E us obtained from the cylinder expansion evaluation of Explosives. For more For more detailed procedure, test method 16 covers an acceptable method for Gurney constant. It can also be obtained by solving from known values of fragment velocities using various warheads or models from the equation

$$V = \sqrt{2E\left(\frac{C/M}{1 + 0.5\ C/M}\right)}$$

where V is the highest velocity to which the particular explosive change accelerates metals C/M is the explosive charge weight to total case + explosive weight and 2E, related to explosive energy, has dimensions of velocity.

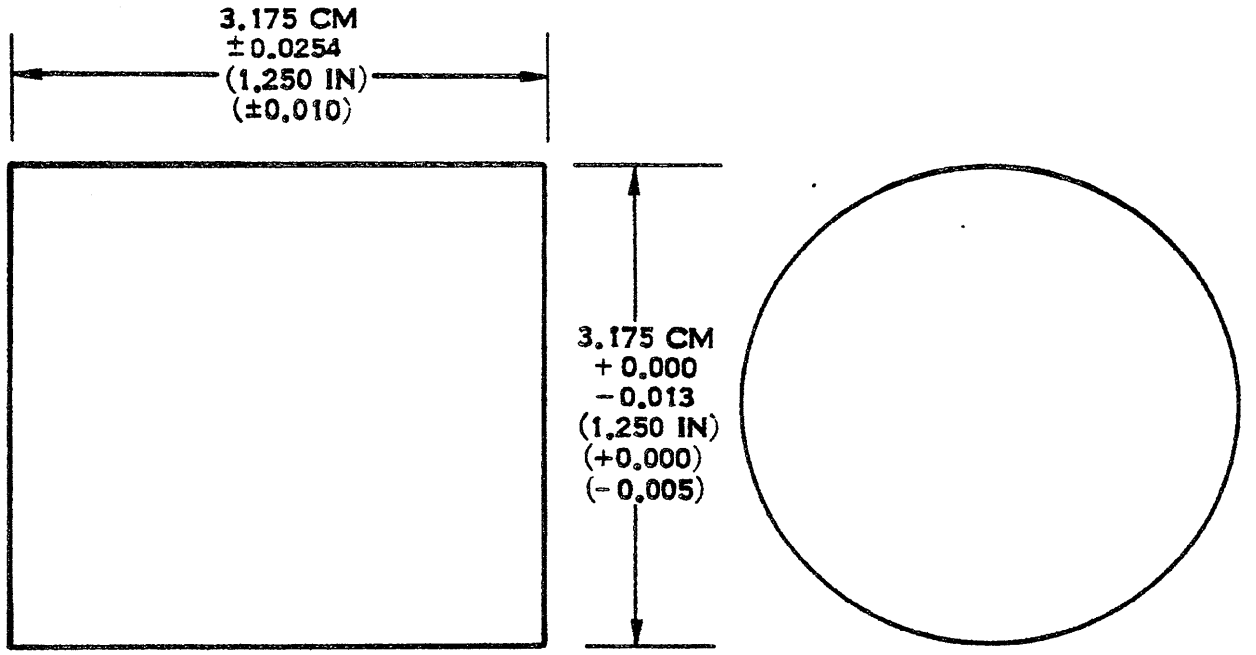
5.7.5 Detonation pressure (Aquarium Technique). Detonation pressure data are derived from measurements of shock waves transmitted into water by the detonation of cylindrical explosive charges. Refer to Test Method 17.

Custodian:
Air Force -99

Preparing activity:
Air Force -99

Review Activity:
Air Force - 18

Project No 13GP-F007



NOTE:
POLISH ALL SURFACES

MATERIAL – KETOS OIL HARDENING TOOL STEEL
HEAT TREAT
TO ROCKWELL C–60 HARDNESS

FIGURE 1 ANVIL FOR IMACT SENSITIVITY TEST

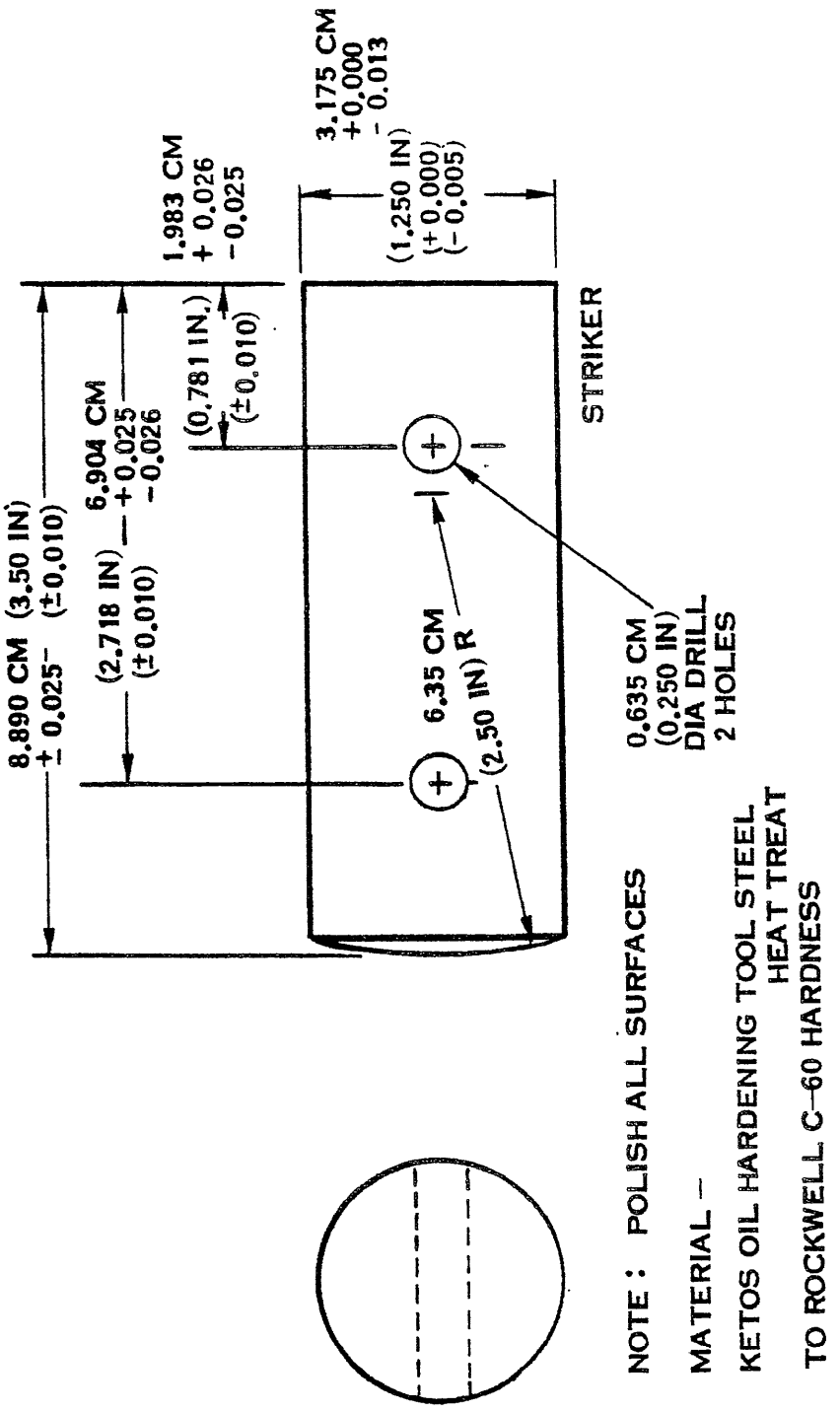
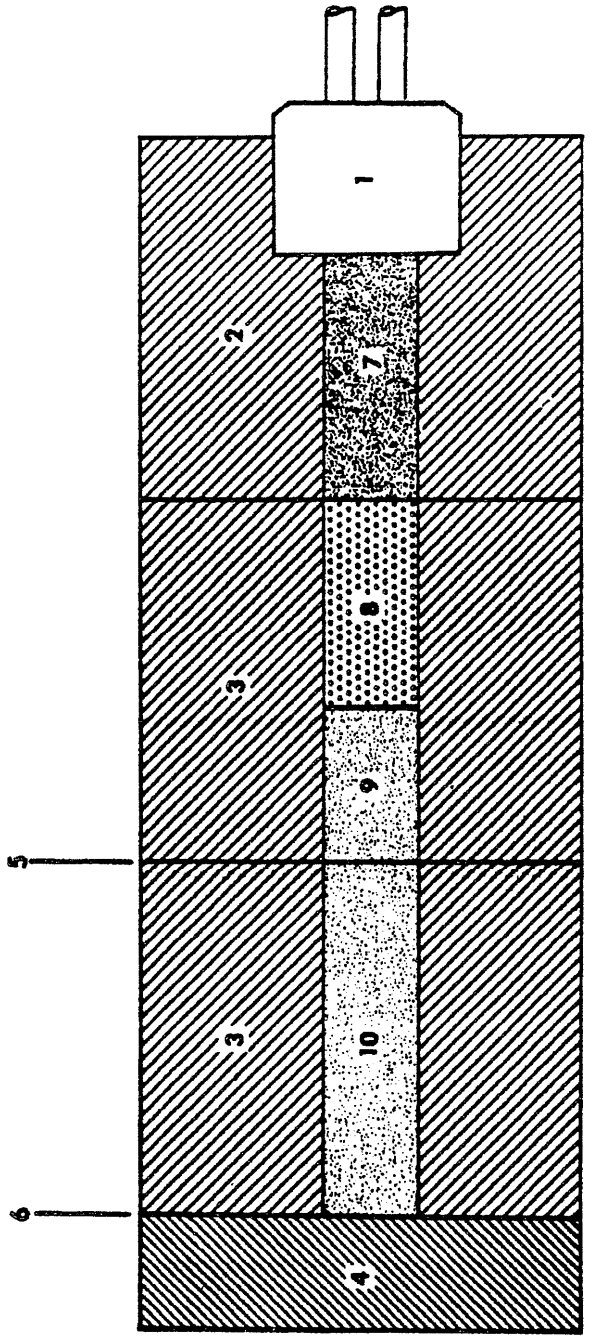


FIGURE 2 STRIKER FOR IMPACT SENSITIVITY TEST



1. MK 114 ELECTRIC PRIMER
2. BRASS CYLINDER—2.540 CM (1.0 IN.) OD X 0.508 CM (0.2 IN. ID X 2.540 CM (1.0 IN.) LONG PRIMER RECESS 0.762 CM (0.300 IN.) ROCKWELL B 70 — 95)
3. BRASS CYLINDER 0.508 CM (1.0 IN.) OD X (0.2 IN) ID X 2.540 CM (1.0 IN.) LONG ROCKWELL B 70 — 95
4. CIRCULAR 1020 STEEL BLOCK —(2.540 CM (1.0 IN.) DIAMETER X 1.27 CM (0.5 IN.) THICK ROCKWELL B 70 — 95
5. START PROBE TO HEWLETT — PACKARD TIMER, MODEL 5275A
6. TIMER STOP PROBE-
7. LEAD AZIDE PRESSED TO 68948.0 kPA (10,000 PSI(AT LEAST (0.5 IN.) LONG
8. RDX PRESSED TO 68948.0 kPA (10,000 PSI)
9. PRIMARY EXPLOSIVE BEING EVALUATED, PRESSED TO 68948.0 kPA (10,000 PSI) AT LEAST 1.016 CM (0.4 IN.) LONG
10. PRIMARY EXPLOSIVE BEING EVALUATED AT 90 — 95% TMD

FIGURE 3 DETONATION VELOCITY TEST

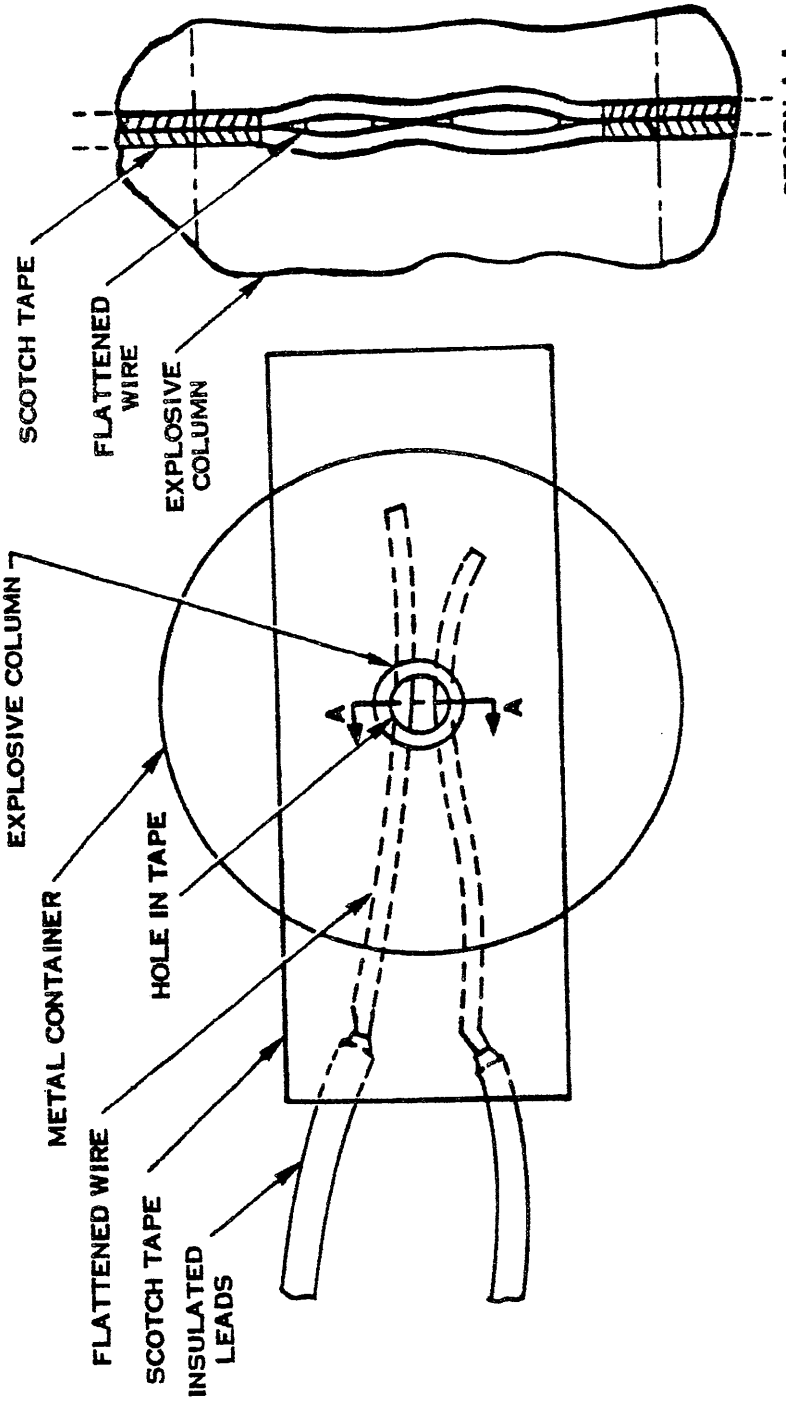
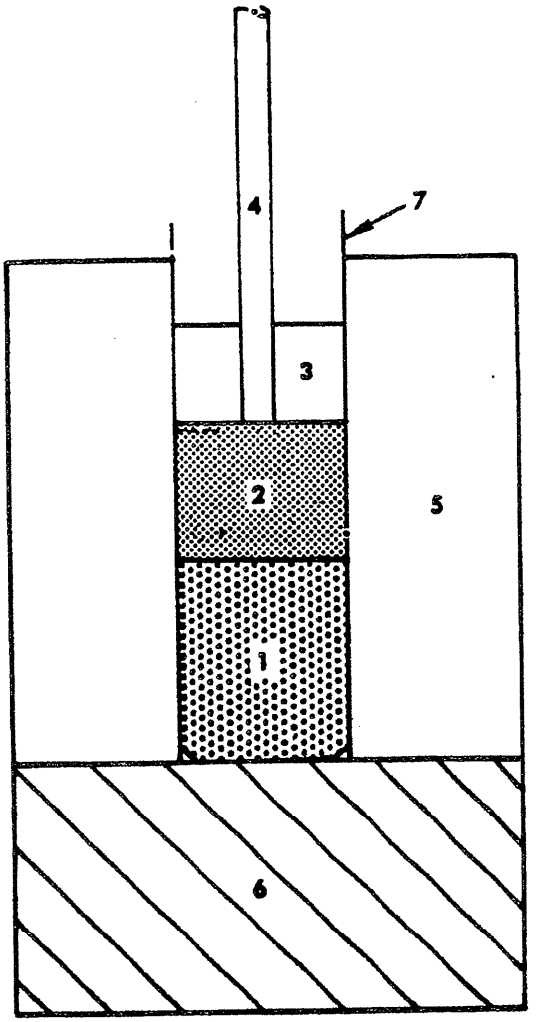
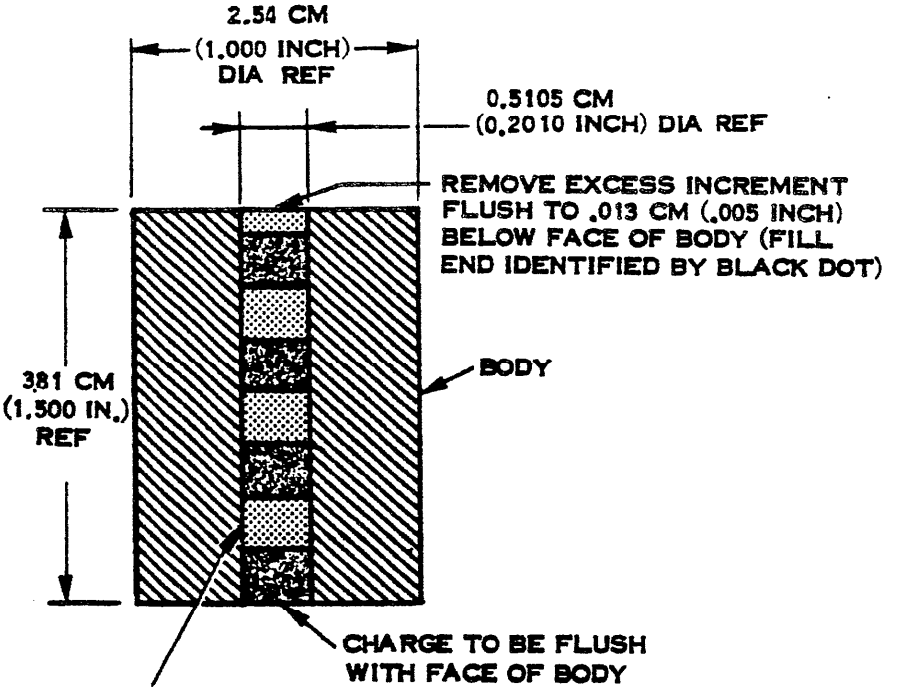


FIGURE 4 PROBE CONSTRUCTION



1. 200 MG RDX PRESSED AT 68948.KPA (10,000 PSI)
2. PRIMARY EXPLOSIVE BEING EVALUATED, LOOSE
3. PLASTIC (OR WOOD) HOLDER FOR SAFETY FUZE
4. SAFETY FUZE 120 SEC/0.9144 M (120 SEC/YD)
5. PMMA HOLDER 2.54 CM OD X 0.724 CM ID (1.0 IN. OD X 0.285 IN. ID)
6. 1020 STEEL PLATE 2.54 CM DIA. X 1.27 CM (1.0 IN. DIAMETER X 0.5 IN.) THICK ROCKWELL B 70–95
7. ALUMINUM CUP 0.699 CM OD X .660 CM I.D. X 3.81 CM (0.275 IN. O.D. X 0.26 IN. I.D. X 1.5 IN.) LONG

FIGURE 5 TYPICAL ARRANGEMENT FOR PRIMING ABILITY TEST



EACH INCREMENT TO BE LOADED AT A PRESSURE OF 110,316.11 ±6895. kPa (16,000 ± 1,000 PSI). MOISTURE CONTENT AT TIME OF LOADING MUST NOT EXCEED 0.3%. A MINIMUM OF 4 HOURS DRYING TIME AT 50° C (122° F) UNDER 724 MM (28.5 INCH) MERCURY VACUUM JUST PRIOR TO LOADING

FIGURE 6 DONOR ASSEMBLIES. BUWEPS DRAWING 2426913

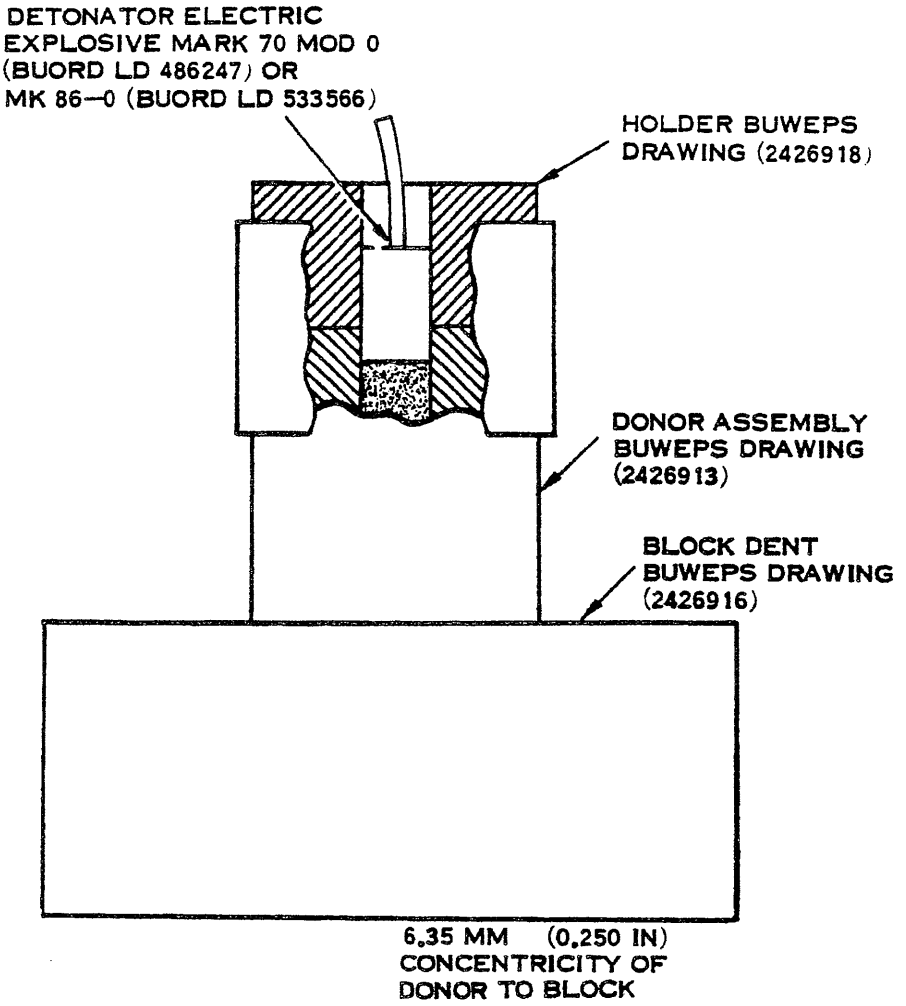


FIGURE 7 SMALL SCALE GAP TEST ARRANGEMENT FOR TESTING DONORS BUWEPS DWG 2426912

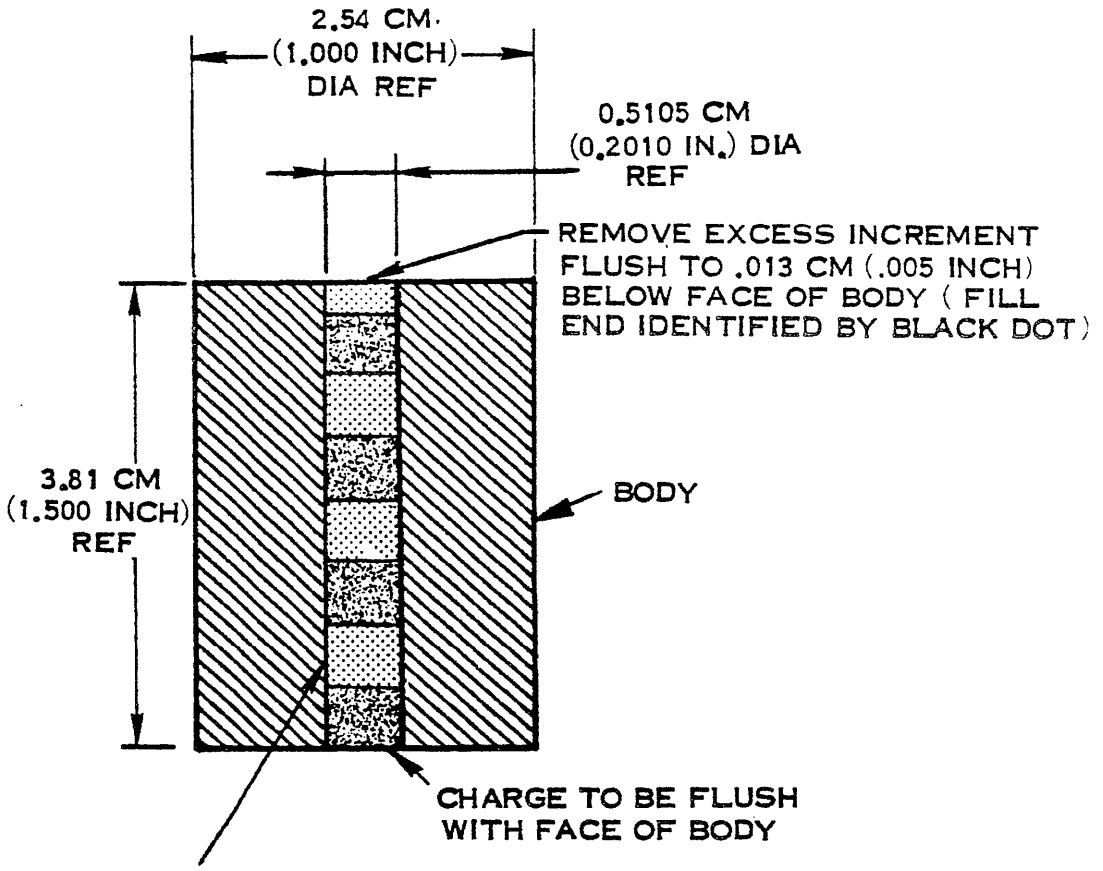


FIGURE 8 ACCEPTOR ASSEMBLY. BUWEPS DWG 2426914

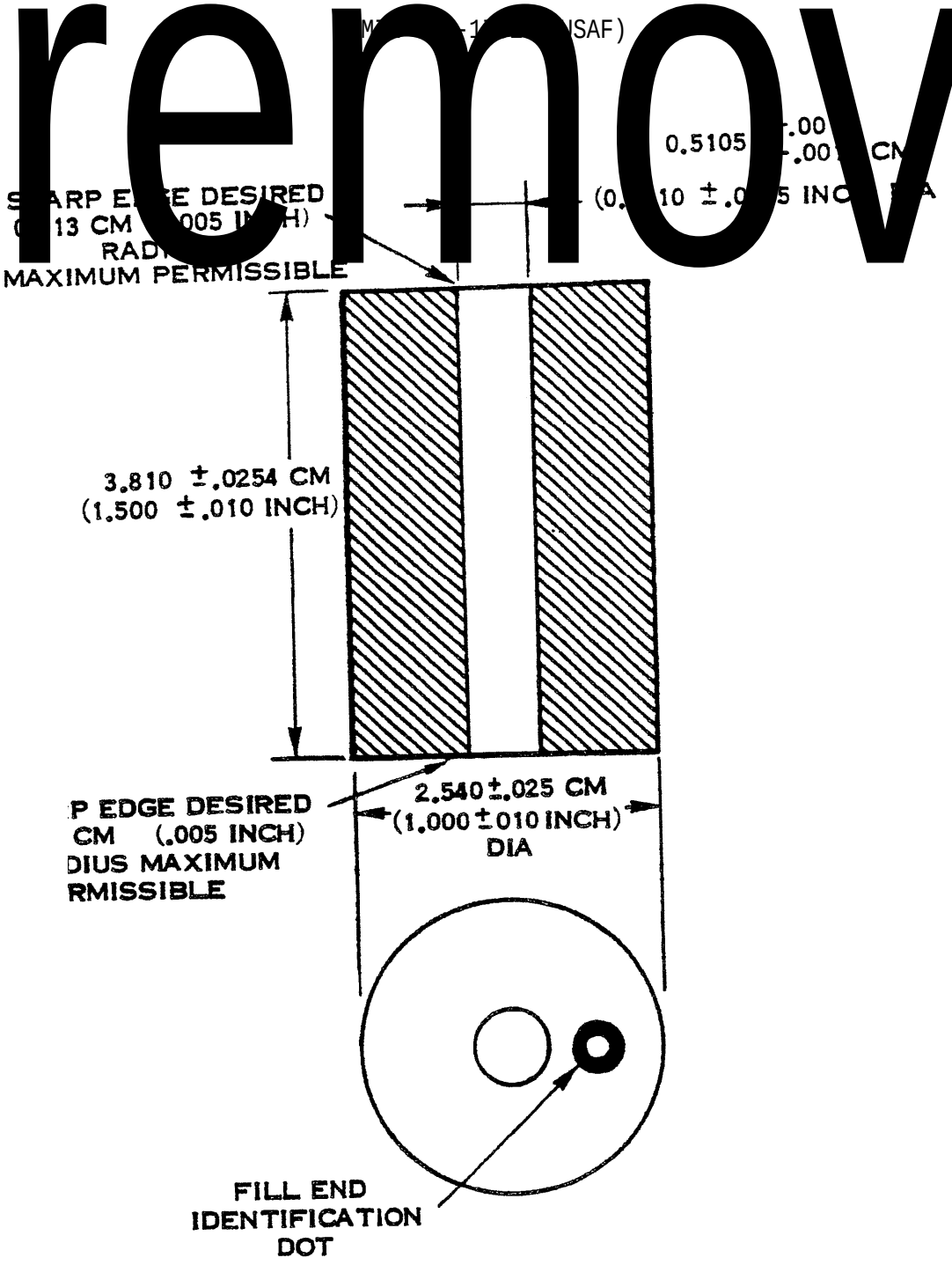


FIGURE 9 BODY. BUWEPS DWG 262915

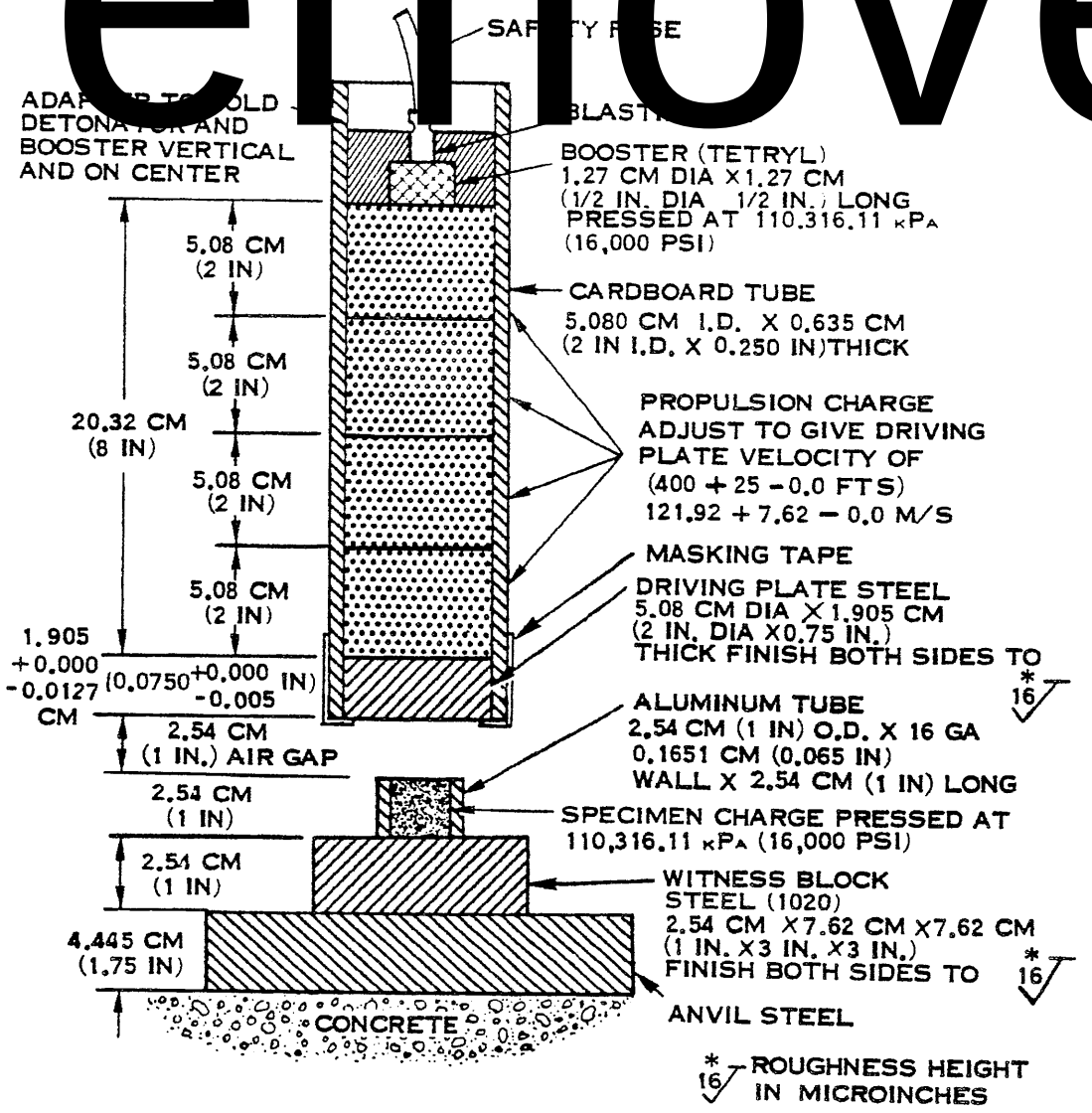


FIGURE 10 IMPACT VULNERABILITY TEST ARRANGEMENT

r e m o v e

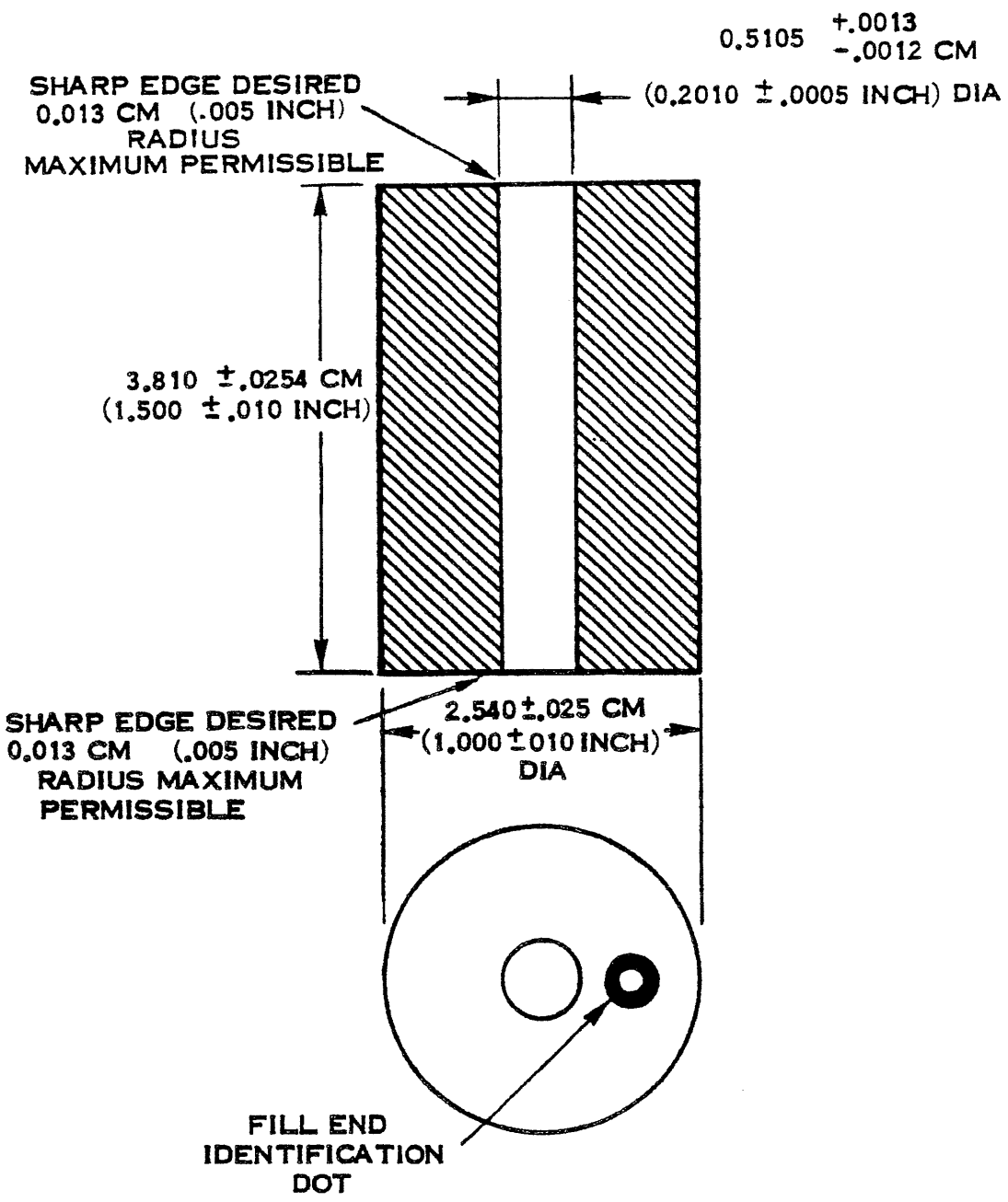


FIGURE 9 BODY. BUWEPS DWG 262915

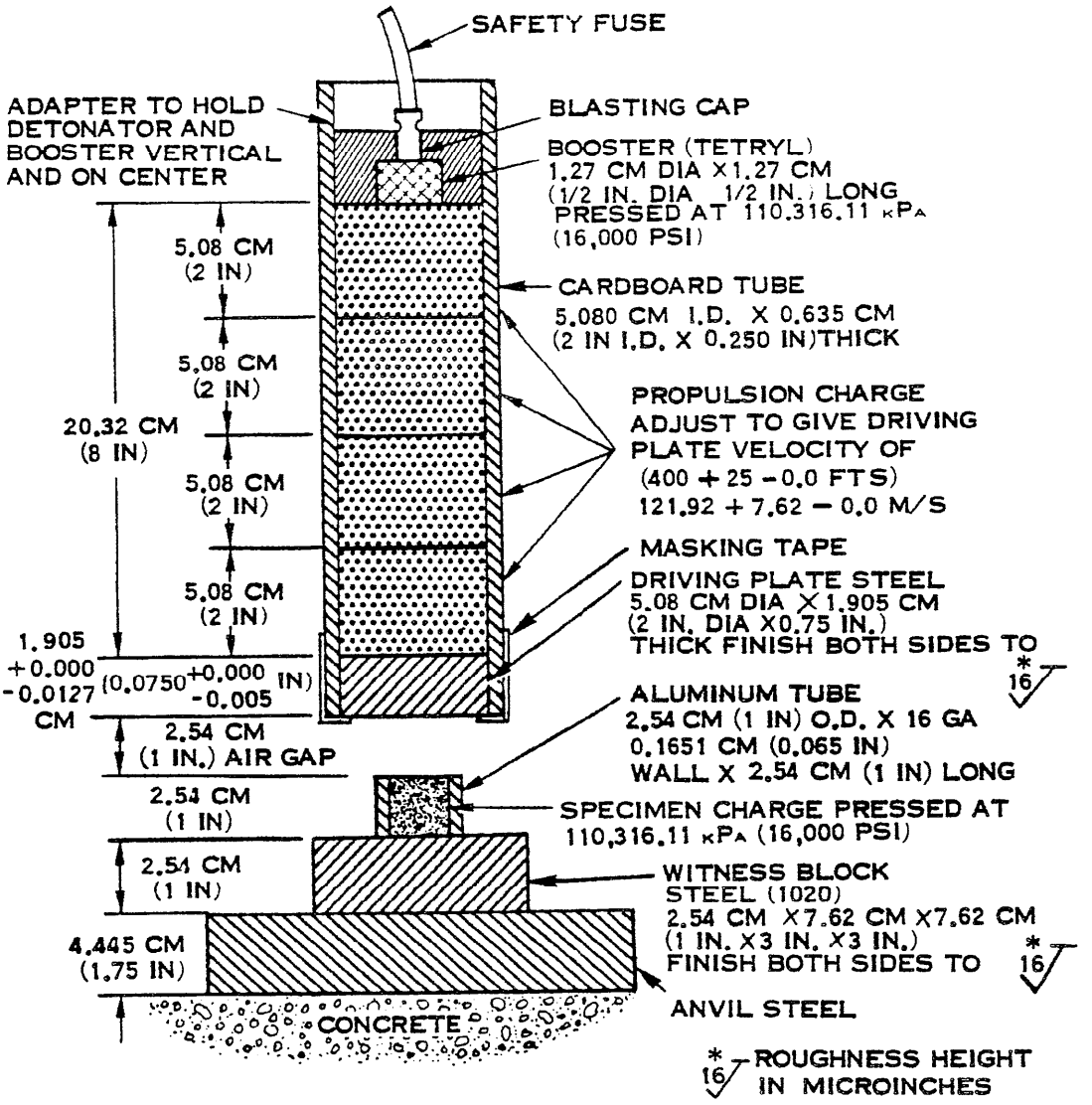


FIGURE 10 IMPACT VULNERABILITY TEST ARRANGEMENT

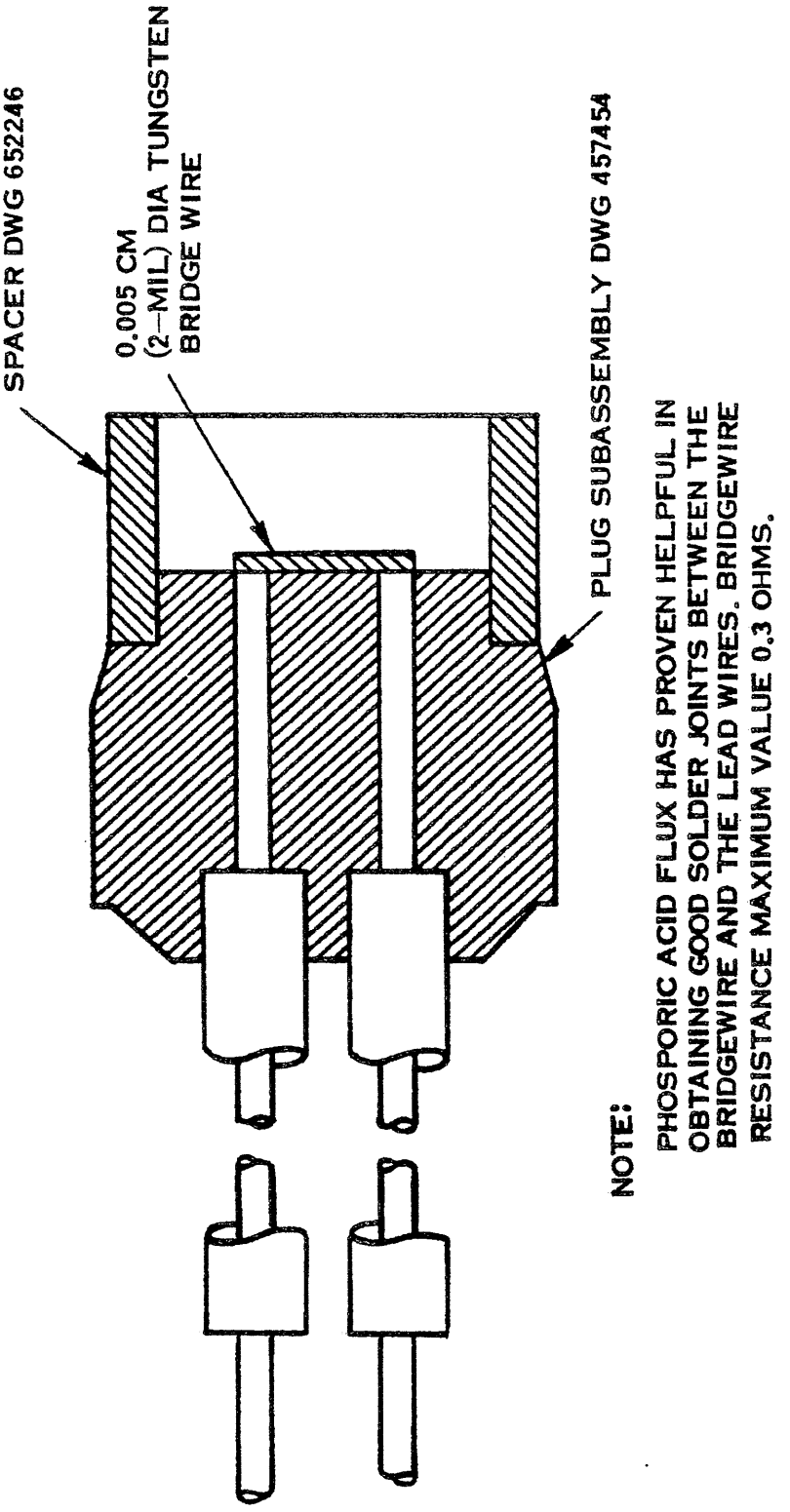


FIGURE 11 HOT WIRE IGNITION ARRANGEMENT

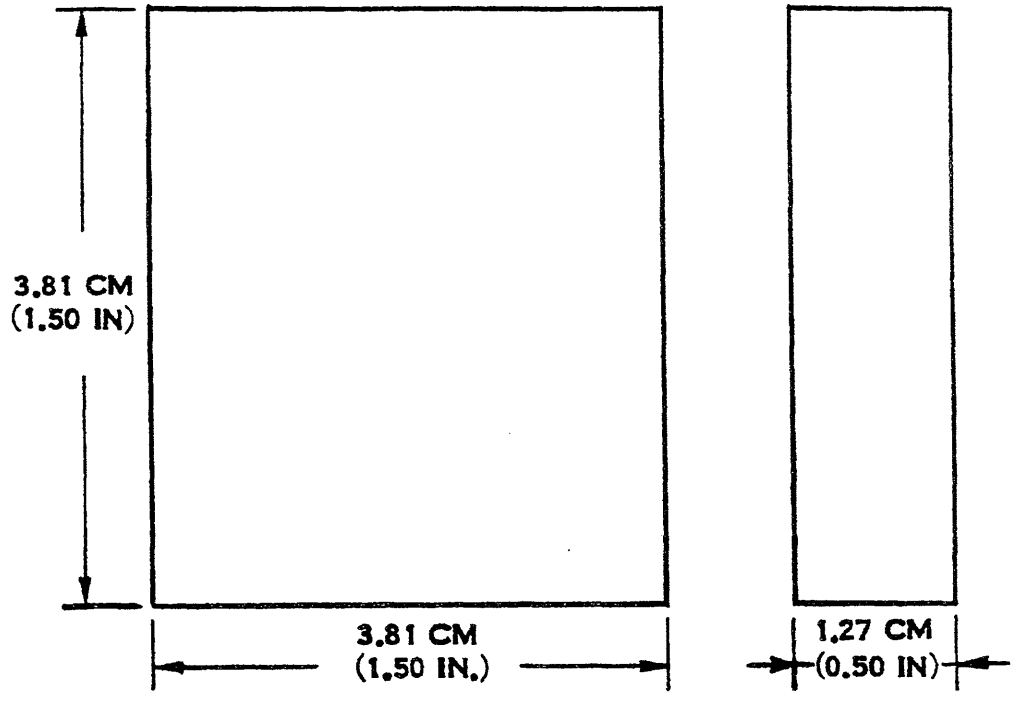


FIGURE 12 ALUMINUM DENT BLOCK

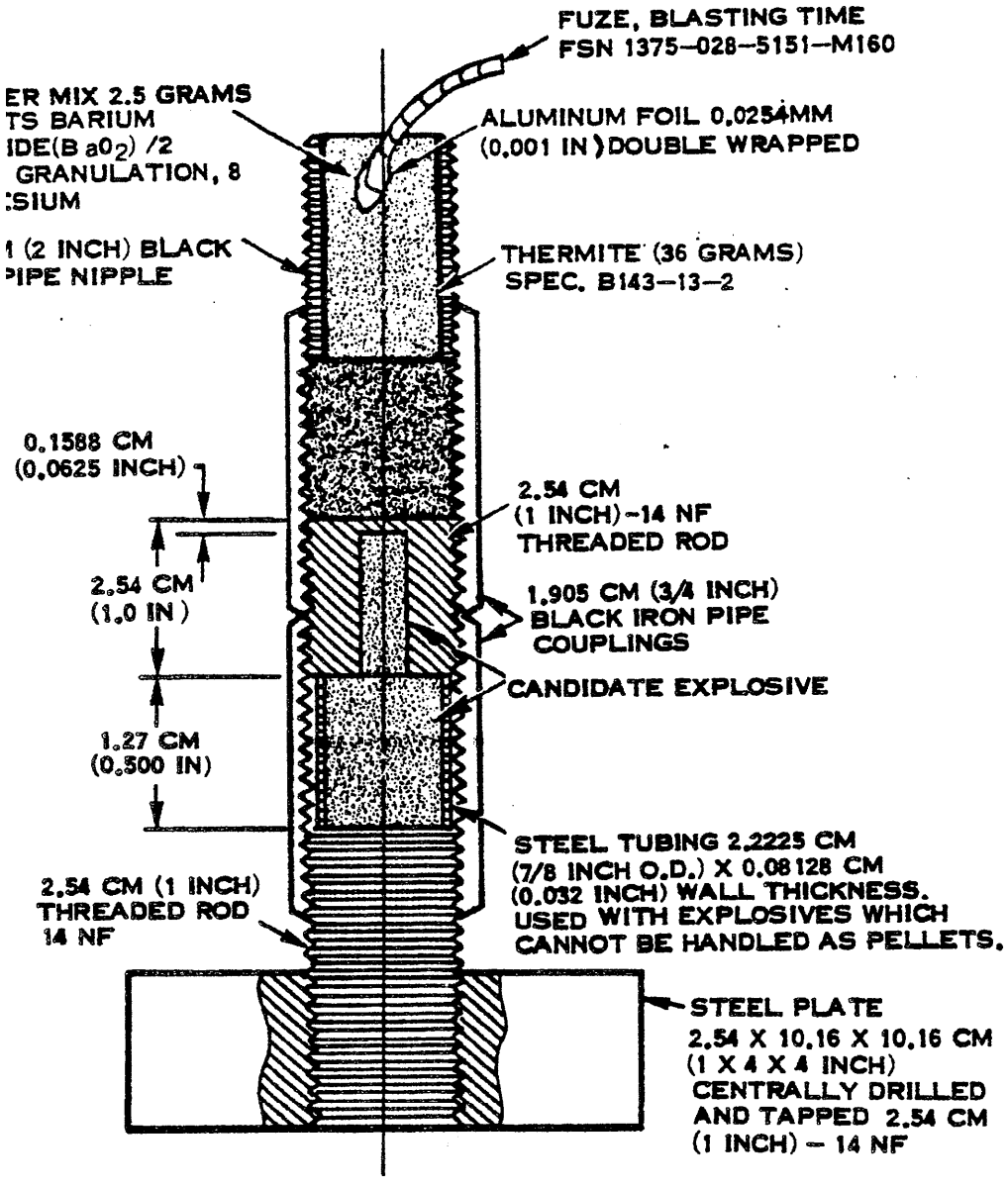


FIGURE 13 BON-FIRE TEST ARRANGEMENT.

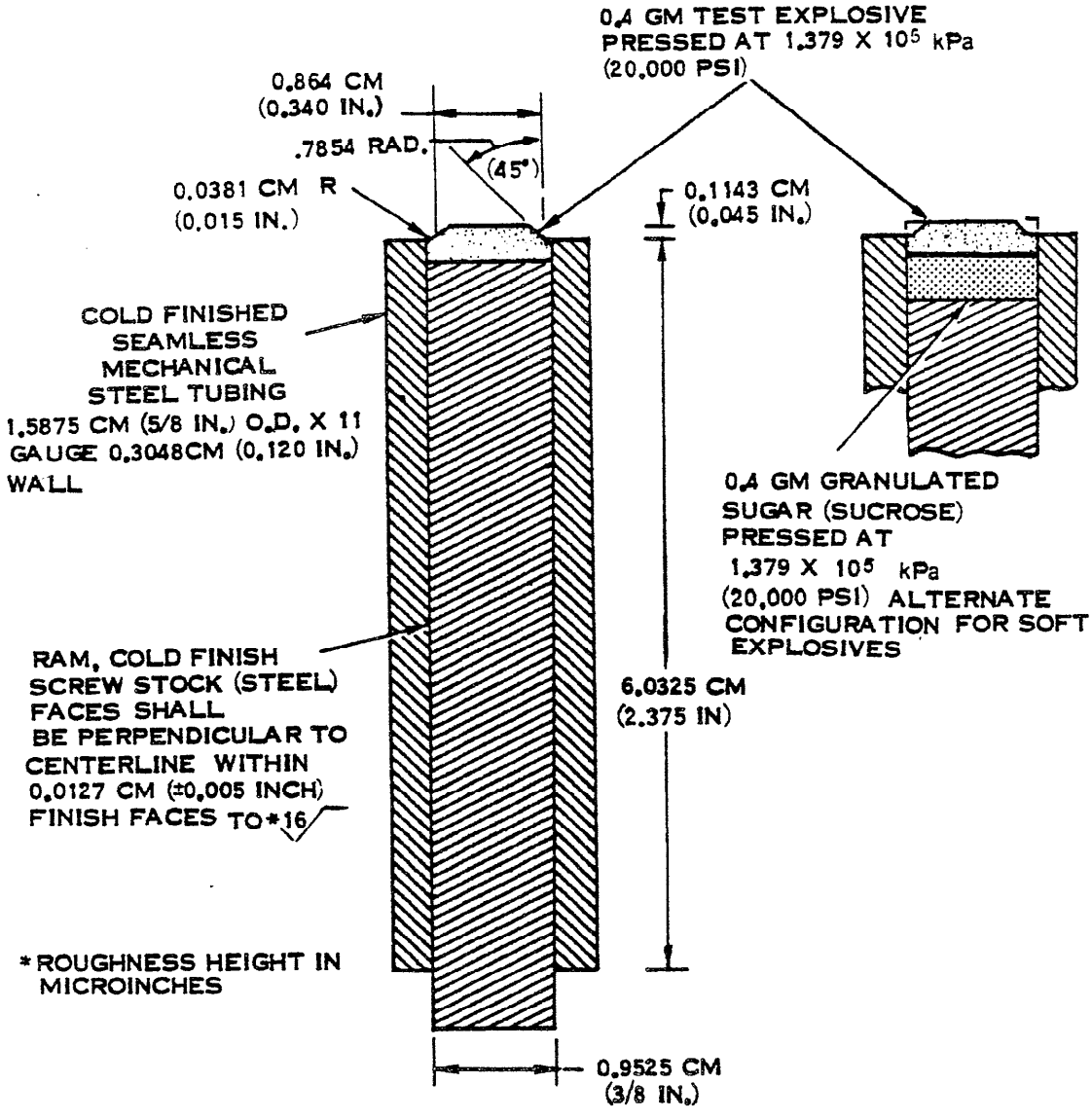


FIGURE 14 FRICTION SENSITIVITY TEST SPECIMENS IN HOLDER.

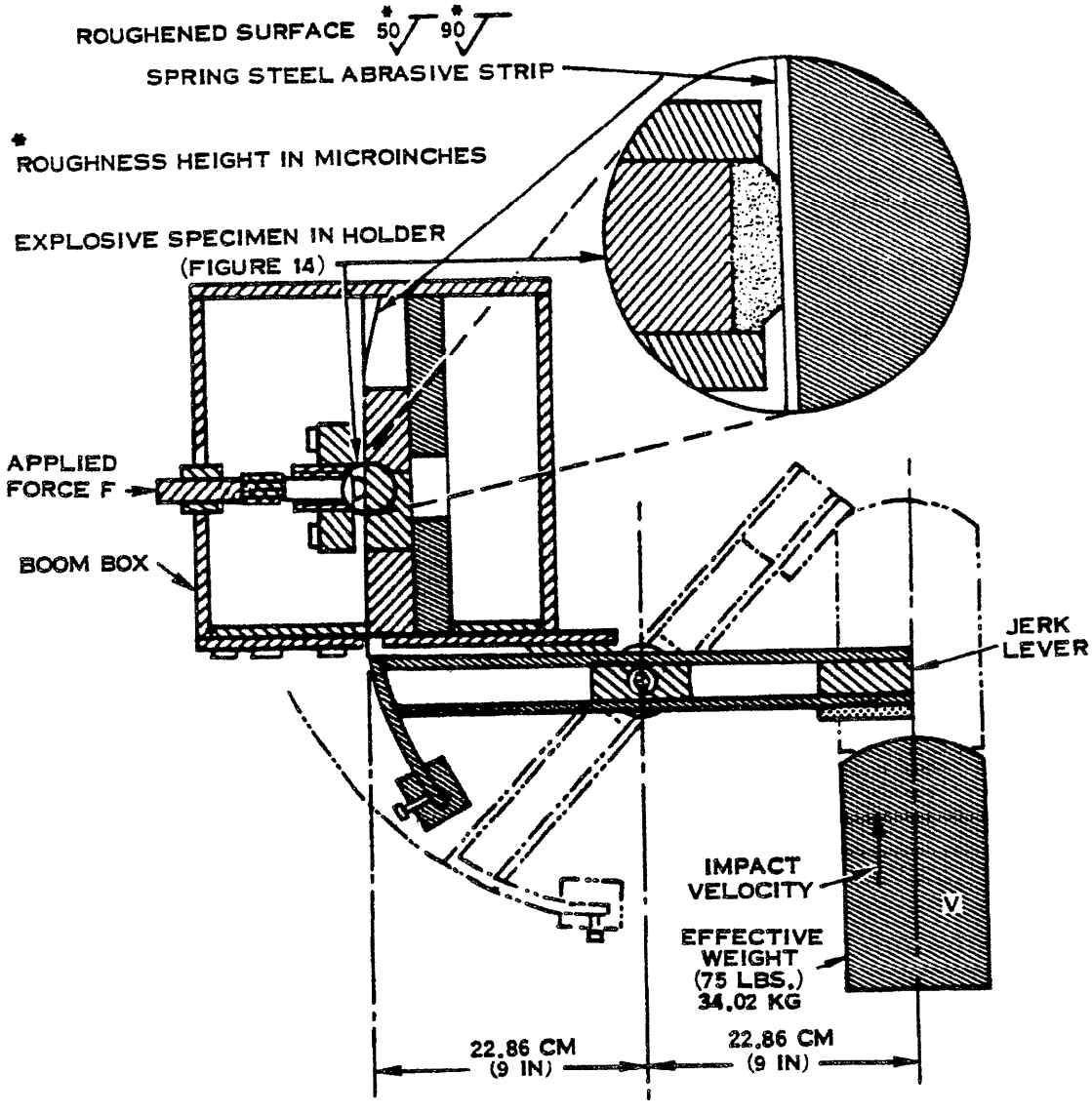
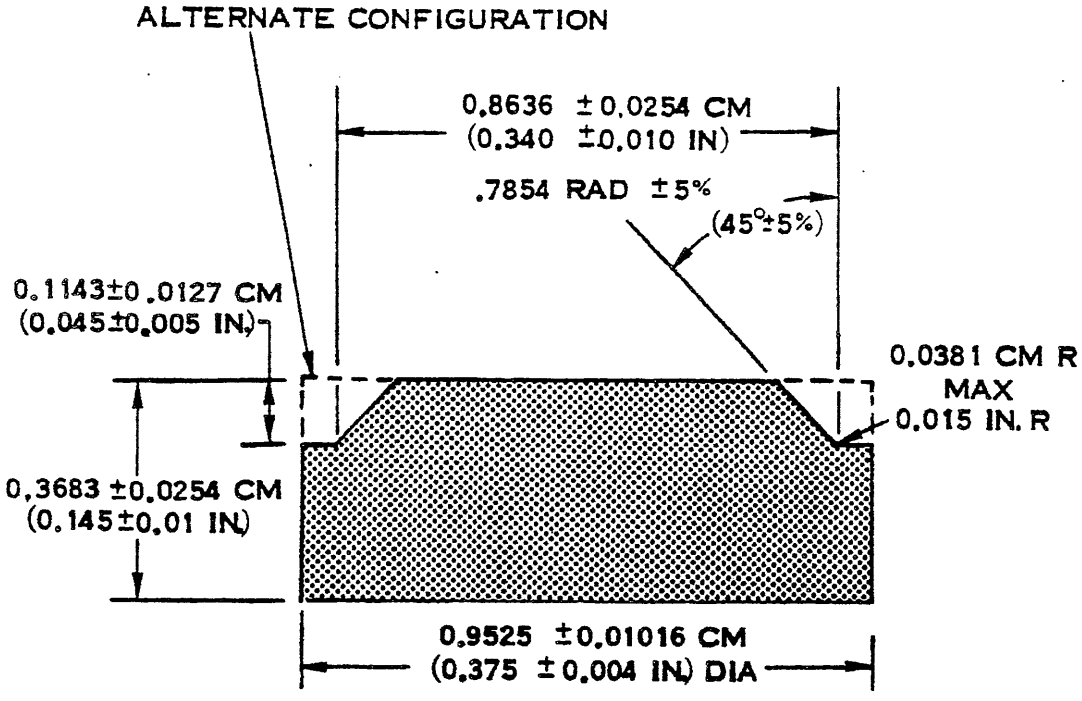


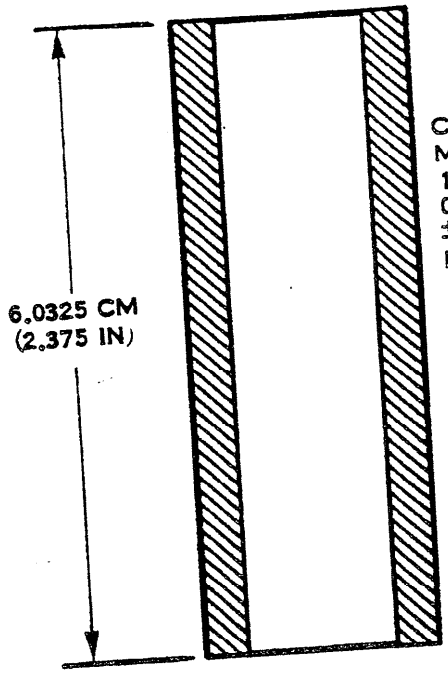
FIGURE 15 FRICTION SENSITIVITY APPATATUS



PELLETS OF TEST EXPLOSIVES MAY BE FORMED BY PRESSING, CASTING, MOLDING, MACHINING, ISOSTATIC PRESSING, EXTRUSION OR BY OTHER MEANS OR BY A COMBINATION OF THE ABOVE MENTIONED FABRICATION METHODS.

NOTE: FOR MOST OF THE MORE COMMON BOOSTER EXPLOSIVES, APPROXIMATELY 0.4 GRAM OF EXPLOSIVE WILL BE SUFFICIENT. PRESSED GRANULAR EXPLOSIVES SHALL BE PRESSED AT 1.379×10^5 kPa (20,000 PSI)

FIGURE 16 TEST SPECIMEN CONFIGURATION.



COLD FINISHED SEAMLESS
MECHANICAL STEEL TUBING
1.5875 CM (5/8 IN) O.D. X 11 GAUGE
0.3048 CM (0.120 IN) WALL O.D. 1.5875
± 0.0127 CM (0.625±0.005 IN.)
I.D. 0.9779±0.0127 CM (0.385±0.005 IN.)

NOTE: THESE TOLERANCES ARE SMALLER THAN STANDARD COMMERCIAL TOLERANCES HOWEVER, DUE TO IMPROVEMENTS IN MILL EQUIPMENT AND PRACTICES, MOST RECENTLY PRODUCED TUBING WILL FALL WITHIN THESE TOLERANCES.

FIGURE 17. SPECIMEN HOLDER TUBE

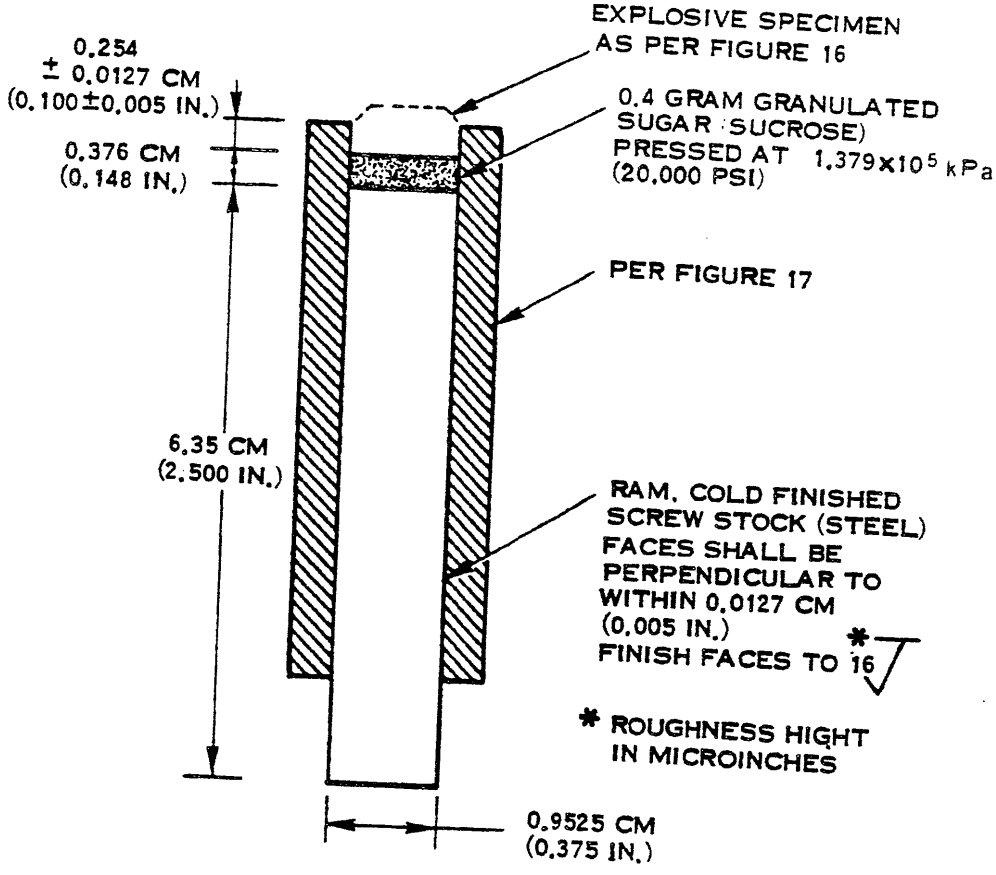


FIGURE 18 SPECIMEN HOLDER ASSEMBLY

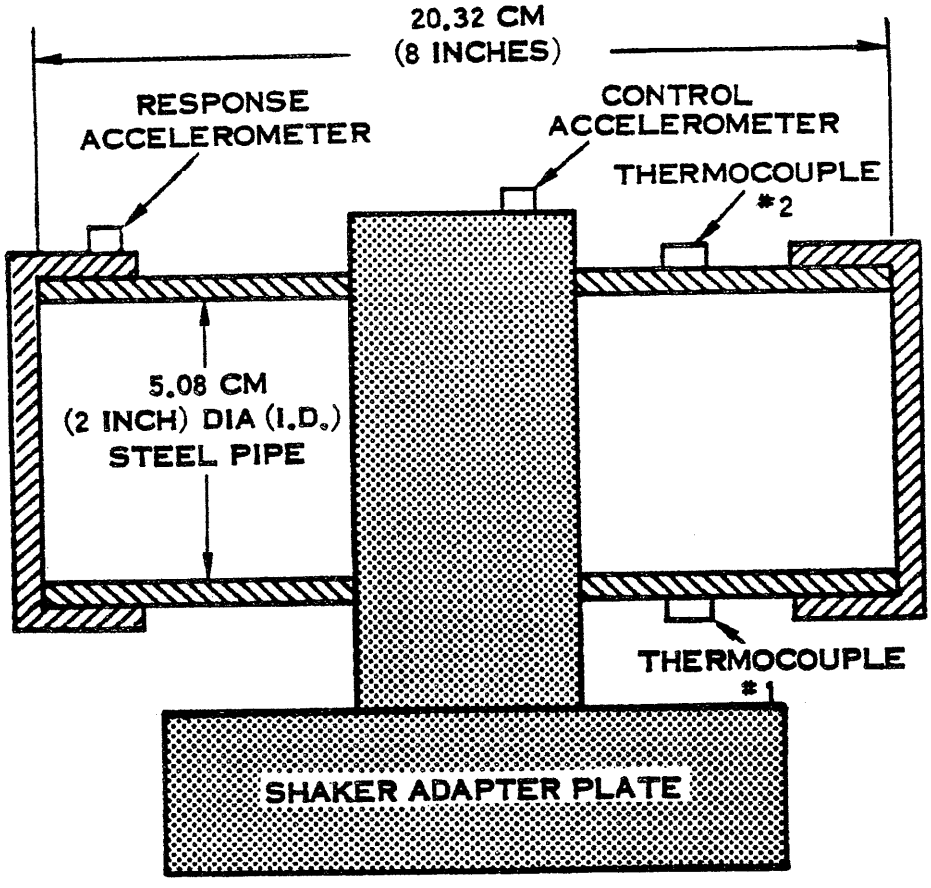


FIGURE 19 VIBRATION RTEST SETUP

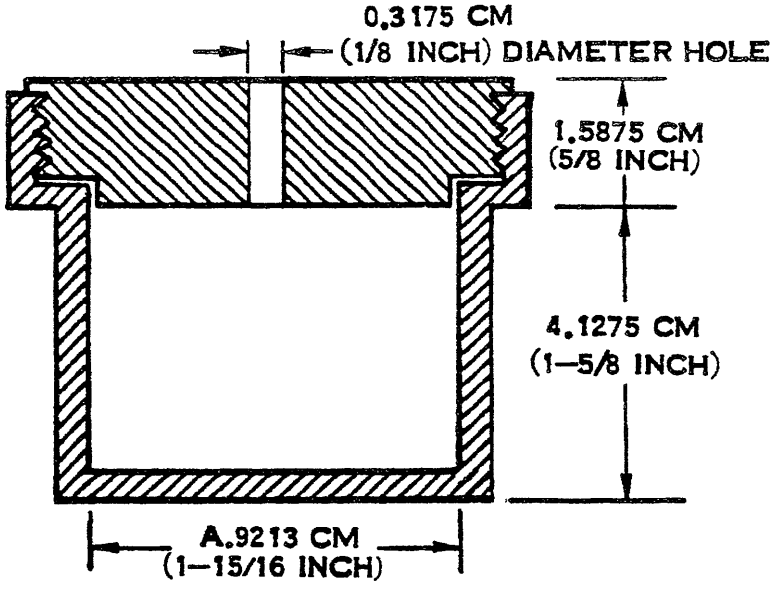


FIGURE 20 ALLUMINUM CUP.

METHOD 1

VACUUM THERMAL STABILITY AND CHEMICAL DECOMPOSITION TEST

1. PURPOSE

1.1 The Vacuum Thermal Stability and Chemical Decomposition Test is used to determine the physical attributes of a candidate explosive when subjected to a specified elevation of temperature.

2. CALIBRATION

2.1 The test shall be run in triplicate on a composite sample of the candidate explosive. The test specimens shall be held at the 100°C temperature for a period of forty eight hours. Determine the volume in ml of the 15.5 cm heating tube Figure 1 by adding mercury from a buret until the tube is filled to the level at which the ground glass joint of the capillary tube will make contact with the mercury. Subtract from the indicated buret reading, the volume of explosive used in the test (0.1 ml primary explosive - 5.0 ml booster explosive). The difference shall be represented by the symbol A. Transfer 7.0 ml of mercury to the cup at the lower end of the capillary. Clamp the tube in an upright vertical position, and measure the height in mm of the mercury column in the capillary tube (approximately 25 mm). Measure the length of mm of each of the three parts of the capillary tube and add these values to obtain total length. From the total length subtract the height of the mercury column in the capillary tube as previously obtained. Represent this diffrence by the symbol B_1. From the total length subtract the height of the column of mercury in the capillary tube measured at the end of the test described in 3. Represent this difference by the symbol B. Determine the capacity of the capillary tube per unit of length as follows: Transfer an accurately weighed sample of approximately 10 grams of mercury to the cup at the lower end of the capillary tube. Manipulate the tube so that it is horizontal, mercureyis contained in the continuous section of the longest part of the tube, and measure the length of the mercury column. Repeat this procedure twice with the mercury in two other parts of the long section of the tube. Calculate the average of the three measured lengths of the mercury column. Represent the unit capacity in ml per-mm of the capillary tubing by the symbol C. This can be obtained from the formula

$$C = \frac{W}{DL}$$

where

C = unit capacity of capillary tubing in ml per mm
w = grams of mercury

D = density of mercury at temperature of determination
L = average measured lengths of mercury column in mm.

3. TEST PROCEDURES

3.1 Transfer a (0.2 ± 0.001 gm Primary Explosive - 5 ± 0.05 gm booster explosive) sample, dried at 65°C for 2 hours, to the heating tube of the apparatus shown in Figure 1. Connect the capillary tube to the heating tube and seal the connection with 1 ml of mercury. Clamp the apparatus so that the long section of the capillary tube is in a nearly vertical position and the lower end rests on a solid support. Transfer 7.0 ml of mercury to the cup at the lower end of the capillary tube and evacuate the system until th pressure is reduced to approximately 5 mm of mercury. Disconnect the pump and measure the total vertical height of the column of mercury in the capillary tube. Measure and subtract the vertical height of the mercury in the cup. The difference shall be represented by the symbol H_1. Note the room temperature (t_1) and the barometric pressure. Subtract the value H_1 from the barometric pressure in mm. Represent this difference by the symbol P_1. Insert the heating tube in a constant temperature bath maintained at 100 ± 0.5°C. Maintain the heating tube at temperature for 48 hours. Remove the heating tube from the bath and allow it to cool to room temperature. Measure the total vertical height of the column of mercury in the capillary tube and subtract the vertical height of the mercury in the cup. This difference shall be represented by the symbol H. Note the room temperature (t) and the barometric pressure. Subtract the value H from the barometric pressure in mm. Represent this difference by the symbol P. It may be desirable to take measurements at several time intervals to establish a time versus decomposition curve. Remove the heatingh tube and the sample from the capillary tube and retain it for the tests cited in 5, conducted on candidate primary explosives.

4. CALCULATION OF GAS EVOLVED

4.1 Calculate the volume of gas (V) in ml, at standard conditions, liberated in the test described in 3 using the value represented by the symbols described in the preceding sections in the following formula:

$$V = \left[A + C(B - H)\frac{273P}{760(273 + t)}\right] - \left[A + C(B_1 - H_1)\frac{273P}{760(273 + T_1)}\right]$$

5.1 A chemical and/or physical analysis shall be made of the material remaining in the heating tube to determine quantitatively the degree of chemical decomposition that has occurred in the test. Since no single analytical procedure can be given for all primary explosive, it will be the responsibility of the organization proposing the candidate primary explosive to provide a procedure meeting the approval of the applicable ordnance systems group. The proposed procedure shall be capable of detecting not less than a 0.075 percent degradation in the primary explosive or any of its major constituents if the primary explosive is a mixture. The tests may be waived if, to the satisfaction of the applicable ordnance systems group, it is shown that the decomposition of each 0.1 gram of candidate primary explosive will be accompanied by the liberation of at least 2 ml of permanent gas at standard temperature and pressure. In those cases where the tests apply, the candidate explosive shall be considered acceptable if not more than 0.1 percent degradation has occurred in 48 hours of 100°C in the explosive or any of its major consitituents, and if no sensitive compounds are formed.

6. QUALIFICATION CRITERION

6.1 The volume of gas evolved as calculated under 4, shall be divided by the weight of the sample. This figure yields the ml of gas evolved per gram per 48 hours. To be acceptable as a candidate explosive none of the triplicate samples shall yield a value of more than 2.0 ml gas/gram/48 hours.

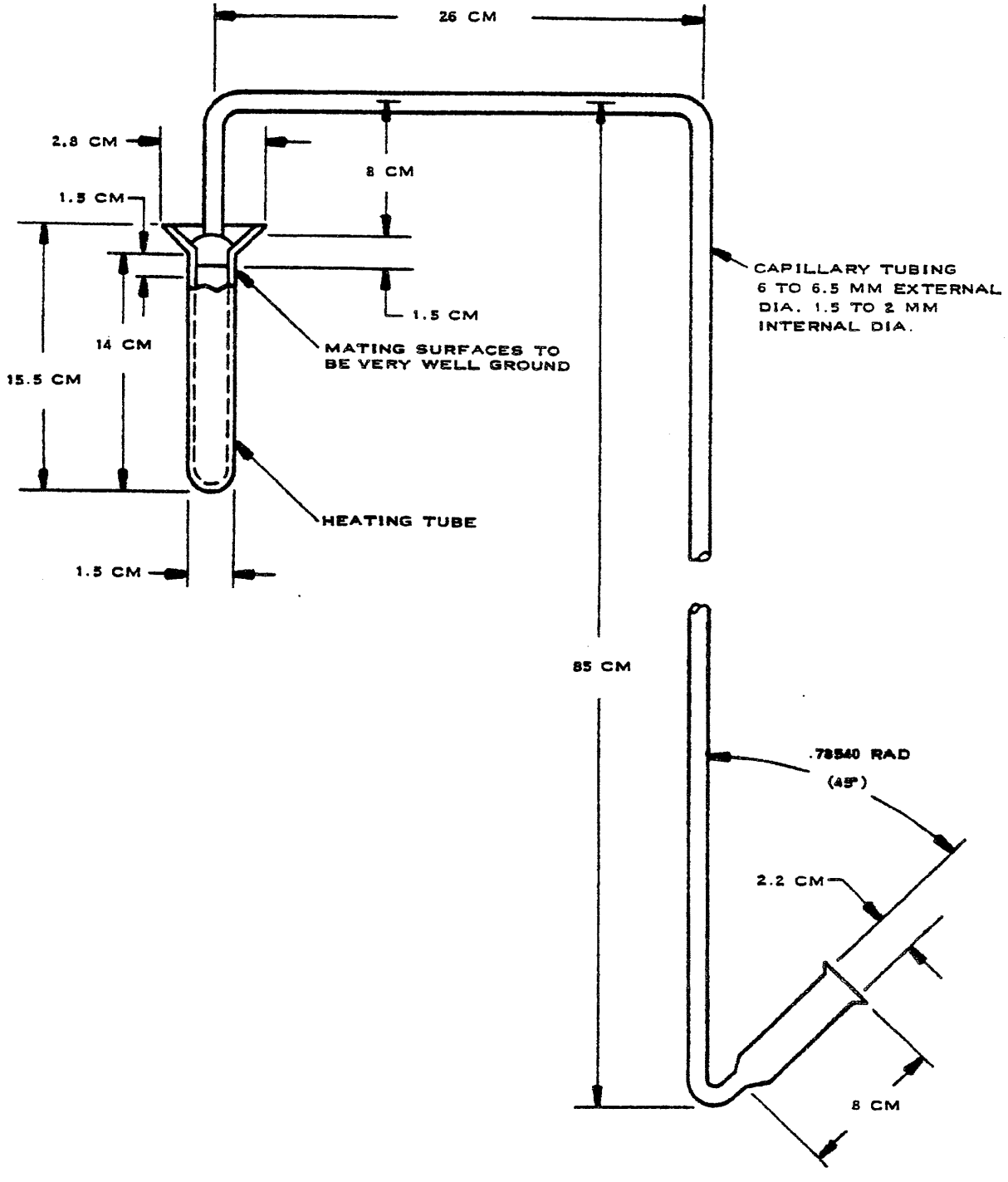


FIGURE 1. VACUUM THERMAL STABILITY TEST

METHOD 2

IMPACT TEST
(LABORATORY SCALE)

1. APPARATUS

1.1 The machine used is based on the design developed during World War 11 by the Explosives Research Laboratory of the National Defense Research Committee located at Bruceton, pa. It is often referred to as an "ERL machine" or a "Bruceton machine". An assembly drawing, Figure 1, depicts the principal features of the test apparatus.

1.2 Essentially, the apparatus consists of a free-falling weights tooling to hold the explosive sample and a supporting frame. The falling weight is made of hardened steel. Several weights are available (2, 2.5, and 5 kg); the weight usually used is 2.5 kg. By means of a hand windlass the drop weight can be positioned at any desired height above the test sample, to a maximum of 320 cm. An electromagnet retains the drop weight until released by the operator.

1.3 The drop weight impacts against a "striker" pin which transmits the shock to the test sample. The striker is 3.175 cm (1.250 in.) in diameter by 8.89 cm (3.500 in.) long, made of tool steel hardened to 60-63 Rockwell "C" scale. The flat surface next to the explosive is ground to a finish of 16µ in

1.4 The explosive sample rests without restraint on a 1-in.-square piece of 5/0 grade, flint sandpaper The sandpaper, in turn, rests without restraint on an anvil 3.175 cm (1.250 in.) in diameter by 3.175 cm (1.250 in.) long, made according to the following specificaitons: tool steel hardened to 60 Rockwell "C", all surfaces ground and polished.

1.5 The anvil is mounted in a tool holder assembly which is rigidly bolted to the machine base. The striker slides freely within a guide. A number of variations in tooling design have been tried. The one descrided here, in standard use for about 20 years, is designated as "Type 12" tools.

2. INSTRUMENTATION.

2.1 A ceramic-type microphone, Astatic Model JT-30C, or equal, is mounted in the horizontal plane of the anvil face at a distance of 96.36 cm (34 in.) from the center of the anvil.

2.2 The signal from the microphone is fed to a variable-gain amplifier which triggers (or fails to trigger) a thyratron tubes Model 2050. Triggering the thyratron lights a neon lamp mounted on the operator’s instrument panel.

2.3 A Burlington Model 431 millivolt meter, or equal, is placed in the circuitry for adjustment of the gain setting and the thyratron cathode voltage.

2.4 The complete instrumentation is commonly designated as a "noisemeter".

3. PRETEST PROCEDURE.

3.1 The test explosives are solid, granular materials which are either pure compounds or mixtures. Materials which are normally cast-loaded into a weapon are prepared for the test by casting as a thin sheet (weight from 3 to 10 g depending on material availability and number of determinations to be made). The The cast sheet is gently ground by hand in a wooden mortar and the material screened through a set of No. 16, 30, and 50 U.S. standard sieves. Equal weights of material retained on the No. 30 and No. 50 sieves are carefully blended on a Fisher-Kendall mixer, or equal, (simultaneous tumbling and stirring action) to furnish the test samples.

3.2 Other solid, granular materials are tested "as received" without further pretest processing.

3.3 Each test sample consists of 35 ± 2 mg of explosive placed in a loose pile in the center of the sandpaper. The first few samples are weighed on a laboratory balance; the remainder are volumetrically loaded by use of a small scoop which, when used by an experienced operator, measures the quantity of explosive within the desired tolerance.

3.4 In setting up the noisemeter for operating the following adjustments are made at the start of each day of testing:

a. The millivolt meter is calibrated across a 100-ohm resistor by adjusting the setting to 50 millivolts.

b. The amplifier gain is initially adjusted to read 25 millivolts. Final adjustment is determined by means of two test switches which make the thyratron tube alternately conductive and nonconductive. When proper gain setting has been achieved, the neon lamp will glow every time the thyratron is energized as demonstrated by 10 or more consecutive tests.

3.5 At least once each week the apparatus is calibrated for proper elimination of background noise. Instrumentation is adjusted as described in 3.4. The drop weight is released from maximum height to impact on the test anvil. Under these condi-tions the neon lamp must not glow.

4. TEST PROCEDURE.

4.1 A test sample (explosive on sandpaper) is placed in the centerof the anvil. The striker is lowered gently so that it rests on the top of the explosive pile.

4.2 The drop weight is elevated to a preselected height. Selection of the height used for the first drop is a matter of judgment. If the sensitiveness of the test material has been previously measured, the first drop height will be chosen in the range where "fires" have occurred. If the material is of completely unknown sensitivity an arbitrary starting height is used based on the sensitivity of similar compositions or the sensitivity which would be predicted from molecular structure.

4.3 The weight is dropped and the result is indicated by the noisemeter. If the neon lamp glows, it is a "fire"; if not, the test is a "no-fire". The weight is caught by a sliding stop moved into position by the operator after initial rebound from contact with the striker. This prevents multiple impacts between weight and striker.

4.4 After the first fire is obtained (which may take 3 or 4 preliminary drops with an unknown material) successive drop heights are governed by the results of the previous drop according to the following procedure. The weight is dropped from a height lower than the previous one by 0.093 log unit (where the log of a 10cm drop is taken as 1.0). If the result is a fire, the next drop is 0.093 log unit lower; if no-fire the next drop is 0.093 log unit higher. Testing continues by this "up and down" procedure for a total of 25 drops (usually called a "run").

4.5 After each drop, the test sample is discarded and a fresh sample used for the next drop. The striker and anvil faces which are in contact with the test sample are cleaned with solvent (such as acetone) after each test.

4.6 Striker and anvil are replaced when working surfaces become roughened as determined by making carbon paper impressions of eh surfaces. Old tools are refinished and reused. The The striker is replaced when its height has diminished by 0.635 cm (0.250 in.).

5. RESULTS REPORTED AND CRITERIA FOR EVALUATION

5.1 The data recorded for each test are the log of the height from which the weight was dropped and the decision as to whether the drop resulted in a fire or a no-fire.

5.2 The data are treated by a procedure developed by the Applied Mathematics Panel of the National Defense Research Committee (AMP Report No. 101.1R SRG-P No. 40). First, the data are examined to determine whether more fires or no-fires occurred. Whichever is the lower number is selected for analysis and the balance of the data are discarded, (If the numbers are equal, either may be used). The data are summarized, statistically, by use of the following table (numbers are inserted in the columns for illustration only):

Log	i	n_i	in_i	i^2n_i
1.7	0	2	C	0
1.8	1	10	10	10
1.9	2	10	20	40

The log of a given drop height is entered in the first column. These are arranged in ascending order, starting wiht the lowest for which a test is recorded as indicated in the example above. In the next column, "i" is a consecutive number corresponding to the number of equal increments above the base, or "zero". line. The next columns "n_i", tabulates the number of fires (or no-fires) which occurred at i_0, i_1, i_2, etc. The other columns are computations of i times n_1 and i^2times n_1.

5.3 A mean is computed from the formula:

$$m = c + d\left[\frac{A}{N} \pm \frac{1}{2}\right]$$

Where $N = \Sigma n_i$

$A = \Sigma in_i$

= normalized height of the lowest line (i_0),

and d = normalized interval between drops (0.093).

In the formula, the sign inside the parentheses is (+) if no-fires are used and (-) if fires are used.

5.4 The mean computed in accordance with 5.2 and 5.3 is reported as the "50% point". It represents a 50% probability of fire. The number may be reported in log units as determined directly from the computation. More often, the antilog is found and this is reported as a height in centimeters.

5.5 Often, the standard deviation is also estimated by the following technique: A number, "M", is computed from the formula:

$$M = \frac{\Sigma i^2 n_i}{N} - \left[\frac{\Sigma i n_i}{N}\right]^2$$

using a table or graph appearing in the Applied Mathematics Panel report mentioned in 5.2, [a] value is obtained. The Standard deviation (σ) is then:

$$\sigma = ds$$

It is always expressed in log units.

5.6 The table below sets out typical test results for 8 common explosives.

	50% Point	
Explosive	cm	σ
Lead azide	4	0.12
PETN	12t	0.13
RDX	24t	0.11
HMX	26t	0.10
Tetry1	38t	0.07
Comp B	60t	0.13
TNT	157	0.10
Explosive D	254	0.05

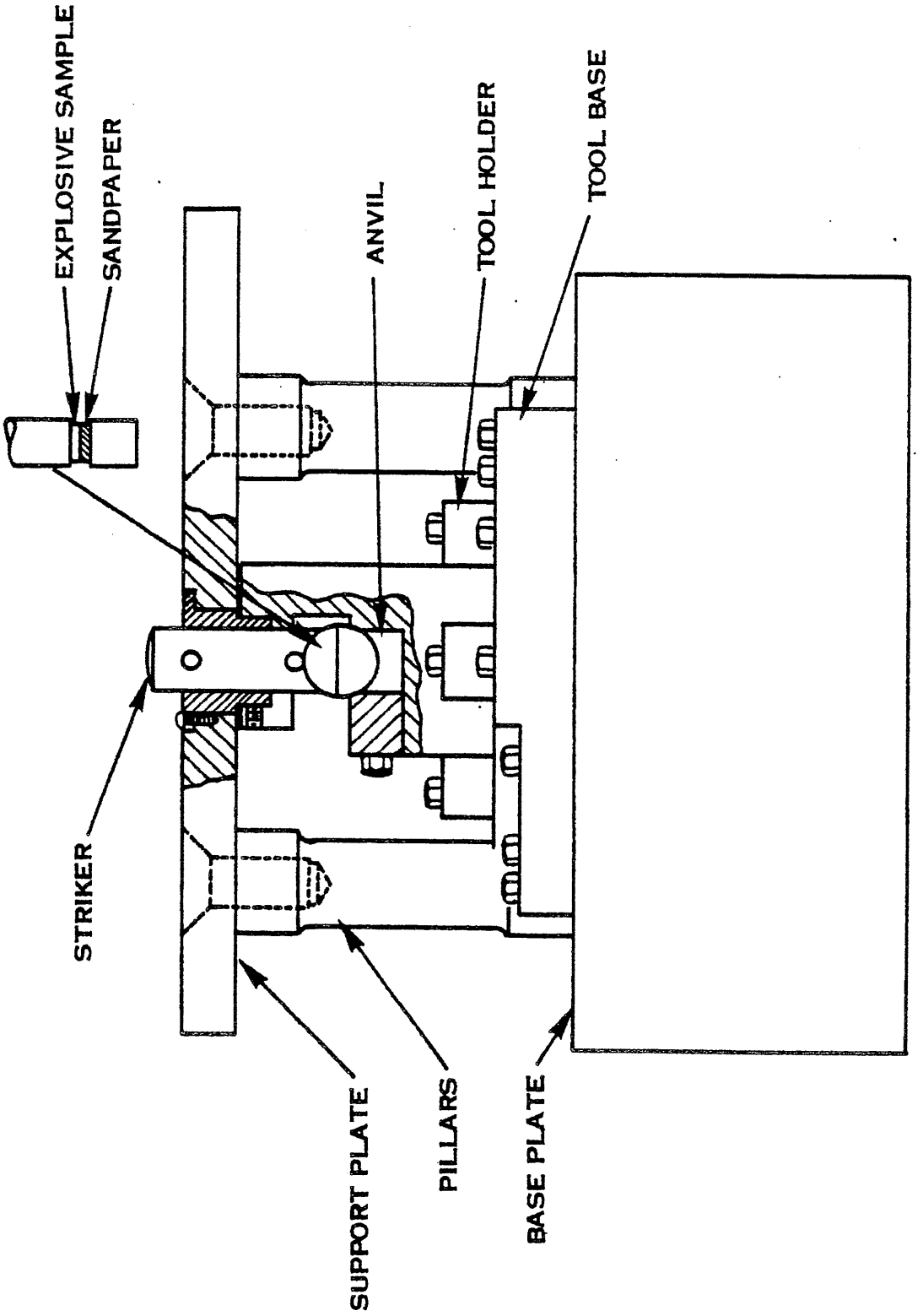


FIGURE 1. TOOL HOLDER ASSEMBLY TYPE 12 TOOLS

METHOD 3

EXPLOSIVE SHOCK SENSITIVENESS TEST (SMALL SCALE GAP)

1. PURPOSE

1.1 The small scale gap test was devised in 1950 in order to provide a test which could be used to investihgate the sensitive-ness of explosives to an applied explosive shock but which, at the same time, would require a minimal quantity of the test explosive. The test was extensively restudied in 1960, primarily to achieve standardization and closer agreement with the larger scale gap test (US/Explosive Shock/02). At that time the test apparatus and procedure acquired their present form.

2. APPARATUS

2.1 The apparatus consits, essentially, of an explosive doner, an attenuating spacer, an explosive acceptor and -a steel dent bloxk. The apparatus is shown schematically in Figure 1. The components of the test are described in the U.S. Naval Ordnance Laboratory List of Drawings LD No. 549486 and all drawings called for therein.

2.2 A MK 70 Mod.0 electrical detonator is set within a plastic detonator holder. No doubt other modes of initiation can be used --- blasting caps, electric blasting caps, or other detonators, or mild detonating fuse terminated in an end booster or end coupler. It is felt that a change to some other detonator would be justified only after enough testing demonstrated that there was no modification of the donor output.

2.3 The donor and acceptor bodies are identical brass cylinders, 2.54 cm (1.0 in) in outside diameter by 3.81 cm (1.5 in.} long, containing a centrally-located hole, 0.508 cm (0.2 in.) in dia. Input face of donor and output face of acceptor are held flat within a maximum of 0.0508 mm (2 mils) 0.0254 mm (1 mil) is perferable). Although the bodies look deceptively simple to make, quantity production is usually done in screw machines and the manufacturer must exercise considerable care. The axial hole has been a problem. Tolerances on hole size, concentricity and straightness required that the next-to-last step be reaming. Withdrawal of the reamer is often accompanied by chips which form unacceptable longitudinal, radial and spiral scratches Hence, a ball-broaching operation is used as the final step to achieve a smooth internal finish.

2.4 The attenuator is made of Lucite, 2.54 cm (1.0 in.) in dia. with smooth, flat, parallel faces. Stocks of discs of differentt thicknesses, chosen on a logarithmic scale, are used to obtain

the variable attenuator spacing (variable gap). Lucite cut from Lucite cut from rod stock and from flat sheet stock has been used. Attenuators Attenuators have been made by injection molding. Attenuators been Attenuators have been made up into desired thickness by stacking two or three thinner pieces. piexes. None of these variants make a detectable difference in the test results.

2.5 2.5 The dent block is a steel cylinder, hardened to Rockwell B 70-95. B 70-95. Dimensions are 7.62 cm (3.0 in.) in dia. and 3.81 cm (1.5 in.) high. (1.5 in.) high. The upper face (next to the acceptor) is machined to a finish of 1.6 µm (63 microinches). The user has had considerable trouble trying to obtain steel which will finish to the desired hardness of Rockwell B 80 to 87 on the machined face. face. User has tried, with moderate success, to improve uniformity by purchasing a number of bars of steel from a single mill run whose hardness on the outer cylindrical surface runs Rockwell B 80-87. well B 80*87. The hardness of every block is measured. The The dent reading is corrected by applying the following empirical formula:

$$D = D_1 + \frac{2}{3} \quad (H-83)$$

Where D is corrected dent in roils
D_1 is observed dent in mils
H is observed hardness (Rockwell B)

2.6 The detonator holder is merely a device for keeping the dentonator upright. Pieces of broom stick, polystyrene tubing, and out-of-tolerance attenuator disks have been used. All that All that **is** necessary is that the piece be frangible and that it fit loosely around the detonator.

3. PRE-TEST PROCEDURE

3.1 The donor explosive - RDX, Type B. Class B, JAN Spec. R-398 is vacuum dried at 50°C and 28 mm Hg for 4 hours. It is then pressed at 68948. kPa (10,000 psi) in 7 equal increments (165 mg, each) into the donor body, leaving a 0.254 cm (0.1-in) deep recess at the top for the detonator.

3.2 Either 525 or 1050 donors are normally loaded at a time, rejecting and replacing any donors that fall outside of the following limits:

	Min.	Max.	Units
Density	1.537	1.597	grams/cc
Charge weight	1.132	1.178	grams
Charge length	3.523 (1.387)	3.665(1.443}	cm(in)

3.3 All the donors are numbered according to a set of random numbers generated by an electronic data processing program. This program is available to any who wish it. However, comparable ones are normally available in most laboratories.

3.4 Five percent of the donors are fired against steel blocks. The output should fall in the following limits, measured in mils, were "x" is the mean dent and "s" is the standard deviation:

	Min.	Max
$\bar{x}$	62.5	65.0
s	none	2

3.5 The donors are then ready to be used sequentially on the basis of their randomized numbering.

3.6 The sest explosive is dried under the same conditions as the RDX. Loading is volumetric, designed to completeoly fill the acceptor body cavity with explosive flush at both ends. Loading the acceptor body while it rests on the dent block assures intimate contact of explosive with the block. Twenty-two bodies, each, are usually loaded in 8 equal increments at five different loading pressures:

27579.0 kPa (4.0 KPSI) 55158.0 kPa (8.0 KPSI) 110316.1 kPa (16.0) KPSI) 220632.2kPa (32.0 KPSI) and 441264.5kPa (64.0 KPSI)

3.7 Each acceptor body is loaded up to and including the next to the last increment. Knowing the increment weight (each increment is measured on a torsion balance) and measuring the column height, the weight necessary to fill the column flush is computed. This process usually eliminates the necessity for shaving or breaking off any protruding explosive. As the original report brought out[1], up to a 0.381 mm (15 mm) recess on the output end of the acceptor can be tolerated. The input end should be flush to within 0.0508 mm (2 mils).

3.8 The computed densities for the twenty-two acceptor bodies loaded at a particular pressure are inspected. Any acceptors grossly out of density tolerance are rejected and replaced. User then selects the two, out of the final group of twenty-two, whose densities are furthest away from the average density. These two acceptors are each fired with a donor without any attenuator piece between. The average of th dent outputs is recorded as the zero-gap output. The average density of the

remaining twenty units in the group is the reported density in the test. Standard deviation of the loaded density is controlled within 0.25% of the theoretical maximum density.

3.9 If the physical properties of the test explosive so require, the acceptor can be loaded by other means. Each special case requires establishment of standards for charge density.

3.10 Before loading donors or acceptors, the hole diameter is measured at four different heights and with a 0.78540 rad (45°) angular rotation about the measurement fixture between each, determination. User has a measurement accuracy of about ± 12.7 µm (- 0.0005 in) on the diameter.

3.11 Column heights are measured to the nearest 0.0005 in with a dial indicator having a flat-tipped probe. From the difference between the weights of the loaded and empty body, from the average hole diameter and from the column length the density of every charge is computed. For a group of charges (average density usually running from 1.3 to 1.7 g/cc) the standard deviation will be from 0.003 to 0.005 g/cc and rarely exceeds 0.009. Thus density is controlled to an accuracy of about 0.6%. User has found that processing the data and computing density is greatly facilitated, and errors minimized, by using electronic data processing.

3.12 The donors and acceptors are weighed before and after loading. Each weighing is repeated, preferably by independent workers, and must check to within 0.3 milligrams. Since the bodies (loaded or empty) weight in the order of 160 grams the necessary precision is about two parts in a million.

4. TEST PROCEDURE

4.1 Components of the test apparatus are assembled as shown in Figure 1. A peripheral wrap of cellulose tape holds the donor, plastic attenuator and acceptor together and in alignment. A piece of masking tape bridges the entire assembly to prevent motion of the detonator and to keep components aligned on the dent block.

4.2 The selection of the thickness of attenuator (i.e. length of gap) is arbitrarily chosen with the intent that it should be close to the value for 50% probability of a "fire". Because only twenty bodies are allocated to a particular data point it pays to be as careful as possible about selecting the proper point ot begin testing. If a bad guess wastes a number of shots before a first reversal or a first zone of mixed response is observed, it is legitimate (but quite inconvenient) to load and test pieces to replace the lost information. It is not correct,

however, to increase the sample size beyond the first reversal or mixed respone zone because "we don't like what we saw" or "because we want a better answer". This is apt to introduce a bias in the final answer.

4.3 Successive tests are made by choosing a thicker attenuator if the previous result was a "fire" or a thinner attenuator if p-receded by a "no-fire". This is the "up-and-down procedure described in the Naval Ordnance Laboratory's laboratory-scale impact tests, Test Method 2 (US/Impact/02). Testing contimues by this "up-and-down" procedure for a total of 20 times, normally.

5. RESULSTS REPORTED AND CRITERIA FOR EVALUATION

5.1 Results recorded for each test are the thickness of the Lucite attenuator and the decision as to whether the test resulted in a fire or no-fire. For the latter, refer to 3.8 which describes determination of the average dent, D, at zero gap. The criterion for assessing each shot is set at 0.5 D. Dent readings less than this level are recorded as a no-fire, and greater than this level as a fire.

5.2 The data are analyzed statistically and the value of the point representing 50% probability of a fire is computed according to the same mathematical procedures described, and referenced, in US/Impact/02. (Sometimes called the "Bruceton Procedure".)

5.3 5.3 This test uses a unit of initiation intensity called the Gap Decibang, Gap Decibang, DBg, which is analogous to the decibel used in acoustics. acoustics. The expression of intensity is described by the following equation

$$x = 10 \log \frac{\text{Reference gap (in mils)}}{GT}$$

where X = initiation intensity in DBg

GT = observed gap (thickness of Lucite) in mils

Since the 'reference gap is chosen as 1000 mils, the expression for initiation intensity then takes the following form:

$$x = 30\ 10 \log GT$$

As previously stated in 2.4 the Lucite Attenuators were chosen with thicknesses which vary logarithmically; the difference between each is one which corresponds to 0.125 DBg difference. This, then, is the normalized interval between the successive firing tests and is used in computing the 50% point, standard deviation, etc.

5.4 Results are reported as the 50% point in DBg and the standard deviation in log units. When comparing the relative sensitiveness of two explosives, the confidence limits are sometimes computed for each according to the expression X $\pm$ 1.4 s where X is the mean (the 50% point in DBg) and s_m is the standard deviation of the mean. If the limits do not touch or overlap then it is predicted at 95% confidence that a difference in sensitiveness has been demonstrated.

5.5 Use of the DBg to express susceptibility to initiation results in reverse ordering when these results are compared with explosive shock tests which express the 50% point as a computed barrier gap (in linear units as cm or in.) between donor and acceptor. High DBg values correspond to small gaps, and hence mean the explosive is relatively insensitive.

5.6 The Bruceton Procedure is used to collect the data because this is the most efficient way of allocating a limited number of test pieces in order to obtain an optimum estimate of the 50% response point. In the Bruceton Procedure, it is necessary to have a number of observations of go and no-go at each of several livels of stimulus. Stimulus in this test is measured as 10 times the logarithm of a ratio between reference gap thickness and the Lucite attenuator thickness. Obviously it would be uneconomical to fabricate every piece exactly to the thickness corresponding to a particular stimulus. Yet the data analysis procedures are based on the assumption that there is no error in the stated value of the stimulus. During 1964-1965 has developed new procedures for analyzing the data in which the true thickness of each attenuator is used rather than its nominal value. Under these conditions, the tolerances controlling thickness need not be as stringent. One needs know only what the thickness of each attenuator actually is.

5.7 The procedures developed by Hampton and Blum 6.2 can be applied to data where each and every test is at a unique stimulus level different from all others in the test. This then eliminates the contribution to the standard deviation of the sensitivity by the error in true stimulus. The electronic data processing program that is being adopted:

(a) takes into account the zero-gap dent after correcting for block hardness.

(b) Corrects each observed dent for the twenty shots according to the individual block hardness,

(c) decides whether the observed response for each shot was a "go" or a "no-go”,

(d) computes the shock intensity value in DBg for the measured thickness of attenuator,

(e) performs a maximum likelihood analysis of the data and

(f) estimates various levels of response and confidence intervals around these levels assuming a logistic distribution function.

5.8 User feels that the logistic distribution function is a better choice than the normal distribution function for describing the probabilistic aspects of explosive sensitiveness in response to shock. This is based in part on direct evidence and in part simply on the fact that the logistic distribution is the more conservative.

5.9 One more set of variables is studied: output as a function of charge density. This may be reported in three groups:

(a) The average of the two zero-gap shots

(b) The average of the "go”

(c) The average of the "no-go”

For some explosives, (b) will be in the range of 70% to 80% Of (a) and (c) will be a measurable value in the order of 5 to 10 mils, or above. Other explosives give essentially the same value for (a) and (b) and negligible-values for (c). User suspects that this is a measure of rate of build-up to detona-tion.

5.10 Some typical test results are set forth below for 4 common explosives, all measured at ca. 92% of theoretical maximum density:

Explosive	50% Pt. - DBg
HMX	3.9
RDX	4.35
Tetryl	4.4
TNT (Pressed)	6.0

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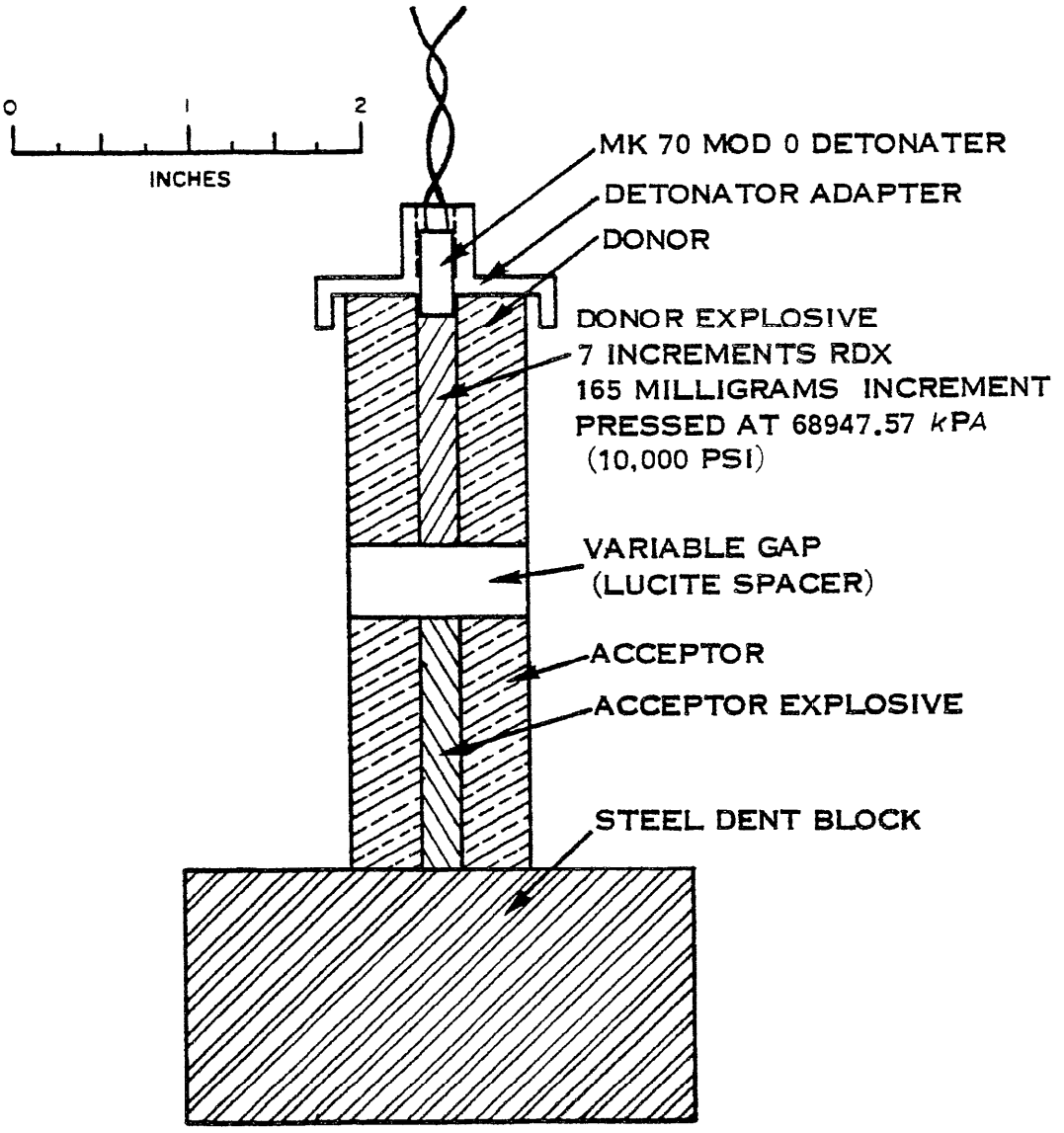

FIGURE 1. SCHEMATIC DRAWING OF SMALL SCALE GAP TEST U.S. NAVAL ORDNANCE LOABORATORY

METHOD 4

RESPONSE OF PRIMARY EXPLOSIVES TO GASEOUS DISCHARGES IN AN IMPROVED APPROACHING-ELECTRODE ELECTROSTATIC SENSITIVITY APPARATUS

1. PURPOSE

1.1 The electrostatic sensitivity test is used to assess the electrostatic hazards associated with the processing and handling of explosives..

2.1 The approaching-electrode apparatus consisted of a charging circuit, an approaching-electrode assembly, and a recording system.

2.2 Charging Circuti: High voltage was provided by a variable 0 to 25 kilovolt power supply. The voltage was measured with an electrostatic voltmeters ranges: 0 to 2000V, 1500 to 5000 V, and 2000 to 10,000 V. Low inductance, high voltage, ceramic-cased, exteded-foil capacitors (PK series) were used as the energy-storage-discharge capacitors. The circuit was designed so that the appropriate capcitance, from 54 to 50,000 pF could be manually connected in the circuit$_s$ as either a single capacitor or a group of capacitors in parallel, by double-pronged bridge plugs with nonconductive plastic handles. The capacitance of the storage capacitors and the stray capacitance of the electrical leads in parallel with the storage capacitor were measured in situ in the circuit using an Impedance Bridge. The stray inductance responsible for the oscillatory discharge was calculated from the decay of the current trace as a function of time by means of the following formula:

$$L = \frac{(t_2 - t_1)^2}{C\left[4\pi^2 + \left(\ln \frac{I_1}{I_2}\right)^2\right]}$$

where L is the inductance in henries, C is the capacitance in farads, and t_1 and t_2 are the times in seconds for the values of two consecutive peak cunrents, I_1 and I_2. The stray inductance of the experimental apparatus was approximately 1.3 microhenries. The resistance of the gap is dependent upon the gap length. The The resistance of the discharge circuit with a 0.28 mm gap was calculated from the decay of the current trace as a function of time by means of the following formula:

$$R = \frac{(t_2 - t_1)^2}{C\left[4\pi^2 + \left(\ln \frac{I_1}{I_2}\right)^2\right]}$$

where R is the resistance in ohms. The calculated resistance of the experimental apparatus with a 0.18 mm gap was approximately 7.5 ohms. The capacitor output is connected to the approaching-electrode assembly. A current-limiting resistor may be placed between the charged capacitor and the electrode assembly. High voltage carbon film resistors were used as the current-limiting resistors. A schematic of the charging circuit is shown in Figure 1.

2.3 Approaching-Electrode Assembly: Teh approaching-electrode assembly Figure 2 was a spring-operated device in which the upper electrode was rapidly lowered to a preset distance above the base electrode and immediately raised again to its initial position. Adjustments in the gap length were made by raising or lowering the flat, lower (base) electrode by means of a micrometer, which was connected to the lower electrode and was located outside the firing chamber. The approaching-electrode assembly could be used in the conventional point-to-point configuration Figure 3 or a plane-plane geometry Figure 4. This was accomplished by attaching to the vertical, actuating rod of the approaching assembly either a phonograph needle holder with a removable steel phonograph needle Figure 3 *or* a pin holder with a removable steel pin.

2.3.1 A schematic diagram showing’ the principle of operation of the approaching-electrode assembly is given in Figure 2. Either a needle electrode or a plane-pin electrode "A" was mounted on a vertical actuating rod "B", shich was free to slide through the guide housing "C". Handle "D" was connected to the toggle level assembly "E" and the spring “F". The spring was attached to a wall hook "G" When the handle was pulled to the left position (cocked position), the toggle level assembly raised the vertical actuating rod and engaged the release rod "H". The spring was under maximum tension at this point, When the release rod was pulled, the spring contracted, thereby rapidly lowering the vertical actuating rod to its lowest position and immediately raising it again to its initial position. Handle "D" must be pulled to the left again to cock the device for another trial.

2.3.2 The high-voltage power supply was disconnected from the discharge circuit during the gap-closing operation Figure 1. In the raised position, the storage capacitor was connected to the high-voltage source. As soon as the approaching electrode

started to move downward, the high voltage contact was broken, thus disconnecting the high side of the capacitor from the charging source during discharge. For safety, a high-voltage, double-pole, double-throw pressurized relay (switch) was included to prevent the capacitor from being recharged in the raised position until the reset button was pushed. The relay also discharged to ground any residual voltage remaining in the discharge circuit after the discharge operation was completed.

2.3.3 The upper portion of the base, or lower electrode, served as the explosive sample holder. It was a detachable, solid cylinder of hardened steel, 19 mm diameter by 9.5 mm long. When the approaching electrode was a steel pin (plane-plane geometry) a layer of 0.19 mm thick electrical tape with a 4.8 mm diameter hole for the explosive was taped to the top surface of the steel cylinder. The removable steel pin had a 4.8 mm diameter, 14.9 mm length and rounded edges on the flat ends. The explosive powder was semiconfined between the plane pin and the sample holder. The desired gap between the upper electrode and the sample holder was set and maintained by a micrometer; the latter was connected to the base electrode and was located outside the firing chamber. This gap length was accomplished in the dynamic mode since the gap length setting varies depending on whether the upper electrode is depressed dynamically or remains station-ary. The gap was set by first adjusting the micrometer until the electrodes just touched in the dynamic mode. A peak-reading. voltmeter and a 6 V battery were connected between the two electrodes to aid in this determination. The base electrode was then Lowered the desired length, usually 0.18 mm.

2.3.4 The firing chamber (29.2 cm cube) was made of 1.27-cm thick, clear polymethyl methacrylate (PMMA) and sized to fit into an available humidity control box for future controlled humidity experiments. To reduce charge build-up on the PMMA, the plastic was coated with a layer of an anti-static agent. The chamber should be made of a plastic with a conductive coating and the chamber grounded.

2.4 Recording System: The current and voltage characteristics of the gaseous discharge were recorded photographically on a storage oscilloscope. The voltage across The spark gap was determined by direct measurement with a 1000x attenuator, voltage probe. The current through the gap was determined with a current transformer or by measuring the voltage drop across a 3.3 ohm resistor in series with the gap. The instantaneous current was taken as V_R/R, where V_R was the instantaneous potential drop across the 3.3 ohm resistor, R. The total charge flowing through the gap was determined by using a electrometer to measure the final voltage across a one microfarad capacitor in

3. SAFETY FEATURES

3.1 The apparatus incorporated several safety features to protect the operator. The high-voltage power supply was connected to the storage capacitor by means of the high-voltage double-pole, double-throw relay switch. The relay switch could not be energized until a series of switches were closed. In the deenergized (open) positions the relay switch shorted to ground the storage capacitor and the approaching-electrode assembly. It also shorted to ground any residual voltage which may have remained in the discharge circuit after the discharge operation was completed. A momentary and a reset switch were in series in the coil circuit of the relay switch.The momentary switch was connected to the approaching-electrode assembly and was closed mechanically by it only when the assembly was cocked in the raised position. The reset switch prevented the storage capacitor from being charged acceidentally when the electrode was in the raised position. The reset switch had to be closed manually and could only function after all the other switches in series were closed. It opened automatically whenever any switch was opened and had to be reclosed manually.

3.2 In the proposed design, the door of the firing chamber should be provided with an interlock switch, which will be ccnnected in the coil circuit of the relay switch. When be door is opened, the relay will be deenergized, which will automatically disconnect the high-voltage power supply from the storage capacitor and short to ground the charged capacitor and the approaching-electrode assembly. The proposed electrical circuit is shown in Figure 5.

4. ELECTROSTATIC SENSITIVITY TEST PROCEDURE.

4.1 The electrostatic-sensitivity test is divided into two parts, Part 1, a screening test to distinguish between primary, booster, or main-charge explosives and Part 11, an optional test using a more intensive procedure to rank or compare primary explosives. The approaching-needle apparatus is used for all the tests. The unit is designed to provide an electrostatic discharge at any voltage up to 5 kV from any capacitance from 250 pF to 0.01 mfd. The discharge occurs across an adjustable gap. Explosives are tested confined in either the powder or granular state. The sensitivity level reported is the highest energy level at which no reaction occurred in 25 trials. A reactionis indicated by a severed confining tape, whereas no reaction is evidenced by a punctured but otherwise intact tape.

4.2 In Part 1, the test materials are to be assessed by using an oxcillatory discharge. The energey for this test was fixed at 0.020 J, which is the charge energy that an ungrounded person can accumulate (Ref 5.4, 5.5). However, this value is about five times the maximum energy that an ungrounded person could discharge (ref 56). There is no electrostatic distinction

between booster and main-charge explosives.Those materials which are ignited at the 0.02 J level are in the primary explosive category and are relatively sensitive. A further study is recommended according to the procedure in Part 11 to determine what other precautions are likely to be required. Part 11 is optional. In this test, primay explosives are to be assessed using oscillatory spark, and contact discharges.

4.2.1 Test Procedure - Part 1

4.2.1.1 The test materials shall be subjected to an oscillatory discharge. To operate:

4.2.1.1.1 Set selector switch to "secondary”. [This connedts the 0.002 mfd capacitance (high-capacitance bank) to the discharge circuit and shorts the low-capacitance bank to ground.]

4.2.1.1.2 Set resistance switch to "oseillatory" discharge. (No series resistance is connected for an oscillatory discharge, whereas 100 k Ω resistance is connected in series for a spark discharge.)

4.2.1.1.3 Set electrode spacing (gap) to 0.18 mm (0.007 inch). This is accomplished in the dynamic mode because the gap length setting is different depending on whether the upper electrode is depressed dynamically or remains static. The gap is set by adjusting the micrometer (attached to the base electrode) until the electrodes just touch when the upper electrode is depressed dynamically. A peak-reading voltmeter and a 6 V battery or equivalent may be connected between the two electrodes to aid in this deternination. The base electrode is then lowered 0.18 mm by means of the micrometer. It shall be necessary to readjust the electrode spacing before starting a test or when the upper electrode (needle) is replaced.

4.2.1.1.4 Place sample holder containing the test material, prepared according to 4.2.1.3 on the base electrode with the powder directly under the needle. Raise the upper electrode to cocked position by means of handle "D”. Close the door (door must be clOsed to engage interlock).

4.2.1.1.5 Turn on power supply and adjust voltage control to 4.5 kV.

4.2.1.1.5 Activate reset switch to charge the capacitor. Adjust power supply until the electrostatic voltmeter reads 4.5kV.

4.2.1.1.7 Pull release rod "H" to release the approaching electrode The charged electrode will rapidly move downwards to the preset gap distance. The needle will puncture the tape, penetrate the sample material, discharge through the interstices of the material, and rise again to its initial position. (The threshold voltage for gay breakdown will determine the distance at which the needle will be above the base electrode when the

4.2.1.1.8 Record reaction or no reaction. A reaction is indicated by a severed tape, whereas no reaction is evidenced by a punctured but otherwise intact tape.

4.2.1.1.9 Repeat the procedure until no reaction is obtained in 25 consecutive trials. If a reaction is obtained, discontinue the test and record that explosive falls in the primary category.

4.2.1.2 Qualification Criterion: An explosive shall be reported to have passed the electrostatic sensitivity test and to be acceptable as a booster or main-charge explosive if there are no reactions in the 25 consecutive trials at the 0.02 J level (0.002 mfd capacitor charged to 4.5 kV).

4.2.1.3 Sample Preparation: Materials are normally tested dry, in either the powdered or the granular state. The materials shall be stored in desiccators for at least 24 hours prior to test. For cast, molded, and cured extruded explosives, it shall be necessary to pulverize the cured or formed samples in a bell mill. Explosives containing binders or solvents or with curing binders shall be dried, then ground in a ball mill using a dispersing fluid in which none of the ingredients, including the binder, are soluable and finally heated to constant weight at 65°C. Since some explosives are subjected to segregation with respect to particle size or components of mixture came shall be exercised to insure that the material actually used constitutes a representative sample, with respect to both particle size distribution and composition.

4.2.1.3.1 The explosive power shall be placed in the sample holder. The sample holder shall consist of a 0.9 - 1.6 mm thick nylon washer (4.8 mm i.d.), or equivalent, fastened (double adhesive tape may be used) to the top of a 19 mm (0.750 in.) diameter, flat steel disc leaving a space 4.8 mm diameter by 0.9 to 1.6 mm high to contain the explosive. Electrical insulating tape, 0.19 mm thick, shall be placed over the explosive opening to confine the explosive sample. The sample holder shall then be placed on the base electrode with the powder directly under the needle.

4.2.1.4 Electrode Replacement: The needle (upper electrode) shall be wiped with a "kimwipe", or equivalent absorbent paper, after every trial. The needle shall be placed and the steel sample holder shall be cleaned and polished after any trial in which there is evidence of a reaction, whenever a test of a new material is started, or when any other condition dictates. In any event, the number of trials prior to cleaning should not exceed ten. Cleaning is done using first, No. 400, then No. 600 emery cloth, and finally, polishing with crocus cloth.

4.2.1.5 Relative Humidity: The relative humidity shall not exceed 40%. Humidity shall be determined by wet and dry bulb hygrometry or by any other instrument of equal or better accuracy. The firing chamber of the tester may be maintained at the required humidity by continuously passing dry air through the chamber.

4,2.2 Test Procedure - Part 11 (Optional)

4.2.2.1 The test material shall be subjected to contact discharge as well as to an oscillatory and to spark discharge. The oscillatory and the spark discharge tests shall be as follows:

4.2.2.1.1 Set selector switch to "primary”. (This connects the bank of low capacitances to the discharge circuit and shorts the high capacitance bank to ground.)

4.2.2.1.2 Set resistance switch to "oscillatory" or "spark" discharge. (No series resistance is connected for an oscillatory discharge, while a 100 k Ω resistance is connected in series for a spark discharge.)

4.2.2.1.3 Set primary capacitance switch to the selected capacitance: 2,000, 1,000, 500, on 250 pF, for oscillatory discharge, and 10,000, 5,000, 2,000, 1,000,500, or 250pF, for spark discharge. The starting capacitance is usually the largest value unless a more efficient value based on experience is known.

4.2.2.1.4 Set electrode spacing {gap} to 0.18 mm (0.007 in.). This is accomplished in the dynamic mode since the gap length is different depending on whether the upper electrode is depressed dynamically or remains static. The gap is set by adjusting the micrometer (attached to the base electrode) until the electrodes just touch when the upper electrode is depressed dynamically. A peak-reading voltmeter and a 6 V battery, or equivalent may be connected between the two electrodes to aid in this determination. The base electrode is then lowered 0.18 mm by means of the micrometer. It shall be necessary to readjust the electrode spacing before starting a test or when the upper electrode (needle) is replaced.

4.2.2.1.5 Place sample holder containing the test material (prepared according to 4.2.1.3) on the base electrode with the powder directly under the needle. Raise upper Raise upper electrode to cocked position by means of handle "D". Close the door. (Door must be closed to engage interlock).

4.2.2.1.6 Turn on power supply and adjust voltage control for desired voltage.

4.2.2.1.7 Activate reset switch to charge the capacitor. Adjust power supply until the electrostatic voltmeter reads the selected voltage. The starting voltage is 4 kV except for either 2,000 pF capacitance (oscillatory discharge) or for 10,000 pF capacitance (spark discharge), when the voltage is to be set at 4.5 or 5 kV, respectively.

4.2.2.1.8 Pull release rod "H" to release the approaching electrode. The charged electrode will rapidly move downwards to the preset gap distance. The needle will puncture the tape, penetrate the sample material, discharge through the interstices of the material, and rise again to its initial position. (The threshold. voltage for gap breakdown will determine the distance at which the needle will be above the base electrode when the discharge occurs.)

4.2.2.1.9 Record reaction or no reaction. A reaction is indicated by a severed tape, whereas no reaction is evidenced by a punctured, but otherwise intact, tape.

4.2.2.1.10 Repeat the procedure until no reaction is obtained in 25 trails. If a reaction is obtained, the energy is reduced by decreasing the potential on the capacitor in 500 V increments and the above procedure repeated. The voltage is reduced until the charging voltage is 2500 V and then the next lower capacitance is selected by means of the primary capacitance switch. (Note: Turn off the power supply before changing capacitance.) The test shall be conducted for both oscillatory and for spark discharges.

4.2.2.1.11 The results are reported as "No reaction at J for oscillatory discharge" and "No reaction at J for spark discharge" according to the following table.

Oscillatory Discharge

Capacitance (pF)	Voltage (V)	Approx. delivered energy (10^{-7} J)
2,000	4,500	200,000
	4,000	160,000
	3,500	120,000
	3,000	90,000
	2,500	62,000
1,000	4,000	80,000
	3,500	60,000
	3,000	45,000
	2,500	31,000
500	4,000	40,000
	3,500	30,000
	3,000	22,000
	2,000	15,000
250	4,000	20,000
	3,500	15,000
	3,000	11,000
	2,000	7,500

Spark Discharge

Capacitance (pF)	Voltage (V)	Approx. delivered energy (10^{-7} J)
10,000	5,000	200,000
	4,500	350,000
	4,000	125,000
	3,500	100,000
	3,000	75,000
	3,500	50,000

Spark Discharge (continued)

Capacitance (pF)	Voltage (V)	Approx. deliviered energy (10^{-7} J)
5,000	4,000	65,000
	3,500	50,000
	3,000	37,000
	2,500	25,000
2,000	4,000	26,000
	3,500	20,000
	3,000	15,000
	2,500	10,000
1,000	4,000	13,000
	3,500	10,000
	3,000	7,500
	2,500	5,000
500	4,000	6,500
	3,500	5,000
	3,000	3,800
	2,500	2,500
250	4,000	3,200
	3,500	2,500
	3,000	2,000
	2,500	1,250

4.2.2.1.12 Conduct another series of tests for contact discharge.

4.2.2.1.13 Set resistance switch to "oscillatory".

4.2.2.1.14 Set primary capacitance switch to the selected capacitance, 1,000, 500, or 250 pF.

4.2.2.1.15 With the upper electrode completely depressed dynamically, adjust base electrode for zero gap (electrodes touching) by means of the micrometer. It shall be necessary to readjust for zero gap before starting a test Or when the upper electrode (needle) is replaced.

4.2.2.1.16 Repeat steps 4.2.1.5 through 4.2.2.1.9 except that the starting voltage is 1,000 V and discharge is obtained only upon contact.

4.2.2.1.17 Repeat procedure until no reaction is obtained in 25 trials. If a reaction is obtained, the delivered energy is reduced gy decreasing the potential on the capacitor from 1,000 V to 500 V to 250 V and/or changing the capacitance to the next lower value. (Note: Turn off the power supply before changing capacitances.)

4.2.2.1.18 The result is reported as "No reaction at J for contact" according to tie following table.

Contact Discharge

Capacitance (pF)	Voltage (V)	Approx. delivered energy (10^{-7} J)
1000	1,000	5,000
	500	1,250
	250	310
500	1,000	2,500
	500	625
	250	150
250	1,000	1,250
	500	310
	250	75

4.2.2.2 Qualification Criterion: There is no qualification for this test. The test results shall be reported along with those for normal lead styphnate. and dextrinated lead azide obtained using the same apparatus and procedure and conducted at the same time.

4.2.2.3 Sample Preparation, Electrode Replacement and Relative Humidity

See Electrostatic Sensitivity - Part 1.

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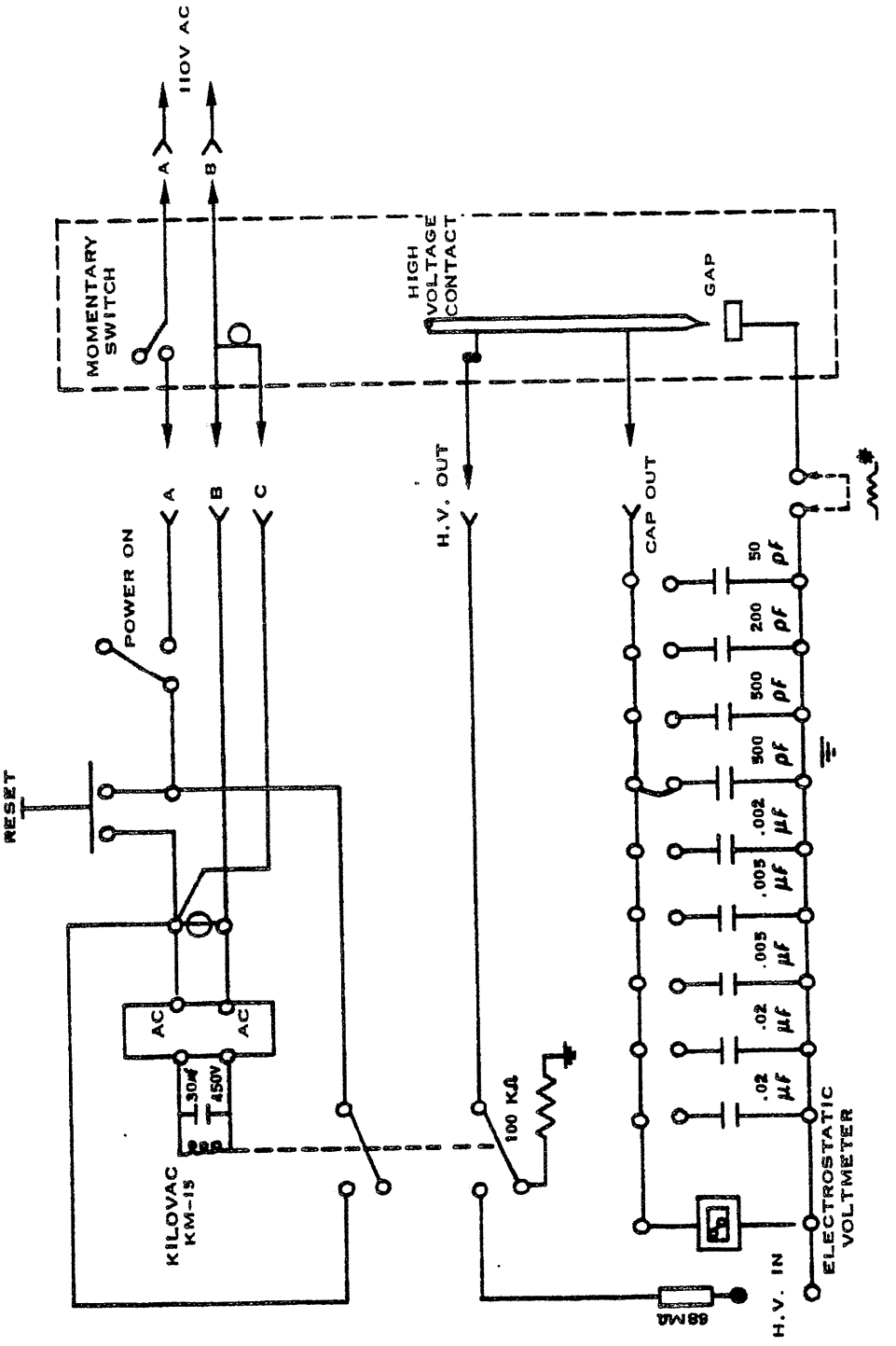

A 2 KΩ OR A 100KΩ RESISTOR IS ADDED TO PRODUCE
THE ARC OR THE SPARK DISCHARGE, RESPECTIVELY.
NO RESISTANCE IS ADDED FOR THE OSCILLATORY DISCHARGE.

FIGURE 1. CHARGING CIRCUIT

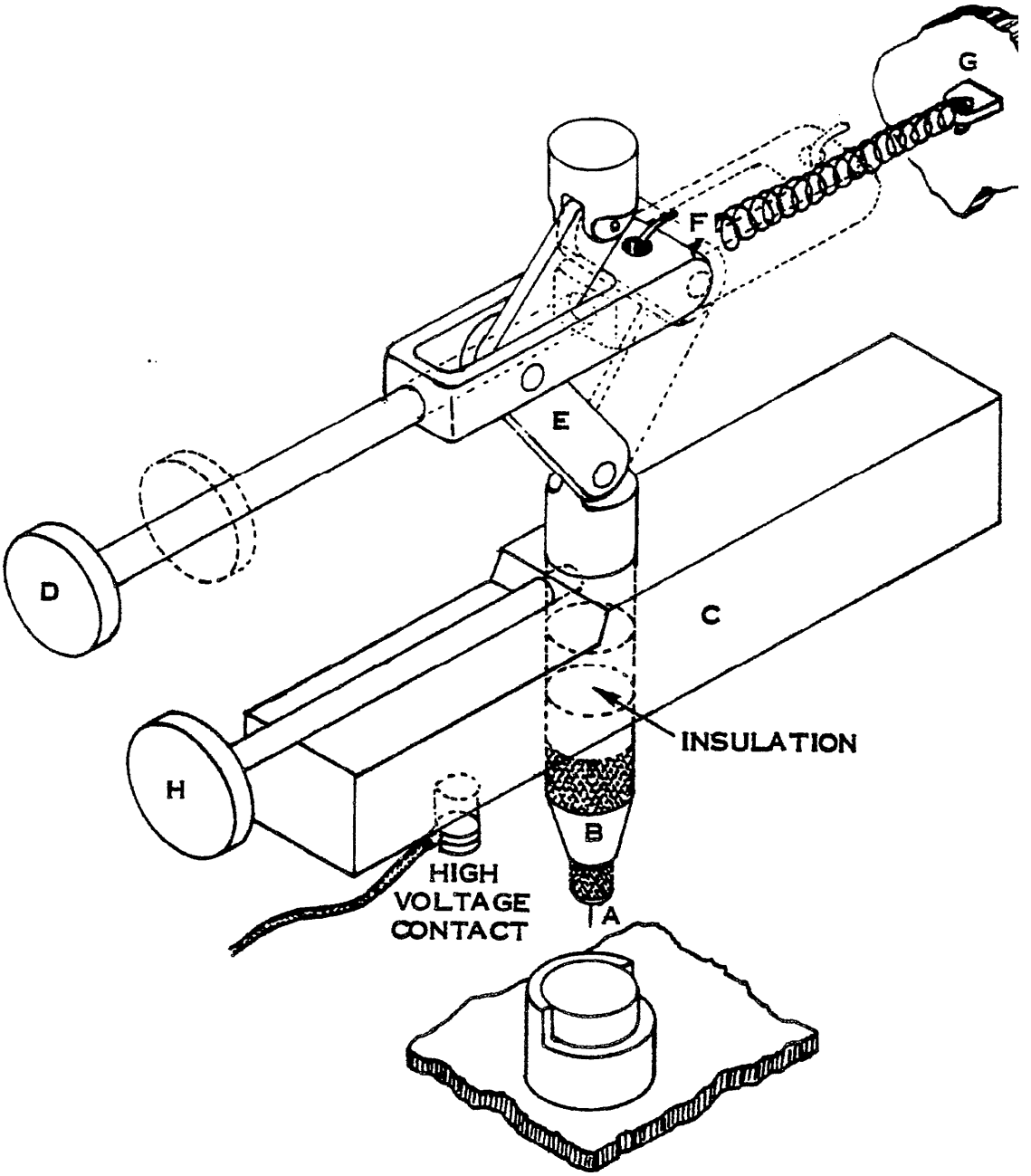

FIGURE 2. SCHEMATIC SHOWING OPERATION OF ROAHING ASSEMBLY

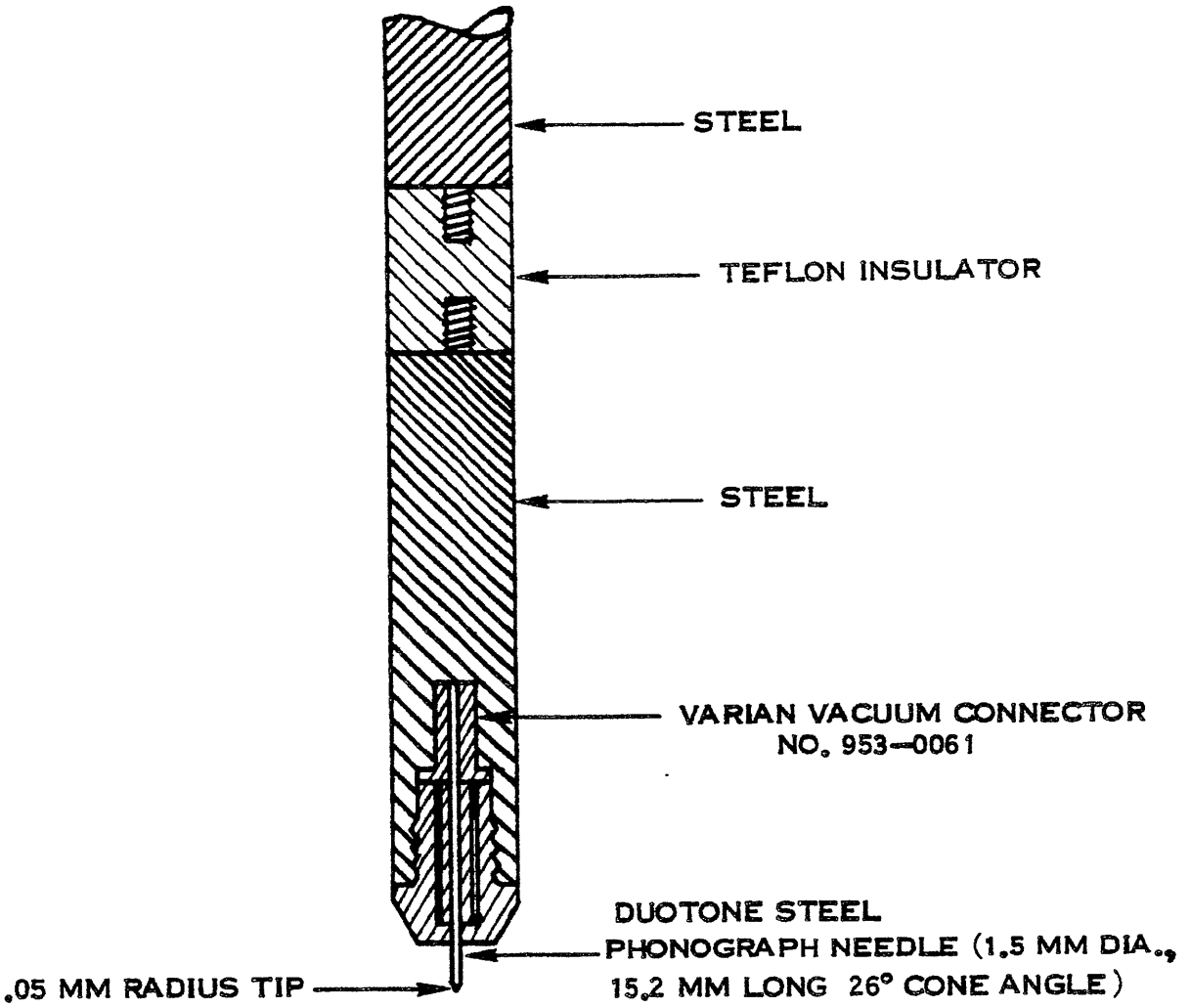

FIGURE 3. NEEDLE ASSEMBLY

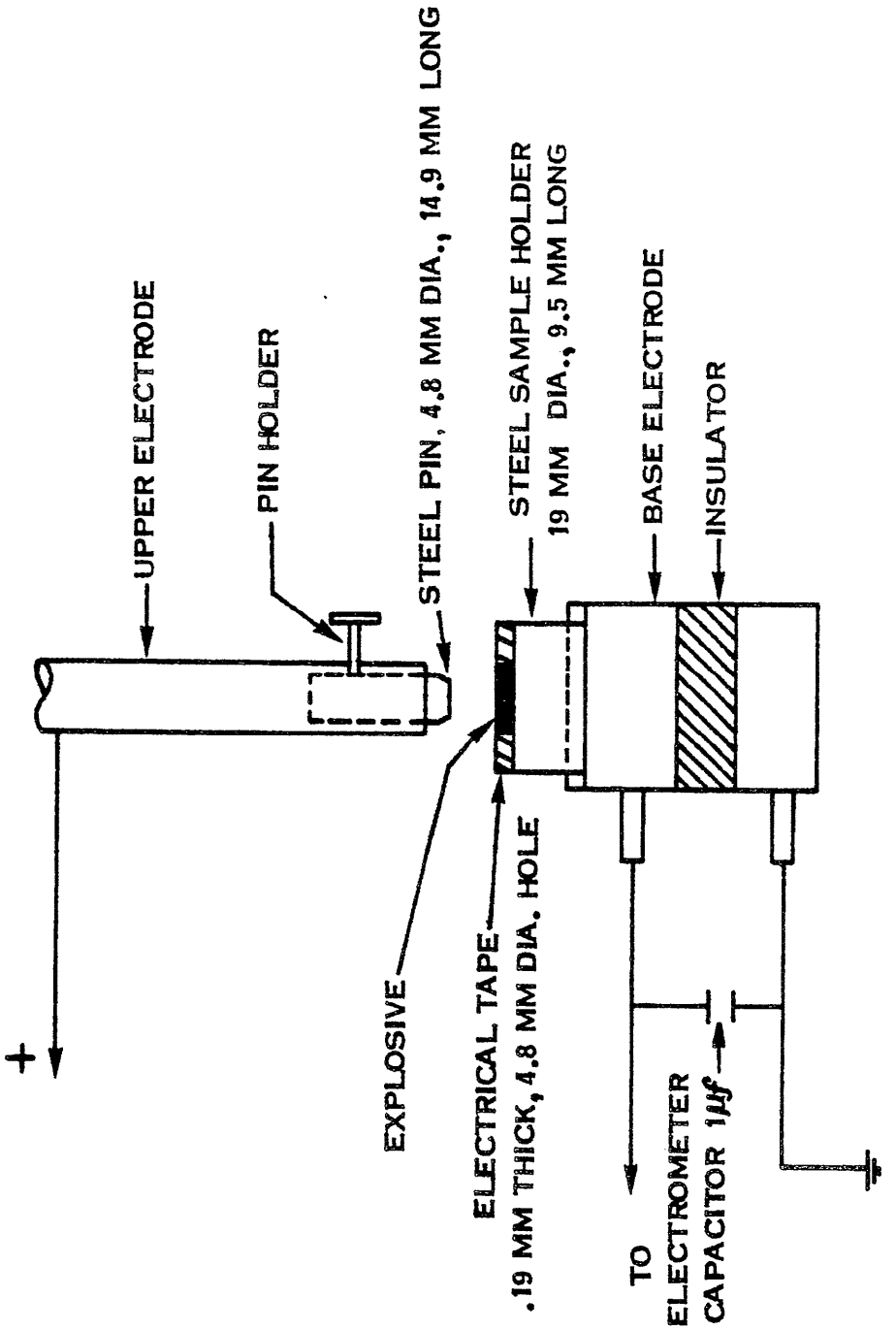

FIGURE 4. PLANE-TO-PLANE ELECTRODE ASSEMBLY

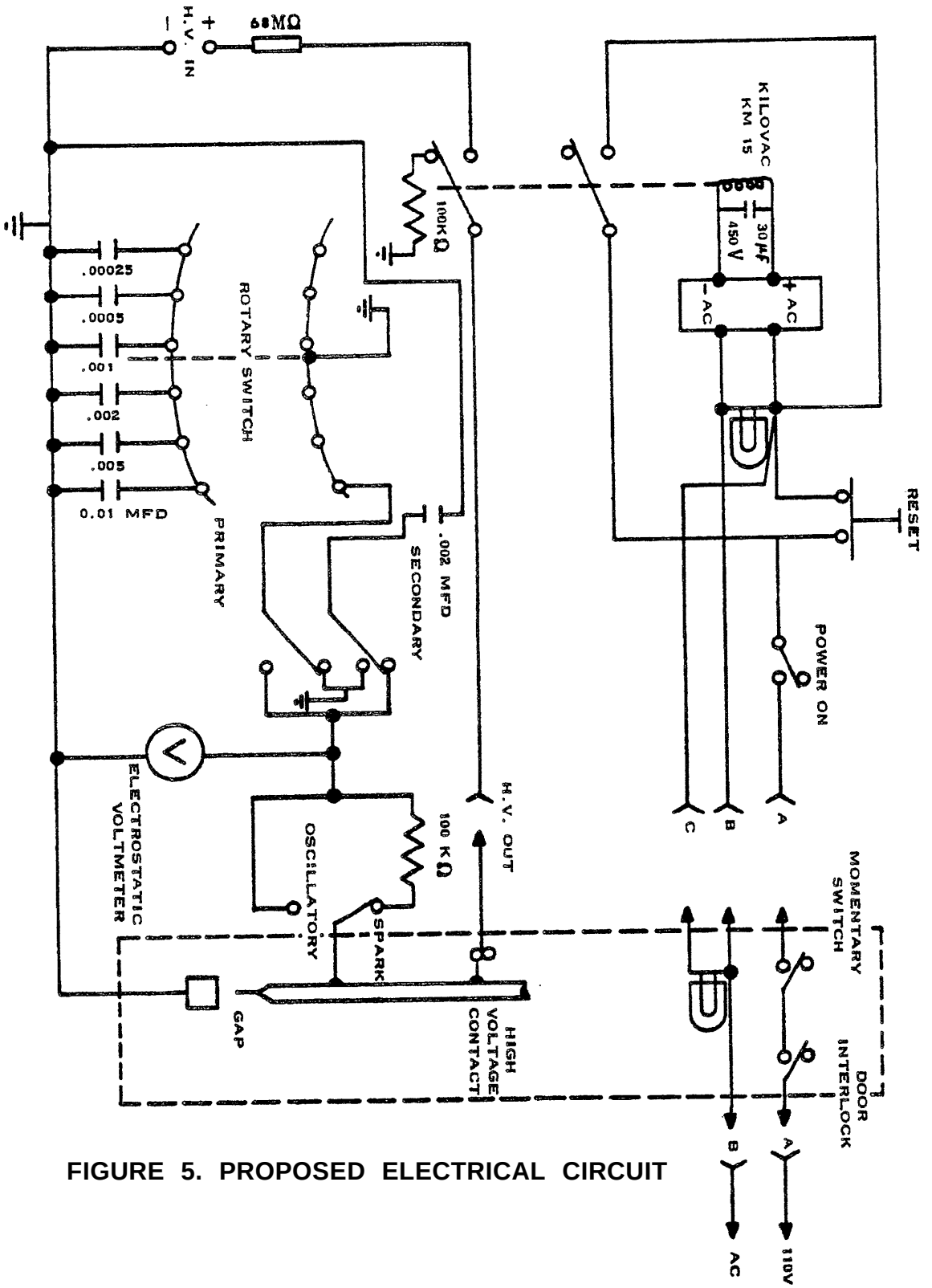

FIGURE 5. PROPOSED ELECTRICAL CIRCUIT

METHOD 5

CARD GAP SENSITIVITY

1. PURPOSE

1.1 The test is designed to evaluate the sensitivity of condensed-phase explosives onto initiation of a high-order detonation by a shock derived from an explosive donor and attenuated by passage through a barrier.

2. APPARATUS

2.1 The system consists essentially of a standard explosive charge (donor), a barrier Of variable thickness (gap), a container with the test charge (acceptors and a steel witness plate (target). A clean hole punched through this plate indicates that a high-velocity detonation was initiated. The Bureau uses two versions of the card-gap method - one is the standard card-gap test and the other is a modified procedure instrumented so as to permit measurement of wave velocities in the sample.

2.2 The donor is a 50-gram cylindrical tetryl pellet 2.54 cm (1 inch) high by 4.3.28 cm (1.625 inch) diameter with a density of 1.57 ± 0.03 grams/et$_a$

2.3 The gap is built up with discs punched from 0.254 mm (0.010 inch) thick cellulose acetate stock and measuring 3.937 cm (1.55 inches) in diameter. The sheet material should be of uniform thickness, with smooth surfaces free from ripples and dimples; it should be dimensionally stable. Because of its thermoplastic nature, acetate sheet is not suitable as a gap material when the test is to be carried out at temperatures much above 100°C. In this case, another gap material that remains dimensionally stable at higher temperatures must be substituted. When repetitive tests are made at large gap values, accurately-machined cylinders of polymethyl methacrylate may be substituted for thick stacks of plastic cards. Intermediate gap thicknesses are attained by adding plastic cards to the cylinders.

2.4 The witness plate is a cold-rolled mild steel 10.16 by 10.16 cm (4 by 4 inch) plates 0.635 cm (0.25 inch) thick.

2.5 The container or cup used in the standard test is a 7.62 cm (3 inch) long section of 2.54 cm (1 inch), Schedule 40, black steel pipe with smoothed finished ends. The bottom of the pipe is closed with a thin diaphragm of polyethylene or Teflon (or equal).

2.5.1 The container used in the instrumented version is similar except that it is 40.64 cm (16 inches) long. Ionization or pressure switches are used in conjunction with a 10 megahertz counter chronograph.

3. PROCEDURE, STANDARD VERSION.

3.1 The sample cup, the gap, and the donor charge are aligned on a common axis as shown in Figure 1. A paper mailing tube is used for this purpose, with additional spacers to align the acceptorr and donor charges.

3.2 The test is normally conducted at ambient temperature, but higher temperatures can be obtained by wrapping electrical heating tape around the sample container. The element may be fabricated from 0.475cm by 0.008cm (0.187 inch by 0.003 inch) Nichrome ribbon, insulated with 0.535cm (0.250 inch) Fiberglass sleeving,

3.3 A No. 8 commercial electric blasting cap is used to initiate. the donor.

3.4 The witness plate is placed directly above the sample cup and supported at a stand-off distance of 0.158 to 0.318cm (0.062 to 0.125 inch) from the tube end by a tightly-fitting cardboard collar on the cup or by a cork washer.

3.5 The gap thickness at which there is a 50-percent probability of a high-velocity detonation is determined from a minimum number of shots (usually 20), using the Bruceton up-and-down technique 6.1. For each successive shot, the number of cards is increased or decreased by a constant amount, depending upon whether the previous result was positive or negative.

4. PROCEDURE, INSTRUMENTED VERSION.

4.1 Except for the 0.4064m (16 inch) long sample container, the assembly and alignment of the test components are the same as for the standard version. In addition, pressure switches such as T-2 targets are inserted in the charge as shown in Figure 2; they are connected to the counter chronograph by single-pulse-generating circuitry.

5. RESULTS REPORTED AND CRITERIA FOR EVALUATION.

5.1 Following a shot, the witness plate is examined. A clean hole in the plate indicates a high-velocity (normal) detonation, although a very hard plate may be broken by such a reaction. A bulge or rip in the plate indicates a low-velocity (incomplete) detonation; this is considered to be a negative result, as is an undamaged plate.

5.2 Wave velocities are measured by the instrumented method which provides a means of distinguishing low-velocity detonations from unstable (accelerating or decelerating) detonations which have an effect on the witness plate. Steady low-velocity detonations destroy the entire pipe and produce a dome or bulge in the witness plate; a decelerating (decaying) detonation destroys only the portion of the pipe next to the gap.

5.3 The result is expressed as the number of 0.254mm (0.01 inch) thick cards, or the equivalent thickness in inches, for which there is a 50-percent probability of a high-velocity detonation.

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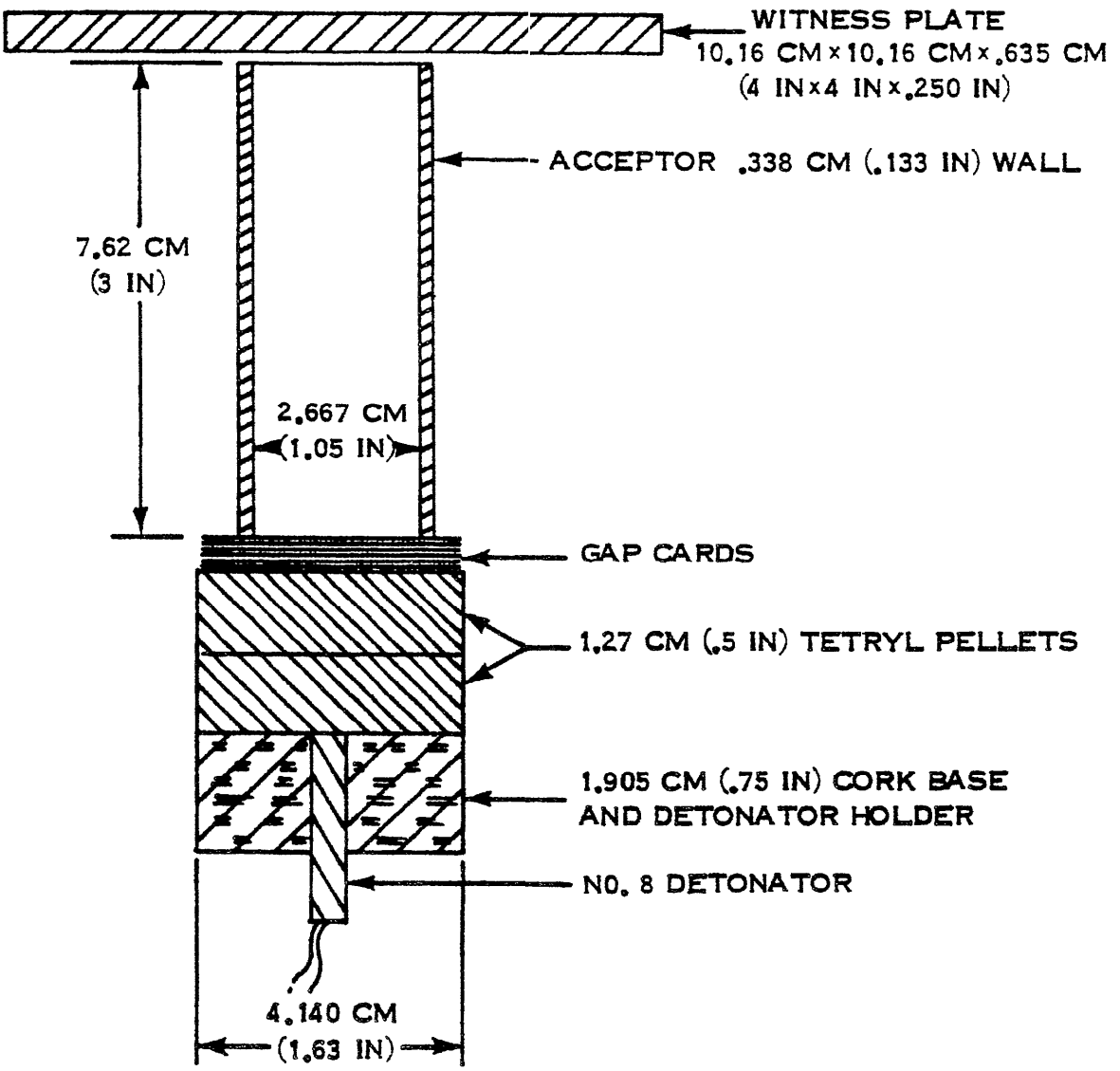

FIGURE 1. SCHEMATIC OF CARD GAP TEST

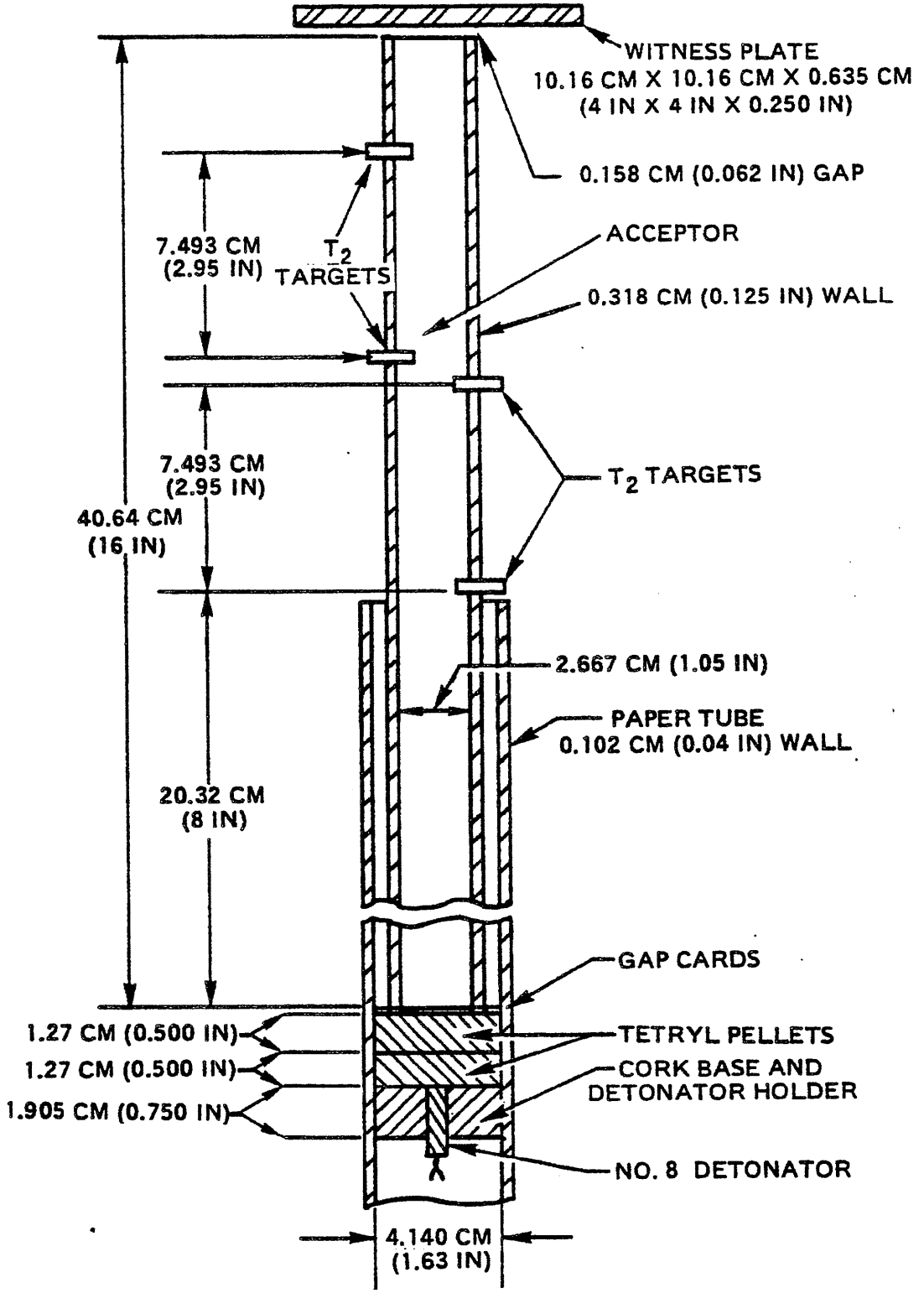

FIGURE 2. SCHEMATIC OF INSTRUMENTED CARD GAP TEST

METHOD 6

FRICTION SENSITIVITY

1. PURPOSE

1.1 The Allegany Ballistics Laboratory (ABL) Sliding Friction Machine or equivlents is a means of obtaining initiation-of-combustion data using a small amount of sample between two metal sufaces; also, the test results reflect the effects of force, velocisty, particle size, sample thickness and materials of construction. The sliding friction machine provides force data for comparison or application purposes and, the coefficient of friction and sliding distance values necessary to calculate the frictional zero initiation energy as ft.-lb. (Table 1). Methods and procedures to establish the force, coefficient of friction and sliding distances can be obtained from (9.2).

2. APPARATUS

2.1 To operate the ABL sliding friction machine, a given sample is placed on the movable sliding block and pressure is applied to the sample by a stationary wheel attached to a hydraulic ram. A weighted pendulum is dropped from a pre-determined height to strike a block with sufficient energy to slide the block. Then, the block slides perpendicular to the vertical vector of normal forces as applied by the stationary wheel. The distance of slide can be regulated by an adjustable positive stop.

3. VELOCITY

3.1 A velocity greater than 2 ft/sec is used to provide the lowest coefficient of friction and therefore the lowest zero initiation data.

4. SURFACE FINISH

4.1 Test components with a 64-micro-inch finish are used, since it generally duplicates the finish on process machinery and handling equipment. When materials other than steel are used, the applicable finish is duplicated. Although additional work is planned to establish the effect of metal finishes between the limits of 8 and 200 micro-inch on sensitivity values, it is anticipated that the effect will be insignificant.

5. HARDNESS OF ‘TEST COMPONENTS

5.1 Test components with a hardness of Rockwell B-83 are used, this duplicates the hardness of most metals used in the process. When materials other than steel are used, the appropriate hardness is duplicated.

TABLE 1

SLIDING FRICTION MACHINE DATA

Test Sample	Coefficient of Friction	Zero Initiation Level Force (lbs)	Zero Initiation Level Energy (ft.-lbs)
Ingredients			
Nitrocellulose	0.14	36	0.42
Ammonium Perchlorate	0.16	<2	<0.03
Casting Powder			
Single-Base	0.08	343	2.30
Double-Base	0.07	268	1.60
Composite-Modified Double-Base	0.15	157	2.00
Cast Propellant			
Double-Base	0.08	583	3.90
Composite-Modified Double-Based	0.08	364	2.40

6. SAMPLE AND/OR PARTICLE SIZE

6.1 The sample size is regulated by using enough sample to provide a monolayer or the thickness of material duplicating that phase of the process investigated. The use of a monolayer of sample generally duplicates the thickness resulting from spilling materials. The particle sizes of the test samples duplicates the size of the materials for that phase of the process investigated.

7. CONTACT AREA FOR WHEEL AND SLIDING BLOCK

7.1 The instantaneous area of contact between the wheel and block is held constant.

8. TEMPERATURE AND RELATIVE HUMIDITY

8.1 All testing is performed at a temperature of 75± 5°F and at 50 ± 10% relative humidity.

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METHOD 7

MEASUREMENT OF THERMAL CONDUCTIVITY

1. PURPOSE

1.1 It is interesting to compare heat leakage in measurements of thermal conductivity to current leakage in measurements of electrical conductivity at room temperature. In the electrical measurements, there are solid insulating materials available which have electnical conductivities about 10^{-25} that of the best electrical conductors. This means that it is not difficult in most cases to reduce electrical leakage to a very small amount. However, the best solid thermal insulators at room temperature have thermal conductivities only about 10^{-4} that of the best thermal conductors. Therefore, one cannot expect to minimize heat leakage to the extent that one can minimize electric current leakage. Furthermore, in measurements of thermal conductivity, even when all surrounding material is removed, heat transfer by radiation may still be quite large.

1.2 It is thus apparent that the problem of avoiding unwanted heat transfer may be serious in thermal conductivity measurements; For example, in a copper rod having a circular cross-sectional area of 1 cm^2, the power required to produce a 1°C temperture difference in a 1 cm length is about 4 watts near room temperature. If the rod is surrounded by insulation 1 cm thick having a thermal conductivity 10^{-3} that of copper, the radial heat flow through the insulation for 1°C radial temperature difference is about 0.02 watts for 1-cm length of rod. Since this is only about 0.5% of the Longitudinal heat flow, the problem of avoiding error from radial heat loss is not too difficult. This is accomplished by surrounding the length of specimen with a "guard" with a matching temperature gradient so that the radial temperature difference between the specimen and the guard is small.

2. APPARATUS

2.1 A simple apparatus for measuring thermal conductivity of bight conductivity solids (such as metals) is shown schematically in Figure 1.

2.1.3 A known power, introduced at one end of the specimen, flows along the specimen to the heat sink. The speciment is surrounded by a "guard" in which temperatures are matched as nearly as possible to the corresponding temperatures in the specimen.

Measurements of temperatures (using thermocouples), the distance between thermocouples, the electric power in the heater, and the cross sectional area of the specimen are sufficient in principle to permit calculation of thermal conductivity. Thermal insulation is used between the guard and specimen in order to minimize any transfer of heat by radiation or convection. The use of this insulation is not without disadvantages, however. As shown in Figure 1 some of the heat introduced at the end of the specimen will be used to set up the longitudinal temperature gradients in the insulation, so that all of the electric heat input does not flow along the speciment. If the specimen has a high thermal conductivity relative to that of the insulation, then this error may not be serious. If the specimen has a low thermal conductivity, the error may be serious. With metal alloys such as stainless steel, an error of 1% due to this heat flow down the insulation can exist in a typical apparatus.

2.1.1.1 In the apparatus shown in Figure 1, a relatively small longitudinal temperature difference is usually used, so that in order to determine the thermal conductivity over a temperature range, a number of experiments must be made. If a relatively large temperature difference is set up along the specimen and a number of thermocouples are spaced along the length, by determining the average temperature gradient over each span along the bar, the thermal conductivity can be determined as a function of temperature in one experiment.

2.1.1.1.1 The above longitudinal heat flow experiments are usually considered applicable to specimens having relatively high thermal conductivities. In this case, the errors due to uncertainties in radial heat flow may not be excessive. As a general rule, the simple longitudinal heat flow method described can be considered applicable to solids having conductivities greater than 0.1 watt $cm^{-3}°C^{-1}$. In experiments at temperatures of 1000° or higher, the radial heat transfer uncertainties become more serious because (1), it is usually more difficult to match the guard temperatures to those of the specimen and (2), the insulating materials have higher thermal conductivities at the higher temperatures. When using the longitudinal heat flow method on specimens having low thermal conductivities, the radial heat flow can cause serious errors even at ordinary temperatures. For example, take the case where the specimen has a thermal conductivity of 0.03 watt cm^{-1}°C-1, which is in the range of conductivities of the thermoelectric materials of present interest. In this case, the heat flow (power) for l°C temperature difference in 1 cm of rod (1 cm^2 cross sectional area) is 0.03 watts. Using the same insulating material as before, (K_T=0.004 watt cm^{-1}-°C^{-1}) the radial heat flow (per cm length) in the insulation 1 cm thick is still 0.02 watt for 1°C difference in temperature.

It is obvious that with this relatively large radial heat flow, longitudinal heat flow experiments of the type described must be carried out with extreme care to obtain accurate results with low-conductivity materials.

2.1.1.1.1.1 One method of minimizing the error due to radial heat flow is to increase the power so that the heat flow through the specimen is larger. In this case, it is possible to make the longitudinal heat flow larger by comparison with the radial heat flow. Of course, this increased power gives a larger temperature difference alonbg the rod-in fact so large that it is not convenient to use a long specimen because of very large temperature differences. Instead, a specimen whose length is comparable to or even considerably less than its diameter is usually taken for materials of low thenmal conductivity. This is the case in the "Guarded Hot Plate Method". With this method, the cross-sectional area is made large relative to the length as shown in Figure 2. The relatively thin specimen is placed between hot and cold plates. The measured power put into the hot plate to produce a temperature difference of one degree in the specimen is now much larger because the cross sectional area is large and the length is less. Thus, the heat transfer out form the circumference of the specimen has much less relative effect. As an additional refinement, the hot plate is surrounded by a "guard ring" held at the same temperature as the hot plate so that radial heat conduction is minimized in that part of the specimen between the hot and cold plates. This method of measuring thermal conductivity of insulating materials is used generally with some variations. While it is usually convenient to put in measured power electrically in the guarded hot plates one interesting variation measures the power through the specimen by the amount of liquid evaporated. A schematic diagram of the apparatus is shown in Figure 3. An unmeasured quantity of heat is put on the bottom of the specimen while the top of the specimen is in contact with a "boiler," usually containing water. With this method, the temperature of the top surface of the specimen is automatically kept near the boiling point Of water, near 100°C. This means that in the measurements at high temperatures, The temperature difference in the speciment is quite large. Since thermal conductivity is a function of temperature each experiment is a measure of an "average" thermal conductivity analogous to an experiment in calorimetry using the drop method to measure an "average" heat capacity over a temperature range. The true thermal conductivity can be derived from experiments using different temperatures of the hot plate.

2.1.1.2 We have considered longitudinal beat flow experiments, showing that the undesired radial heat flow may become serious when measuring low-conductivity materials especially at high temperatures.

We have seen also that one method of minimizing errors in longitudinal heat flow experiments due to this radial heat flow is to use the guarded hot plate method. Another aproach to the problem of measuring thermal conductivity is the use of a "radial heat flow method". An example is the cylindrical sample method.

2.1.1.2.1 Power, P (per cm length of cylinder), is introduced along the axis of a cylindrical specimen and flows out radially producing temperatures of T_1 and T_2 at the radii r_1 and r_2, respectively, of the specimen. The equation:

$$P = \left[\frac{2\pi k_T (T_1 - T_2)}{\ln \left(\frac{r_2}{r_1} \right)} \right]$$

assumes that all the heat flow is radial and that the thermal conductivity k_T is constant in the range between T_1 and T_2. The big advantage of this method is that the radial heat leak which causes concern in the longitudinal heat flow experiments now may not cause andy error. In fact, it is necessary now to have this leak in order to maintain the radial temperature difference for the experiment. However, it is necessary also to use a cylindrical specimen long enough to justify the original assumption that the heat flow in its central portion is radial. This condition is not difficult to meet, since a length to diameter ratio of four has been shown to be adequate in many cases. In this case, the ends of the cylinder act as guards to avoid longitudinal "heat flow. Sometimes, the desirable length-diameter ratio can be obtained by using stacked disks for the cylinder. Here, the thermal contact resistance between disks reduces the longitudinal heat flow. This method is most effective when the material has a high thermal conductivity. The cylindrical method of measuring thermal conductivity has disadvantages which limit its applicaiton. Possibly the most serious is that it usually requires a larger specimen than does a longitudinal heat flow method. The diameter must by large enough to permit accurate measurements of radial distance and temperature difference. A diameter of 2.54 to 5.08 cm (1 to 2 inches) is usually considered the minimum for accurate measurements. To avoid the effects of conduction out the ends of the cylinder, its minimum length would be 10.16 to 20.32 cm (4 to 8 inches). The fabrication of a uniform specimen of this size may be quite difficult, even though it can consist of a number of stacked disks. The measurement of temperatures at known radial distances is also usually more difficult than the corresponding measurements in longitudinal heat flow.

2.1.1.2.2 Another radial heat flow method is called the "Envelope Method" in which the guard completely surrounds the specimen.

In the cylindrical heat flow method, the cylinder must be made relatively long to minimize. effects of heat conductivity out the ends. If a spherical specimen is used, this is no longer a problem, in that the heat source is completely surrrounded (in principle) by the material whose thermal conductivity is being measured. The heat flow equation is:

$$P = \left[\frac{4\pi k_T (T_1 - T_2) r_1 r_2}{(r_2 - r_1)} \right]$$

where P is the power introduced in the central part of the sphere, and T_1 and T_2 are the temperatures at the radii r_1 and r_2, respectively. While this method is ideal in that. it is essentially free from heat leak errors, its experimental attainment is usually difficult. The method requires a uniform heat flux through an inner spherical surface and a uniform heat flux through an outer spherical surface, with constant temperatures measured over each spherical surface. In this respect, the spherical method is similar to the cylindrical method. However, the measurement of temperatures on a spherical surface is more difficult than on a cylindrical surface.

2.1.2 The general methods which have been described are applicable to solids which may or may not be electrical conductors. In the case of electrical conductors, where a significant electric current can be passed through the specimen, it is possible to evaluate thermal conductivities in experiments which are somewhat different than those described previously, the difference being due to the production of electric heat throughout the specimen, rather than at an end (longitudinal f1ow), an axis (cylindrical flow), or a center (spherical flow). Let us consider the ideal longitudinal heat flow experiment with electric heat developed in a specimen having constant electrical resistivity. If there is no radial heat flow the ends being held at some temperature To then the temperature at any point along the specimen is a function of the electric heat input, the dimensions of the specimen, the location of the point along the specimen and the thermal conductivity of the specimen. In this ideal case, all of the heat produced in the rod is conducted to the ends of the specimen and the evaluation of the thermal conductivity from the -measured dimensions, temperatures and electric heat input is relatively simple. In the actual experiment where radial heat flow exists, the electric heat produced in the rod is dissipated not only by conduction along the specimen but also by the radial heat flow which must be taken into account. Possibly the most useful application of this method has been at very high temperatures where the usual methods encounter difficulties. Using an incandescent filament, it has been possible to measure thermal conductivities of metals up towards their melting points.

There are other variations of the electrical method, some using radial heat flow instead of longitudinal heat flow.

2.1.3 Absolute values of thermal conductivity are obtainable from the methods discussed thus far. As a rule, absolute measurements are more difficult for a given accuracythan comparative measurements. When compring the thermal conductivity of one specimen to that of another, some of hte errors are likely to be the same so that the ratio of conductivities is more accurately known than the absolute values. However, one must remember that a comparative measurement is not a magic "cure all", the extent of the compensation for certain errors depends upon the procedure and design of the experiment.

2.1.3.1 To obtain absolute values of k_T from comparative measurements of thermal conductivity, we must use as the reference specimen one of known thermal conductivity. At the present time, the material most generally accepted as a standard in the temperature range from room temperature to perhaps 700° C is Armco, or equal, iron. This material, commercially available with a purity of about 99.9%, has been investigated by a number of experimeters who agree on the thermal conductivity values usually to within several per cent in this temperature range. While this material is not ideal. it is being used widely as a tentative standard until a better one is available.

2.1.3.1.1 Comparative measurements may be classified into two types. In one type, the apparatus is used successively to measure the standard and the unknown material. In this type of experiment, the measurement on the standard can be considered as a calibration of the apparatus. In the second type of comparative measurements. the standard and unknown materials are measured simultaneously, letting the same heat flow through both the standard and unknown materials. In comparative measurements of this type, longitudinal heat flow is used in most cases. A typical case is the "Cut Bar Method”. Here, the unknown is placed in good thermal contact with the specimen of the standard material having the same cross section. If there is no radial heat loss, the temperature gradients in the standard and unknown materials will be in inverse proportion to the thermal conductivities of the two materials. independent of the longitudinal heat flow. Now if there is radial heat flow, there will not be the same heat flow in the two materials, so that the temperature gradients will no longer be a direct measure of the relative conductivities.

2.1.3.1.1.1 Where radial heat flow is significant, sometimes the unknown specimen is placed between two standard specimens, all surrounded by a "guard" whose temperatures are controlled so that its longitudinal gradient corresponds closely to those in the standard and unknown specimens. In this way, the radial heat flow is minimized. The purpose of using two standard specimens is to correct the radial heat flow which may be the same in both unknown and standard specimens.

2.1.3.2 When the cut-bar method is applied to measurements of metals, the thermal contact resistance between standard and unknown materials can be made relatively small by soldering or welding. If the thermal conductivities of the standard and unknown materials are considerably different, the control of the matching temperature gradients or the guard may be very difficult because of the abrupt change in slope of the temperature-length curve. Any significant thermal contact resistance between specimens may make this problem more difficult. In applying the cut-bar method to measurements on materials having low thermal conductivities, the relative errors due to any radial heat flow are larger. This means that at the higher temperatures where radial beat transfer coefficients are larger, extreme care is necessary to make accurate measurements on thermoelectric materials which might have thermal conductivity values in the range 0,01 to 0.05 watts/cm-°C.

2.1.4 To summarize the status of experimental measurements of thermal conductivity at moderate to high temperatures, it appears that the longitudinal heat flow method has been used more than any other method. For solids with relatively high thermal conductivities, specimens have been used which are long relative to their diameters. Errors caused by radial heat transfer are minimized by surrounding the specimen with a guard with matching temperature gradients. Frequently, this method is used to compare the thermal conductivity of a specimen with that of a standard material such as Armco, or equal. For solids having relatively low thermal conductivities; speciments have been used which are short relative to their diameters. Errors caused by radial heat transfer are minimized by providing a guard ring. Radial heat flow methods also have been used, especially at the higher temperatures where heat transfer coefficients are likely to be greater.

2.2 UNSTEADY-STATE MEASUREMENTS (THERMAL DIFFUSIVITY): All of the preceding discussion has been concerning the direct experimental measurement of thermal conductivity, using steady-state expeiments that is, experiments where the temperature at any point does not change with time. However, it is possible to obtain thermal conductivities indirectly by "unsteady-state experiments" in which the quantity "thermal diffusivity" is evaluated. Thermal diffusivity (a) is defined by the equation:

$$a = \frac{k_T}{Cd}$$

where k_T is thermal conductivity, d is density and C is heat capacity per unit mass. In other words,

$$a = \frac{\text{thermal conductivity}}{\text{heat capacity per unit volume}}$$

2.2.1 If the heat capacity per unit volume is known, thermal conductivity values can be obtained directly from thermal diffusivity values. The most obvious disadvantage of this method is that heat capacities (per unit mass) and densities either must be known to the desired accuracy or must be easily obtainable by measurement. The measurement of density to the desired accuracy is one of the simplest experimental measurements. While measurements of heat capacity are not simple, their measurement within a given accuracy is usually easier than the corresponding measurement of thermal conductivity. Also, there are a large number of heat capacity values available in the literature which frequently can be extrapolated to higher temperatures with adequate accuracy, since heat capacities at high temperatures usually do not change rapidly with temperature. Therefore, thermal conductivity values usually can be obtained from thermal diffusivity values with reasonable effort.

2.2.1.1 The primary advantage of diffusivity measurements is obvious when one realizes that the dimensions of thermal diffusivity are $(\text{length})^2/\text{time}$. This means that in principle, only time intervals must be measured in addition to the usual measurements of length on the specimen. Of all the physical measurements, time intervals are probably the easiest to measure with high accuracy. The big experimental difference, therefore, between thermal conductivity experiments and thermal diffusivity experiments is that in diffusivity experiments, time interval measurements are substituted for power measurements. Since the power measurements (actual heat through the specimen) are frequently the primary source of error in thermal conductivity measurements, this substitution seems a real advantage, at least in principle. In a way, we can consider that the diffusivity experiments dodge the power measurements by making them a separate experiment the heat capacity experiment when the power can be measured more accurately. measurements of thermal diffusivity frequently have another advantage over thermal conductivity measurements in that less time is required.

2.2.1.2 In spite of certain advantages that thermal diffusivity experiments appear to offer, they have not been regarded as very accurate, at least until recent years. Recently, there has been a trend to thermal diffusivity measurements at the higher temperatures which is a consequence of increased difficulties with thermal conductivity measurements at the higher temperatures. As the experimental measurements are extended upward to higher temperatures, it seems likely that thermal diffusivity measurements will become more popular. Particularly, in an investigation of a series of thermoelectric materials where the thermal conductivity may vary considerably while the heat capacity changes very little, the thermal diffusivity method seems to offer quick measurements of the change in thermal conductivity.

2.2.2 Experimental measurements of thermal diffusivity involve problems similar to those in thermal conductivity measurements. Let us consider first a longitudinal heat flow method for diffusivity measurements. On one end of a semi-infinite rod there is impressed a sinusoidal temperature variation $T = A \sin \omega\tau$, where T is temperature, t is times A is amplitude, w is $2 \pi f$, where f is the frequency of the sine wave. Taking first the ideal experiment with no radial heat flow, a temperature wave is propagated along the rod with a velocity υ and an amplitude attenuation q. In this ideal experiment, the velocity of propagation is a measure of the thermal diffusivity (a) through the relation:

$$\upsilon = \sqrt{2\alpha\omega}$$

A measurement of thermal diffusivity requires only a measurement of the frequency of the sine wave and the time required for the wave to travel a known distance. Thus only two time interval measurements and one length measurement are required in this ideal diffusivity experiment. It is also possible to use a measurement of attenuation of this temperature wave to determine the thermal diffusivity, independent of any velocity of propagation measruements. Attenuation is defined as the ratio of amplitudes at two locations along the rod. In this case, the logarithm of the attenuation (q) is given by the relation:

$$\text{In } q = L\sqrt{\frac{\omega}{2\alpha}}$$

where L is the length over which the attenuation is measured. Thus in this experiment, one time interval measurement (frequency of teh sine wave), one length measurement and one measurement of the ratio of amplitudes (over the known length) must be made to evaluate thermal diffusivity.

2.2.2.1 In longitudinal heat flow measurements of thermal conductivity, any radial heat flow introduces an uncertainty in the power through the specimen. In the longitudinal heat flow measurement of thermal diffusivity, radial heat flow affects both velocity of propagation and attenuation. However, it is easier to reduce the resulting errors from radial heat flow in the diffusivity experiment. One method is to use sinusoidal temperature waves with higher frequencies so that the radial heat flow has less time to influence the propagation of the wave. This is perhaps analogous to increasing the power in the thermal conductivity experiment so that radial heat transfer has less relative effect. With thermal diffusivity, however, there is another method of accounting for radial heat loss which gives it a tremendous advantage over thermal conductivity measurements using longitudinal heat flow. Consider now the sinusoidal

longitudinal heat flow together with radial heat flow. Let us Let us assume that (1) the surroundings of the rod are at a constant temperature, (2) the rod is semi-infinite in length and has a diameter small enough so that any radial temperature gradient in the rod is negligible, (3) the rod is radiating to its surroundings with a heat transfer coefficient which is constant and (4) the physical properties of the rod are constant within the temperature variations on the rod. A thermal diffusivity experiment is performed, simultaneously observing the velocity of propagation υ and the attenuation (q) over a distance L. The mathematical solution to this problem, making the above assumptions is:

$$\alpha = \frac{L\upsilon}{2 \ln q}$$

This means that the value of thermal diffusivity obtained form measurements of L, υ, and q, is independent of both the frequency of the sine temperature wave and the heat radiated to its surroundings. Within the assumptions made, here is a method which enables longitudinal heat flow measurements of thermal diffusivity to be made without errors due to radial heat flow. Unlike many other assumptions which are made to idealize an experimental measurement, the assumptions made above are not too difficult to fulfill reasonably, for many materials, even at moderately high temperatures.

2.2.2.1.1 It may be of interest to give some idea of the range Of frequencies useful for a material having a given thermal diffusivity. For a material such as iron, frequencies in the range 0.01 to 0.1 cycles per sec are appropriate, giving velocities of propagtion of perhaps 1 to 2 mm per sec with attenuation per cm varying from less than 2 to perhaps 4 or 5.

2.2.3 It is possible to use radial heat flow in thermal diffusivity experiments to minimize errors arising from unwanted heat transfer in a manner similar to thermal conductivity measurements.

2.2.4 If a sinusoidal temperature wave is imposed on the outside of a long cylindrical specimen, the radial attenuation and velocity of propagation are both functions only of the thermal diffusivity of the material. It is assumed that the physical properties of the material are constant in the variation of temperature of the specimen. The effects of heat conduction out the ends can be avoided by making the cylinder relatively long. In this cylindrical diffusivity experiment, observation of either the radial attenuation or velocity of propagation is sufficient for evaluating thermal diffusivity. If the velocity of propagation is observed, the experiment consists of measuring the dimensions

of the specimen and the time interval required for the temperature wave to travel a given distance along a radius. The mathematical solution of this problem involves Bessel's functions which have been tabulated. Some idea of the desired frequencies and specimen radius can be obtained from Figure 4. In this figure are plotted some values of the radius and logarithm of frequency corresponding to three different diffusivity values and to a phase lag of about 180° between the outside of' the cylinder and its center. For example, for a material having a thermal diffusivity of 0.01 cm^2/sec and a radius of about 0.7 cm, a sinusofidal temperature wave having a frequency of 0.1 hertz, will be propagated from the outside of the cylinder to the center of the cylinder with a time lag of 5 sec (180° phase lag).

2.2.4.1 Both of the methods measuring thermal diffusivity use sinusoidal temperature waves. Sometimes it is difficult to develop the temperature waves having the desired amplitudes and frequencies because there must be both cooling and heating available. To produce a sine wave of frequency of 0.1 hertz and an amplitude of 10 degrees, the maximum cooling (or heating) rate must be about 6 degrees/see. With the better conducting materials (high diffusivity) where relatively high frequencies are needed to give measurable quantities, the rate of cooling obtainable on the outside of the cylinder may be a real limitation. At very high temperatures, cooling by radiation may be adequate. In general, even with the lower-diffusivity materials, temperatures higher than 1000°C are required to produce sufficient radiative cooling for diffusivity experiments using sinusoidal temperature waves.

2.2.4.1.1 Sinusoidal temperature waves of the form $T=A \sin \omega\tau$ have been considered previously because they are the simplest of the periodic functions to solve mathematically. However, it is not necessary to use periodic temperature functions in diffusivity experiments. In fact, in many cases, it is incomnvenient if not impossible to design diffusivity apparatus with sufficient cooling for periodic temperature variations. Fortunately, there are several methods available which do not require periodic temperature variations. Several of these will now be described.

2.2.5 One of these the "Forbes Method", was devised almost a century ago. In this method, two types of experiments are made. One experiment uses a long bar heated at one end until the temperatures become steady. The bar is long enough so that the end farthest from the source of heat comes essentially to the temperature of its surroundings. The power flow at any distance x is $P = k_T A \partial T/\partial X$. The quantity, $\partial T/\partial X$, is measured along the rod using thermocouples attached to the rod. Knowing the cross section A, the thermal conductivity could be evaluated if the power flow were known. The second type of experiment is an

unsteady-state experiment, used to evaluate this power. This experiment consists of heating a short piece of rod of the same material (having the same diameter and surface condition). This rod is heated to a known temperature and placed in the same environment as the long rod. The rate of heat loss (power) from the element dx or, this short rod is $AdxCd\frac{\partial T}{\partial t}$. Assuming That the rate of heat loss from the short rod is the same as from a section of the long rod at the same temperature, the power flowing across x in the steady-state experiment is

$$P=k_T A\frac{\partial T}{\partial X}=ACd\int_z^\infty \frac{\partial T}{\partial t}dx$$

or

$$\alpha=\frac{k_T}{dc}=\frac{1}{\partial T/\partial x}\int_x^\infty \frac{\partial T}{\partial t}dx$$

Thus the thermal diffusivity is determined by these two experiments, and thermal conductivity can be calculated if d and C are known. The value in the Forbes method seems to be mostly historic, having little utility in measurements at high temperatures.

2.2.6 Thermal diffusivity can be measured in a transient type of experiment where the temperature of one part of the specimen is suddenly changed and the time measured for this change to appear on another part of the specimen. If this transient type of experiment is applied to longitudinal heat flows there are difficulties in approaching the ideal experiment where all the heat goes to heating the specimen. With radail heat flow in a long cylinder, this ideal experiment can be approached more closely. However, the experimental problem of suddenly changing the surface temperature by a fixed value may be very difficult.

2.27 There is another method of measuring thermal diffusivity which does not require this sudden change in surface temperature and which may be easier to realize experimentally. This method consists of heating one part of a specimen at a constant rate of change of temperature with time. Take the ideal case of longitudinal heat flow where all the heat goes to heat the specimen. The solution of this case is simply:

$$\alpha=\frac{1}{2\Delta T}\left(\frac{dT}{dt}\right)L^2$$

where AT is the steady temperature difference between the two ends of the specimen (of length L), heated at one end at a con-

stant temperature rate dT/dt. Of course, this solution is only valid (1) after the starting transient has disappeared, and (2), if sand dT/dt are constant within the temperature range of the experiment. Since dT/dt is assumed to be constant, it may be convenient to use the above solution in the form:

$$\alpha = \frac{L^2}{2\Delta t}$$

where $\Delta^L\tau$ is the time lag. In the non-ideal case where there is radial heat transfer from the specimen, the solution is complicated. Consequently, such an experiment may be designed to minimize this radial heat loss, such as surrounding the specimen with a guard of the same material, heated in the same manner.

2.2.7.1 Here again, this error due to radial heat transfer can be avoided by using a. radial method. If the surface of a cylinder with radius R is heated at a constant rate dT/dt, then the steady temperature difference AT between the surface and the axis of the cylinder is:

$$\Delta T = \frac{R^2 \, dT}{4 \alpha \, dt}$$

2.2.7.1.1 With this method, it is possible, in principle, to measure the thermal diffusivity over a large temperature range in one experiment requiring perhaps a few hours. Probably the biggest difficulty with this method is the measurement of temperature, both on the outer surface of the cylinder and at some point in the cylinder, perhaps near its axis. If a hollow cylinder is used the value of the thermal diffusivity α is:

$$\alpha = \frac{1}{2\Delta T} \frac{dT}{dt} \left[\frac{1}{2}(r_2^2 - r_1^2) - r_1^2 \ln \frac{r_1}{r_2} \right]$$

where $\Delta\tau$ is the difference in temperatures at two radii. However, it is not necessary to know either ΔT or dT/dt. If two thermocouples are used to measure the two temperatures and these two thermocouples have the same linear calibration, (even though the calibration values are not known) then it is possible to determine the time interval (time lag) required for the temperature at the inner radius to come to the temperature of the outer radius at the beginning of the time interval. If this time interval is $\Delta\tau$ then the solution is:

$$\alpha = \frac{1}{2\Delta t} \left[\frac{1}{2}(r_2^2 - r_1^2) - r_1^2 \ln \frac{r_2}{r_1} \right]$$

2.2.8 For measurements on small specimens at very high temperatures there has been increased interest in heating the specimen by radiation and in measuring temperature changes by radiative means. In this way, the problem of attaching thermocouples to the speciment is avoided. At temperatures greater than 1000°C, this method appears to offer considerable advantages in the measurement of thermal diffusivity. It is possible that a periodic heat flow method will he found quite useful here.

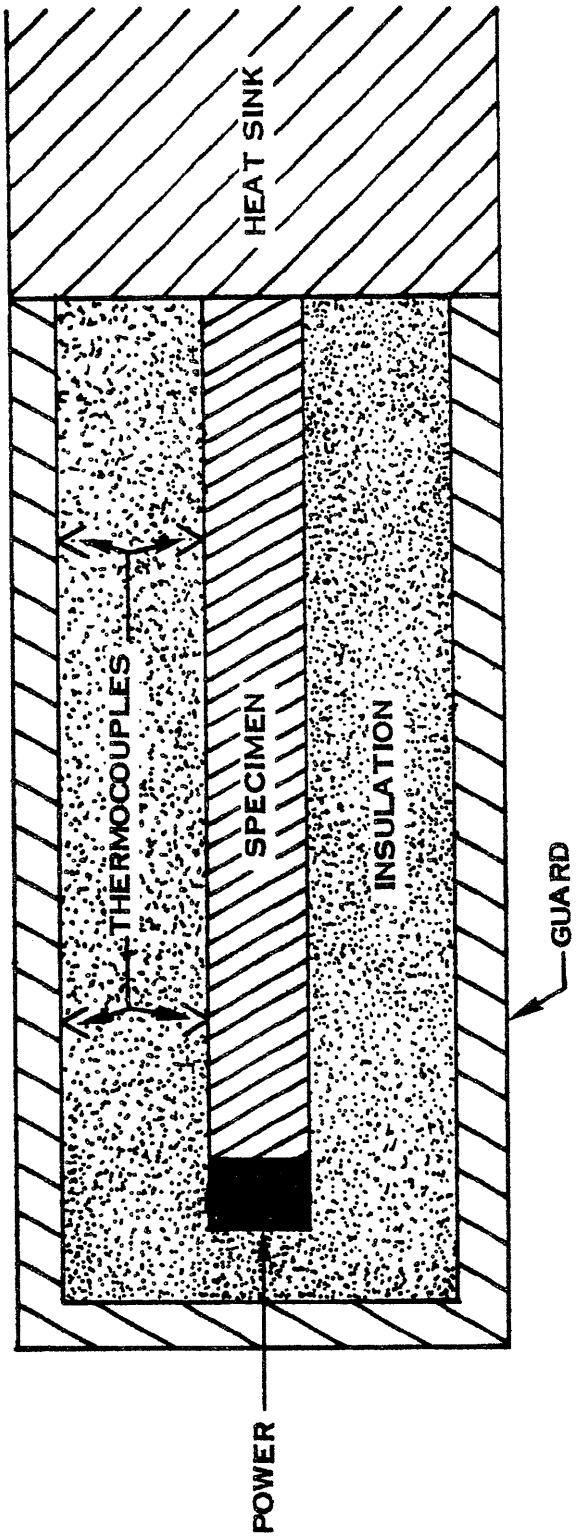

FIGURE 1. SIMPLE GUARD CIRCUIT.

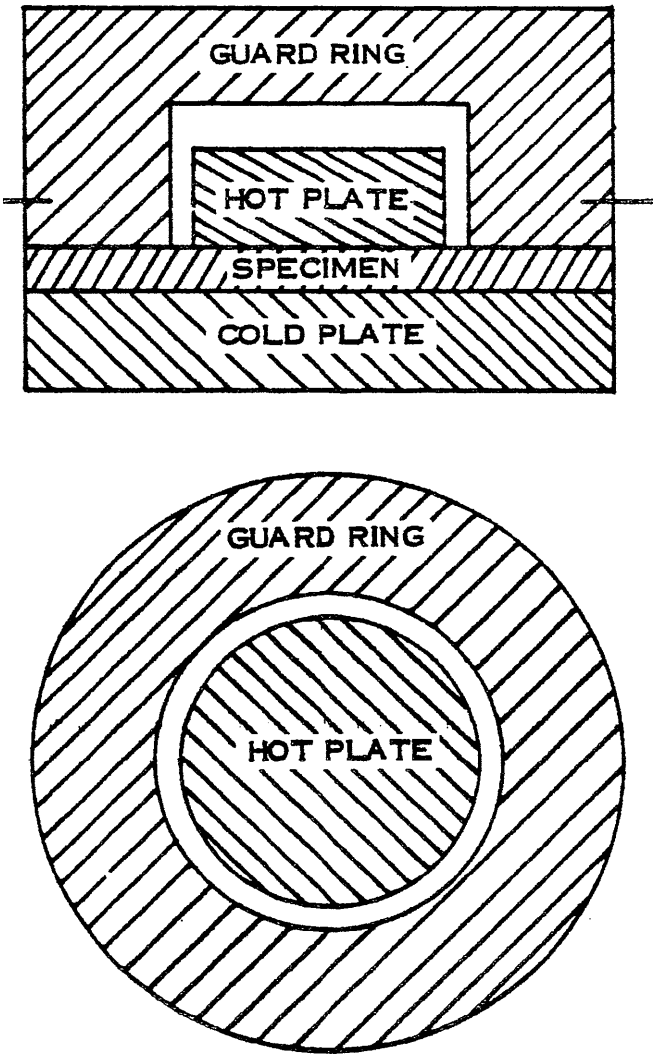

FIGURE 2. GUARDED HOT-PLATE APPARATUS.

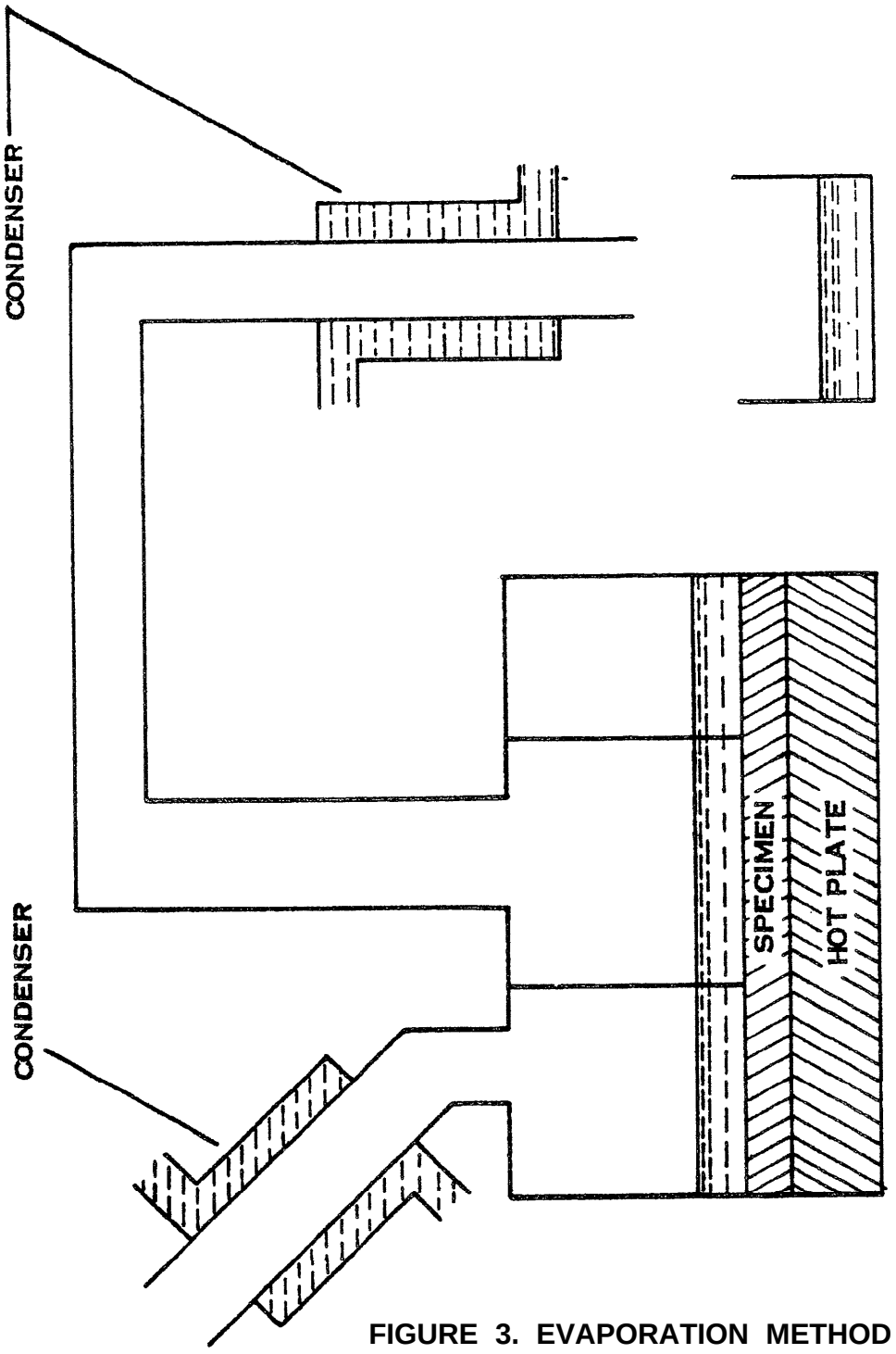

FIGURE 3. EVAPORATION METHOD

FOR OBTAINING HEAT TRANSFER THROUGH SPECIMEN.

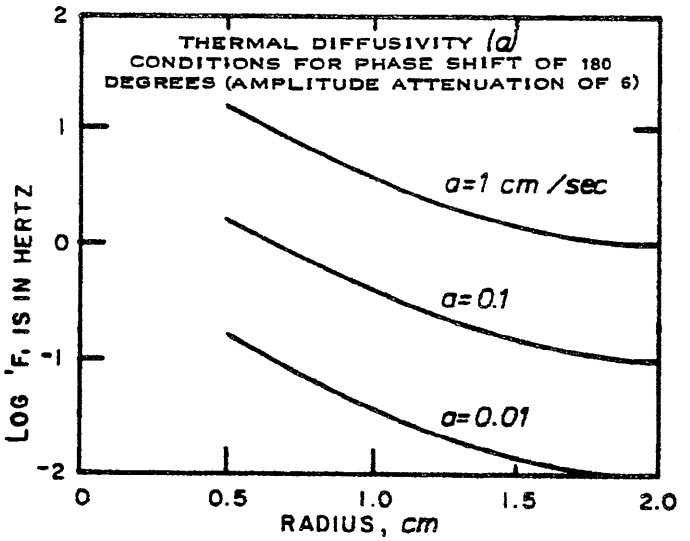

FIGURE 4. PARAMETERS FOR THERMAL DIFFUSIVITY MEASURMENTS.

METHOD 8

MEASUREMENT OF DETONATION VELOCITIES

1. PURPOSE.

1.1 The various methods used in the measurement of detonation velocity can be divided into two basic categories: optical or photographic methods and chronographic methods. The optical methods commonly employ either a rotating drum to which film is fixed or a rotating mirror which sweeps an image across stationary film. In the chronographic method as generally used, probes are placed at fixed points on or in the explosive. The pressure discontinuity or ionization present in the detonation wave then causes the external circuitry associated with the probes to produce a signal as the detonation wave reaches each probe in turn. The signals are sent to a mechanical or electronic recording instrument which also provides the necessary time base. An excellent historical account of these methods has been provided in a recent text by Taylor. The Mettegang, or equal, chronograph and the method of Dautriche proved adequate for velocity measurement in the period when the techniques available for the fabrication of solid explosives were relatively imperfect and when the detonation theory was in its preliminary stages. However, continuing refinement of explosive charge fabrication methods and further developments in detonation theory have required improved precision in detonation velocity data. The higher speed rotating drum cameras of Dixon as improved by Payman, Shepherd, and Woodhead, and the rotating mirror cameras of Frazer, Cairns, and Herzberg represented important advances. Improvements in the chronographic technique, particularly in the replacement of mechanical by electronic components were developed by Nisewanger and Brown, Brimley, and Gibson. Piezoelectric crystals, in conjunction with a raster-type oscilloscope as a recorder and time base, which were developed during World War II at the Taylor Model Basin and at the Underwater Explosives Research Laboratory (Woods Hole Oceanographic Institute), were later applied by Berets, Greene, and Kistiakowsky to precise measurements of detonation velocities in gaseous mixtures.

3.2 In this documents some further refinements of the chronographic method, as applied to the measurement of detonation velocities in liquid and solid explosives are presented. They They comprise the "pin technique" which has been in use and under development at Los Alamos from approximately the year 1944 to date. A modification of the technique for use in the measurement of detonation velocities in gaseous detonations has been reported by Knight and Duff. The improved precision attained with this technique has enabled us to detect and explore some interesting small

effects, e.g., certain diameter and particle-size effects in solid explosives and diameter and temperature effects in liquid explosives which otherwise could not have been resolved.

2. ELECTRONIC COMPONENTS AND CIRCUITRY.

2.1 Oscillograph. The principal electronic component is the oscillograph, or "pin machine," which provides a time base of the raster type upon which transit time signals are presented. A block diagram is presented in Figure 1. The raster pattern consists of a series of horizontal sweeps approximately 2.5 µsec in duration. The number of lines per raster pattern can be varied up to a maximum of about 60. It will be noted from the block diagram that each machine contains two indicator units upon each of which a raster pattern is presented. These may be operated in parallel to funish duplicate records and thereby increase the precision of analysis, or they may be operated in tandem to increase the total time coverage.

2.2 Referring again to Figure 1, the output from the crystal-controlled oscillator is shaped by the market generator to provide square-pulse timing marks at 0.5 µsec intervals for the indicators. The master indicator receives these timing marks directly. When the indicators are operated in parallels the slave indicator receives the timing marks after they have passed through a 0.15 µsec delay line: it may also receive them directly when the indicators are operated in tandem.

2.3 The marker generator also supplies 0.5 µsec pulses through a 0.2 µsec delay line to a 5:1 frequency divider which in turn drives the horizontal trigger generator. The master horizontal sweep generator thus receives trigger pulses at 2.5 µsec intervals. The slave horizontal trigger generator receives the same pulses after they have been delayed a time corresponding to one marker interval or 0.5 µsec. The 0.5 usec delay serves to stagger the occurrence of the backsweeps so that a common signal appearing in the backsweep of one indicator will not be lost in the backsweep of the parallel indicator, The 0.35 µsec delay staggers the occurrence of the timing marks so that a common signal which is distorted by appearinq close to a timing mark in one indicator will not be so distorted in the parallel indicator.

2.4 The horizontal trigger pulses are divided by the four-stage divider to provide internal vertical sweep trigger pulses at approximately 200 per second. The V-sweep trigger pulses must be synchronized with the H-sweep trigger pulses in order to prevent apparent vertical rolling or jitter in the steady pattern used to adjust the number of lines, intensity level, and focus before a single-sweep record is taken. In addition to the

internal trigger generator, the V-sweep and intensity gate generators may be triggered from an external source of repetitive pulses, the single sweep clamp circuit, or the manual test trigger.

2.5 The 5:1 and 4-stage frequency dividers used in these circuits are of the blocking oscillator type. The V-sweep generator is a conventional bootstrap circuit.

2.6 The precision attainable from these chronographs derives from the close control of the time-base referencefrequency and the horizontal sweep linearity. The oxcillator is a 2 megahertz, crystal controlled, free-running Miller, or equal, oscillators The crystal is temperature regulated and has a manufacturer's tolerance of ± 40 hertz. The oscillator and marker generator are diagramed in Figure 2.

2.7 The horizontal sweep generator is a continuously-running Miller, or equal, integrator type. The circuit diagram of this generator is given in Figure 3. Three variable capacvitors are included in the circuit for adjusting the sweep wave form. capacitor C_1 affects the fly-back wave form and consequently the amount of ringing at the initial end of the sweep. Capcitors C_2 and C_2, together with R_1, determine the slope of the saw tooth and thus the width of the sweep. Capacitor C_2 is a high-frequency by-pass condenser which controls the writing speed at the beginning of each line. In addition to these adjustments of the sweep generator, it has been necessary to select the 6AG7 output tube; the 51UCP11 cathode-ray tube is also specially selected by the manufacturer for linearity of deflection vs applied voltage on the horizontal deflection plates. The departure from linearity is guaranteed to be less than 1% over a square area approximately 63.5mm (2.5 inches) on an edge, centered on the tube face. The 51UCP11 tube contains two sets of vertical deflection plates. One pair of plates is used for the vertical sweep control, one plate for timing mark input, and one plate for the signal input. In this way the use of a mixing circuit for mixing transit time signals with the vertical sweep is avoided.

2.7.1 The linearity of each horizontal line is controlled to 1% between adjacent clibration marks (0.5 µsec), i.e., the distance measured from one mark to the succeeding mark does not differ from the distance between marks of an adjacent interval by more than 1%. The oscilloscope trace is recorded on a 35-mm oscilloscope camera which employs fast panchromatic film and an f/2 lens. For purposes of analysis the record is enlarged twelve diameters on a Recordak, or equal, film reader and the measurements of the positions of the signals are made by using a specially selected transparent plastic scale held against the ground glass. Distances are read to 0,1mm. The standard error of a

single measurement resulting from errors in sweep calibration, linearity, and judgement of the data analyst is found to De approximately $3x10^{-9}$ second for the time intervals normally encountered.

2.8 The mixer circuit is a network of capacitors and resistors which form and send to the chronograph the electrical pulses indicating the arrival of the detonation wave at the various pin positions along the explosive charge. Figure 4 shows a diagram of the circuit used with most solid explosives. The condensers C are charged through isolation resistors R_1. When the detonation wave closes a pin switch S (which may be either an ionization or mechanical type} the capacitor discharges into the RG-21-412 signal cable, producing a signal pulse. The terminal impedance R_1 prevents reflection of the signals from the terminal end of the RG-63/U. If pulses are reflected toward the inital end of the cable due to a faulty connection or other mismatch they will be absorbed by either R_3-R_5 or R_2.

2.9 When the pin switches must be closely spaced in the charge, the mixer circuit is modified as shown in Figure 5. With close spacing, the conductivities of the detonation wave and explosive products serve to connect the discharging capacitor with those which have already been discharged. The resulting signal has a verv poor rise time and a small amplitude. The diodes D serve to isolate the individual pin circuits.

2.10. 2.10 Another modification of the mixer circuit employed when the undetonated explosive is moderately conducting is shown in Figure 6. Figure 6. When the specific resistivity is as low as 30,000 ohms it is necessary to replace resistors R_1 with diodes. This allows This allows the condensers to be charged to almost the full supply voltage in spite of the leakage current through the pin switches.

2.11 To reduce the occurrence of spurious signals and signals with poor rise times, the mixer circuits should be constructed with the shortest leads possible. Stak-ons are used to connect the components together, and the finished mixer is mounted close to the terminal end of the explosive charge. Both the signal mixer circuit and a section of the RG-21-412 coaxial cable are destroyed by the blast from the charge. Unless all pin switch leads are of the same length (to within a few feet} the transit times of the electrical pulses in the leads must be taken into account for precise work.

2.12 Still another precaution which must be taken in applying the above mixer circuits is that of maintaining the detonation wave at ground potential. When an explosive rate stick is detonated, it is found that a potential difference, commonly of the order of a Few hundred volts hut as high as 1000 volts under

some circumstances, develops between the detonation wave and ground. It is thought that at least part of this potential difference may be a result of the difference in nobilities of electrons and of positively charged ions in the detonation front. This difference in nobilities produces charge separation in the rapidly moving front and may result in spurious signals at the pin switches unless adequate precautions are taken. A grounding foil placed near the pin switch so that the detonation wave will strike it just before reaching the switch will. eliminate these spurious electrical signals.

2.13 Another important electrical effect which may cause difficulty is that most plastic and insulating materials (rubber: glass, varnish, etc.) will develop potentials of several thousand volts when hit by a strong shock wave. It is important, therefore, to keep insulated wires out of the path of the detonation wave until the measurement is completed.

3. THE PREPARATION AND ASSEMBLY OF CHARGES.

3.1 The precision permitted by the pin technique cannot be attained unless every precaution is taken in the preparation of the charges for rate measurements. It is quite possible to obtain precise data which, nevertheless, are not accurate because of overlooked systematic errore. Some of the precautions necessary are discussed below. Assuming that uniform explosive either liguid or solid, is at hand and that density and composition are known, the first problem in charge preparation is the positioning of the pin switches. In the case of liquid explosives, charged probes may be either inserted directly into the liquids as shown in Figure 7 or located somewhere in the confining material as shown in Figure 8. In Figure 7 where the confining medium is a glass tube, the pins, consisting of 0.4064mm (0.016-in), o.d. hypodermic tubings are inserted through small holes in the wall and fastened in place with cement. The distance between successive probes can be measured with a cathetometer with a reproducibility of less than 0.0254mm (0.001 in). By means of the common grounds the detonation wave is maintained at ground potential and the discharge of the signal mixer capacitors takes place via the spaced probes and the detonation wave to ground. In experiments with certain liquid explosives, it has been found that the insertion of pin switches, such as those shown in Figure 7 directly into the liquid results in a detectable perturbation of the detonation wave. With such liquids. if high accuracy is desired, external pin switches such as those shown in Figures 8 and 9 are superior to those shown in Figure 7. In the arrangement shown in Figure 8, the confining medium is a metal tube. Flat-bottomed holes, known distances apart, are made in the tube wall using a milling machine. A disk of mica, 0.0127mm(0.0005 in)

thick, placed on the bottom of the hole serves as insulation after the pin assembly shown in Figure 8 is inserted in the hole The pin is charged, and the tube wall is maintained at ground potential so that a discharge occurs when the moving metal wall contacts the bottom of the pin after rupturing the mica. A somewhat simpler modification of this external pin technique is shown in Figure 9. Here, again, the confining medium is a metal tube, but the pins are simply bent" into a convenient shape and held in place on the outside of the tube wall with cement. Thin mica is used as insulation between the pins and the tube wall. The distances between the pins is measured with a cathetometer. This modification of the external pin technique requires less machining time than the one previously described. but also requires that care be taken that the pins not be moved in the time between cathetometer reading and firing. In both this arrangement and that of Figure 7. Armstron's Adhesive A-1, or equal. has been found to be dimensionally stable over moderate temperature ranges. This cement also withstands the solvent action of many liquid explosives. The 0.127mm (0.005-in) flat on the bottom of the pins as shown in Figure 11 facilitates the cathetometer readings and also gives consistently clean signals when the pin is charged to 125 volts. The flats are out on the bottom of the pins with a jeweler's lathe used in conjunction with a Bausch and Lomb, or equal 40X shop microscope which has a reticule reading directly in thousandths of an inch. For granular explosives at low loading densities, an arrangement which may be used is shown in Figure 10. Each pin switch consists of a pair of fine copper wires stretched taut by means of a clamp on the outside of the confining tube. The spacing between wires is made at least several multiples of the maximum grain size. In order to avoid premature closure of the pin switch as a result of photoionization, enameled wipes are used. The holes through which the wires fit (which control their axial spacing) are carefully made in the milling machine. In high density pressings and in castings, thin metal foils are used to form pin switches. The most commonly used type of switch is the one shown in Figure 11 which depends upon ionization for closure. A modification of this method often employed is to use a common ground on the outside of the charge, much the same as was described for liquid explosives, and to use a single, charged foil extending in to the center of each segment of the rate stick. Metal foils are used which are as thin as possible, but which still have sufficient mechanical strength to withstand the manipulations necessary in preparing the switch and charge. The most commonly used foils are made of silver, aluminum, or copper, in thicknesses ranging from 5.08 to 38.1µm (0.0002 to 0.0015 in).These are usually procured as spooled 3.175mm (0.125 in) ribbon. Gold leaf, 0.254µm (0.00001 in) thick, is occasionally used, but lacks mechanical strength and tends to

stick to objects brought near it because of electrostatic attraction. The gap width on the pin switch shown in Figure 11 is usually about 1.016 to 3.048mm (0.040 to 0.120 in). The detonation front has been found to be quite irregular in two-component cast explosives and in some pressed explosives, the irregularities being comparable in size to the grains of the explosive. Therefor, in order to improve the statistics of the switch closure it is desirable to have the dimensions of the pin switch gap at least several times that of the largest grains of explosive. A further requirement in using this type of switch is that the end of each charged foil be in the same position relative to the center of the rate stick so that a curved detonation front will close them in the same manner. Occasionally the ionization switch is found to be inadequate. One instance is encountered in the study of non-steady-state detonation waves e.g., initiation phenomena. Here the detonation wave may proceed without sufficient ionization to operate properly the switch described above. In this event, a switch involving mechanical closure may be used. Such a switch is shown schematically in Figure 12. The mechanical closure is effected by the motion of a thin metal foil which is accelerated by the high pressure of the detonation wave. In order to keep the closing delay as small as possible, and for other reasons described below, the combined insulating foil and metal foil assembly should be kept very thin, usually less than 0.0254mm (0.001 in). Typical insulating materials include mylar, nylon, and mica. Closure times of 10^{-8} second can easily be attained. In the case of cast or pressed explosives after the particular type of pin switch and the method of insertion have been decided upon, some method of assembling the segments must be devised. The simplest method is to tape them together using a pressure sensitive tape. The use of such tape, however, has some disadvantages, chief among which is the danger of "jetting" if the tape is applied loosely. When a gap as small as a few thousandths of an inch exists between the lateral surface of the charge and the tapes a gaseous "jet" may be formed. This jet may lead the detonation front, causing the pin switches to be discharged permaturely. A preferred method of charge assembly is that of clamping. This leaves the sides of the charge unconfined and at the same time provides positive contact between charge segments. The foils themselves are moistened slightly with water to hold them in place during the clamping operation, thus avoiding a layer of glue. It is well to point out here again that the thinnest possible foils are used between segments so as to keep the stand-off as small as possible. This is necessary because an air gap results in a momentary slowing of the detonation wave, perhaps by dissipating the von Neumann spike. Quantitatively, in some

explosives a small air gap increases the transit time of a piece of explosive by about 10^{-8} second per 0.0254mm (0.001 in) thickness of gap. Thus in a 5.08cm (two inch) segment of such explosive having a detonation velocity of about 8000 m/see, a gap of 0.0254mm (0.001 in) would result in a velocity error of approximately 13 m/sec. When using high-energy boosters on rate sticks which have low detonation velocities, it has been found necessary to impede the expansion of the booster gases by using a blast shield or a coating of putty near the booster. In some cases the boaster gases might otherwise precede the detonation wave, closing the pin switches prematurely. In making velocity measurements on low-energy explosives or on charges of large diameter, it is frequently advisable to provide grounding in addition to that furnished by the ground side of the detonation. switch. In such cases, the ground side of the pin switch may fail to ground the wave near the lead from the signal mixer, because of the relatively high resistance of the detonation wave and explosive products. Without the additional grounding the signal mixer would begin to respond to the generation of charge on the shock front discussed above, and would introduce noise on the oscillograph record. This noise may be of such amplitude and duration that the records are not readable. It is the practice in such instances to run an additional ground lead close to the charged probes and extending beyond the limits attained by the shock wave during the observation. A final precaution which must be taken if high precision and accuracy are to be obtained is the maintenance of temperature control of the changes. The detonation velocity of liquid nitromethane, for example, has been found to vary with the initial temperature at the rate of -3.7 m/sec/°C. In the case of the solid explosive, Composition B, Mautz has found the transit time to vary inversely with the temperature at the rate of 1% per 100°C. Taking the linear coefficient of thermal expansion of Composition B to be $5X10^{-5}$ per °C, the velocity dependence would be 0.5 m/sec/°C. It is evident that rate sticks should not be exposed to direct sunlight nor fired without suitable thermal insulation if precise data are desired.

4. SAMPLE DATA.

4.10 In Table I and II are shown sample data taken with the methods described above. In taking such data, as mentioned above, it is common practice to operate several sweeps in parallel to

obtain replicate records. This is done to guard against the failure of a single circuit to operate properly and, also, to enable several records to be. read to reduce the error of analysis. It is a common experience to obtain standard errors of a single Transit time observation as small as 0.003 μsec for time intervals of the order of 50 μsec. For longer times the error may increase somewhat because of errors in the frequency of the crystals controlling the marker generators. By reducing the time measurement error to such a small value small charge intervals can be used. This is desirable since the smaller charges generally permit better control of the density and composition ranges present.

TABLE I

Sample transit time data for pressed TNT. The charge consisted of six section, each 5.08cm (2 in) long and 1.27cm (0.5in) in diameter, arranged in a column. Transit time data were taken over the last four sections, using ionization foils. The sections were the same length to within a thousandth of an inch.

Density (g/cc)	Transit time (μsec) Sweep-3	Sweep-4	Sweep-5	Sweep-7	Average	Detonation velocity (m/sec)
1.642	7.335	7.329	7.329	7.329	7.331	6928
1.642	7.330	7.331	7.331	7.328	7.330	6928
1.641	7.335	7.338	7.345	7.340	7.340	6923
1.641	7.336	7.326	7.327	7.331	7.330	6930

TABLE II

Sample transit time data for nitromethane. The explosive was contained in a standard wall Pyrex tube, 6.5278cm (2.570in) i.d. and 0.762 m (30 in) long. Pin switches were arranged as shown in Figure 7.

Switch interval (mm)	Transit time (μsec) Sweep-2	Sweep-4	Sweep-5	Average	Detonation velocity (m/sec)
126.27	19.903	19.893	19.896	19.897	6346
134.99	21.252	21.272	21.274	21.266	6348
129.42	20.388	20.385	20.379	20,384	6349

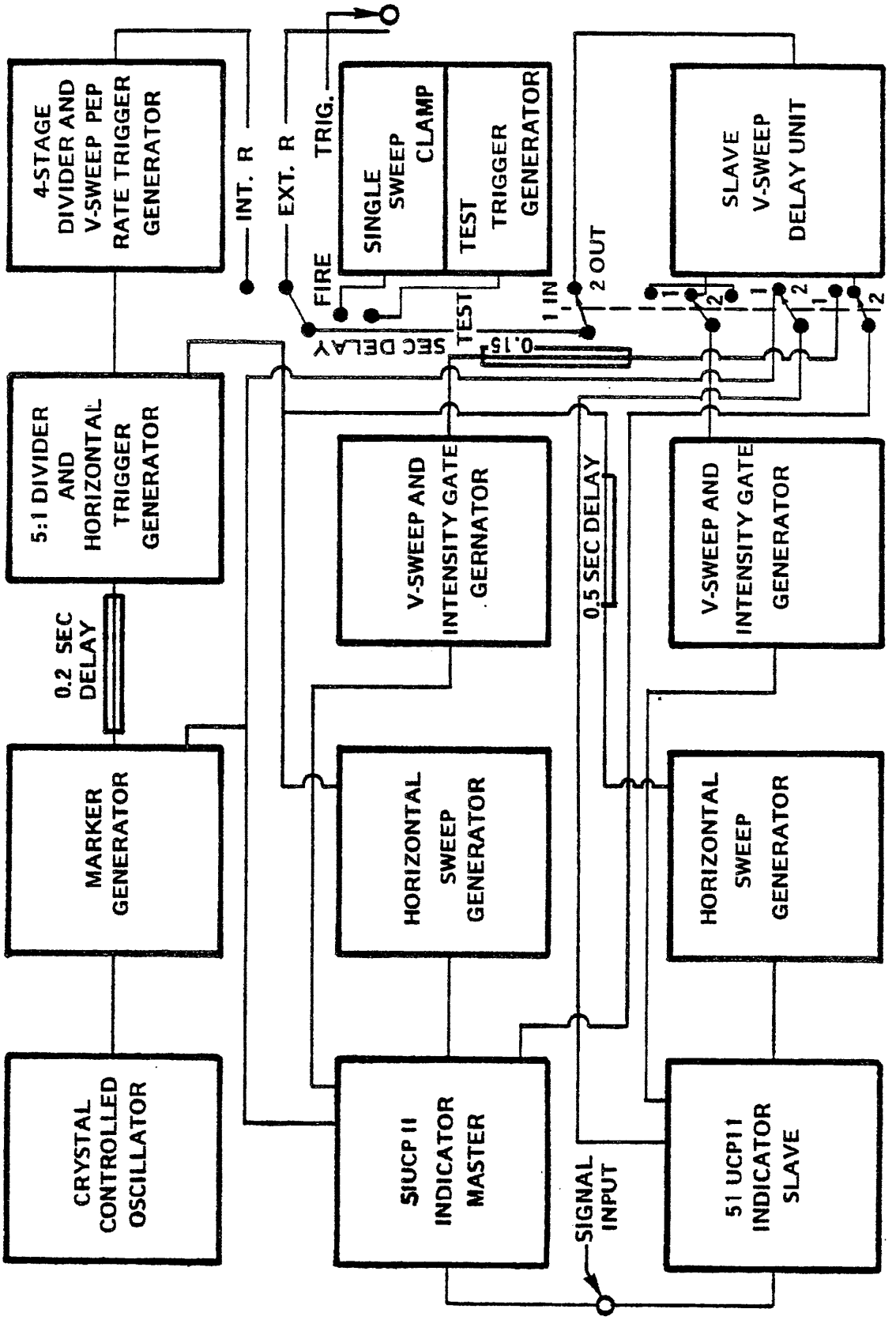

FIGURE 1 - BLOCK DIAGRAM OF RASTER-GENERATING CIRCUITRY.

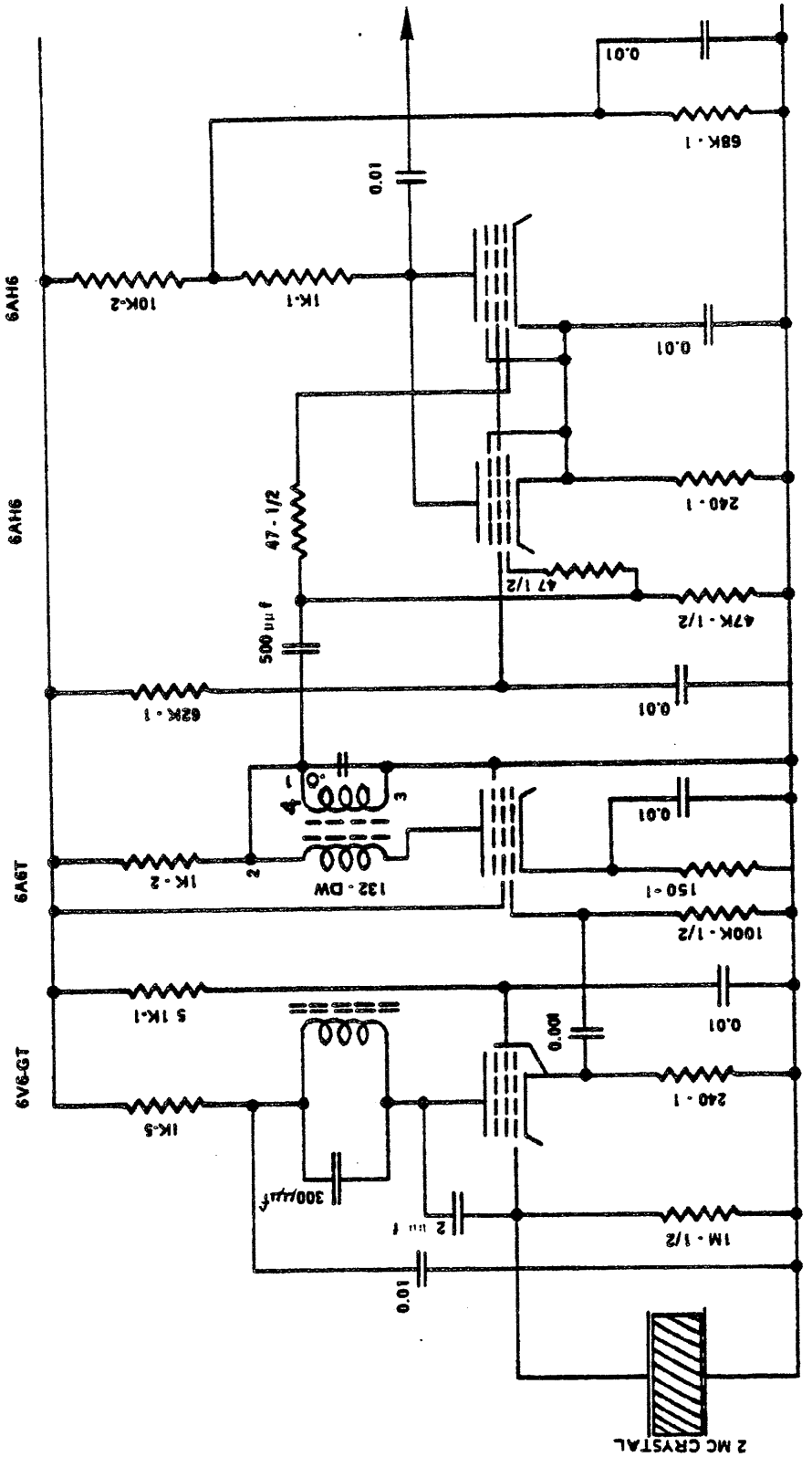

FIGURE 2 - CRYSTAL-CONTROLLED OSCILLATOR AND MARKER GENERATOR CIRCUIT. ALL

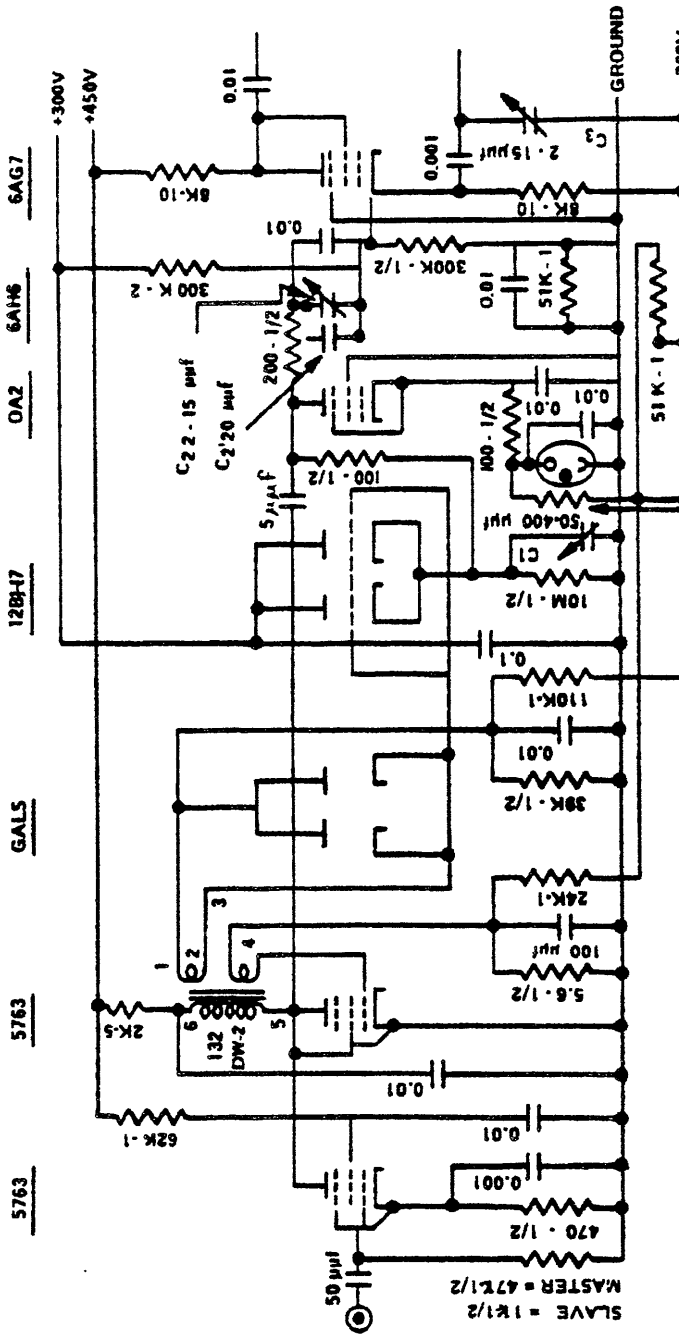

FIGURE 3 - HORIZONTAL SWEEP GENERATOR CIRCUIT. ALL CAPACITANCES ARE IN MICROFARADS UNLESS OTHERWISE INDICATED.

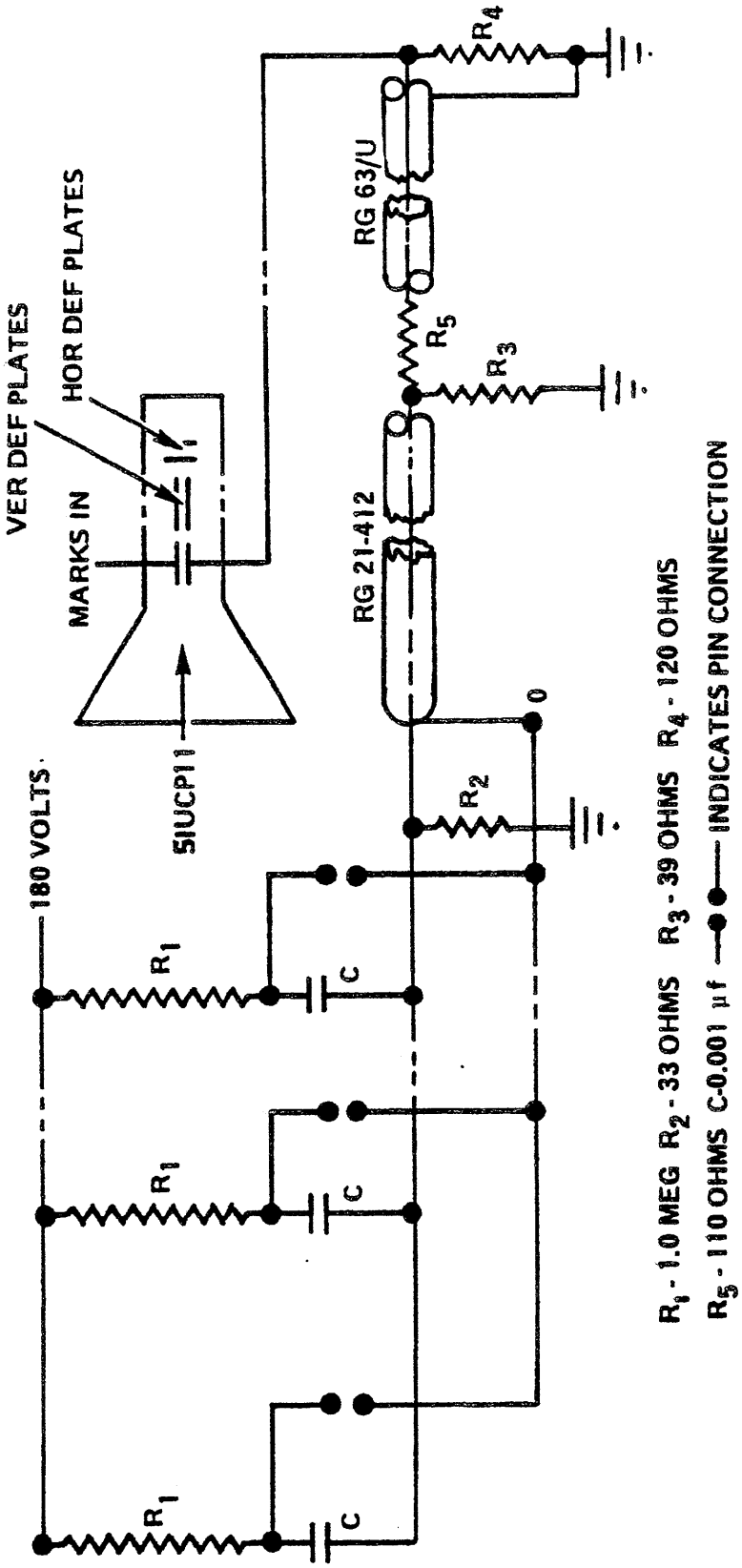

FIGURE 4 - BASIC SIGNAL-MIXING CIRCUIT USED WITH MOST SOLID EXPLOSIVES.

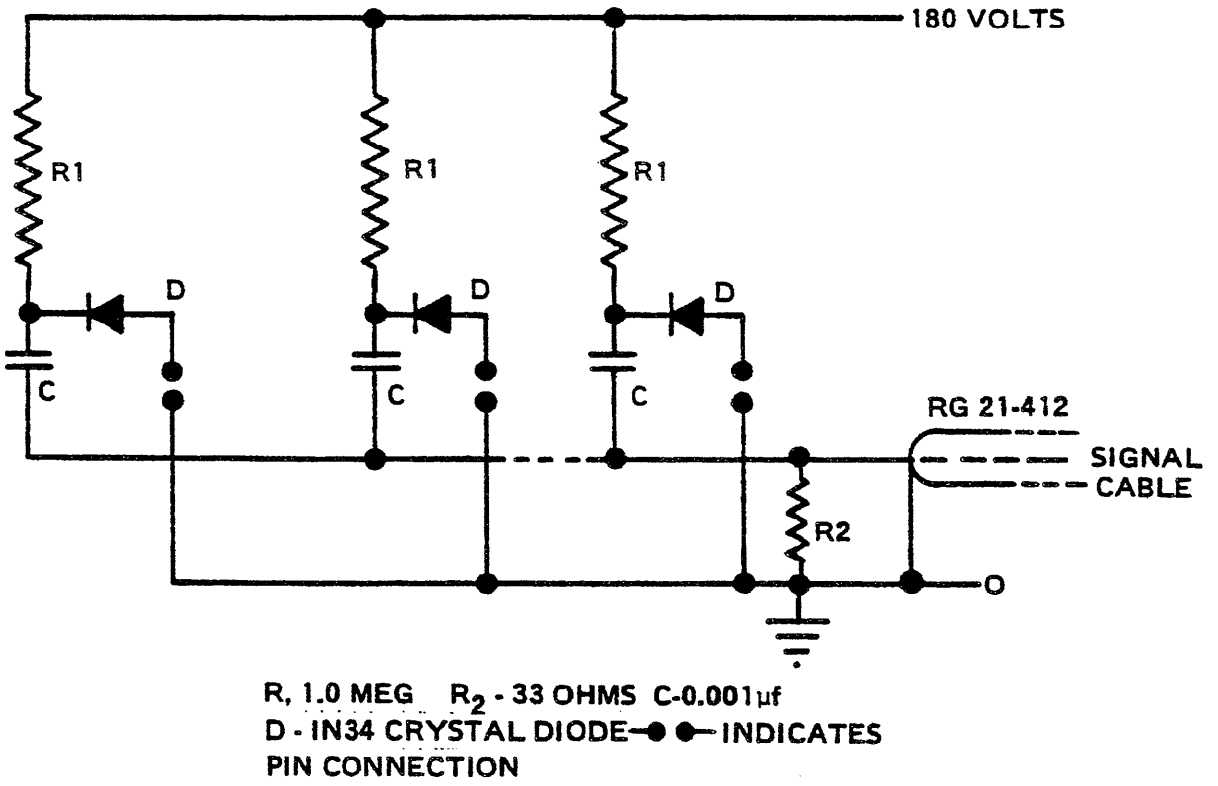

FIGURE 5 - MODIFIED SIGNAL-MIXING CIRCUIT USED WHEN PIN SWITCHES ARE CLOSELY SPACED

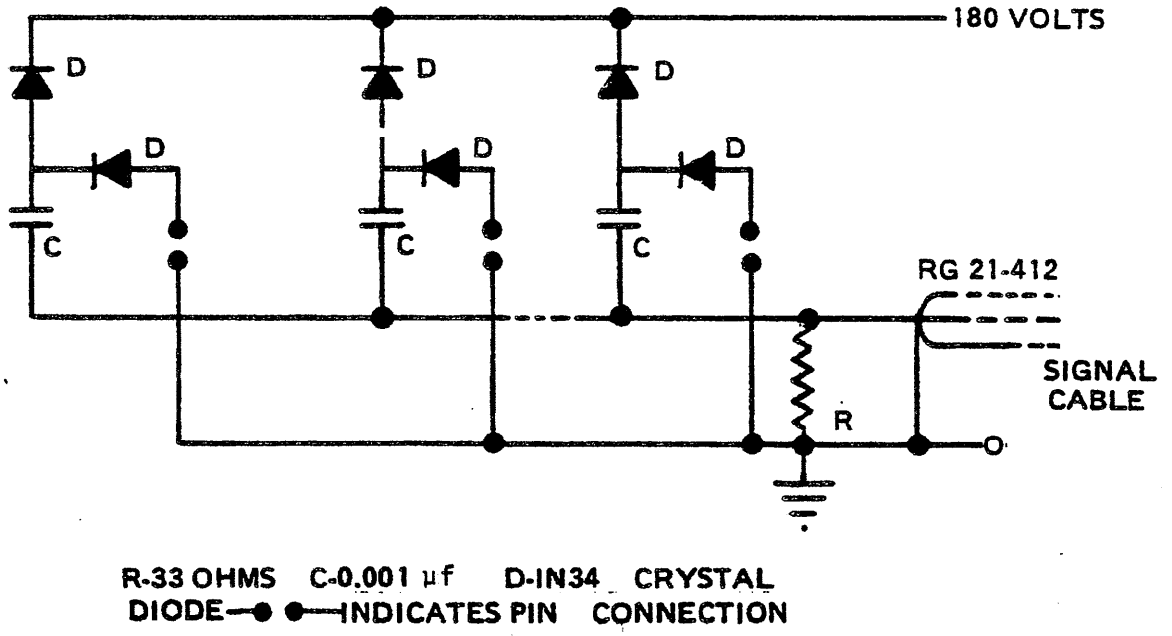

FIGURE 6 - MODIFIED SIGNAL-MIXING CIRCUIT USED WHEN THE UNDETONATED EXPLOSIVES IS MODERATELY CONDUCTING.

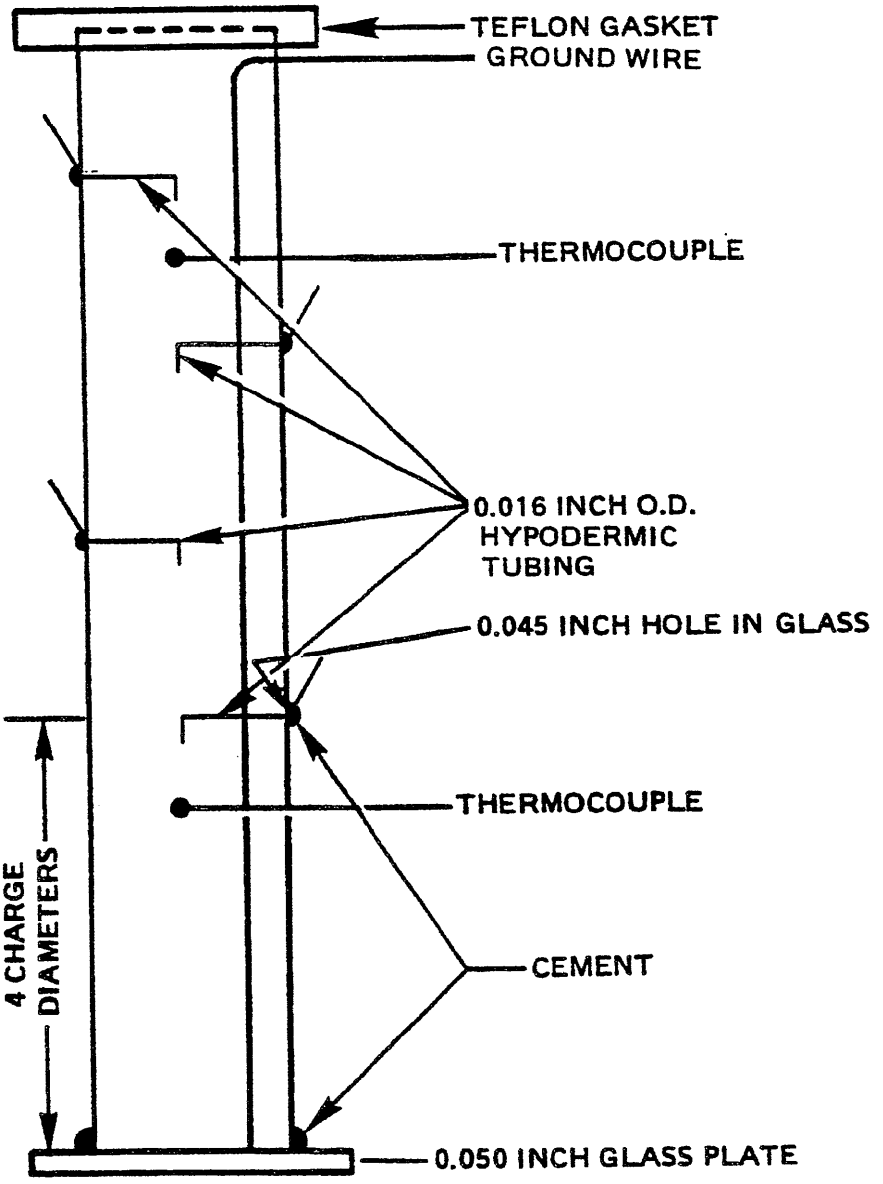

FIGURE 7 - CHARGE ARRANGEMENT WITH PROBES INSERTED INTO LIQUID EXPLOSIVE.

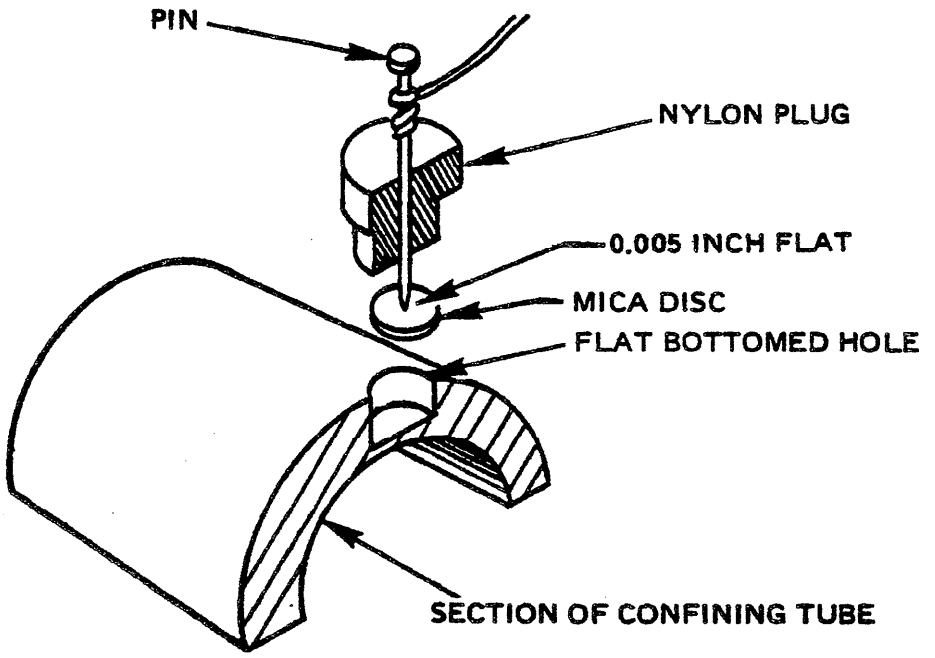

FIGURE 8 - METHOD OF INSERTING PROBE IN THICK CONFINING WALL.

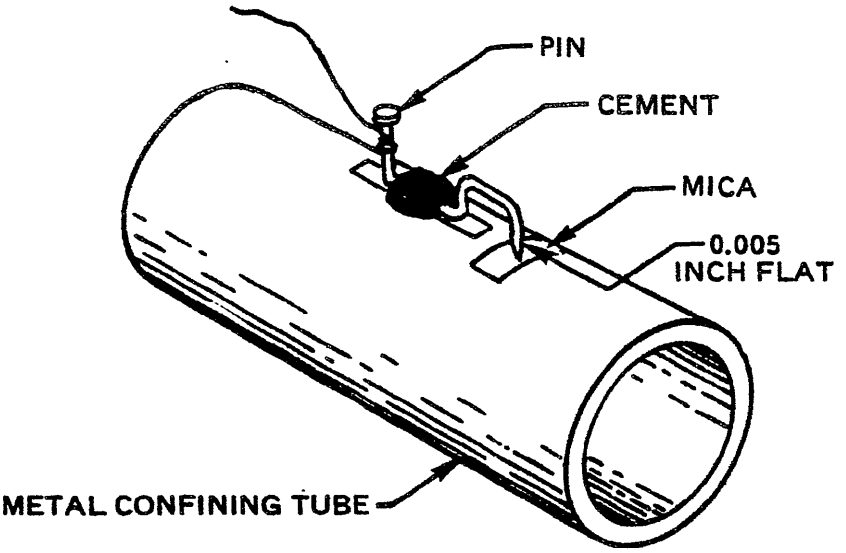

FIGURE 9 - PIN SWITCH MOUNTED ON THIN CONFINING WALL.

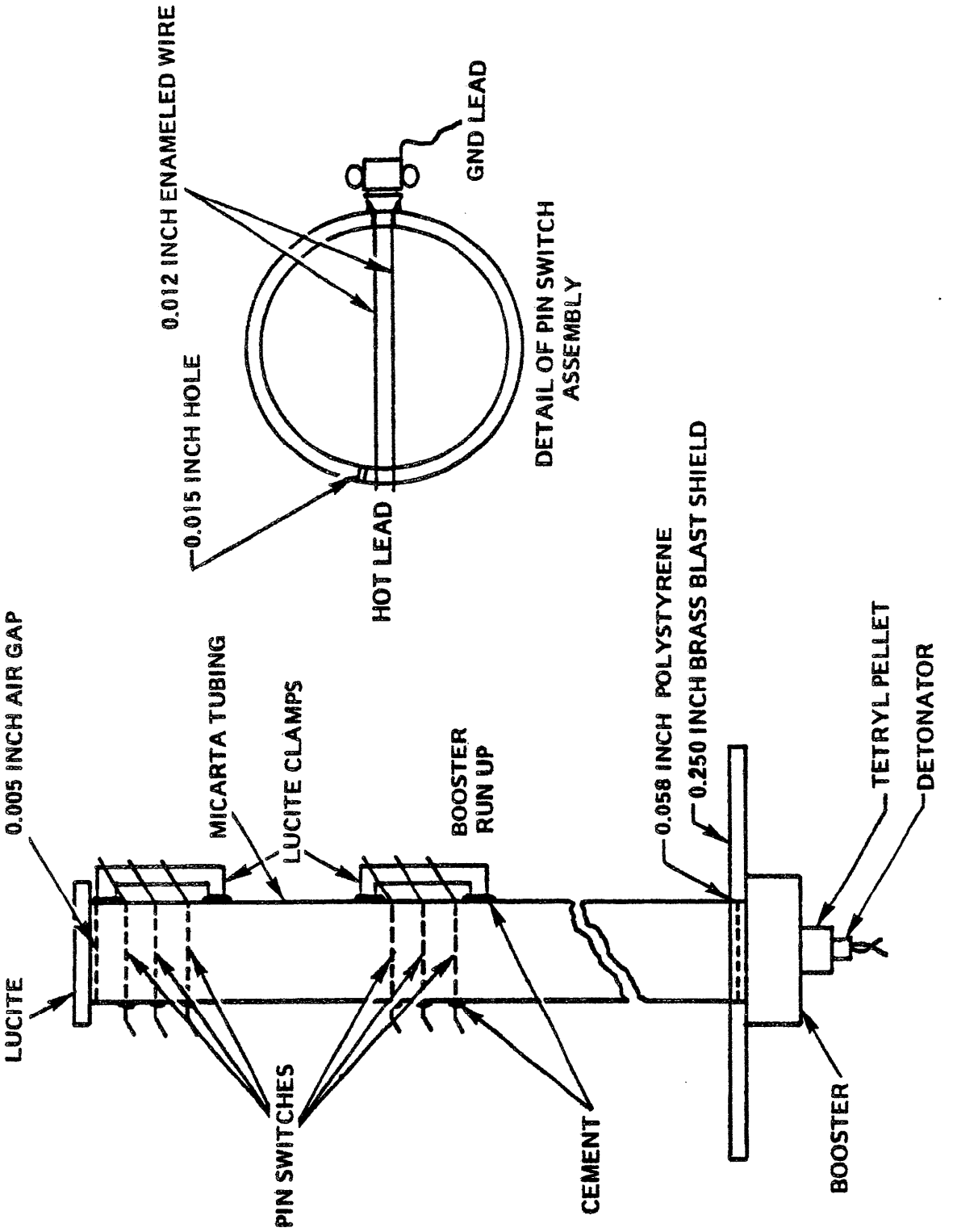

FIGURE 10 - PIN SWITCH USED WITH GRANULAR EXPLOSIVES AT LOW LOADING DENSITIES.

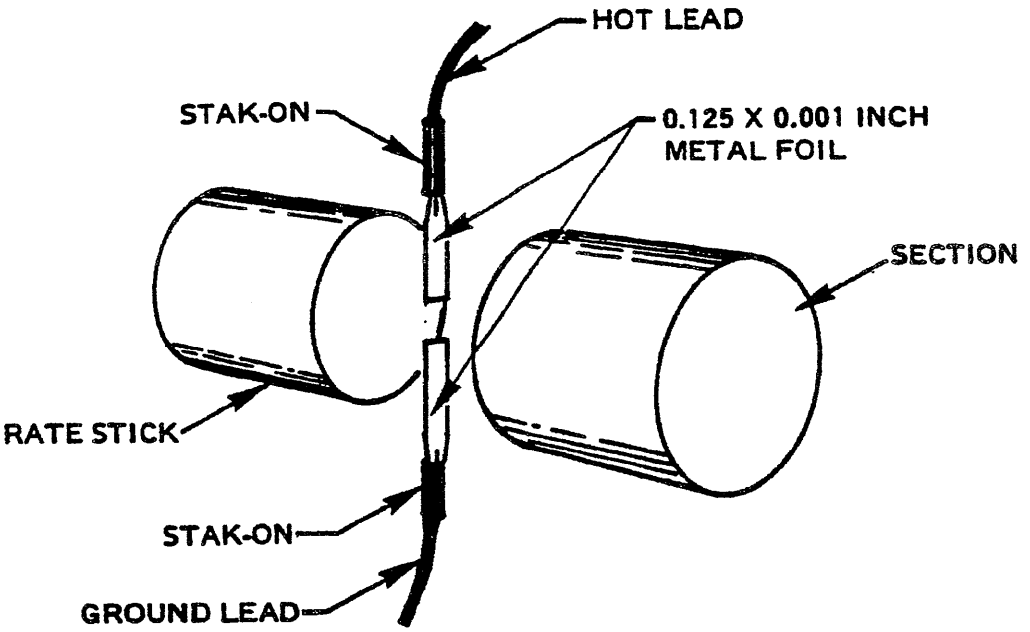

FIGURE 11 - IONIZATION TYPE PIN SWITCH.

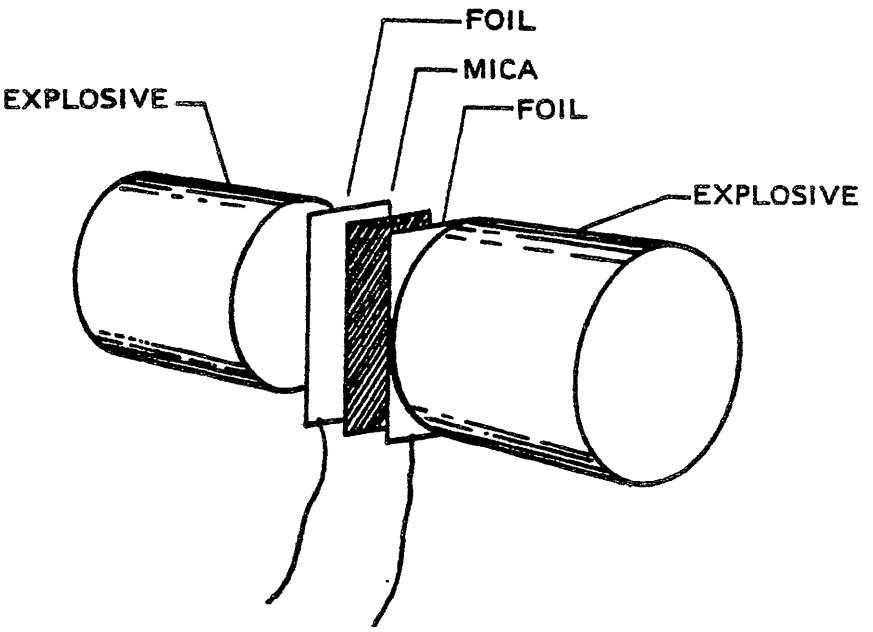

FIGURE 12 - MECHANICAL - CLOSURE - TYPE PIN SWITCH.

METHOD 9

50 Caliber Projectile Impact Sensitivity

1. APPARATUS

1.1 A .50 caliber smooth bore gun rebuilt from a 1918 Mauser antitank gun action is used. It is mounted on a steel frame that moves on cylindrical bearings to absorb recoil. The projectiles usually employed are 12.7mm (0.5 inch) by 12.7mm (0.5 inch) right cylinders of "free cutting" brass, but projectiles of other metals may be employed. Loaded rounds are prepared by reloading stand- and service .50 caliber cartridges after reforming the neck of the cartridge case to accept the projectile. The propellant charge is adjusted to give the desired velocity. The void space above the propellant in the cartridge is filled with a tissue paper wad.. The projectile is set into the case to a depth of 6.35mm (0.250 inch). The gun is fired by remote control, using a solenoid actuated lever to pull the trigger, and is protected from fragment damage by firing through a hole in a heavy steel plate.

1.2 Liquid and granulateed solid explosives are tested in containers made of 7.62cm (3 inch) lengths of schedule 40, 3.175mm (0.125 inch) wall, aluminum pipe cylinders. The pipe ends are sealed with Teflon, or equal, or polyethylene film. The container cylinder has a 6.35mm (0.250 inch) hole at its center that is fitted with a plug. No containers are used for pressed or cast explosives.

2. PROCEDURE.

2.1 The gun is calibrated by determining the velocity given to the projectile by various loads of propellant. Velocities are measured with a 10-megahertz counter chronograph; the start and stop signals are provided by breaking conductive tapes spaced 0.5 meter apart between the gun and the sample; the tapes are stretched across wooden supports mounted on pedestals. The measured velocity is a linear function of the square root of the propellant weight.

2.2 Liquid or granulated solid explosive is poured into the container through the center hole, leaving as little ullage as possible; the hole is then closed with its plug. The filled container is positioned on a pedestal of modeling clay 3.048m (10 feet) from the muzzle of the gun, with its axis aligned with the projected path. The end of an 20.32cm (8 inch) length of detonating cord, which rests on a steel witness plate [(10.16cm by 10.l6cm by 0.635cm) 4 inches by 4 inches by 0.250 inch], is

placed in contact with the face of the sample opposite the gun and below the line of flight of the projectile. With cast explosives, the sample is an uncased cylindrical pellet [(2.54cm by 2.54cm) 1 inch by 1 inch].

3. RESULTS REPORTED AND CRITERIA FOR EVALUATION.

3.1 A positive result is reported when initiation of the primacord occurs, as indicated by a dent in the witness plate. The sensitivity of the sample is expressed as the projectile velocity, shich gives an initiation in 50 percent of the trials (V_{50}). This 50-percent point is determnined by the Bruceton up-and-down technique, varying the square root of the propellant weight in about 0.048 gram increments, shich corresponds to velocity increments of about 61 meters per second.

3.2 Shock pressures in the acceptor may be estimated by a graphical solution of the impedance mismatch (4.1), (4.2) using Hugoniot relations for brass and for an explosive having approximately the same density as the test sample.

4. BIBLIOGRAPHY

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METHOD 10

IMPACT TEST (LARGE SCALE-SUSAN)

1. PURPOSE

1.1 The test was designed by Lawrence Radiation Laboratory in 1961 to assess the relative behavior of explosives under field conditions of impactl Explosive billets, 5.08cm (2 in) in diameter by 10.16cm (4 in) long and fabricated by normal fabrication techniques, are employed. The test is conducted by loading the explosives into standardized projectiles, and firing the projectiles against a target at velocities higher than those achieved in gravity drop tests. The actual test apparatus used is located at the Naval Weapons Laboratory, Dahlgren, Virginia. User commonly refers to this as the "Susan Test".

2. APPARATUS

2.1 The standard Susan test employs the test vehicle shown in Figure 1. The projectile weighs approximately 5.4432kg (12 lb) assembled, and contains slightly less than 0.4536kg (1 lb) of explosive. Overall dimensions are 8.12Bcm (3.20 in) in diameter by 22.4028cm (8.82 in) long.

2.1.1 The projectiles are fired from a smoothbore gun which is a coverted 3.in/70 naval gun. The gun muzzle is circa 0.3048m (12 ft) from the 2.5 in thick, smooth-surface, armor steel target plate. Impact velocities are varied by adjusting the propellant charges. For velocities below 91.44m/a (300 fps) the charges consist of granulated black cannon powder. For higher velocities a five-to-one ratio mixture of 5in/38 smokeless powder (Index NPFB-234) and black cannon powder is used. The range of velocities employed in most Susan tests is 30.48-365.76m/s (100-1200 fps) although velocities up to 1066.8m/s (3500 fps) are possible.

2.1.2 A schematic of the firing range showing the target-gun layout and the relative positions of some of the diagnostics is given in Figure 2. The flight path is about 1.2192m (4 ft) above ground level.

3* 3. INSTRUMENTATION.

3.1 Velocities are measured with 5 sensing devices: Two wide angle photoelectric screens, two infarared detectors (Ektrons, or equal) and a magnet containing 50 turns of magnet wire. These These devices are placed at known points along the line of flight of the projctile, the magnet being attached to the target surface.

Signals generated when the projectile passes each sensing device are fed into an oscillograph and recorded on a drum camera. Two such recording systems are operated in parallel to increase reliability. Velocities are calculated by measuring the elapsed time between any two signals.

3.2 The pressure measurements are made with four piezo-electric blast pressure transducers (manufactured by Crystal Research, Inc.). The transducers are located as shown in Figure 2, and are positioned about 0.6096m (2 feet) above the horizontal plane which intersects the flight path. measurement of light intensity is made with two silicon diodes (Texas Instrument Corp., type 1N217S N-P-N diffused silicon photo-duo-diode, or equal). The outputs of the transducers and diodes are recorded on two four-beam oscilloscopes (Electronic Tube Corporation, mocel H4GEL, or equal. Two of the transducers and the two diodes are recorded On One Oscilloscope, the other two transducers, together with the -two diodes again, are recorded on the other. A typical record is shown in Figure 3. The records are in th form of time traces traces obtained by-photographing the oscilloscope with a high speed 35 mm reel camera having a film speed of 5.08m/s (200 in./sec), a one millisecond timing marker is imposed on each of the gun traces to facilitate timing calculations. The calibration section of the record gives a displacement of the pressure gauges (traces 2 and 4) for a given voltage.* The impact section of the record is a time history of the impact and subsequent events. When impact occurs, an impact grid switch** fires two squibs. One squib (placed some distance from the impact area) is observed by one of the silicon diodes which is recorded on trace 1. The displacement of this trace from the film record marks the time of impact. The second squib is placed in the impact area in the field of view of the cameras; it is also viewed by the second silicon diode which is recorded on trace 3. The small initial displacement of trace 3 due to the squib light is a back-up determination of the time of impact. Any chemical reaction which releases light is recorded as a second displacement of this trace. The delay time to such light evolution can thus be de-termined. Finally, the shock wave in air generated by the impact and/or chemical action of the explosive is recorded by displace-ments in.

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*The calibration section permits calculation of overpressure at the gauge via the expression $\Delta P = \frac{M\ V\ C}{L\ G}$, where

ΔP is the overpressure
L and M are the trace displacements shown in Fig. 3
V is the calibration voltage which produced the displace-ment, L
C is the circuit capacitance
G is a calibration constant characteristic of the gauge.

**The switch consists of a series of very thin parallel copper lines covering a 12.7 x 15.24cm (5 x 6 in) area (fabricated by printed circuit techniques). A set of alternate lines are connected together to form one side of the switch; the other lines connected together form the second side of the switch. Contact Contact of the aluminum nose cone of the projectile with any two adjacent lines closes the switch circuit.

traces 2 and 4. The time of arrival of this wave at each gauge is directly observable, and is used to calculate the relative "point source detonation" energy see 6.6.1.1.3. A bloxk diagram of the recording system of one oscilloscope is given in Figure 6.

3.3 Several cameras are used to observe the impact phenomena. Two 16mm Fastax framing cameras are used to view the events long range. One camera records in color; the other records in black and white. Typical framing speeds are 5000 frames/sec. For close-up work a modified 16mm Fastax, or equal, which takes two time-displaced "8mm" frames per normal 16mm frame is used. Color film is employed; the framing rate is ~ 10,000 frames per sec. Eastman Kodak Tri-X black and white and Super Anscochnome Daylight Balance color film, or equal shall be used.

4. PROCEDURE.

4.1 Normally, a minimum of eight projectiles are fabricated for the test of a new explosive formulation. For explosives of expected moderate or low sensitivity six of these projectiles are fired at pre-selected velocities in the 30.48 to 304.8m/s (100 to 1000 fps) range (e.g., velocities of 30.48, 60.96, 91.44, 152.4, 228.6 and 304.8m/s (100, 200, 300, 500, 750, and 1000 fps) might be chosen). After examination of these data, the additional projectiles are used to provide duplicates, or to fill in or extend the velocity range. For explosives of expected high enesitivity, only four of the projectiles are used in the first assessment, and 30.48 to 152.4m/s (100 to 500 fps) is selected for the initial range of velocities.

5. EXPRESSION OF TEST RESULTS.

5.1 One of the principal ways of expressing the results of a set of Susan experiments is by a Susan "Sensitivity Curve". This curve is a plot of the relative "point-source-detonation" energy against projectile velocity (see Figure 4). The "point-source-detonation" energy is calculated from the air shock data see 6-6.1.1.3. These curves depict the amount of chemical energy released by the explosive as a result of the impact; is is apparent that the greater this energy release for a given velocity, the more sensitive the explosive. The relative energy scale is set so that a truly violent deflagration or detonation consuming all of the explosive gives a value of about 100. A milder deflagra-

tion, shich also consumes all the explosive, gives only “about 30-40 on the scale. Compared to the more violent reaction, the deflagration is thus equivalent to the dentonation of less than half as much explosive. A calorimetric energy meaurement would presumably give energy values nearly the same for the two cases.

5.2 The camera information supplements the Sensitivity Curve. There is quite naturally good correspondence between the violence of the impact process as ofserved visually, and the relative energy release as calculated independently from air shock data. The camera data, however, uniquely supply detailed information on modes of deformation and ignition, and on the deflagration process, which is not derivable from the air shock data alone.

6. DATA REDUCTION.

6.1 The calculation of the explosive energy released as a result of the impact is accomplished via the air shock data. The procedure is outlined in the following paragraphs.

6.1.1 H. Brode. 7.1 has calculated the relation between the two dimensionless variables, λ_S as and τ_S, for a point source of energy in air. λ_S and τ_S in air are difined as

$$\lambda_s = \frac{R_s}{Q} P_o \quad 1/3, \text{ and} \qquad \text{(Eq. 1)}$$

$$\tau_s = \frac{t_t C_o}{Q} P_o \quad 1/3, \qquad \text{(Eq. 2)}$$

where

λ_S As is the dimensionless shock radius.

R_S is the shock radius.

Q is the cube root of the total energy of the source.

P_o is the ambient pressure.

t_t is the transit time for air shock from the point source to the point R_S.

C_o is the velocity of sound in air at the pressure and temperature of the measurement, and

τ_S is the dimensionless transit time.

The ratio, λ_S/τ_S is derivable from the experimental quantities

t_t, C, and R_S. This ratio fixes with reasonable precision λ_s is and τ_s (See Figure 5). From either λ_s or τ_s Q can then be calculated.

6.1.1.1 A useful check on the relationships in 6.1.1 is provided by the calibration charge which is fired at the start of a day of Susan testing. The calibration charge is a carefully weighed 70.5 g pellet of a plastic bonded explosive mounted on a Styrofoam-plywood fixture 15.24cm (6 inches) in front of the target area. A standard detonator is used to detonate the charge. For a given distance, R_S, a given energy of the point. source, Q^3 and a reasonably constant ambient pressure, PO, it is apparent from an inspection* of equations 1 and 2 that the quantity $t_t C_o$ should be constant. In Table 1 is tabulated this quantity for the three nominal 3.048m (10 feet) gauges of Figure 2 (gauges 2, 3, and 4). The values are indeed quite constant. (For reference purposes the measured gauge overpressures are also shown in Table 1. From the standard deviations of the overpressure measurements, compared to the standard deviations of the transit time measurements, the gauges appear to be more precise as "timing" gauges than as "overpressure" gauges.)

6.1.1.2 The energies (Q^3) calculated for the calibration charge from the timing data of guages 2, 3, and 4 give the values of 350, 230 and 180 kcals, respectively. The energy of the calibration charge, from detonation calorimetry, appears to be 100 kcal. Two things are evident from these data: First, the calculated energies are too high by a factor of 2 or 3, and second, the calculated energy is dependent on the position at which it is measured. Both facts are related at least in part to the lack of a point source geometry. Shock reflections from the large steel plate behind the charge both shorten the transit time and disturb the sphericity of the shock wave. This is borne out by the reduction in calculated energy as the point of measurement is moved from in front of the steel plate (gauge 2) to the side of the plate (gauge 4). The important fact about these data would seem to be that for a given geometry and gauge position, the data are quits reproducible. This implies that this calculational approach is valid even though absolute values are not obtainable. In calculating energies for Susan impact tests by this approach, the situation is fortunate in that impact geometry is reasonably the same at explosion time. Thus the requirement of a reproducible geometry seems to be met. As with the calibration charge, different energies are calculated for the impact depending on the location of the gauge. The scaling rules are different, however, gauge 2 now calculating

*For the conditions cited, τ_s is a constant. This fixes the value of τ_S, which in turn fixes the value of $t_t C_o$.

the lowest energy. This is undoubtedly due to the fact that energy in a Susan impact is expended much more to the side (as evidenced from camera observations).

6.1.1.3 A relative "point source detonation" energy is determined by calculating Q for gauges 2, 3, and 4, and applying scaling rules (determined by the average of many experiments) to reduce the gauge 2 and gauge 3 values to that of gauge 4. The scaled values of Q are then averaged (the advantage of this procedure rather than using just one gauge is that occasionally a gauge does not record or gives a spurious reading). The average value of Q is then cubed, and multiplied by an arvitrary factor of 2.2 to give the arbitrary energy scale of Figure 4. By these means, then, the chemical energy released by impact is expressed in terms of the point source detonation energy which would give an equivalent signal at the pressure—monitoring gauges.

7. BIBLIOGRAPHY

7.1 "Point Source Explosion in Air, "H.L. Brode, Rand Corporation Research, Memorandum 1824-AEC, Dec. 1956 (ASTLA Document Number AD 133030).

TABLE 1

RESULTS OF CALIBRATION SHOTS

DATE	GAUGE 2 (R_M = 299.2 CM)		GAUGE 3 (R_M = 315.3 CM)		GAUGE 4 (R_M = 313.5 CM)	
	$t_t C_O$ *	P	$t_t C_O$ *	P	$t_t C_O$ *	P
NOV 27, 1962	191.7	2.56	213.1	3.04	217.2	3.19
DEC 5, 1962	190.3	2.53	215.0	2.77	216.7	3.39
DEC 13, 1962	191.2	2.73	215.1	3.03	220.0	3.14
DEC 14, 1962	193.6	2.69	216.7	3.00	219.0	2.93
JAN 12, 1963	189.6	2.53	212.0	2.96	218.1	2.56
MAR 22, 1963	189.7	2.67	216.4	2.70	215.8	3.30
MAR 27, 1963	192.6	2.56	216.8	2.78	217.8	1.21**
MAR 28, 1963	193.7	2.75	217.7	2.87	219.8	2.03
APR 1, 1963	191.0	2.76	216.0	3.00	217.1	2.26
APR 8, 1963	190.9	2.70	212.8	2.92	—	—
APR 9, 1963	189.3	2.69	211.0	3.10	213.8	2.56
AVERAGE	191.2	2.65	214.8	2.92	217.5	2.82
STANDARD DEVIATION	1.5	0.09	2.2	0.13	1.9	0.48
%	0.8%	3%	1%	4%	0.9%	17%

* THE ACTUAL GAUGE POSITIONS VARIED A FEW CM FROM THE VALUES GIVEN IN THE COLUMN HEADINGS. A SMALL CORRECTION WAS THEREFORE APPLIED TO THE MEASURED VALUES OF $t_t C_o$ TO CONVERT ALL RESULTS TO THE SAME DISTANCE. THE CORRECTION EQUATION IS

$$(t_t C_o)\ \text{CORRECTED} = \left[1 + 0.004\,(R_M - R_S)\right]\ (t_t C_o)\ \text{MEASURED}$$

WHERE R_M IS THE MEAN OR "STANDARD" DISTANCE CHOSEN AS A REFERENCE, AND R_S IS THE ACTUAL GAUGE DISTANCE.

** NOT INCLUDED IN THE AVERAGE

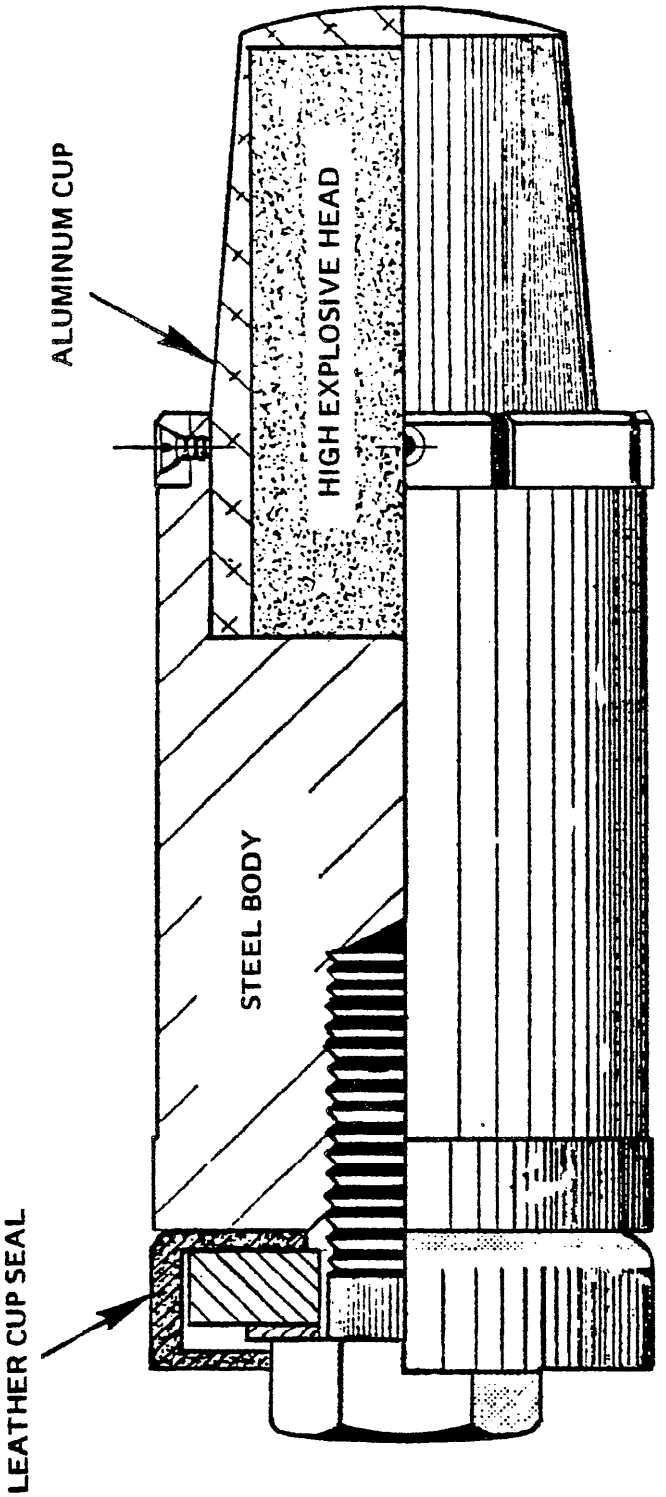

FIGURE 1 - SUSAN PROJECTILE

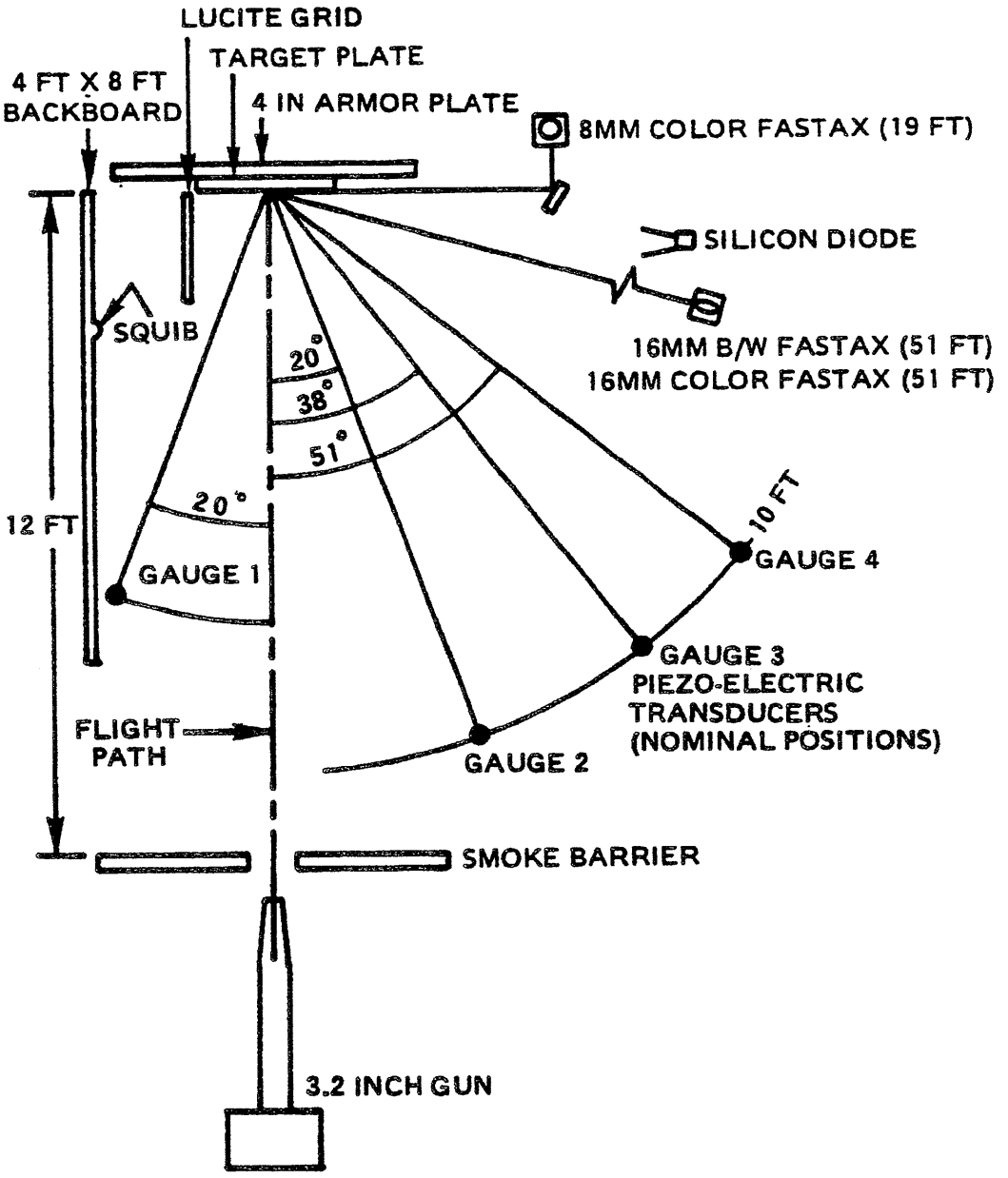

FIGURE 2 - SCHEMATIC LAYOUT OF GUN FIRING SITE (TOP VIEW)

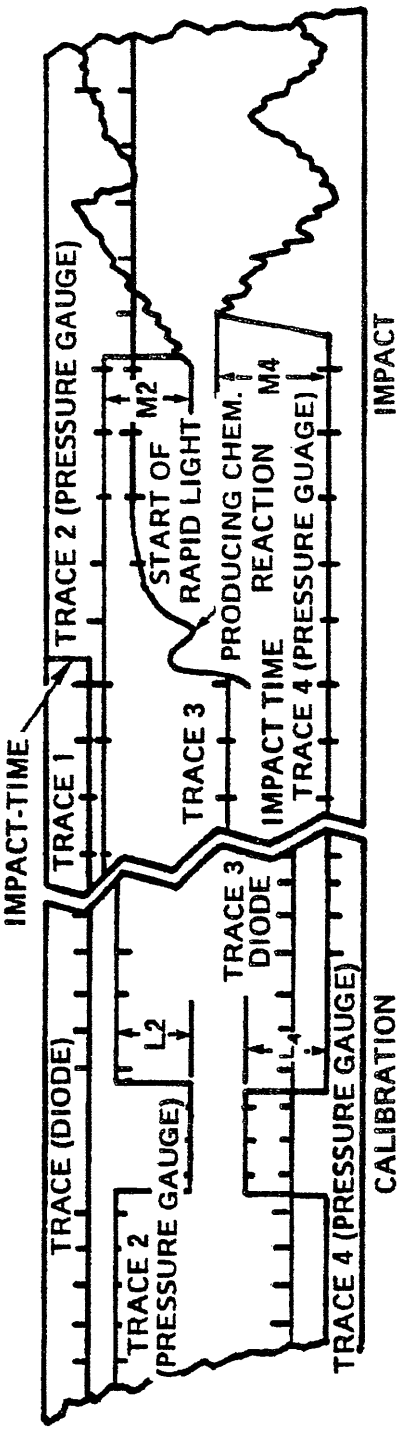

FIGURE 3 - TYPICAL TRANSDUCER AND DIODE RECOD (TIMEING MARKS ARE 1 MILLISEC APART)

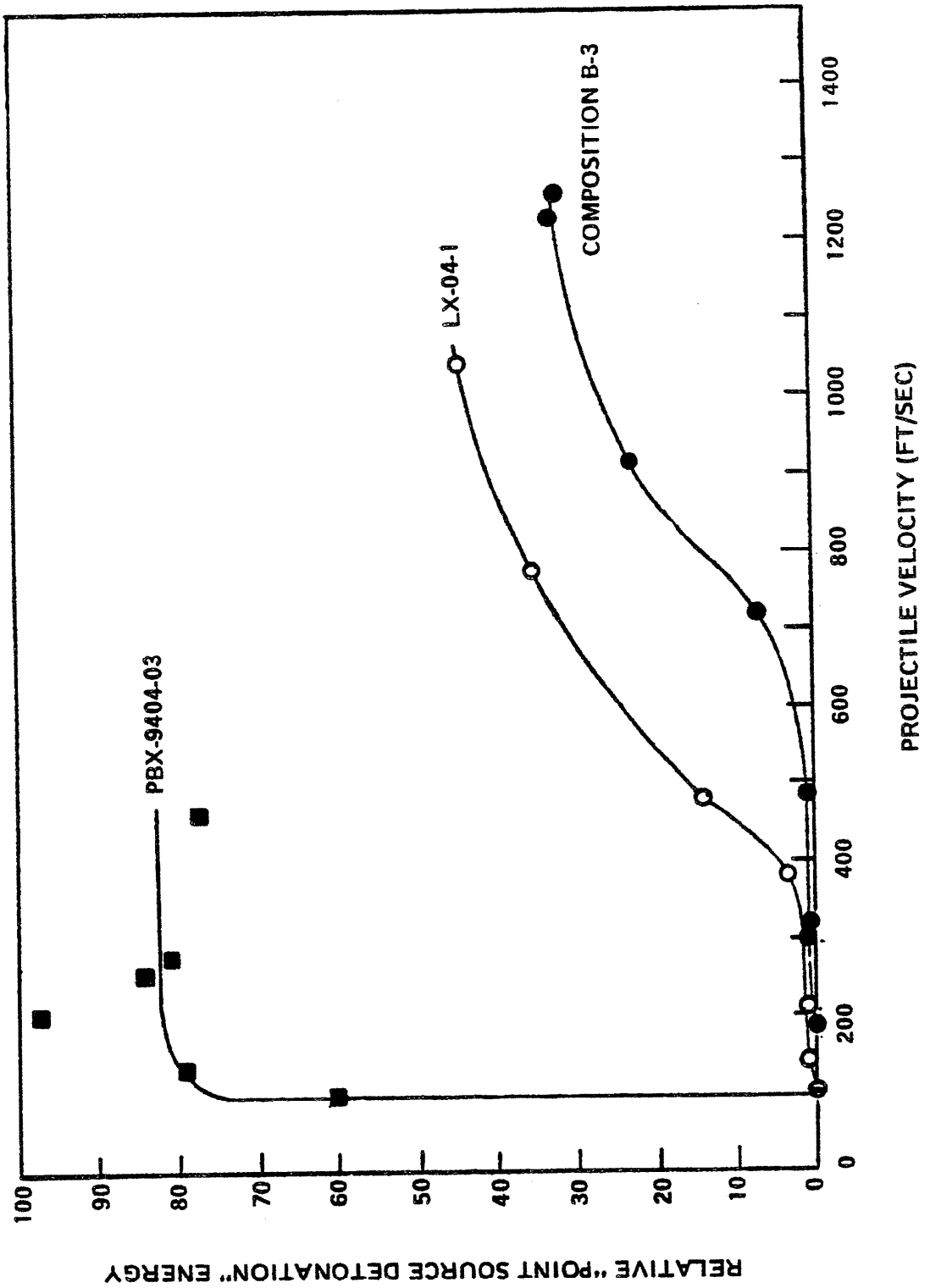

FIGURE 4 - SUSAN SENSITIVITY CURVES (ENERGY SCALE)

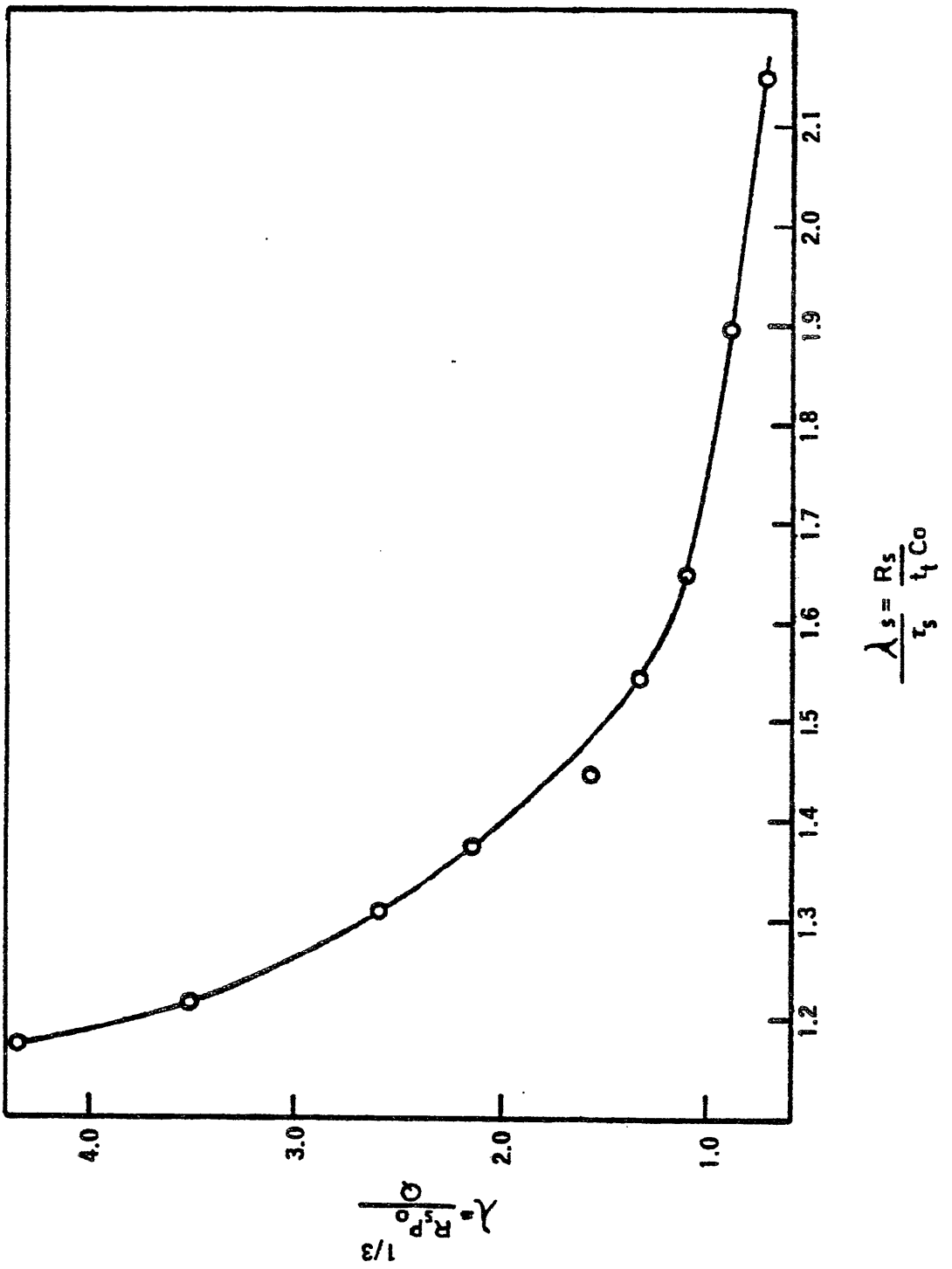

FIGURE 5 - RELATION BETWEEN THE DIMENSIONESS VARIABLES λ s AND λ s FOR A POINT SOURCE EXPLOSION IN AIR.

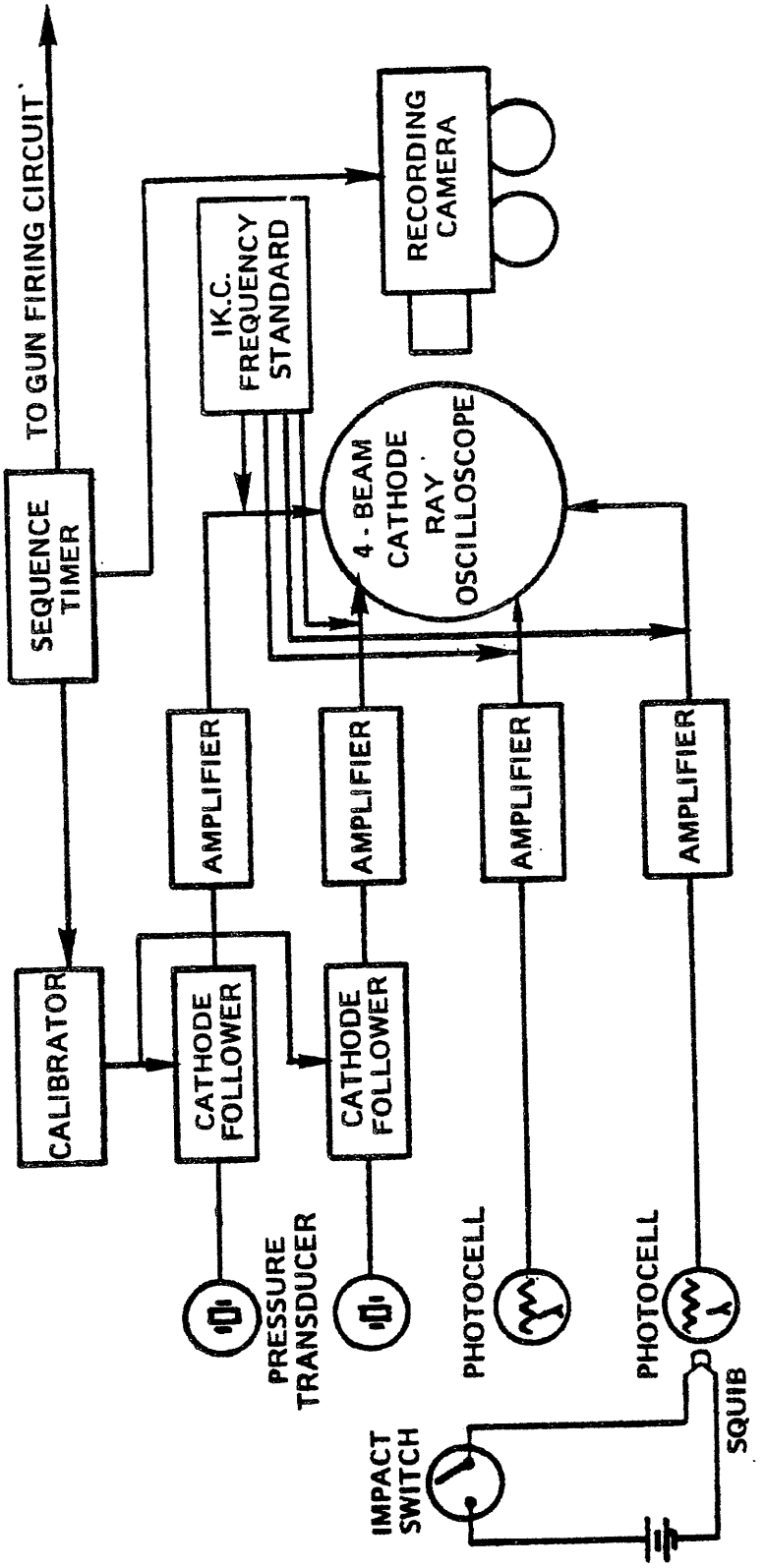

FIGURE 6 - BLOCK DIAGRAM OF SUSAN TEST RECORDING SYSTEM.

METHOD 11

Impact Test (Large Scale - Skid)

1. PURPOSE.

1.1 In this test a horizontal target plate is impacted by a mass of explosive at a pre-selected angle. Because the velocity of this explosive at impact has both horizontal and vertical components, the test is commonly called the "skid test".

2. APPARATUS

2.1 A wooden pole and crossarm 12.192m. (40 ft) high, is used to suspend the tent vehicle from cables arranged as a bifilar pendulum. A second wooden pole of equal height is equipped with a cables pulley and winch capable of elevating the test vehicle to a vertical height of 8.534m (28 ft). The test vehicle swings with its equator always horizontal. Figure 1 is a sketch of the test arrangement.

2.2 The test vehicle is an 27.94cm. (11-in) diameter hemisphere of explosive weighing approximately 11.34kg (.25 lb.) (In the development of this test during 1961, hemispheres of explosive weighing 22.68kg. (50 lb.) were used. Changeover to the 11.34 kg (.25 lb.) hemisphere was made ca. April 1962). The explosive hemisphere rests freely in a wooden support ring. In assembled condition, the plane surface of the hemisphere is up and the curved suface impacts the target. The pendulum cables and the cable for elevating the test vehicle are attached to the support ring.

2.3 The target is a rectangular concrete block, 76.2cm by 76.2cm by 20.32cm. (30 in. by 30 in. by 8 in.)thick, which rests on the ground. The concrete base is topped by a 50.8cm (20-in.) square steel plate, 6.35mm. (0.250 in.)thick, cemented at a central location on the concrete by an epoxy resin (Permagile, or equal) and sand mixture. The upper (target) surface of the steel plate is coated with 50-70 mesh crystal-white silica sand which has been previously silver plated to a thickness of ca. 1.27mm. (50 μ in.). The sand is cemented to the steel plate with an electrically conductive epoxy glue.

3. INSTRUMENTATION

3.1 Two Fastax, or equal, 16mm, 121.92 m. (400 ft.) capacity, cameras are used, one with a small field of view {shout 0.6096 bY 0.9144m. (2 bY 3 ft.)}, 250-mm f/4.5 lens, the other larger {about 1.8288 by 2.4384m (6 by 8 ft)}, 100-mm f/3.5. Both are run at ca. 4000 frames/see with color film (High Speed Ektachrome, or equal, daylight). Lighting is daylight plus a 60.96cm. (24 in) carbon are at a distance and eight FF 33 bulbs in two aluminum-

foil boxes close in.

3.2 Four Ballistic Research Laboratory "lollipop-type" gauges are mounted in two paths about 1.04720 rad (60°) apart. Each path contains two gauges, one set at 9.144m (30 ft.) and one at 12.192 m (40 ft.) from the target. All gauges are mounted 1.2192m (4 ft) above the horizontal plane of the target. Signals from each pair of gauges are fed into a separate 4-beam oscilloscope equipped with a 30.48m (100-ft.) 35-mm Fastax, or equal, streak camera normally operated at 3810cm/sec (1500 in./sec) film speed. One pair of gauges is set to read large events, up to 11.34 kg (25 lb) HE detonation without saturation; one pair is set at a higher sensitivity to record small events. A 1kHz square-wave time calibration signal is put on one of the beams in each oscilloscope. Data recored are pressure-time traces of shock arrival for pressure calculation using equations of state of air.

3.3 The test vehicle has a series of six, 0.1016mm (4-mil) wires spaced 10.16cm (4 in.) apart across the polar region of impact of the hemisphere and charged with 165 volts. Contact with the silver-plated sand on the target grounds the circuit, creating a time-zero signal which triggers a fiducial light source and two oscilloscopes: one dual-beam, single-sweep (200 μ sec/cm) Tektronix 55, or equal, and one single-beam, single-sweep (50 μ see/cm) Tektronix 545, or equal.

3.4 3.4 The fiducial light source is a small wire-filled flash bulb (exact type unimportant) fired by a capacitor discharge, ca. 1 pf at 2 kv. Until June 1963, a small detonator was used to provide the optical time zero in the fields of view of the cameras. test show that a more prompt (< 1 μ sec flash is produced by the capacitor discharge; the flash bulb actually burns much later.

3.5 A barium titanate crystal (Army Ordnance "Lucky" type), buried in the concrete target pad, yields a reaction signal which is read on both the single and dual-beam oscilloscopes. A photo-diode responds to light generated by explosive action and its signal is displayed on the dual-beam oscilloscope. The crystal and the photo-diode signals yield times that are not in agreement, the crystal signal being ca. 200μ sec earlier than the light.

3.6 Figure 2 is a schematic drawing of the instrumentation.

4. TEST PROCEDURE

4.1 The target plate and base are positioned on the ground so that the test vehicle will impact it at the chosen angle. Several angles have been tried ranging between 0.12217 and 1.32645 rad (7° and 76°) (angle between tangent to arc of flight and the hoizontal, at time of impact). Current procedure is to

test at 0.24435 and 0.78540 rad (.14° and 45°), chosen to yield ratios of horizontal to vertical velocity velocity vectors of 4/1 and 1/1. User considers a 0.24435 rad (.14°) impact to be the more severe test.

4.2 An explosive hemisphere is placed in the support ring and the test vehicie is elevated, remotely, to a chosen vertical height. Standard test heights are spaced in ten equal log increments of 0.15 (where log of 10 ft is 1.0) from 0.381 to 8.5344m (1.25 to 28 ft.) The first drop height is chosen one increment (0.15 log unit) below the height where a reaction is expected. The test vehicle is released on actuation of the release gear by the test operator. Since the pendulum cables provide no restraint to lateral motion (sway) due to wind, the operator exercises his judgement as to the proper release moment. By visual observation he decides when the test vehicle should swing in the proper plane to impact centrally on the target.

4.3 Successive drop heights are chosen shove or below the previous drop depending on whether the previous test was a "no-go" or a "go". A fresh explosive charge is used for each drop. The high cost of the test has restricted the number of trials such that no statistical treatment has been attempted. Generally the heights are chosen so that results will indicate points where a change in response of the material can be expected.

4.4 Data recorded includes drop height, angle of impact, air blast pressure, time lag between impact and reaction, and a film record of the event. Data analysis is concerned principally with determining an ordering of the reaction.

4.5 Useful information is derived principally from the films and supported by the blast gages and light signals. User has not yet been able to correlate the time to reaction to any variable (partly because user has not yet looked at the data with aa "statistical" eye). The time of reaction has never been much under 500 μ see nor more than 1500 μ sec. The reactions are classed from 0 to 6, as follows:

0 - None
1 - Burn or scorch marks on H. E. or target, no puff of smoke in high-speed films nor response from other instruments.
2 - Puff of smoke but no flame nor light visible in high-speed films. May be acccompanied by burn or scorch marks on H. E. or target and perhaps some Lucky response, but no positive photo-diode response.
3 - Mild low-order reaction, with flame or light; detectable pressure; minor portion of H. E. is consumed, rest may be widely scattered.

4 - Medium low-orders with bright flame or light, low to moderate pressure, major part of H. E. consumed, rest should be widely scattered; it may seem, in chamber or by observation, to be a strong event.

5 - Strong reaction, moderate to high blast pressure, bright light but not brilliantly white to film saturation; all or virtually all H. E. consumed. To an onlooker will be indistinguishable from full detonation. In terms of blast damage, sound and scatter of debris may seem to or actually be stronger than 6 (detonation).

6 - Detonation, mostly characterized by brilliant white light, saturated film one or several frames (can't be distinguished by direct viewing of the event) and high blast pressure.

4.6 User has not determined conclusively whether 6 is a true detonation or an extremely fast, violent deflagration.

4.7 Some test results are shown in Table 1.

TABLE 1

Impact Test (Skid) Results

Explosive	Vertical Drop Height m (ft)	Overpressure at[a] 4.572m (15 ft), Pa (psi)	Remarks
PBX-9404	1.524 (5)	(b)	High order detonation
	0.9144 (3)	0.0	Dud
LX-03-0	3.048 (10)	3240.5358 (0.47)	Very low order partial
	2.19456 (7.2)	3102.6407 (0.45)	Very low order partial
	1.524 (5)	4964.255 (0.72)	Very low order partial
PBX-9010	1.0668 (3.5)	75152.851 (10.9)	High order detonation or very vigorous burn
	0.762 (2.5)	92389.744 (13.4)	High order detonation or very vigorous burn
	0.4572 (1.5)	0.0	Dud
LX-04-0	2.19456 (7.2)	2275.2698 (0.33)	Very low order partial
	1.524 (5)	482.63299 (0.07)	Very low order partial
	1.0668 (3.5)	0.0	No overpressure or light but a slight blackening of the impact area

(a) Three grams of explosive detonated high order gives an overpressure of about 1378.9514-2068.4271 Pa (0.2-0.3 psi) in this particular experimental setup.

(b) Pressure reading lost.

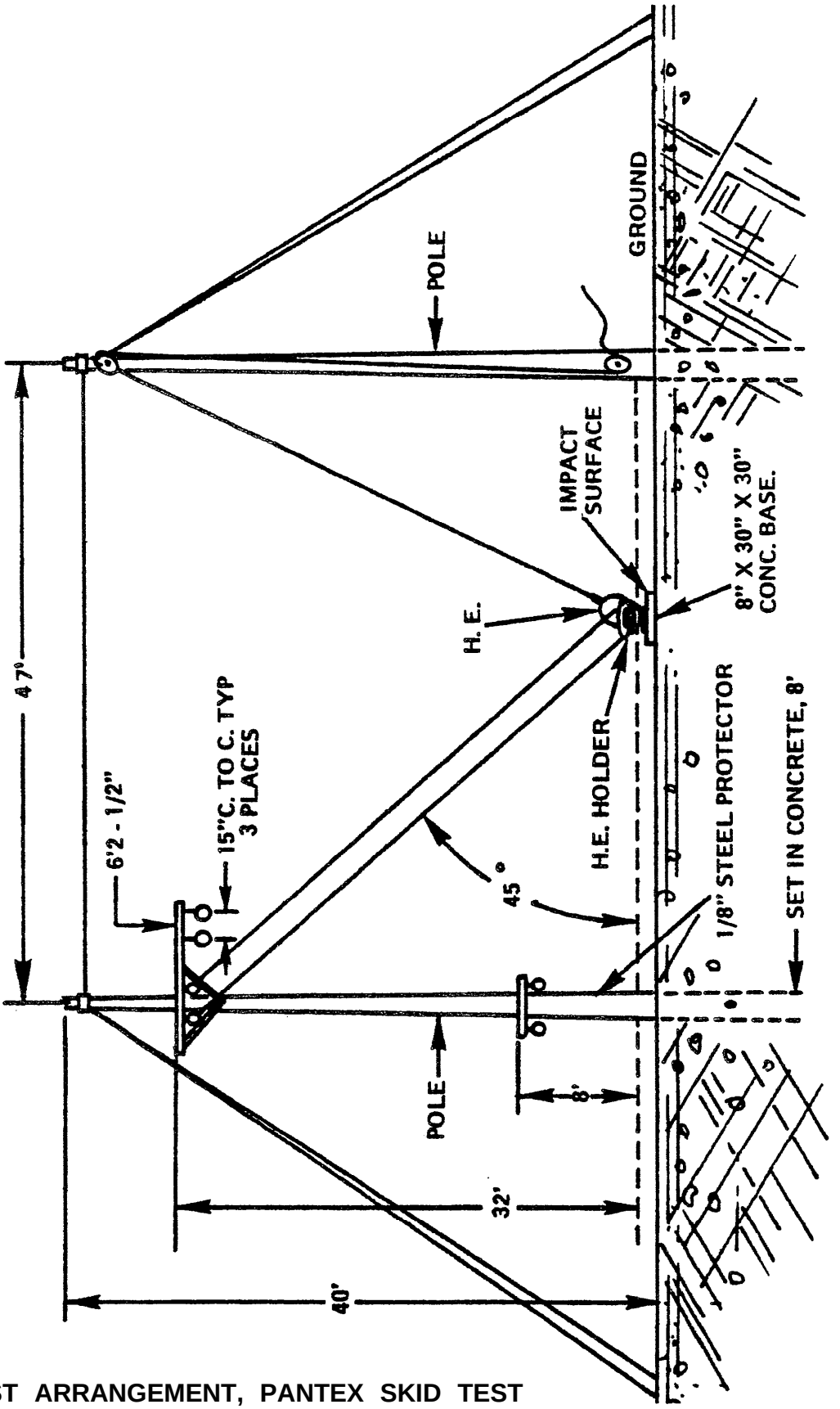

FIGURE 1 - TEST ARRANGEMENT, PANTEX SKID TEST

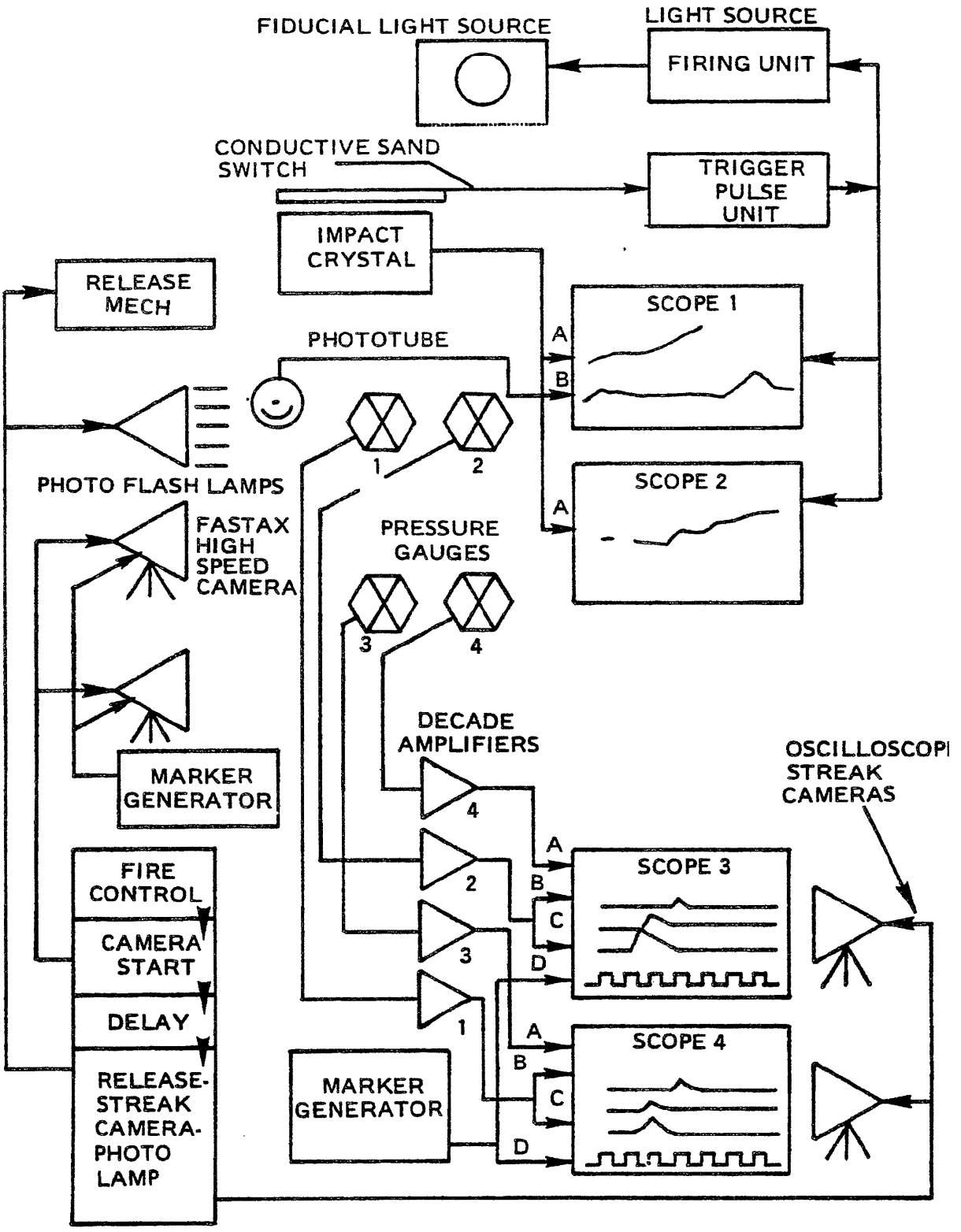

FIGURE 2 - SCHEMATIC DRAWING OF SKID TEST INSTRUMENTATION

METHOD 12
ADIABATIC SENSITIVITY TESTING

1. ADIABATIC SENSITIVITY TEST

1.1 Tests are performed on an Adiabatic Sensitivity Testing Machine, or equal, described in Figure 1. Weights of 2.5 and 5.0 kg are available for impact on the air compressing piston. Samples are press-loaded in sample holders as described in 2.1.

1.2 A 50% sensitivity height (centimeters) is calculated on the basis of 25 shots at 0.05 log height intervals. The sample size is approximately 1 gram and is press-loaded into the sample holder. Positive stops are fixed to the loading tools to insure a constant explosive height of 9.525 ± 0.0254mm (0.375 ± 0.001 inches). Explosive weights are adjusted to give the required loading density. In general an explosive will be tested at the munition loading density. A detailed operation procedure, drop height sequence selection of gap sensitivity test heights, preparation of samples, and an example of sensitivity calculations are included in the following sections.

2. PROCEDURE FOR ADIABATIC SENSITIVITY TESTING

2.1 Sample Preparation.

2.1.1 Press Loaded Compositions

2.1.1.1 Clean sample holder with 1,1,1-trichloroethane followed by an acetone rinse. Dry thoroughly.

2.1.1.2 Weigh the required sample on an analytical balance.

2.1.1.3 Pour sample in holder and compress to stop on loading ram

2.1.1.4 Twenty-five samples are required for test. Extra samples may be required to establish a starting point.

2.1.2 Castable PBX Systems and Other Fluid or Semi-Fluid Systems.

2.1.2.1 Clean sample holder as specified in step 2.1.1.1.

2.1.2.2 Cast, extrudes press, or otherwise load a quantity of material in the sample holder to the required density.

2.1.2.3 Machine excess to a depth of 25.4 $\pm$ 0.0254mm (1 ± 0.001 inch) using a reamer by appropriate explosive machining operation. Explosive sample height should be 9.525 ± 0.0254mm (0.375 ± 0.001 inch).

2.1.2.4 Twenty-five samples are required for test. Extra samples may be required to establish a starting point.

2.2 Machine Operation.

2.2.1 Select the weight specified on the data sheet and install in the machine.

2.2.2 Ensure safety stops are operable and in the loading position. (In position to prevent weight from impacting on sample holder).

2.2.3 Engage vacuum plate and raise weight to starting position.

2.2.4 Install loaded sample holder with desired ram/explosive gap in machine-ensure pressure relief holes are in alignment and wood barricades are in good condition.

2.2.5 By remote control, withdraw safety stops and permit weight to impact on pressure ram.

2.2.6 Clear machine by raising weight and reinserting safety stops. Remove sample holder, Sample may or may not have been completely expended. Soak holder and piston in acetone to loosen piston and dissolve explosive residue.

2.2.7 Carefully remove piston from sample holder and clean.

2.2.8 Discard sample holder in explosive contaminated scrap.

2.2.9 Do not retest or reimpact any sample test holder.

2.2.10 Record results. A failure to fire is recorded N, a fire as E.

2.2.11 Repeat Steps 2.2.2 throught 2.2.10 for each of the 25 samples.

2.2.12 Pistons should be charged when the surface is scored from the shot and must be cleaned between shots.

2.3 The initial gap selected is largely dependent on the sensitivity of the material to he tested. With unknown materials, a minimum gap of 1.5748mm (0.062 inch) should be selected on first trial, up to the limit of the machine. If within the limit of the machine the samples fail to detonate, a larger gap may be selected. The gap should be selected in increments of 1.5748 mm (0.062 inch). This process or selection of gap should proceed until a drop height is established with the smallest gap that will permit the sample to detonate. When recording data, it is important to also record the gap used for any given trial.

3. RECORDING AND CALCULATION OF RESULTS

3.3 Data Sheet.

3.1.1 Record on data sheet (Figures 2 and 3) information required at heading for each set of samples to be tested.

3.1.2 Record drop weights results on data sheet (E or N). Record multiple detonations or other abnormal conditions on back of data sheet indicating height level at which event occurred.

3.2 Calculation of Results.

3.2.1 Calculation of the 50% point (Figure 4) is done by either of the following methods:

If $\sum E$ is the smallest, use

$$50\%\ \text{pt.} = (\text{lowest normalized ht}) + (\text{normalizing intervals})\frac{\sum AE}{\sum E}$$

log interval

If $\sum$ is smallest or if $\sum E$ and $\sum N$ are equal, use

$$50\%\ \text{pt.} = (\text{lowest normalized ht}) + (\text{normalizing interval})\frac{\sum AN}{\sum N} + \text{Log interval}$$

3.2.2 When reporting a 50% pt, the following information is also required.

a. Gap (space between raam surface and explosive surface)

b. Drop weight size

c. Loading method

The above equation is described in detail in Applied Mathematics Panel Report 101:1R, Statistical Analysis for a New Procedure in Sensitivity Experiments 1945-1948 and in general in the analytical method used in the Bruceton Impact sensitivity test. Normalized log heights are shown in Table 1 for a common log interval of 0.05.

4. DEFINITION OF TERMS

4.1 Schematic of test - see Figure 1.

4.2 509% pt. = Adiabatic sensitivity of the sample lot under test conditions.

4.3 Lowest normalized ht. = log value of the lowest height used in the run of 25 shots.

4.4 Normalized interval = the difference between log hts.

4.5 A = level of the step height (the lowest step height in the series is designated as level zero) the next step height upward is considered Level 1; the next Level 2, etc.)

4.6 E = number of explosions at a given A level.

4.7 N = number of non-explosions at a given A level.

4.8 AE = A times E.

4.9 AN = A times N.

TABLE 1. Impact Sensitivity Test Heights.

Level	Height, cm	Log height	Level	Height, cm	Log height
0	4	0.6051	19	40.5	1.6051
0.5	4.5	0.6551	20	45	1.6551
1	5	0.7051	21	50.5	1.7051
2	6	0.7551	22	57	1.7551
3	6.5	0.8051	23	64	1.8051
4	7	0.8551	24	71.5	1.8551
5	8	0.9051	25	80.5	1.9051
6	9	0.9551	26	90	1.9551
7	10	1.0051	27	101	2.0051
8	11.5	1.0551	28	113.5	2.0551
9	12.5	1.1051	29	127.5	2.1051
10	14.5	1.1551	30	143	2.1551
11	16	1.2051	31	160.5	2.2051
12	18	1.2551	32	180	2.2551
13	20	1.3051	33	202	2.3051
14	22.5	1.3551	34	226.5	2.3551
15	25.5	1.4051	35	254	2.4051
16	28.5	1.4551	36	285	2.4551
17	32	1.5051	37	320	2.5051
18	36	1.5551			

4.10 $\sum$AE = summation of AE values.

4.11 $\sum$AN = summation of AN values.

4.12 $\sum$E = total number of explosions.

4.13 $\sum$N = total number of non-explosions.

4.14 Air gap - the distance between firing punch face and explosive surface. See Figure 1.

4.15 Loading density - normally the explosive sample will be loaded by the same method and to the same density as expected in the service munition.

4.16 Non-impact punch - A punch so ground to length that machine stops preclude the punch from impacting on the sample. In the NEDED machine and sample holder design, the length is 2.54cm (1.000 inch) from shoulder to face of punch.

4.17 Impacting punch - A punch of sufficient length to impact on the explosive sample. In the NEDED machine and sample holder design, the length is 3.175cm (1.250 inches).

5. ADIABATIC SENSITIVITY MACHINE, DROP HEIGHT SEQUENCE

5.1 Use the starting height and conditions designated on the data sheet, or select one in the range where the 50% pt is expected. Go up the height scale sequence until a detonation occurs; record this on the data sheet as the first shot. If a detonation occurs on the first shot, go down the height scale sequence until a non--explosion occurs. Example: When an explosion occurs, go down one step height, continue down in step increments until a non-explosion occurs, then proceed up in step increments until an explosion occurs. Repeat up and down through explosions and non-explosions until sample of 25 has been completed. Calcu- Calculate 50% pt as specified in Section 3.

6. GENERAL COMMENTS

6.1 The number of variables in this test make it imperative that a standard procedure be established and followed for loading sample holders and conducting test runs. The test is designed to show worst conditions; a sample tested in this machine may be, in fact, less sensitive when tried in the actual munition but not the reverse. Finally, it is expected to show an ordered ranking of sensitiity to this stimulus. The ranking of explosives by this test must also be judged by other sensitivity tests.

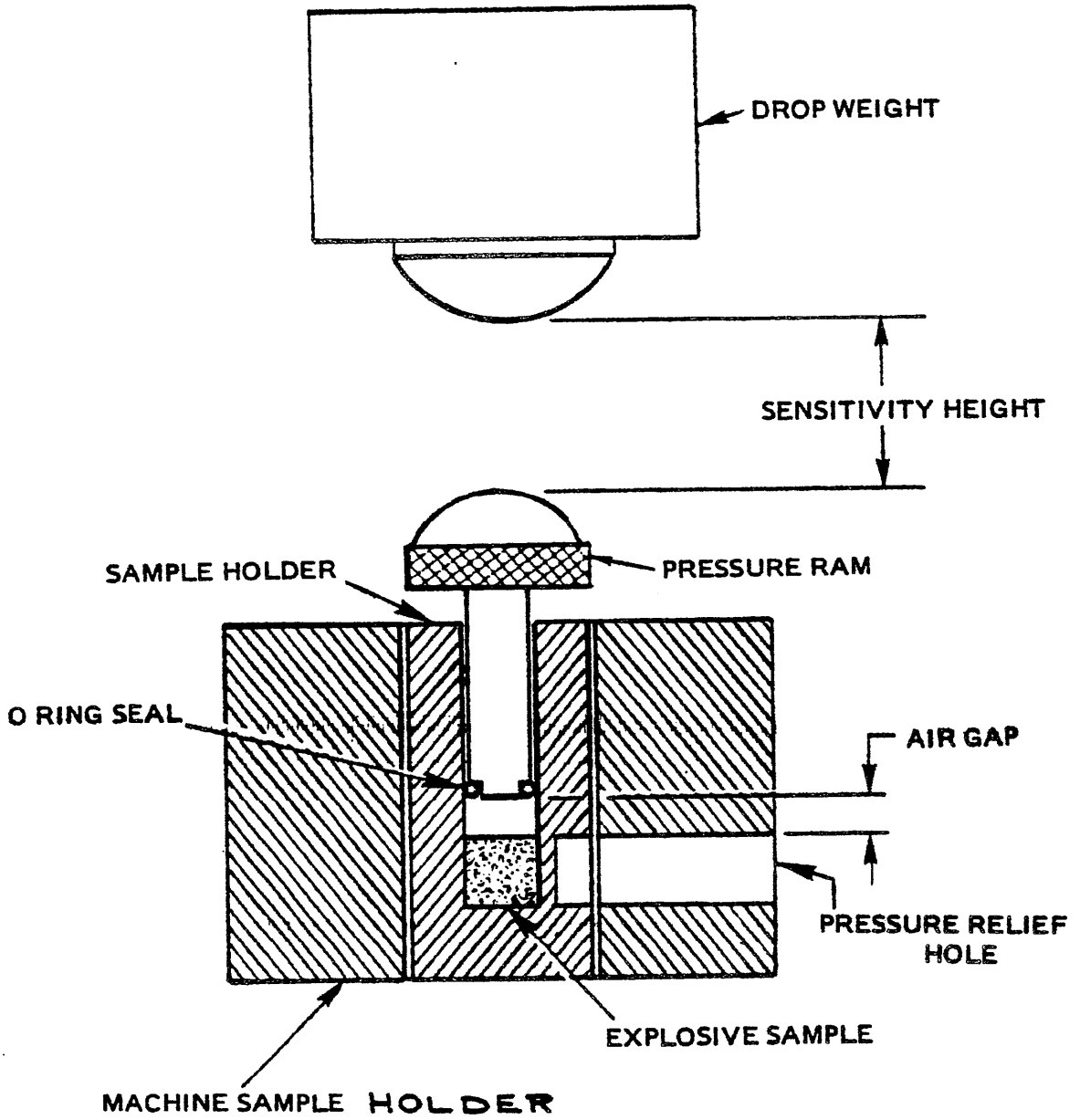

FIGURE 1 - ADIABATIC SENSITIVITY TEST MACHINE.

DATE _____ RUN NO. _____
GAP _____ DENSITY _____
MATERIAL _____
REMARKS _____

Ht	EN	Ht	E/N

Ht	E	N	A	AE Or AN

50% Ht _____

DATE _____ RUN NO. _____
GAP _____ DENSITY _____
MATERIAL _____
REMARKS _____

Ht	EN	Ht	E/N

H	E	N	A	AE Or AN

50% Ht _____

FIGURE 2 - SAMPLE DATA SHEET.

DATE_____ ROOM TEMP_____ SAMPLE TEMP_____

EXPLOSIVE_____ GAP_____ IN.

Ht	E/N	LO/HO*

Ht	E	N	A	AN

50% Ht _____cm

*A "LOW ORDER" (LO) EXPELS THE PISTON BACK OUT OF THE SAMPLE HOLDER, A "HIGH ORDER" (HO) RUPTURES THE SAMPLE HOLDER BLOWOUT DISC AND THE PISTON REMAINS IN PLACE.

FIGURE 3 - 1ST REVISION TO DATA SHEET, REQUIRED FOR PBXW-106 TYPE EXPLOSIVES.

DATE: 21 JUN 1966 RUN NO.: 1

SCOOP NO.: 3 PARTICLE SIZE: THRU 20-MESH U.S. STANDARD SIEVE

MATERIAL: (TYPE OF EXPLOSIVE)

REMARKS: SINCE $\Sigma E < \Sigma N$ USE:

50% ht. = (LOWEST NORMALIZED ht.) + (NORMALIZED INTERVALS) $\left[\frac{\Sigma AE}{\Sigma E} - 0.05\right]$

HT LEVEL	E/N
20	E
19	N
20	N
21	E
20	E
19	N
20	N
21	N
22	E
21	E
20	E
19	E
18	N
19	E
18	N
19	N
20	E
19	N
20	N
21	E
20	N
21	N
22	N
23	E
22	E

HT LEVEL	E	N	A	AE OR N
18	0	2	0	0
19	2	4	1	2
20	4	4	2	8
21	3	2	3	9
22	2	1	4	8
23	1	0	5	5
	12	13	-	32

LOG.50% HT = 1.5551 + 0.05 (32/12 - 0.05)

= 1.5551 + 0.130

= 1.685

FROM TABLE B-1:

ANTILOG 1.685 = 48.4 CM

$\therefore$ 50% HT IS 48.4 CM

FIGURE 4 - EXAMPLE OF DATA SHEET.

METHOD 13

THERMAL DETONABILITY TEST

1. PURPOSE

1.1 The small-scale cook-off bomb (SCB) was used to study the dynamic thermal characteristics of explosives when confined within a closed container subjected to a rapid increase in temperature. This technique was considered as a possible preliminary test that would be performed before employing a full-scale vessel in a fast cook-off test.

2. APPARATUS

2.1 A schematic diagram of the basic body of the SCB is shown in Figure 1. The body of the bomb is a steel gas-generator canister from an aircraft rocket.

2.1.1 The outside wall of the body is first covered with a single layer of 0.127mm (0.005 inch) thick mica. This preents the heating ribbon from being shorted out by the underlying metal. Then, 3.47472m (11.4 feet) of TOPHET-A, or equal, nickel chrome ribbon {width 3.175mm (0.125 inch), thickness 0.14224mm (0.0056 inch), 0.880 ohms\0.3048m (0.880 ohms/ft)} is carefully wound around the mica-covered exterior wall, spacing the ribbon so that there are no shorted junctions. The ribbon should indicate a resistance of 10 ohms. A single layer of glass-type string is applied over the ribbon to prevent the ribbon from moving and possibly shorting itself. Provision must be made for attaching the heating ribbon to a 110-volt line, with the necessary off-on safety switch. The body is insulated by applying a 6.35 to 12.7mm (0.250 to 0.500 inch) thick wrapping of asbestos ribbon, which is 3.81cm (1.5 inches) wide and 1.778mm (0.07 inch) thick. The bottom and top of the bomb are not insulated. A ground wire is attached to the bottom of the body. When ready for testing, the closed container is placed on a 19.05mm (0.750 inch) thick, 0.6096m (2 foot) square steel plate, and a 19.05mm (0.750 inch) steel plate {~0.3048m (~1 foot) in diameter} is placed On top Of the bomb.

2.2 The basic bomb may be altered so that additional information can be obtained. If internal bomb temperatures are required, a hole is drilled and tapped in the bottom center of the body. A stainless-steel compression fitting is inserted that will accommodate the desired number of thermocouples. Additional thermocouple beads can be welded onto the outside top and bottom areas that are not isxulated. The temperature-sensing probes are

made of 24-gauge type-K (chromel-alumel) thermocuople wire. Temperature data can be recorded on any indicating device, strip chart recorder, or data acquisition system.

2.3 If internal pressure data are desired, a 0-6894757. Pa (0-1,000 psi) pressure transducer is installed. A hole is drilled and tapped in the cover (lid) of the bomb and the transducer is installed, with provision made for recording the data.

2.4 Before starting the test procedure, the thermocouple (TC) probes should be in position. The locations of TC 1, 2, and 3 are indicated in Figure 2. Additional internal locations could be at the quarte radius of the explosive, top surface of explosive, and the area above the top surface. A protective layer of tape is used to cover the threads of the body. In required, and inner liner is applied to the inside walls and bottom of the body, and the sample is cast or melted inside the container. The tape is removed and the threads are inspected for any explosive contamination, which should be removed. The cover is screwed onto the container with care. The thermocouple (and possible pressure transducer) connections are made to their respective data-recording instruments. The closed container is placed on a steel plate, and a smaller steel plate is positioned on top of the bomb. The steel plates will cause the bomb fragments to travel in a fairly horizontal direction. After all personnel take shelter within a protective structure, full power from a 110-volt line is applied to the heater. The size and number of fragments will indicate the type of reactions i.e., deflagration, explosion, or detonation. The recorded data are reduced and plotted as desired.

2.5 The small-scale pressure bomb (SPB) setup has been used in decomposition and explosive aging studies. All items but one were readily purchased and then assembled for operational use. The exception was the heating block, which was machined from a 13.97cm (5.500 inch) diameter piece of solid cylindrical aluminum stock. An alternate approach would be to utilize a commercially available vertical furnaces band heaters, or a heating ribbon.

2.5.1 A schematic diagram of the SPB setup used is shown in Figure 3. The sample container is a Parr No. 4712, or equal, 45-ml T303 stainless-steel GP bomb with an A7AC7 head. The overall length of the bomb is ll.684cm (4.6 inches). Two additional items are required for the basic bomb configuration; the Matheson No. 939-SS, or equal, diaphragm valve and the Matheson No. 63-5307, or equal, precision pressure gauge. The three items are connected to each other so that leakage will be eliminated. Two SPB setups can be placed in each aluminum

heating block. However, due to the size of the gauges and the limited operational area on top of the heating block, it is necessary to use additional metal piping on one bomb so that one gauge will be located just above the other. If it is desired to have both gauges at identical heights above the body of the bomb, the gauges may be placed back-to-back, using a mirror arrangement to read the dial of the rear gauge.

2.5.2 Two cartridge-type heaters are used in each heating block. The heaters are 19.05mm (0.750 inch) OD by 8.89mm (3.500 inches) long and are rated at 250 watts at 120 volt-s. These specifica- These specifications are not critical, as the desired temperature setting is maintained by an off-on type of controller such as a Brown Pyrovane, or equal, or a time-proportioning controller such as a Whellco, or equals (Barber Colman) Capacitrol.

2.5.3 All thermocouple wiring is made up of 24-gauge Type-K (chromelalumel) thermocouple wire. This includes the control thermocouple probe 7.62cm (3 inch) depth in the center of the heating block, and the bomb-temperature. probe 5.842cm (2.3-inch) depth adjacent to each well that houses the bomb.

2.5.4 The heating block is insulated by applying a 12.7mm (0.500 inch) layer of asbestos ribbon around the side of the block and attaching a 3.81cm (1.500 inch) thick asbestos pad on the bottom. Additional insulation is provided by placing the completed assembly within a box or cylindrical-type enclosure of asbestos, or similar type of insulating material. An insulation-type cover is placed on top of the enclosure, allowing the gauges and valves to be readily accessible above the enclosure.

2.6 Before starting the test procedure, the interior of the bomb and the piping should be thoroughly cleaned and dried, and each SPB setup should be tested for any leakage. Also, the heating block assembly should be checked out at the desired temperature setting; this will indicate if the controller and heaters are working properly.

2.7 The body of the bomb should be only about one-half full with the sample, which is to be weighed accurately. After the bomb is loaded and assembled it is positioned within the well in the heating block. The block is placed inside the insulated en-- enclosure.

2.7.1 The pressure and temperature data should be recorded at least once per working day. If desired, the temperature of the bomb can be recorded continuously on a strip-chart recorder. A gas sample may be obtained by temporarily attaching an evacuated sample cylinder to the pipe extending from the diaphragm valve.

This valve, and the valve on the sample cylinder, opened to obtain the gas sample and then both are closed securelybefore detaching the sample container. The gas sample may be analyzed by the mass spectrophotometer or the infrared spectrophotometer. Instead of using an evacuated sample cylinder as a transfer medium, the gas sample may be transferred directly from the SPB to the mass spectrophotometer. The initial gas sample should be taken immediately after the setup is made or 1 day after the start of the test, then at specified periodic intervals. It is necessary to record the pressure within the SPB before and after each gas sample is withdrawn. At the completion of the test the residual sample may be analyzed by convenient techniques.

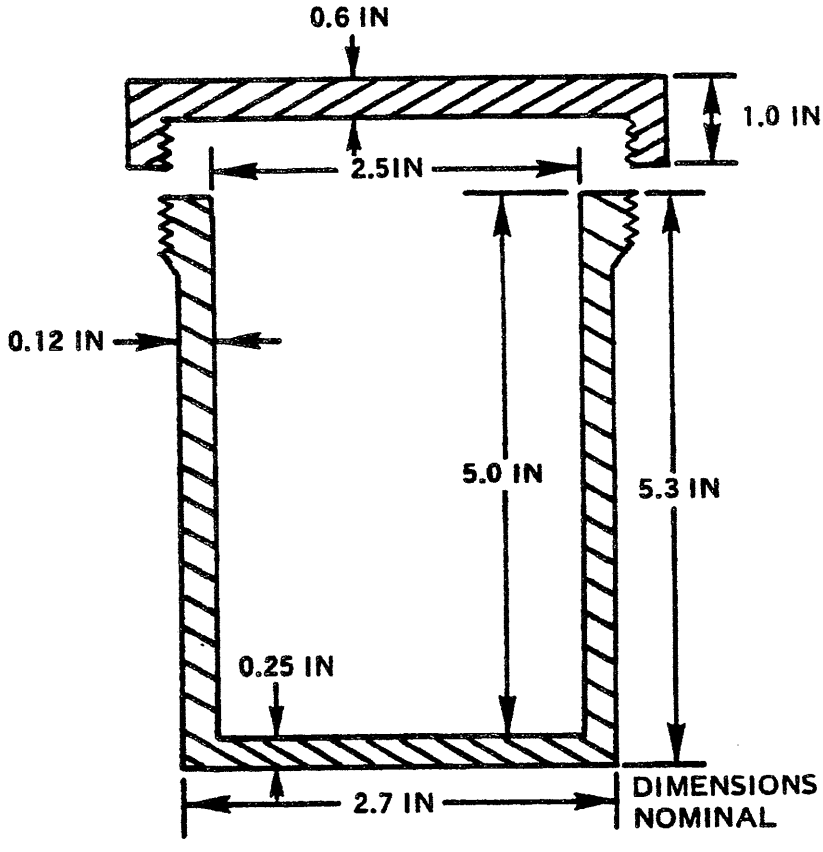

FIGURE 1 - SCHEMATIC DIAGRAM OF BASIC BODY OF SMALL-SCALE COOK-OFF BOMB (SCB).

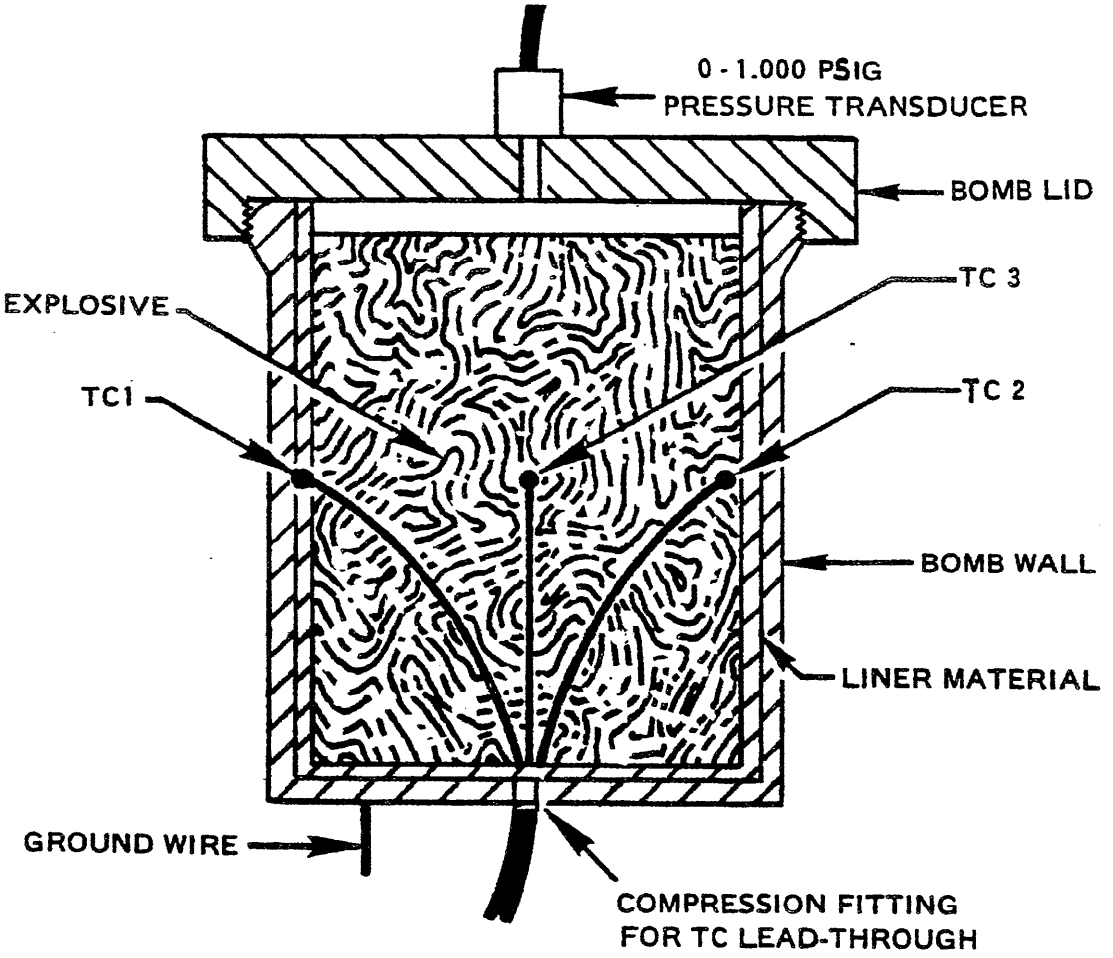

FIGURE 2 - SCHEMATIC DIAGRAM OF LOADED SMALL0SCALE COOK-OFF BOMB (SCB)

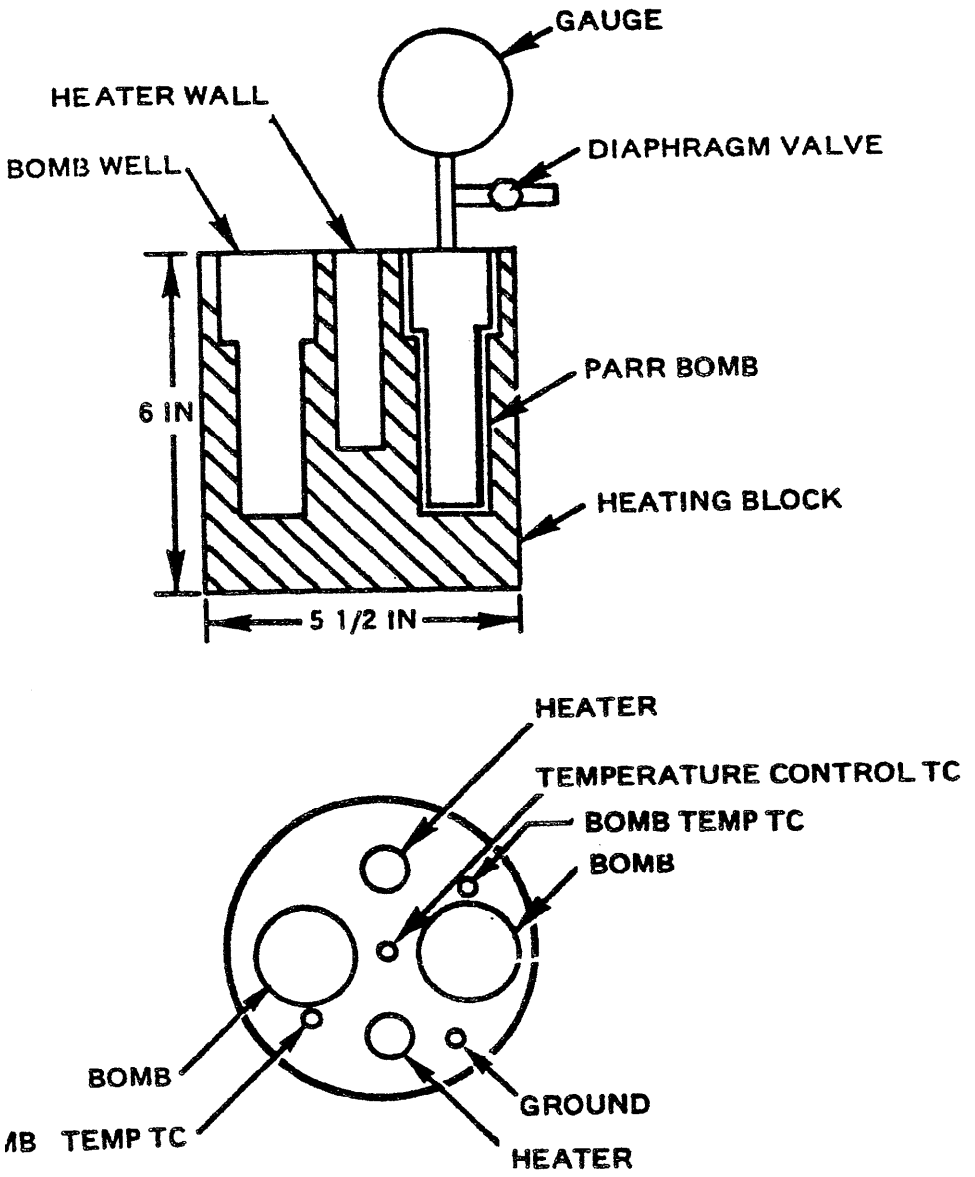

FIGURE 3 - SCHEMATIC DIAGRAM OF SMALL-SCALE PRESSURE BOMB (SPB) SETUP.

METHOD 14
SHOCK INITIATION SENSITIVITY

1. INTRODUCTION

1.1 When a high explosive (HE) is subjected to a one-dimensional shock of long duration at a pressure someshat below it detonation pressure, then the shock can travel an appreciable distance into the HE before transforming to a full detonation wave. The lower the pressure of the initial shock, the longer the distance and time of run till full detonation. At a given pressure, the shock sensitivity of HE will be indicated by its run distance, the more sensitive HE having shorter runs (so long as the initial pressure does not approach the detonation pressure). A series of shots at varying pressures provides a pressure sensitivity profile for the HE.

2. EXPERIMENTAL

2.1 The test HE is formed by an appropriate method into a square-based triangular wedge in the shape of an inclined plane. The angle of inclination must be kept small enough to minimize rarefactions as the shock wave exits the upper surface. The maximum useful inclination angle is 0.52360 to 0.61087 radians (30 to 35 degrees) for HEs with short reaction zones. (For various reasons of conveniences 0.39270 Radians (22 degrees, 30 minutes), has been employed at Pantes.) Because of the low length to diameter ratio (L/D) of this configuration, neither diameter nor confinement need be considered. Extinction due to edge effects cannot occur with such a small L/D. Any HE which cannot achieve detonation without strong confinement is not adaptable to the test in this particular form.

2.2 The donor system supplies a planar shock to the base of the wedge. At the thin end (toe), the shock immediately begins to emerge from the wedge through the top surface. The locus of the shock front on the top surfaces indicated by a distinct change in reflectivity. A rotating mirror streak camera is used to view the top of the wedge and obtain a distance-time record. Illumination is provided by an Argon flash bomb of the type used at Lawrence Livermore Laboratory.

2.3 The planar shock is provided by a donor based upon an explosive plane wave lens (PWL). An 20.32 cm (8-inch) diameter system (P-081, or equal is the smallest that should be used for any size wedge and is easily useful with wedges as large as 10.16 cm (4 inches) on the base. Materials requiring 12.7 to 17.78cm (5 to 7-inch) wedges require a P-120, or equal, lens. Because of differences in pulse duration, all shots in a comparison test series should be fired with lenses of the same size. For a particular shot, the desired shock pressure is obtained by a combination of booster HE and the attenuator plates on top of the PWL.

The PWL, booster, attenuators, and wedge are bonded together by very thin layers of diluted polyurethane elastomer. The final attenuator plate must be of a material whose Hugoniot Equation-of-State (HES) is known. The output pressure from this plate must be monitored, Probably the most accurate method involves observing the free surface velocity by an optical means (this requires polishing the surface and, if necessary, adding a reflective coating). A thin wire suspended above this surface and illuminated by collimated light can be used to cast a shadow on the refelective surface. As the surface moves, the shadow appears to travel at twice the surface velocity. A 0.127mm (0.005-inch) wire suspended on 6.35 to 12.7mm (0.250 to 0.500 inch) thick Plexiglas blocks works quite well. A very good collimated light source consist of an exploding bridgewire IEBW) placed at the focal point of a collimating lens. The EBW should be immersed in a fairly dense, transparent liquid such as E3 Freon, or equal. With a good light source and a well polished surface, it is often possible to observe the spray from the surface directly. On shots where this occurs, data from the direct observation should be given precedence over that from the reflected wire.

2.4 Output pressure can also he measured by various pressure gages but usually their accuracy is not so good as that of the free surface measurement.

2.5 The experiment is easily arranged so that the free surface observation appears on the same streak camera record with the HE wedge surface.

2.6 A schematic of the setup with typical parameters is shown in Figure 1. A list of some donor systems is given in Table 1.

2.7 A framing camera record (interframe time of about 0.5 μsec) is also obtained to provide qualitative information.

3. EQUATIONS

3.1 As seen in Figure 2, the distance the shoc has traveled into the wedge (Y) is related to the upper surface distance (Y_t) by;

$Y = Y_t \sin a$

which is seen on the film as R;

$R = MY_t \cos, (\theta - \alpha)$, M=magnification

so

$$Y = \frac{R}{M} \frac{\sin \alpha}{\cos (\theta - \alpha)} \qquad (1)$$

The shock velocity is then given by:

$$U_s = \frac{dy}{dT} = \frac{dR}{dT} \frac{\sin \alpha}{M \cos (\theta - \alpha)} = \frac{dR}{dx} \frac{W \sin \alpha}{M \cos (\theta - \alpha)} \qquad (2)$$

where
W = camera writing rate and
dR/dx = slope of trace on film (see Figure 3).

By similar argument, the free surface velocity of the final plate (U_{fs}) is given by:

$$U_{fs} = \frac{1}{2} \frac{W}{M} \frac{\text{Tan } C}{\sin \theta} = \frac{W}{M} \frac{\text{Tan } D}{\sin \theta} \qquad (3)$$

where
Tan C is the slope of the wire shadow trace on the film and

Tan D is the slope of the surface spray lines.

Unless it is known to be otherwise for the material in uses the approximation that $U_p = 1/2\ U_{fs}$ is used.

As stated earlier, the HES for the final attenuator must be known. For most materials it is possible to write this as a linear relation between shock and particle velocities:

$$U_{s_1} = A + B\, U_{p_1}.$$

From the streak record, the initial shock velocity in the wedge, U, U, can be determined.

Then; (4)

$$U_{p_w} = \frac{4\rho_1 B U_{p_1} + \rho_1 A + \rho_w U_{s_o} - \rho_1^2 A^2 + \rho_w^2 U_{s_o} + 8\rho_1 \rho_w B U_{p_1} U_{s_o} + 2\rho_1 \rho_w A U_{s_o}}{\rho}$$

Subscript 1 refers to the attenuator, w refers to the wedge.

Finally, the pressure transmitted to the wedge is

$$P_w = 10 \rho_w U_{s_o} U_{p_w} \qquad \text{P in kilobars; } U_s, \text{ Up in mm/µsec} \qquad (5)$$

4. ANALYSIS

4.1 The streak record is converted to digital data by reading it on a precision x-y comparator The reading increments at Pantex are usually of the following order:

Shock Wave in Wedge: 50-100pm of real travel

Attenuator Free Surface: 0.02-0.05 µsec

4.2 4.2 The free surface data is linear over a very wide range, making it easy to calculate the derivative and thus the free surface velocity.

4.3 The wedge trace is more complicated. There is usually an initial region of constant or slowly changing derivative. The initial derivative must be estimated reasonably well, for it represents U_{S_0}, which is necessary to calculate the transmitted pressure. The behavior of the rest of the trace is dependent upon the nature of the HE being tested but two broad categories serve well for discussion.

4.4 Standard HE With Ordinary Binder; these HES usually display little acceleration until a transition zone occurs. This is usually a short zone of rapid acceleration ix-i which th transition to detonation occurs. The HE quickly reaches its stable detonation velocity and acceleration ceases. There is usually a distinct point where the shock front becomes luminous and this is termed the point of detonation. A distance (DD) and time (TD) to detonation can be clearly measured.

4.5 HE-Oxidizer-Fuel Combinations; these materials usually do not display a distinct detonation point or even a transition zone. Instead, there is a long period of acceleration in which a stable velocity is approached almost asymptotically. Luminosity may increase quite slowly. It is still possible to study detonation behavior as a function of pressure, but description of the transition to detonation involves ranges of time and distance rather than distinct values Work on an HMX-ammonium perchlorate-aluminum-system showed that such an HE can display two such gradual trasitions with velocity steps in between.

4.6 Calculations; With the more ordinary materials it is usually sufficient to determine U_{s_0}, the time and distance to detonations and the final detonation velocity. The first and the latter are usually easily determined by plotting the R-T data, visually locating linear segments, and applying linear regression.

4.7 The more exotic systems are not so easily studied and may exhibit interesting structure throughout the trace, making complete analysis desirable. Experience with digital filtering indicates that it is a very powerful tool for obtaining a continuous velocity profile from this type of record.

5. INFORMATION DERIVED

5.1 With standard type HEs, a series of shots at varying pressures provides a relationship between transmitted pressure and delay to detonation. It has been found empirically that str5ainght lines usually result from log-log plots of transmitted pressure versus time to detonation, distance to detonation, and excess transit time (XSTT = TD - DD/U_D where U_D is the final detonation velocity).

5.2 Those materials without distinct detonation points usually display an area of maximum shock acceleration which can be used as a substitute for purposes of comparison of sensitivity. If consistent stable detonatiOn velocity (u_D) is observed throughout a test series, then a total XSTT can be calculated on each shot. by simply measuring R and T at some point after U_D has been reached. Tehn XSTT = T =R/U_D. A log-log plot of this XSTT against transmitted pressure should behave much like that for standard HEs. For HEs which do not exhibit normal detonation, the continuous shock front velocity history can provide insight concerning the sequence of events leading to detonation or to failure. In additons both the streak and framing camera records can yield indirect evidence of reactions taking place well behind the shock front. In fact, with the HMX-AP-A1-binder system referred to above. (4.5) this was the key to the discovery of its two-level reaction sequence.

5.3 As seen in the Equations Section, U_{s_0} and a corresponding U_P are determined for the test HE on each shot. After several shots, these points can be used to describe a so-called unreactive HES in terms of U_S-U_P relationship. This permits quite accurate estimation of the pressure that any known donor would transmit to the HE.

replace

Table 1 (Donors Used as Standards)

Booster 2.54cm (1 inch) thick	Attenuator(s)		Approximate pressure, MPa(kbars)	
	Material	Thickness, cm(in)	Output	Input to PBX-9404
CB-3	Aluminum (2024)	1.27(0.500)	25000(250)	19000(190)
TNT	Aluminum (2024)	1.27(0.500)	18500(185)	13500(135)
LX-04-1	Brass	2.54(1)	27000(270)	10500(105)
CB-3	Brass	2.54(1)	24500(245)	9500 (95)
Baratol	Brass	1.27(0.500)	18000(180)	6500 (65)
Baratol	Plexiglas	1.27(0.500)		
	Brass	1.27(0.500)	15000(150)	5500 (55)
Baratol	Aluminum(2024)	2.54(1)		
	Plexiglas	1.27(0.500)		
	Brass	1.905(0.750)	10000(100)	3500 (35)
Baratol	Brass	1.27(0.500)		
	Plexiglas	1.27(0.500)		
	Brass	1.27(0.500)	6000(60)	1900 (19)
Baratol	Brass	2.54(1)		
	Plexiglas	2.54(1)		
	Brass	1.27(0.500)	5500(55)	1700 (17)

NOTE: All systems employ a P-081, or equal, plane wave lens. All boosters and attenuators are 20.32cm (8 inches) in diameter.

TYPICAL PANTEX PARAMETERS

θ = 45°
α = 22°30'
PWL : P-081
HE BOOSTER: 1-INCH THICK
ATTENUATORS: 0.500 INCH MINIMUM
FILM MAGNIFICATION: 0.6 - 0.8

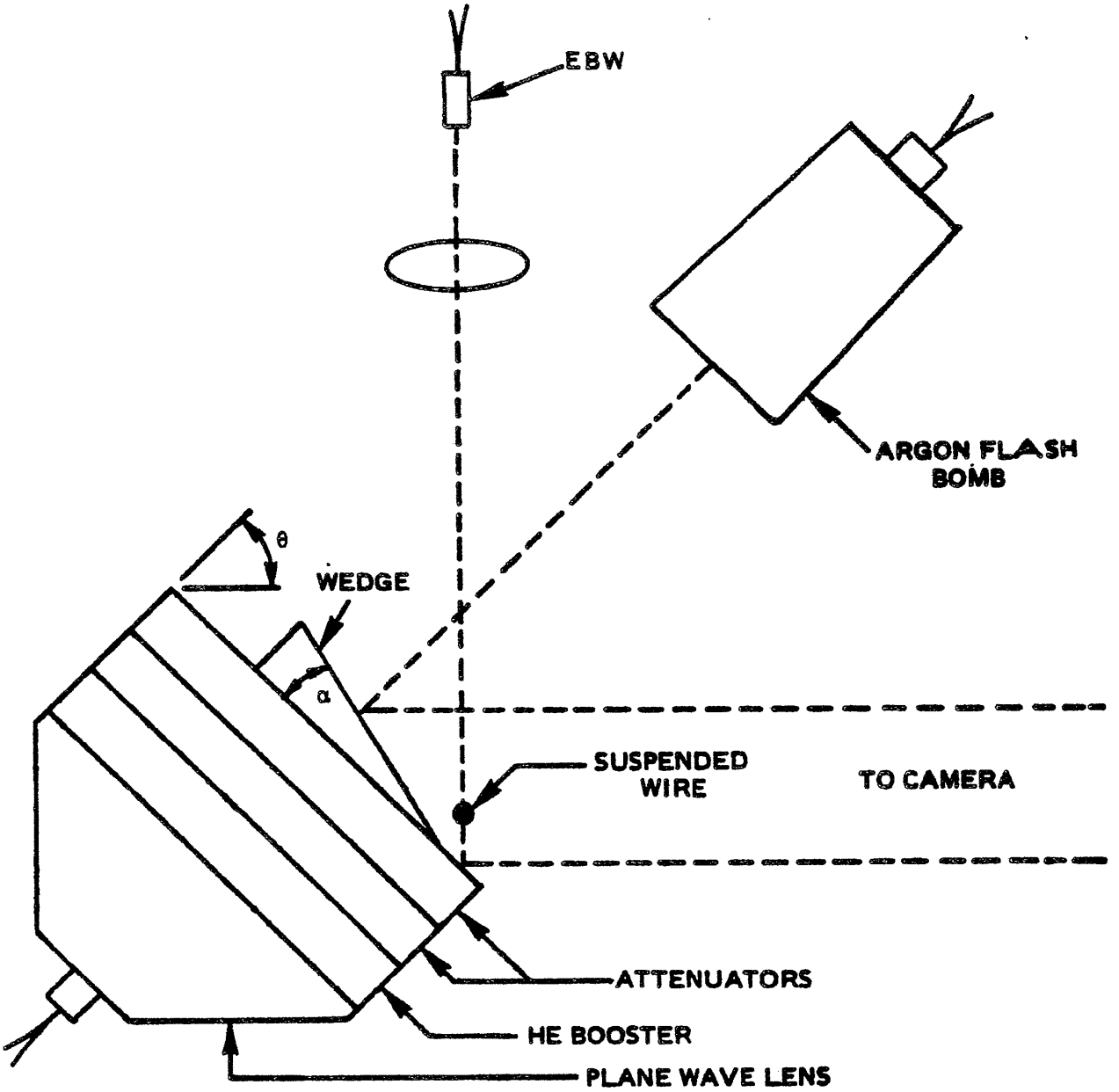

FIGURE 1 - WEDGE TESTSET-UP.

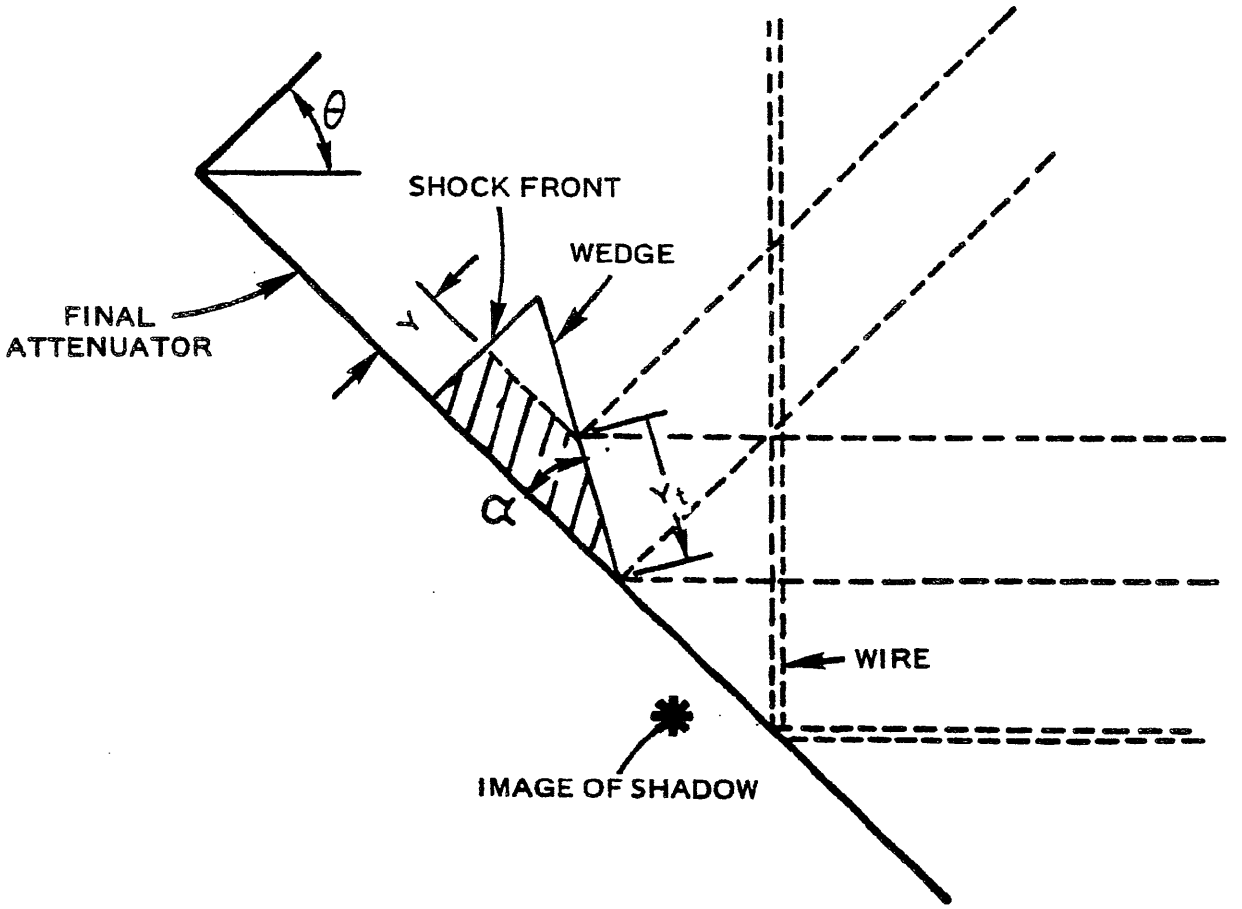

FIGURE 2 - DETAIL OF WEDGE

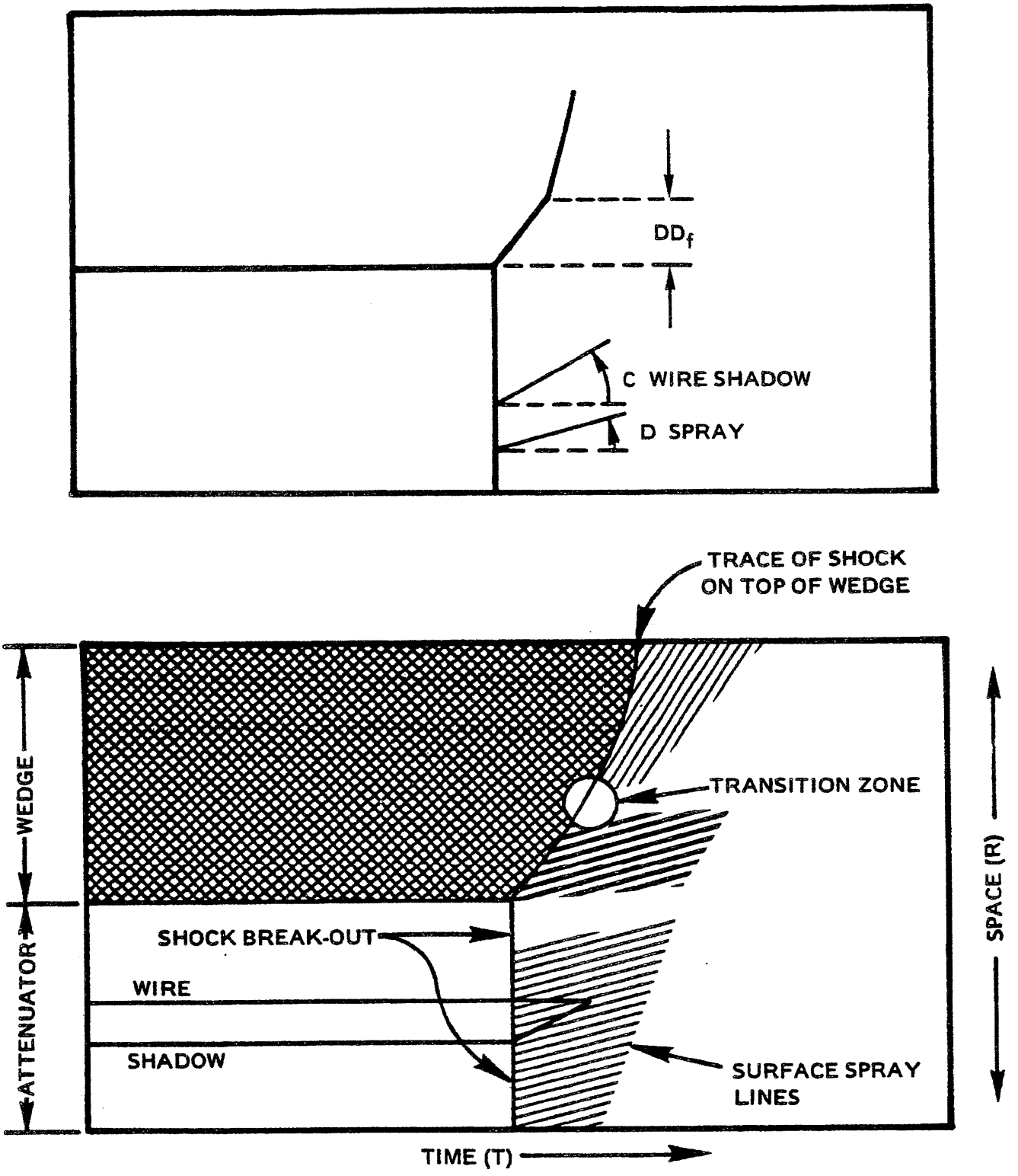

FIGURE 3 - SCHEMATIC OF TYPICAL RECORD.

METHOD 15

Smear-Camera Techniques

1. INTRODUCTION

1.1 Bassically, a smear camera is an instrument which records continuously (as contrasted with intermittent recording, as in a framing camera) the changes of light intensity along a line, as a functiuon of time. Using a detonating cylinder of explosive as an example, the modes of employment of the camera can be divided into three groups according to the orientations of the camera slit and optical axis to the axis of the explosive charge: (1) velocity measurement slit parallel to cylinder axis, camera optical axis normal to cylinder axis; (2) time-of-arrival meas-uerment slit perpendicular to cylinder axis, camera optical axis parallel to cylinder axis: and (3) profile shot slit and camera optical axis perpendicular to cylinder axis. It is this fundamental property of resolving in time the changes of light intensity along the slit that makes the camera so useful.

1.2 Generally, the method of employment of the camera is rather straightforward, as in the determination of the detonation rate in a cylinder, or a slab of explosive. Even here a few "tricks" can be applied to improve significantly the quality of the record. These improvements often produce acceptable records yielding data that otherwise would not have been obtain-ed. The problem in smear camera photography can be simply stated: how can one cause a phenomenon$_s$ such as a shock wave, to produce light intensity changes (and thus signal its location) of sufficient magnitude to permit the camera to record the change? Obviously, if the slit is aligned in the desired manner along the path to be followed by the phenomenon, a position vs. time record is obtained, channels, judiciously placed, could produce highly accurate space-time data. This method has found a great deal of use in obtaining experimentally determined equation-of-state data for solids fop pressures ranging into the hundreds of megapascals (kilobars) 6.1.

1.3 A variant of the shocked-argon system is to use plastic microball.eons glued to the surface under observation. This method hasalso found utility in equation-of-state work on solids 6.1.

2. LIGHT-REFLECTION SYSTEMS

2.1 For events that are not self-luminous, some external intense light source is required such as an exploding wire, 6.5 or shocked argon gas 6.4. The light, reflected off the surface to be studied, acts as a mass-less probe, interposing no interfer-ence with phenomena being observed. Apparently first used in 1953, 6.5-6.7. We have found this system to be the basis of one

of the most useful techniques to be employed with the smear camera. For example, Figure 1 shows the arrival of explosive-generated shock waves at the free surfaces of aluminum and steel. The sharp change in light intensity clearly and instantaneously depicts the arrival of the shock wave at the surface. The delicacy of this system can be appreciated by noting the results obtained with steel, where the pairs of parallel lines are interpreted to indicate the arrival at the free surface of the faster-moving elastic wave ahead of the slower-moving plastic wave .

2.2 We have expanded the light-reflecting technique, for use with nonreflecting or poorly reflecting materials, by employing a thin 15.24 μm (0.0006-in) aluminized plastic (Mylar, or equal film. By placing the 2.54 μm (0.0001-in) thick aluminum layer against the surface to be studied and viewing through the transparent plastic, such surfaces are rendered highly reflective. Attachment of the plastic film to the surface is accomplished by adding a drop of water between the surface and the film, then pressing the film gently to remove the excess water. (The addition of a small amount of a surface-tension-diminishing detergent to the water is beneficial in this connection.) This system has found considerable use in this Laboratory in studying such processes as the build-up to detonation of an explosive under shock loading.

3. SHADOWGRAPH SYSTEMS

3.1 When reflected light is neither practical nor desirable, ordinary shadowgraph techniques are used. For example, Figure 2 contains a shadowgram of the detonation of a thin slab of explosive immersed in water, from which highly accurate space-time data can be obtained. If the detonation wave moves normal to the explosive-water interfaces by extrapolating the resulting water-shock velocities back to that interface, proper data can be obtained to permit a calculation of the Chapman-Jouguet pressure of the explosive 6.10.

3.2 A variant on this scheme is to place the light source and the camera on the same side of the phenomenon under study. Behind the experimental subject is placed some highly reflecting material which is viewed by the camera. As the experiment progresses, the reflected light is modified (or even extinguished) by either a shadow or a light-refracting mechanism (such as a shock), and thus space-time data are obtained. Various light-reflecting systems have been used Successfully such as mirrors or wires 6.11. (Scotchlite reflectors have been used in framing camera shadowgraph photography. The authors have found no references to such use with a smear camera, but can see no reason why it should not be applicable.)

3.3 When exceedingly small changes in light intensity are encountered, schlieren light systems are useful.6.12 We have used it to photograph the extremely weak shocks transmitted in Plexiglas, or equal by an exploding wire Figure 3. In a similar manner, by placing the entire optical system (light source, camera, knife edge, etc.) on the same side of the subject, a schlieren picture with reflected light can be obtained. We have recorded very low-amplitude, low velocity waves in solids in this manner.

3.4 Streak interferometry is another variant of shadowgraph technique which can be a powerful tool for studying transient phenomena.6.13

4. MULTIPLE-SLIT SYSTEMS

4.1 Normally, a smear camera records events occurring along a single line: the line immediately behind an exterior slit (1.e. a slit located at the phenomenon) or else the line along the projected image of a slit that is located at the camera itself. Increased information can often be obtained by the simultaneous use of several slits. These slits can be parallel or crossed, continuous or discontinuous, the exact configuration depending on the desired results. Thus five parallel slits were used in Reference 6.1 to obtain simultaneously data of shock-wave arrival over an area (rather than along a single line).

4.2 Discontinuous, parallel slits are sometimes more convenient, as shown in Figure 4 where eleven discontinuous "slits," each consisting of 25 points, were used to record the formation of a Mach wave in Plexiglas or equal formed by the collision of two regular shocks. 6.9

4.3 Multiple slits need not necessarily be parallel; for selected purposes one can even have them intersect.

5. MISCELLANEOUS SYSTEMS

5.1 Upon occasion it is desired to observe the arrival of a shock or detonation wave at a point not directly observable by the camera. Mirrors are usually used in this case; however, occasions arise when even these cannot serve the purpose. We have found that light pipes 6.14 of 1-mm diameter glass rods gave acceptable signals (Figure 5) thus permitting the camera to record time-of-arrival data at normally inaccessible points.

5.2 When the motion of a phenomenon is essentially uniform, the smear camera can be modified to produce a "still" picture. This is done in a relatively simple manner by matching the writing speed of the camera with the speed with which the image is displayed on the film. 6.15

This technique has the salutary effect of increasing the time of exposure of the phenomenon, and thus finds occasional use in recording selected steady-state phenomena that emit only low-intensity light. A variant of this technique has been used at this Laboratory to measure fragment velocities. 6.16 In this method the anticipated velocity is approximately matched and the flying fragment is recorded as it passes between the drum camera and three lighted slits. This produces a photograph with three exposures which by suitable analysis provides an accurate measure of the fragment velocity.

5.3 The simple smear camera can be readily converted into a spectrograph by placing a transmission grating or a prism before the camera lens, using camera slit as the spectrograph slit. These time-dependent spectra could then be converted to temperatures (e.g. detonation temperatures) by appropriate calculations. For highly luminous phenomena, such as an electrically exploded wire, these spectra are relatively easy to record.6.17 The light from shaped-charge jets can also be recorded and analyzed by this means.6.18 For phenoment emitting light of lower intensity, velocity synchronization permits longer exposures with resulting acceptable spectrograms.6.15

5.4 The use of color film has added another dimension to the smear camera. At NOL an unambiguous change was recorded in the wave length of light reflected from a metal free-surface when a shock wave reached the surface from within the metal.6.19 (A color slide of this phenomenon was shown at the 5th International Congress on High-Speed Photography; October 1960; Washington, D.C. Since the significant features of this photograph would be lost in black-and-white reproductions no copy was included for this publication.) Exploitation of the potentialities of this new tool has only begun!

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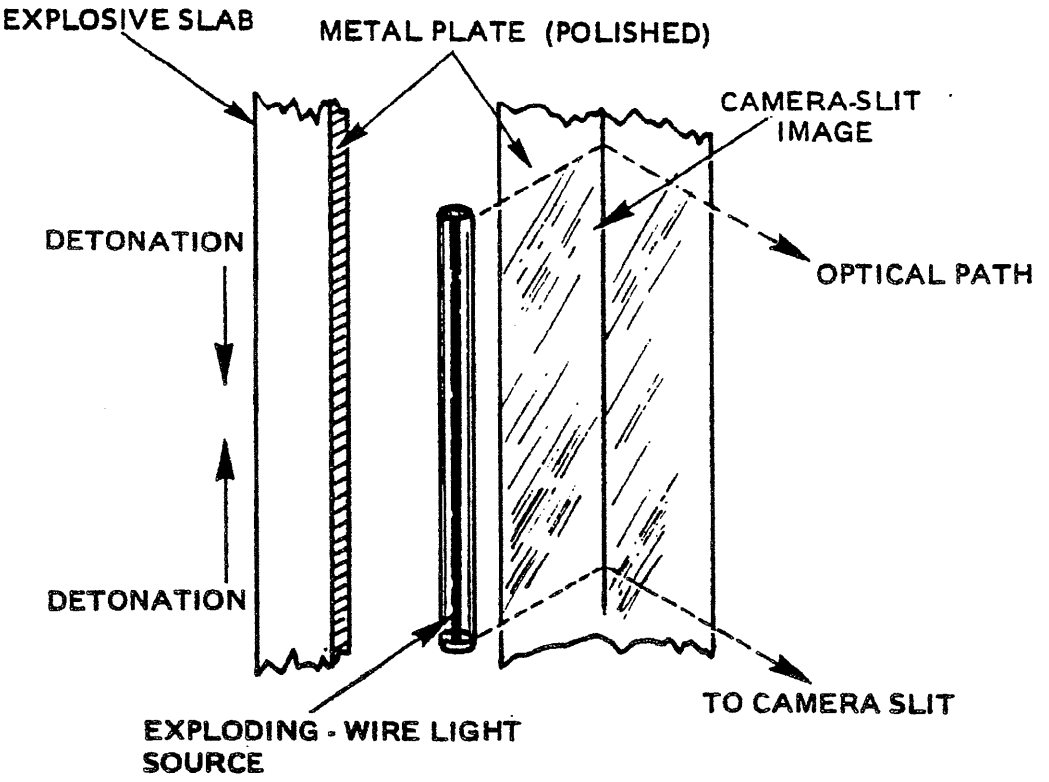


FIGURE 1 - REFLECTED LIGHT TECHNIQUE REVEALING THE ARRIVAL OF TWO COLLIDING SHOCK WAVES AT THE SURFACE OF A METAL PLATE.

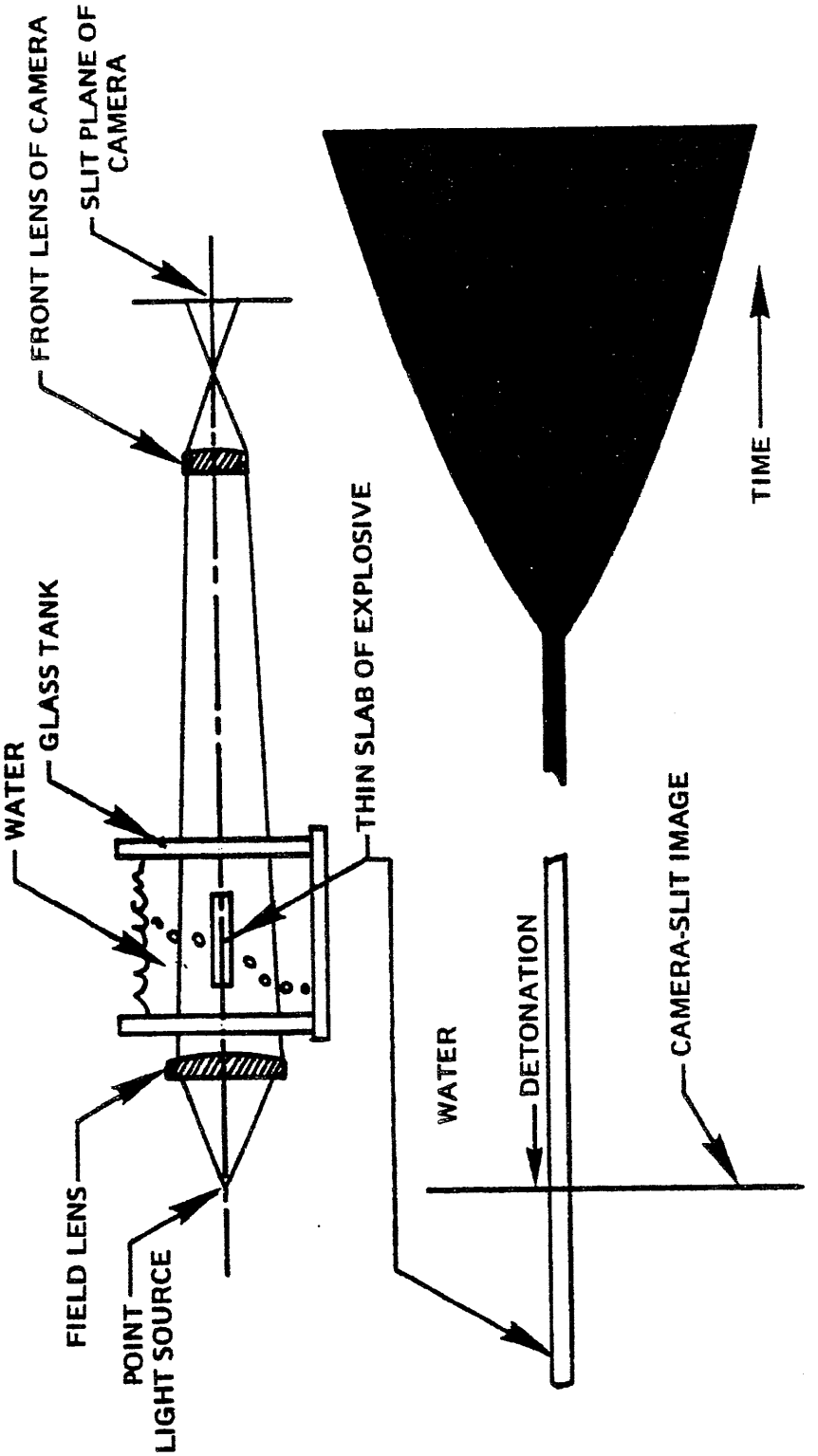


Figure 2 - Smear-camera shadowgram of the shock configuration produced by a thin sheet of explosive detonating under water. The upper figure shows the experimental arrangement and the lower figure indicates alignment of the charge in relation to the camera slit

FIGURE 2

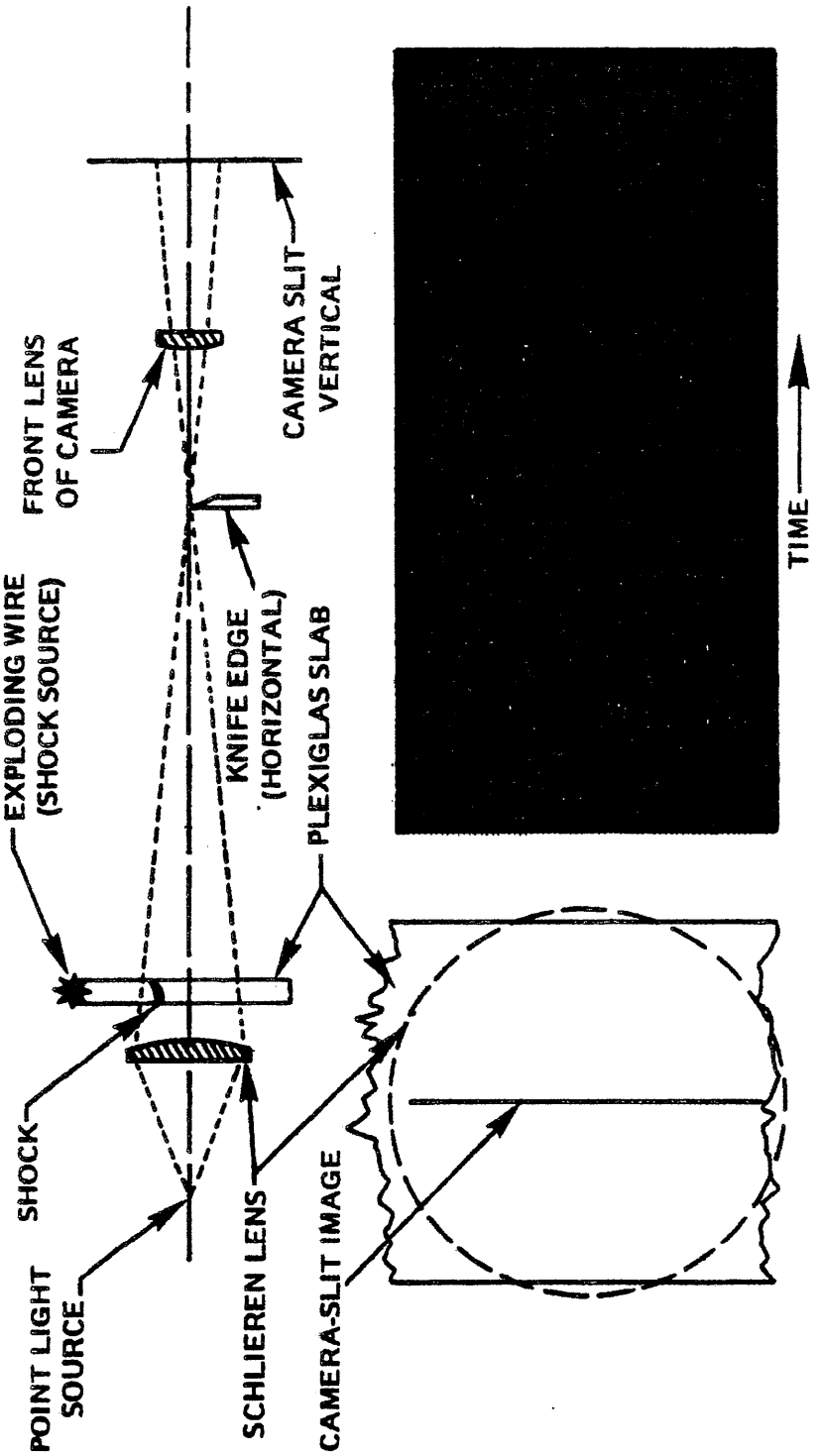


Figure 3-A smear-camera schleiren photograph of weak shock waves generated in Plexiglas by an exploding wire. Such waves are to weak to be recorded by the shadowgraph technique of Figure 2.

FIGURE 3-A

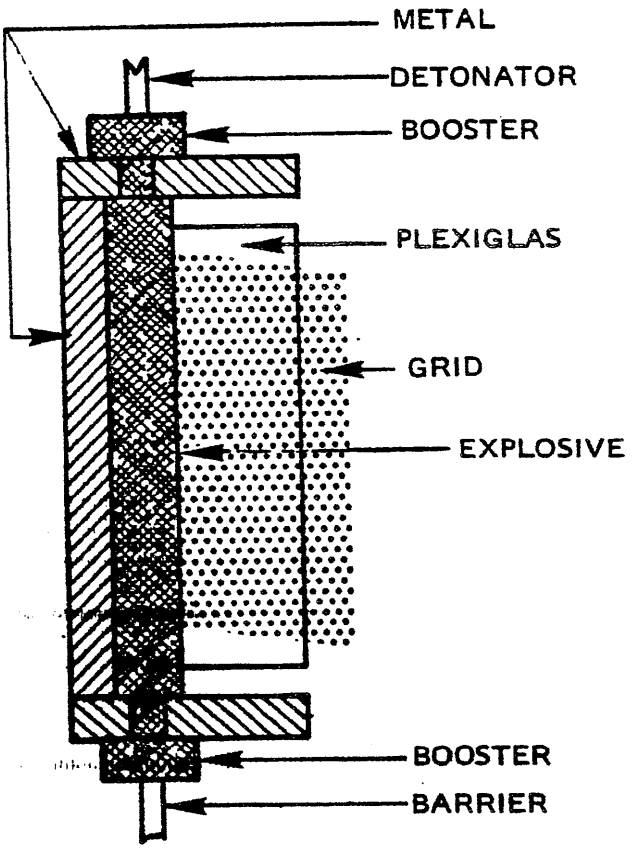
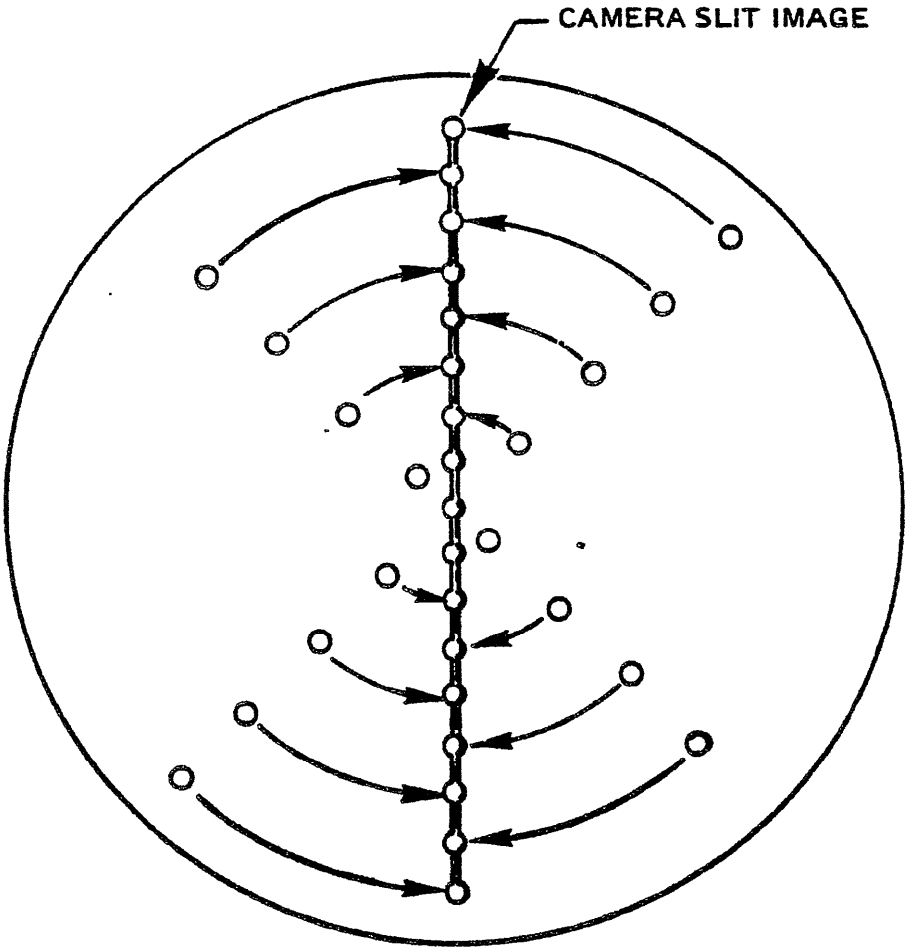


FIGURE 4 - USE OF A POINT-GRIND SYSTEM IN SMEAR PHOTOGRAPHY: OBSERVATIONS OF MACH SHOCK FORMED IN PLEXIGLAS BY COLLISION OF TWO REGULAR SHOCKS.



SEVENTEEN LIGHT PIPES IN FORM OF A CROSS ON THE FACE OF THE FIXTURE, ALIGNED TO A STRAIGHT LINE ON SIDE OF FIXTURE FACING CAMERA

FIGURE 5 - FEASIBILITY STUDY OF LIGHT-PIPE APPLICATION IN SMEAR PHOTOGRAPHY: ARRIVAL OF A DETONATION WAVE ON THE FACE OF PLANE-WAVE GENERATOR.

METHOD 16
CYLINDER EXPANSION, THE GURNEY CONSTANT AND WARHEAD FRAGMENTATION

1. INTRODUCTION

1.1 An important problem faced by the designer of fragmentation warheads, is that he must maximize the energy which is transferred from explosive to meatal during the detonation. The most frequently encountered configuration is that of an explosive-filled metal cylinder detonated by a wave moving axially. The best scaling law that has been-devised for this condition is that of Gurney, who disregarded detonation conditions, shock effects in the metal, and assumed implicitly that all the energy of the explosive is conserved. His equation for cylinders is:

$$v = \sqrt{2E}\left\{\frac{C/M}{1+0.5\ C/M}\right\}^{1/2}$$

where v is the velocity to which.the metal is accelerated by the explosives E is unit energy content of the explosive, C is the weight of the explosive and M is the metal weight. This expression of velocity in terms of C/M implies that weight-ratio sealing of explosive and metal is of prime importance and that dimensional scaling need not be considered at all. The term $\sqrt{2E}$ has the dimensions of a velocity as was pointed out by Gurney in his original repent.

2.2 Determination of the Gurney, constant of a warhead explosive is logically made in the cylinder expansion test where the explosive contained in a metal cylinder is end-detonated and the maximum lateral velocity of the metal is measured. The geometry resembles that of most fragmentation warheads, particularly as to lateral confinement of the explosive. The dimensions of the cylinder can be chosen so as to give the full run-up to detonation velocity before reaching the location of fragment velocity measurements, and teh end-release dffects can be kept far enough downstream so as not to affect fragment velocities. Other techniques for evaluating explosives, while of full value in their own contexts, are all less applicable to the prediction of effects in the fragmentation warhead. The plate-push test transfers only about one-fourth as much of the energy of the explosive to the metal

as does the cylinder expansion; also, the air-cushion between explosive and plate is highly unrepresentative of the warhead configuration. Other rating tests such as the plate-dent, and ballistic mortar and the Trauzl lead block are even more unrepresentative, geometrically.

1.3 The cylinder expansion test has been in use for scme time. Early work at the Naval Ordnance Laboratory (NOL), White Oak successfully used the streak camera to record metal velocities; techniques developed by the Lawrence Radiaiton Laboratory (LRL) and the Losw Alamos, Scientific Laboratory (LASL) in this country and the Atomic Weapons Research Establishment (AWRE) in Britain have given results of good precision and in agreement amoung the three organizations.

2. BACKGROUND

The cylinder expansion test is any test performed where a metal cylinder (relatively thin walled), is loaded with an explosive and this explosive charge detonated as the detonation occurs, the expansion of the cylinder wall is observed and recorded in such a way that the rate at which the wall moves outward can be followed up to the point where the expanding cylinder wall is obscured by the reaction products as they break through the wall.

2.1 The method for observing the wall’s expansion varies. It has been recorded through the use of electronic pin probes and raster oscilloscope recording systems as well as with flash x-ray techniques. It has also been accomplished by the use of streak cameras and framing cameras. The Lawrence Radiation Laboratroy method uses a streak camera for the recording of the wall velocity and a pin probe method for determining the detonation velocity of the explosive while it is expanding the walls of the test cylinder. The AWRE uses both electronic pin probe and streak camera methods to record the wall expansion, and pin probes for the detonation velocity. There is some reason to believe that perhaps in the early stages of the expansion the pin probe method may be more accurate, but the data reduction is also a bit more difficult in some respects than with the streak camera record.

2.2 A standard cylinder geometry is selected and manufactured precisely from a standard metal. The cylinder thus produced, is loaded with a carefully manufactured explosive charge of the material to be investigated.

2.3 The test assembly is then instrumented in any of those methods mentioned above and fired, recording the detonation velocity of the charge, and also the radial expansion of the

cylindrical case, as a function of time. Reduction of these data permits an assessment of the explosive's behavior during the event.

2.4 When various explosives are rated in the standard geometry, the relative performance of these explosives becomes readily apparent. This permits the warhead design engineer to select an explosive compoundfor a specific feature of its performance.

3. CYLINDER EXPANSION (CYLEX) TEST

3.1 Experimental Considerations. The test device consists of a 2.54-cm ID, precision manufactured copper cylinders 12 diameters long and with a wall thickness of 0.25 cm.

3.1.1 Copper was chosen because in cylindrical geometry it is capable of nearly twice the expansion steel demonstrates before the wall ruptures. thus containing the explosive gases until terminal wall velocity is reached. At present, detonation velocity of the explosive is measured using electronic switches.

3.2 Two circuits (each using a nanosecond counter) are employed on each experiment. This permits a more confident determination of the detonation wave's transit time through the measured interval--the time interval is relatively long (25 μ-sec)and the distance traversed is about 21.5 cm. The counters record the signals generated from printed circuit boards, which are placed on the cylinder walls in an area which does not affect the wall and its expansion behavior, but which does record the detonation velocity of the explosive accurately。

3.3 The castable plastic bonded explosive used as the standard of comparison in the Cylex test is PBXN-101 rather than Composition B because it is a more homogeneous composition, and is structurally a considerably better explosive. Further, in making this choice, the undesirable variability of the meltcast TNT explosive system is avoided.

3.4 The instrumentation for this test consists of a streak camera to monitor the expanding cylinder wall and electronic means to record the detonation velocity of the explosive as it is expanding the test cylinder wall. The camera is a Cordin, or equals 70 mm streak camera, which records its image on a large strip of film. Optical magnification is selected for each explosive in order to provide maximum accuracy and precision in recording the data from the firings. The writing speed of the camera (again selected for each explosive compound to maximize the sensitivity of the data recording) is recorded with a period lockout count circuit, so as to obtain as precisely as possible, the exact writing speed of the camera during the revolution of the mirror on which the experiment was fired.

3.5 The printed circuit board pin probe arrays are capable of being semi-mass produced to close tolerances. In addition, they are compatible with automated-record-reading machine calibration procedures.

3.6 The test cylinder is placed at an appropriate distance in front of a tracing paper screen which is illuminated by an argon-filled explosive flash lamp. This system provides aht proper contrast for good photographic rendition of the dynamic event (Figure 1).

3.7 An optical alignment is accomplished through the use of a Laser. The cylinder assembly is so positioned that the projected slit image of the camera which records the radial velocities, one on the upper side of the picture and one on the lower side of the picture, will cross the cylinder at a point at least 6 charge diameters from the initiation end. It has been found that in a series of experiments, where the projected camera slit images were placed at different locations along the cylinder, it was not until 6 diameters from the initiated end of the cylinder that the wall velocity reached a steady state value. Recorded wall velocities remained constant until 1.5 diameters from the free end of the cylinder. After this distance, the wall velocity values again varied downward from the constant, maximum values.

3.8 Data reduction for Cylex testing is an automated procedure see 4.4. It consists of a Mann, or equal, Comparator using IBM, or equal card printout to actually read the data from the film. A computer program written on the IBM 1130, or equal, computer smoothes the radius and time data, fits the data, and then the IBM 1627, or equal, plotter plots it in various ways. one of the interesting plots is the smooth radius data versus time ($(R-R_o)$ versus T) (Figure 2). Figure 3 displays the velocity obtained from the data plotted in Figure 2 as a function of time also. These two plots can be handled either geometrically or analytically to provide a velocity at a radius. This is the first bit of information specifically wanted.

3.9 The final data of interest from the Cylex test is the Alpha or Gurney constant. This is a factor used to calculate initial fragment velocity from an explosive. Figure 4 is a plot of the Gurney constant as a function of time. However, this plot is somewhat fictitious since there is only one Gurney constant for any given geometry, and the constant does not evolve. However, it proves to be easier to allow the computer to calculate

something that is called Alpha and disregard the data until the 19-millimeter expansion point is reached. Therefore, the Gurney values that are given relate to information obtained from Figures 2, 3 and 4.

4. Sources of error in the Cylex Test.

4.1 If the camera's slit should be tilted away form normal or if the charge should be placed in an orientation other than parallel to the camera's time axis, erroneous velocities will be recorded. However, in monitoring the wall's expansion from both sides of the cylinder, a simple averaging procedure will remove all errors introduced in this manner.

4.2 By using a Laser to align the elements of the experiment before the camera, nearly optimum photographic conditions are obtained. This factor plus two others, (1) the standardization on one test geometry, and (2) working at an optical magnification of or near unity, results in high quality photographic records which make precision record reading possible.

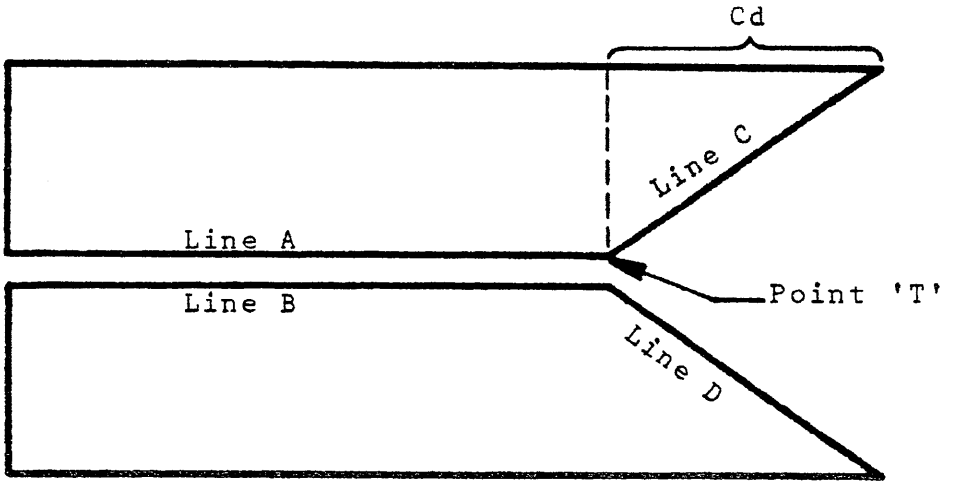
4.3 The velocity of the detonation which is responsible for expanding the cylinder wall is on the order of four to five times higher than the velocity with which the expanding wall is moving. Because of this fact, then, in the time it takes for a point on the wall to move outward 1 millimeter after the detonation front has passed, the detonation wave will have run down the cylinder, 4 millimeters or more. For this reason, great care must be taken to insure that the pin contacts are all placed at both the exact same distance from the cylinder wall and as close as possible to the wall.

4.3.1 Two factors have combined to produce precision results in detonation velocity measurement. The first of these is the production of flat claibrated pin probe arrays through the use of substantial dimensionally stable printed circuit board materials. Second is the assurance that the plane of the contacts on this board is perpendicular to the cylinder axis.

4.4 Cylex Data Reduction Procedure; The following procedure is used for reduction of data from film strip records:

4.4.1 The film strip is read on the Mann, or equal, Comparator in conjunction with a Telecordex, or equals unit and an IBM, or equal, Summary Card Punch.

4.4.2 When the film has been placed on the Comparator the following steps are followed:



4.4.2.1 The film is first aligned in the comparator such that moving along line A from one end of the line to the other will produce a deviation in Y counts (vertical measurement) of no more than +5 machine counts.

4.4.2.2 When film has been properly aligned, an origin point is then determined. This orgin point is normally a point at the extreme left end of line B. When the origin point has been determined, the X and Y digitizers are set to 0.

4.4.2.3 The next step is *to* find the diameter of the Cylex tube in machine counts. In order to obtain this distance, six readings are made of the vertical distance, six readings are made of the vertical distance between lines A and B. The measurements would be punched on cards in the Following manner:

Reading 1	X=O counts	Y=30000 counts
Reading 2	X=5000 counts	Y=30005 counts
Reading 3	X=10000 counts	Y=30000 counts
Reading 4	X=15000 counts	Y=30001 counts
Reading 5	X=20000 counts	Y=29998 counts
Reading 5	X=25000 counts	Y=30003 counts

Past experience has shown that taking these measurements at increments of 5mm in the X (horizontal) direction of movement produces a better average of the vertical distance between lines A and B than taking the measurements at shorter or longer intervals of X.

4.4.2.4 The next step is to obtain readings for trace line C. A minimum of 100 readings are needed for this line. In order to determine how often this line should be read, the following procedure is used:

4.4.2.4.1 The film is advanced to point 'T' on the film and is then raised vertically to the top of the trace pattern and the distance in X counts is recorded. The film is then advanced to the end of the trace pattern and that distance in X counts is recorded. The first distance reading is then subtracted from the second distance reading and this value is distance Cd. Distance Cd is then divided by 100 to obtain the number of machine counts needed in order to obtain 100 readings of trace lines C and D.

4.4.2.4.2 To begin reading trace line C the film is advanced to point 'T' and the following procedure is used:

Assume that the X counts at point 'T' equal 27000 machine counts. It is desired to snake one reading on line A before the trace line C is read. Assume also that it has been determined that trace line C is to be read every 300 machine counts in the X direction of movement. From point 'T' the film is advanced 300 counts in X to the left of point 'T' on line A. When this point has been reached the Y digitizer is set to O machine counts. Therefore the first reading for trace line C is equal to 26700 counts in X, and 0 counts in Y. From this point a reading is made adding 300 machine counts in X for each reading on trace line C. As each reading is made on trace line C the Y value will increase positively in machine counts as it follows the trace line.

Example: Example: Trace line C readings

Reading	1	X=26700	counts	Y=00000	counts
Reading	2	X=27000	counts	Y=00000	counts
Reading	3	X=27300	counts	Y=00258	counts
Reading	4	X=27600	counts	Y=00570	counts

Notice that on trace line C both the X and Y counts increase positively.

4.4.2.5 When trace line (2 has been completely read the film is returned to 'T' and then lowered vertically until line B is reached. For comparison purposes, the readings of the top and bottom trace should begin at the same point in the X direction of movement and readings of trace line D should be made at the same interval of X as was used for trace line C.

Example: Trace line D readings

Reading	1	X=26700	counts	Y=00000	counts
Reading	2	X=27000	counts	Y=-00001	counts
Reading	3	X=27300	counts	Y=-00286	counts
Reading	4	X=27600	counts	Y=-00573	counts

Notice that on trace line D the X counts increase positively in value while the Y counts decrease in value as it follows the trace line.

4.4.2.6 When trace line D has been completely read, the reading protion of the job is completed.

4.4.3 The next step in the reduction of the test data is to 80 x 80 list the deck of cards obtained from the film readings. The listing is then checked to verify that all appropriate readings have been made and that all cards are in their proper order.

4.4.4 The next step is to keypunch control cards containting the control cards containing the information given on the Cylex Calculation Input Sheet. A list of control cards is shown in Table I.

4.4.5 When the control cards have been punched and inserted at the beginning of the data deck, the deck is submitted to the IBM 1130, or equal, Cylex computer program. Data are output in the form of a data listing and 10 plots for each Cylex record, 5 plots for the upper trace reading s an r plots for the lower trace readings.

4.4.6 The next step is to check the listing and each of the plots to determine if all the information required has been obtained.

4.4.7 When the Cylex data computer printout and plotout forms are received, make a work sheet as follows:

The work sheet will be made from a large piece of data paper. This has 22 columns from left to right, laid off by pink lines and 38 lines from top to bottom, laidoff with blue lines. The work sheet is divided so that the first column is for experiment; second, half; third, leave blank; fourth, time at 5 millimeters; fifth, average; sixth, velocity at 5 millimeters; seventh, average eight, leave blank; ninth, time at 19 millimeters: tenth, average: eleventh, velocity at 19 millimeters; twelfths average. The last columns are empty, however, they are useful for additional notes and corrections, etc. At the top of the page, designate the explosive being tested.

4.4.8 Data Reduction.

4.4.8.1 (R_J - R_o) Versus T_J Plot.

4.4.8.1.1 Take the (R_J - R_o) versus T_J plot and lay it out ‘n the table or a light box.

4.4.8.1.2 On the ordinate, mark off the 5 millimeter and 19 millimeter points.

4.4.8.1.4 At the point where they intersect the curve, draw a line perpendicular to the abscissa, thus marking the time at which the wall reached the radii of 5 millimeters and 19 millimeters respectively.

4.4.8.1.5 Record these values in the appropriate columns on the work sheet.

4.4.8.2 V_J Versus T_J Plot.

4.4.8.2.1 Take the V_J prime versus T_J plot and lay it over the R_J minus R_0 versus T_J plots so that the time axes coincide. , and fasten in place.

4.4.8.2.2 Take the triangle again and draw perpendicular lines from the time readings upward until they intersect the velocity plot a-t both 5 millimeter and 19 millimeter point.

4.4.8.2.3 At these two points, run lines that are parallel to the abscissa over to the ordinates thus giving the velocity at these two expansion points respectively.

4.4.8.2.4 Record these values on the appropriate column on the work sheet. This reduction procedure is repeated for each half of each experiment (the corresponding entries being made on the line marked either 21 bottom or 21 top for instance).

4.4.8.3 After calculating the radial wall velocity for each experiment at each point, (the 5 millimeter point and the 19 millimeter point) the Gurney value is determined. The procedure followed is to determine what appears to be the radial wall velocity, averaging all the radial wall velocity determinations for a set of experiments at 19 millimeters, then use this number to determine the gurney value. The easiest method is to use information from the particular plot of Alpha J^1, which corresponds to the average velocity or most nearly corresponds to the average wall velocity. At present, the Alpha J^1 plots Alpha J against radius, against radius, but it is not R-R_0.

4.4.8.4 Alpha J^1 Versus R Plot.

Find the initial outside radius, add 19 millimeters to it, and go along the abscissa until you find this radius.

4.4.8.4.2 Construct a perpendicular line form this point upward until it intersects the curve.

4.4.8.4.3 Finally, construct a perpendicular line from this line to the ordinate which will yield Alpha. Alpha is given in millimeters per microsecond.

4.4.9 Helpful Hints.

4.4.9.1 A rubber ruler is very useful in reducing the data. Velocity, (V_J), time (T_J), Gurney constant (Alpha J^1), and radius (R) use the same graduations requiring one setting of the variable scale.

4.4.9.2 The remainder of the data is on the printout heading for the experiment.

4.4.9.2.1 Charge/mass ratio (C/M) appears on the fifth line of the heading for each experiment.

4.4.9.2.2 Detonation velocity appears on the fifth line also. In some cases, the detonation velocity will be an estimate or will be given fom other work, (not measured in the individual Cylex experiment). If the detonation velocity is not measured, there will generally be a flag in the title section of the computations that indicates this.

4.4.9.2.3 The sixth line carries metal identification and density. (Density is called out as RHOM.)

4.4.9.2.4 The explosive designation and explosive density are also on line 6. (Explosive density is called out as RHOC).

4.4.9.3 If you label the work sheet with the types of explosive being tested, initial and date it,and make a brief statement as to where the data are reported, this makes reduction of the data easier the next time.

TABLE I Cylex - Control Cards

Card #1		
	Shot #:	Columns 1-5
	Date Fired:	Columns 11-26
	Operator:	Columns 31-51
Card #2		
	80 column ID Card.	
Card #3		
	80 Column Comment Card	

Card #4

80 Column Comment Card

Card #5

Type of Metal:	Columns 1-12
sm:	Columns 16-25
Type of Explosive:	Columns 31-42
Sc:	Columns 46-55

Card #6

Writing Rate:	Columns 1-10
Inside Radius:	Columns 11-20
outside Radius:	Columns 21-30
Detonation velocity:	Columns 31-40

Data Card

Al Punch (constant):	Columns 7
Reading #:	Columns 25-27
Machine #:	Columns 37
Shot #:	Columns 47 & 4$
Readout #:	Columns 50
x counts:	columns 62-66
Y counts:	Columns 67-72

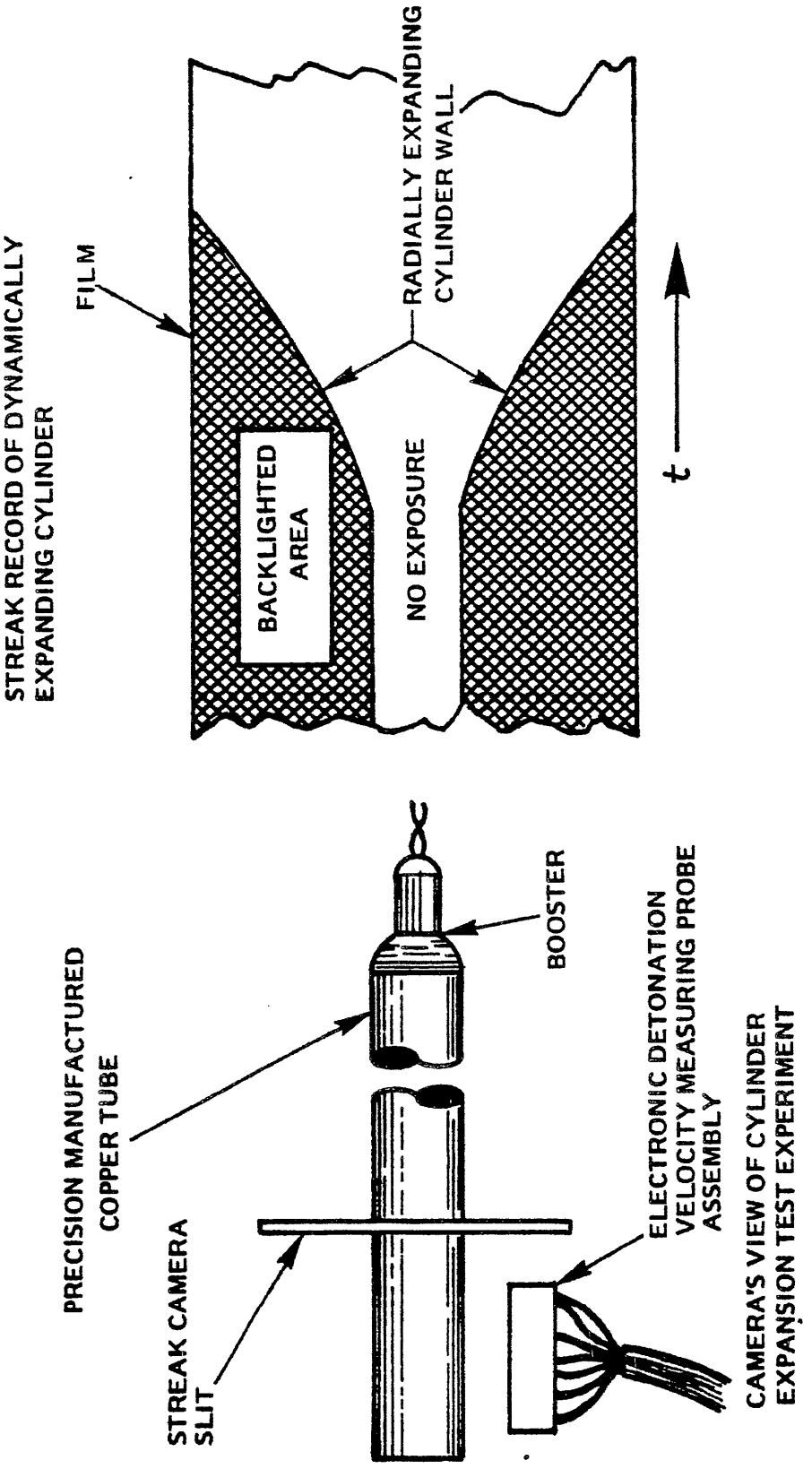


Figure 1 - Streak record of dynamically expanding cylinder.

FIGURE 1

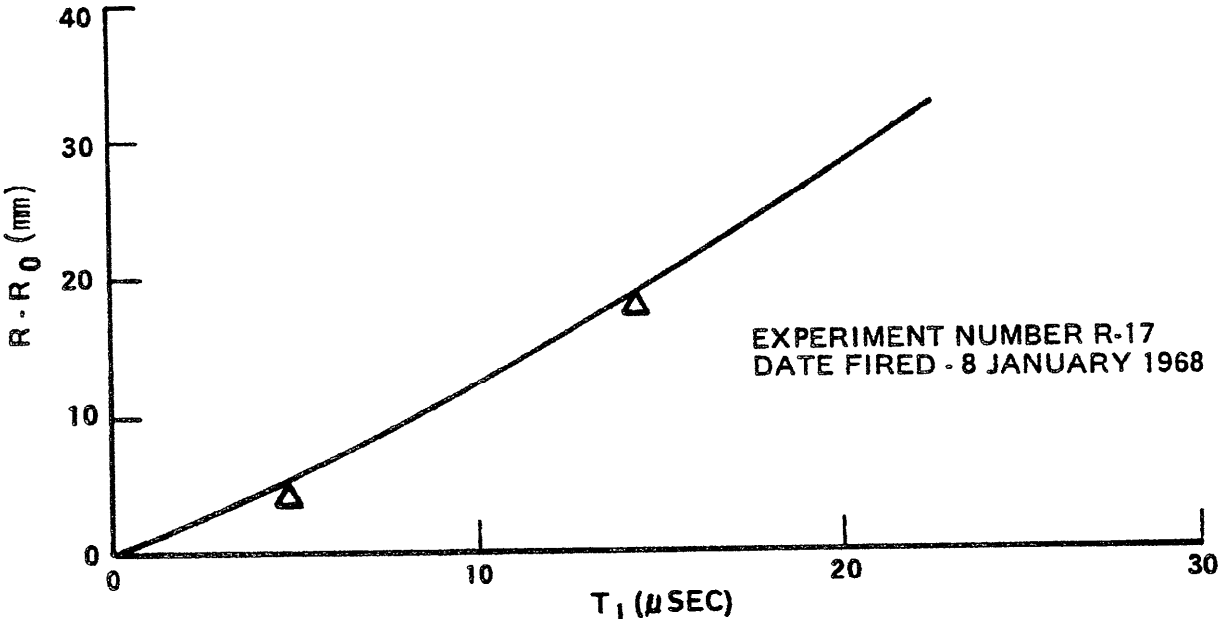


FIGURE 2 - EXPANDING DATA, PLOTTED AS A FUNCTION OF TIME.

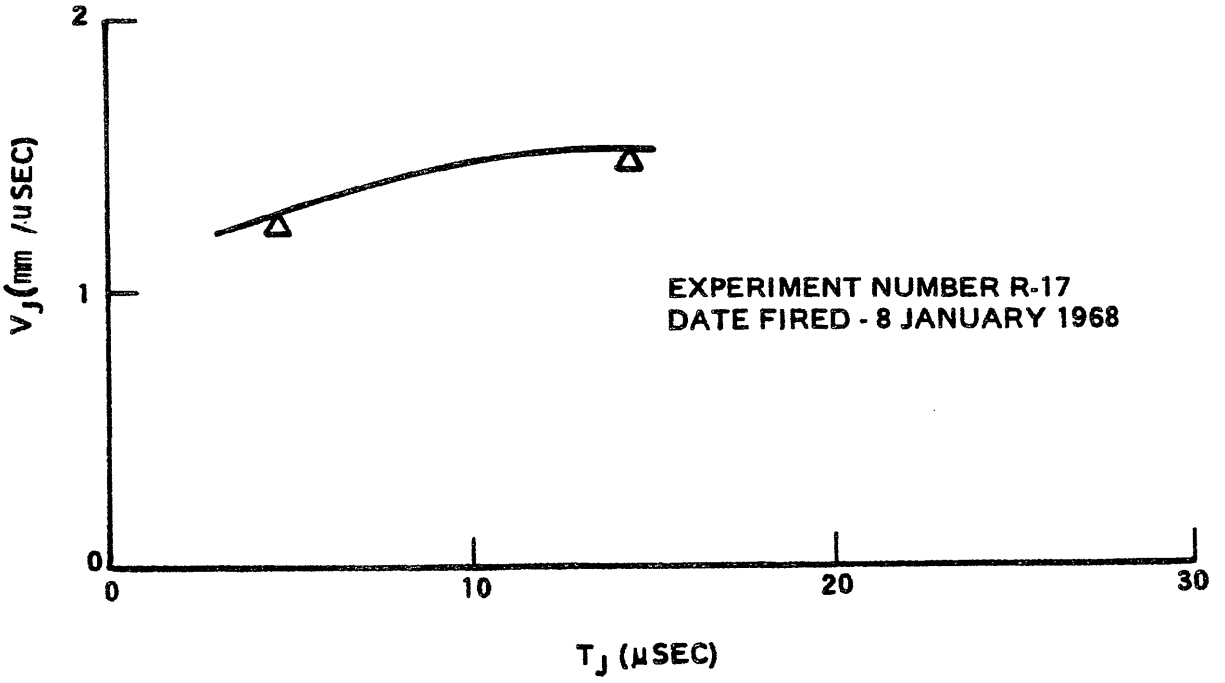


FIGURE 3 - CYLINDER WALL VELOCITY, PLOTTED AS A FUNCTION OF TIME.

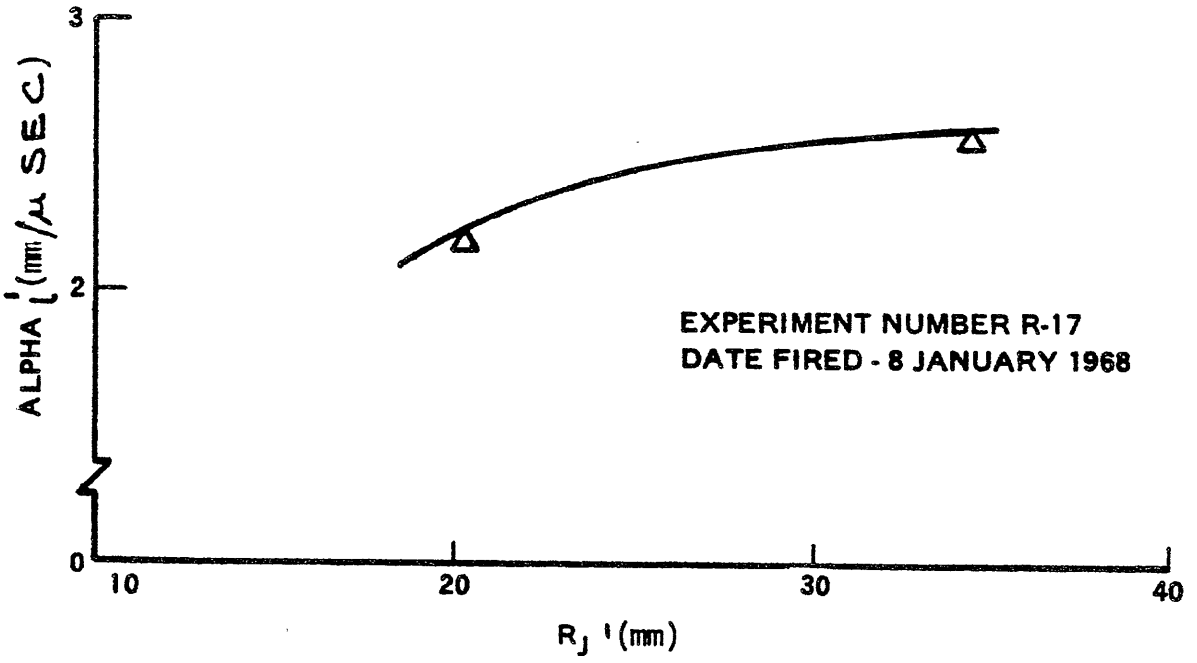


FIGURE 4 - FURNEY CONSTANT PLOTTED AS A FUNCTION OF TIME.

METHOD 17

AN ANALYSIS OF THH "AQUARIUM TECHNIQUE" AS A PRECISION DETONATION PRESSURE MEASUREMENT GAGE

1. INTRODUCTION

1.1 The experimental measurement of shock wave pressures characteristic of most detonating solid explosives is typically expensive, difficult, and generallly Poblematical. Althouth there is currently a number of pressure measurement schemes which are considered to be state-of-the-art [6.1], these methods are often elaborate, sophisticated, and costly to a point that discourages widespread regular usage.

1.2 There is a continuing need, especially in the evaluation of new explosive formulations, for a relatively simple, comparatively inexpensive, yet dependable detonation pressure measurement gage. Recognizing this need, we have attempted to re-evaluate one method which has already enjoyed long usage, but one which we feel has not had its full capabilitie —and therefore its wider applicability—firmly established. This method is most commonly known as the aquarium technique6.2-6.4.

1.2.1 The task of the user of the aquarium technique for detonation pressure measurements is the determination of—to the maximum degree of precision permitted by camera records—the velocity of the shock transmitted into the water immediately at the explosive/water interface. From this shock parameters the magnitude of the incident pressure or detonation pressure may be derived.

1.2.1.1 Aquarium test pressure values are very sensitive to errors in determining the transmitted shock velocity, and for that reason calculation of detonation pressure in this manner has tended to be less favorable than some other methods. Arguments against the technique appear to be the uncertainties involved in arriving at the initial transmitted shock wave velocity.

1.2.2 Probably the most precise method for detonation pressure measurement currently in use is the measurement of free surface velocity of metal plates[6.5]. Analysis techniques for determining the free surface velocity of explosively driven, impedance matched, metal plates over short distances prove to be much less involved than the aquarium technique. The metal plate experiments are much more difficult to perform. Also, as is pointed out in Ref.6.5, Wilkis [6.6]. Lamdbourn and Hartley[6.7], and Petrone[6.8] have indicated there are some uncertainties associated with the

free surface velocity technique or its interpretation, as have Veretennikov, Dremin, et al[6.9], and Craig[6.10].

1. 2.3 Detonation pressures determined via the aquarium technique have characteristically been below the accepted published nominal values from other methods, especially in the early development of the technique. To a large degree, this seems to relate primarily to the lack of adequate treatment of the space-time (R-t) data, from the streak camera records, i.e., a sufficiently "good" analytical fit to the experimental data for differentiation and solution for interface velocity conditions. For this reason, one of our principal concerns has been the methods of numerical analysis by which the initial or “jump-off" velocity could best be deduced from aquarium test data, and from which reliable detonation pressure values could be generated from single (or small sample) shot experiments. We have, based on the exhaustive work of other investigators implicitly assumed the validity and applicability of the impedance match method for calculation of detonation pressure.

2. EXPERIMENTAL

2.1 2.1 The existence of a large quantity of accepted pressure data for most common explosives has given us the opportunity to better evaluate the several analytical approaches as well as the total experiment. PBX 9404, (94/3/3 HMX/nitrocellulose/tris-ß-chloroethyl phosphate) whose detonation pressure has been heavily researched (although there is still some disparity as to what its steady state pressure actually is) was chosen for "calibration" of the aquarium experiment. The detonation pressure, P_{det}, of PBX 9404 is nominally considered to be about 37,200.0 ± 500.0 MPa (372 ± 5 kbars).

2.2 The experiments consisted of aquarium testing ten explosives in right circular cylinder geometry. All specimens were 7.2 cm in diameter. The lengths tested were 1.27, 2.54, 5.08, and 11.4 cm for the PBX 9404 and 11.4 cm only for the remaining explosives tested.

2.2.1 Test samples were carefully prepared and assembled for firing as shown in Figure 1. All shots were initiated with P-40 (~10 cm diameter) plane wave generators [output pressure ~14000.0 MPa (140 kbars)]. This was done to maximize the one dimensionality of the output waves and to avoid any overdriving of the detonation in the test samples.

2.2.1.1 The charges were immersed in distilled water in commercially available glass walled aquariums. Shadowgraphic

backlighting was provided by exploding bridgewires in an atmosphere of liquid Freon [6.11]. The Freon has the effect of improving the quantity of light as well as the useful life of the source. The EBW's were positioned at the focal length of a 12.7 cm diameter, 19 cm focal length lens which was centered with the optical axis and the output surface of the test sample, and attached to the outside surface of the glass wall. This system resulted in significantly improved streak camera records as opposed to argon bomb light sources.

2.2.2 Considerable care was exercised in the alignment of the shots within the optical system. Tilted shots, i.e. shots whose cylindrical axis was not perpendicular to the optical system axis, produced a double trace effect which seriously changed. the pressure results.

2.2.2.1 Alignment was accomplished by replacing the EBW light source with a mercury vapor point light source. The point source was located at the focal length of the condenser lens on the aquarium to produce a beam of parallel light. The entire aquarium was then adjusted such that the parallel beam was centered about the axis of the optical system. Final adjustment of the test samplement by three leveling screws_was then made until a straight shadowgraphic image of the output surface of the charge was observed on the streak camera slit plate. The position of the point source was noted; the EBW backlight source was then located at that point for the test.

2.2.3 The streak camera records obtained were generally of high quality. All shots were fired at magnification of about 1:1 and at camera writing rate of 5.0 mm/μsec.

3. ANALYSIS AND RESULTS

3.1 The measurement of transmitted shock velocity into water permits one to ascertain, by use of the water Hugoniot equation-of-state, the associated particle velocity for the shock. There has been considerable work done to develop the shock properties for water 6.3, 6.12, 6.14. We have used the Rice-Walsh equation because it is probably the most comprehensive effort and because Papetti and Fujisaki[6.15], in a separate theroretical study, thoroughly evaluated and further verified the Rice-Walsh p-v-e data for purposes of extrapolating it to higher pressures. The Rice-Walsh equation was reported [6.12] in the form;

$$U_S - 1.483 = 25.3066 \log_{10}(1 + U_P/5.190)$$

Where U_s and U_P are shock and particle velocity respectively in km/sec. By doing a second order polynomial regression fit to their $U_s - U_P$ data a much more easily used functional relation-

ship was obtained. The quadratic representation is:

$$U_p = -.607 + .372\ U_s + .0238\ U_s^2$$

Values computed via this form differ by less than 0.5% from the above Rice-Walsh equation over the range of interest. Having determined values for shock and particle velocity, one may easily compute the transmitted pressure with the familiar conservation relation:

$$P_1 - P_o = \rho_o U_s U_p$$

The impedance match equation was then used to calculate the incident or detonation pressure. The impedence equation is:

$$P_i = P_t \left| \frac{\rho_o U_s + \rho_{HE} D}{2\rho_o U_s} \right|$$

where: P_i = incident or detonation pressure
P_t = transmitted pressure
ρ_o = initial density
D = detonation pressure
U_s = transmitted-shock velocity
ρ_H = initial density of the explosive

4. ANALYTICAL CURVE FITS

4.1 Initially we attempted five separate methods to obtain the desired transmitted shock velocity. They were:

1. Graphical fits to the first few mm of trace motion by drawing straight lines on 40X photographic enlargements.

2. Polynomial regression fits from one through tenth degree to about 35-40 mm of trace motion.

3. Polynomial regression fits—degree one—to the first 2 mm of trace motion.

4. The combination of an exponential and linear function.

5. The combination of an arc tangent and linear function.

Each streak camera record was analyzed on a Grant comparator. The time, (t), values were read and an IBM card punshed for successive .025 mm increments in the space direction (R) for a total of 2mm. The process was then repeated for a total distance of about 35-40 mm in .250 mm increments.

4.2 Photographic enlargements (.40X) on paper were made of the jump-off region and graphically analyzed to determine the slope of teh trace. Although the calculated results from this method were generally good, and therefore recommended for “quick” evaluations, the results were somewhat sensitive to the experience of the analyst. For this reason,we have not included these data in this paper.

4.3 Teh sefcond method attempted and probably the most commonly used—was one through tenth degrees polynomial regression fits. Polynomial best fits, R= f(t), at first appeared to be ideal, e.g. easily differentiated and solved for t=o to obtain the initial transmitted shock velocity. But in general, high order polynomials failed to yield good results. Table 1 serves to illustrate the point. Referring to Table 1, it can be seen that for the two shots presented, the "goodness of fit” to the R-t values improves with increasing degree of polynomial, as one would expect. This however, does not insure better velocity results upon differentiation and solution at t=o; in fact, the opposite is usually the case. There was no obvious or reliable criterion for selecting the degree of polynomial which would yield the best results. An investigator using this approach would find it very difficult to decide which is the most nearly correct velocity value from tests of an unknown explosive

TABLE 1

Velocity Pressure Data.

Determined by Polynomial Regression Method
for 1st through 10th Degree Polynomials
for TNT and LX-10

Degree Fit	U (cm/μsec)	Correction Codfficient	Standard Error of Est.	P_{det} (kbar)
		TNT (P_{det} ~199 kbar)		
1	.515	.99936655	.54065	168
2	.581	.99995576	.14320	213
3	.540	.99999778	.03216	184
4	.544	.99999790	.03136	187
5	.566	.99999925	.01881	202
6	.571	.99999928	.01851	206
7	.583	.99999938	.01724	214
8	.580	.99999938	.02728	214
9	.600	.99999943	.01651	227
10	.600	.99999943	.01660	227

LX-10
(P_{det} ~ 370 kbar)

1	.635	.99986350	.16939
2	.692	.99998572	.05492
3	.664	.99999695	.02546
4	.649	.99999793	.02106
5	.649	.99999793	.02113
6	.660	.99999803	.02079
7	.868	.99999826	.01952
8	.724	.99999883	.01769
9	.763	.99999877	.01653
10	.769	.99999877	.01656

The tendency of ploynomials, as the degree increases, to try to pass through all the read values, causes the derivatives to behave less and less like the actual physical decay of the shock wiht time. Quadratic fits to slowly decaying shocks such as occur with larger explosive charges produce reasonable results, but not without a potential for error larger than one is usually satisfied with.

4.4 The third approach taken was the least squares fitting of a straight line to the first 2 mm of shock travel. This method is of course based on the assumption that the shock velocity is constant over the 2 mm or the deceleration for that distance is zero. This assumption proved to be quite good, especially with the longer charges which produce more slowly decaying shock waves in the water. The use of the first 2 mm of shock travel for linear fits is easily the most expedient of all the methods attempted The success of this method, however, is contingent upon very high quality streak camera results at the jump-off portion of the trace, and the early portion of streak camera records for this type test is often the most troublesome. This fact prompted us to examine other approaches which would allow use of an order of magnitude more of the streak trace by taking advantage of the improved shadowgraphic effect produced after the shock wave began to have some slight curvature. The one-dimensionality assumptions are increasingly affected as the system becomes more divergent; however, here we are only interested in matching an equation to the actual shock decay characteristics for purposes of solution for interface conditions.

4.5 On the assumption that the acceleration of the shock wave in the water decayed in some exponential manner with time, we preceded to develop a curve fitting model with that characteristic behavior[6.16]. $R''(t) = Ae^{-k^2t}$, $R^1(0) = N$ and $R(0) = 0$, then by successive integration, $R = AK^{-4}(e^{-k^2t}-1) + (N^2+AK^{-2})t$

Rewriting this equation and combining the constants one gets the general form of what we have called curve fitting Model 1, or:

$$R = A_1 + A_2 t + A_3 e^{A_4 t}$$

The constraint imposed by the above boundary conditions that the curve passes through the origin at t=o has been removed in Model I by addition of the constant, A_1 in order to further increase the versatility of the model.

4.5.2 The Model I equation was fitted to each of the R-t data sets. The A's are constants determined by computer after force fitting the curves to three data points (first, middle, and last) followed by subsequent refinement through successive iterations until convergence to within the desired limits is attained. Shock velocity values are then computed by differentiation of the resulting equation for any desired t value within the range of the data.

4.6 The last of the above mentioned techniques was developed from observation of computer plots of R-t data sets. Examination of plots of incremental slopes as a function of time, $\Delta R / \Delta t$ vs t, had behavior similar to a specialized form of a "Witch of Agnesi" curve. The characteristics of the larger shots, namely a very slow intial decay, followed by a region of faster decay, which subsequently leveled off to practically constant velocity, indicated that integration of a form:

$$R' = C + \frac{8A^2B}{t^2+4A}$$

would yield a general equation having properties similar to the R-t data. The constants A and B, are the major and minor axis of an ellipse, and C represents the almost constant value of velocity attained after the shock has propagated some distance.

4.7 Integration of this equation produced the Model III curve fit of the general form:

$$R = A_3 t + 4A_1 A_2 \tan^{-1}(t/2A_1).$$

4.7.1 Model III was fitted to each of the R-t data sets; the constants being determined in the same manner as with Model I.

4.8 Velocity-pressure values from the last three methods described above were the most successful. These data are presented in Tables 2 and 3. Table 2 summarizes the PBX 9404 data. Referring to Table 2, the straight line fit appears to offer the best precision followed by the Model I, then the Model III.

The straight line fit seems to show an effect of charge length on detonation pressure. Considering only the straight line fit averages, the 1.27 and 2.54 cm shots are 5.8% below the nominal; the 5.08 cm shots are 3% below, while the 11.4 cm values agree with the nominal within <1%.

PBX 9404 Aquarium Test Results

All Charges d = 7.2 cm

Charge Length (cm)	Density (g/cc)	Det. Vel.* (cm/μsec)	Transmitted Shock Vel., U_s (cm/μsec.) St. Line Fit 2 mm	Model I	Model III	Measured Detonation Pressure, P_{det} (kbar) St. Line Fit 2 mm	Model I	Model III	Average Detonation Pressure P_{det} (kbar) St. Line Fit 2 mm	Model I	Model III
1.27	1.846	.882	.657	.662	.645	349	355	338	350	360	346
1.27	1.845	.882	.659	.679	.660	351	364	353			
2.54	1.844	.881	.658	.671	.658	351	363	351	351	357	342
2.54	1.843	.881	.658	.657	.640	350	350	332			
5.08	1.844	.880	.669	.663	.659	360	355	350			
5.08	1.843	.881	.672	.671	.685	364	364	377	361	357	357
5.08	1.845	.882	.668	.658	.649	360	351	343			
11.4	1.844	.882	.677	.680	.694	370	373	384			
11.4	1.844	.882	.676	.671	.677	369	364	370	370	369	377

*Detonation velocities calcualted from D = .36 + .2176

Model I: $R = A_1 + A_2 t + A_3 e^{A_4 t}$

Model III: $R = A_3 t + 4A_1 A_2 \tan^{-1}(t/2A_1)$

TABLE 2

TABLE 3
Single Shot Results for Ten Explosives
All Charges d= 7.2 cm, L = 11.4 cm

Explosive	Density (g/cc)	Det. Vel. (cm/μsec)	Transmitted Shock Vel U_s (cm/μsec.) St. Line Fit 2 mm	Model I	Model III	Measured Detonation Pressure, P_{det} (kbar) St. Line Fit 2 mm	Model I	Model III	LRL Values[1] Density	Det. Vel ±5	P_{det} kbar
HBX 9404[a]	1.844	.881	.677	.676	.686	370	369	377	1.846	.882	375
PETN[b]	1.638	.692	.561	.553	*	201	195	*	1.632	.694	190
Pentolite[2],[b]	1.644	.752	.618	.624	.630	257	262	250	1.644	.752	252
Comp. B[3],[c]	1.729	.798	.641	.637	.647	297	294	302	1.733	.800	300
LX-04-1[4]	1.858	.846	.654	.688	.660	338	372	344	1.867	.848	345
LX-07[5]	1.850	.859	.694	.684	.694	381	370	381	-	-	-
LX-09[6]	1.861	.882	.662	.682	.682	354	372	373	-	-	-
LX-10[7]	1.841	.881	.679	.675	*	374	370	*	-	-	-
Cyclotol[8],[c]	1.757	.830	.644	.659	.668	312	325	333	1.760	.830	316
PBX-11-AY[9]	1.876	.625	.540	.639	.541	190	187	191	-	-	-

Model I: $R = A_1 + A_2 t + A_3 e^{A_4 t}$
Model III: $R = A_3 t + 4A_1 A_2 \tan^{-1}(t/2A_1)$

[a] Average of two shots

[b] Pressed

* Model III failed to converge to a solution

[c] Cast

[1] Values determined by the LRL "Standard Test for Detonation Pressure Measurement" (Ref. 6.5)
[2] 50/50 PETN/TNT average PETN particle size 10
[3] 60/40 RDX/TNT
[4] 85/15 HMX/Viton
[5] 90/10 HMX/Viton
[6] 93.3/4.2/2.5 HMX/DNPA/FEFO
[7] 95/5 HMX/Viton
[8] 75/25 RDX/TNT
[9] HMX/Potassium Perchlorate Formulation

4.8.1 The mean pressures given in Table 2 are shown in Figure 2 in a plot of the ratio of the measured pressure, to the nominal pressure as a function of charge length. A "best fit by eye" curve has been drawn through the data to roughly indicate the capabilities of the technique as determined by these experiments.

4.8.2 Table 3 includes the velocity-pressure data for the nine other explosives tested. Since the 11.4 cm PBX 9404 changes produced the best results—best agreement with nominal detonation pressure—that length was chosen as "the standard for the remaining explosives. Where the data was available, the detonation pressure as determined by LRL's "Standard Tests for Detonation Pressure Measurement"[6.5] are also presented for comparison. For the most part, there is very good agreement; when normalized for density by $\Delta P/\Delta\rho \sim 0.5$ kbar/mg/cc form $P \sim \rho D^2/4$, the straight line fit values are within 1% or less for all explosives for which there are comparative data, except for TNT and 50/50 Pentolite, where the differences are 4% and 2%, respectively. It should be noted here that an error of fixed size in the measurement of initial transmitted shock velocity will result in a proportionately greater error in P_{det} at lower pressures than at higher ones simply because it is a larger proportion of the absolute transnitted shock velocity.

5. CONCLUSIONS

5.1 Clearly, the aquarium technique is capable of yielding good detonation pressure data. The experiments performed and the results obtained show that it is feasible to use the aquarium technique on a non-statistical experimental basis.

5.2 The cost of a test was generally much lower than our cost for a metal plate free surface velocity experiment and the technique has the added potential of collecting useful shock data at distances from the HE/water interface.

5.3 Good agreement between nominal and measured pressure values was obtained for the 7.2 cm diameter, 11.4 cm long charges. The discrepancy in the results for the L = 1.27, 2.54, and to some extent the 5.08 cm shots appears to be real but is not explained. The analytical precision seems to be somewhat enhanced when the records are produced by charges on the order of at least 10 cm long.

5.4 Aquarium test space-time streak camera shadowgraphs from explosive charges of this magnatude are well suited to the analysis schemes we have tested. For the numerical analysis techniques

attempted, the following conclusions are made:

a. Graphical fits to paper photographic enlargements of the streak camera records are recommended only for a first order analysis.

b. One through tenth degree polynomial regression fits. although generally a routine exercise in curve fitting can produce erroneous results if one selects the degree to be used by the normal "goodness of fit" criteria, i.e., correlation coefficient and standard error of estimate, etc.

C. Straight line fits to about the first 2 mm of the shock travel produces good results with large charges providing the record quality in that region is very good and sufficiently large magnification is used in performance of the experiment.

d. The alternate methods examined, while considerably more involved, take advantage of much more of the trace recorded in a typical aquarium type experiment. Velocity-pressure values derived by these methods were generally good; perhaps these or similar functions can eventually be made to more closely approximate the actual physical decay of the shock in water.

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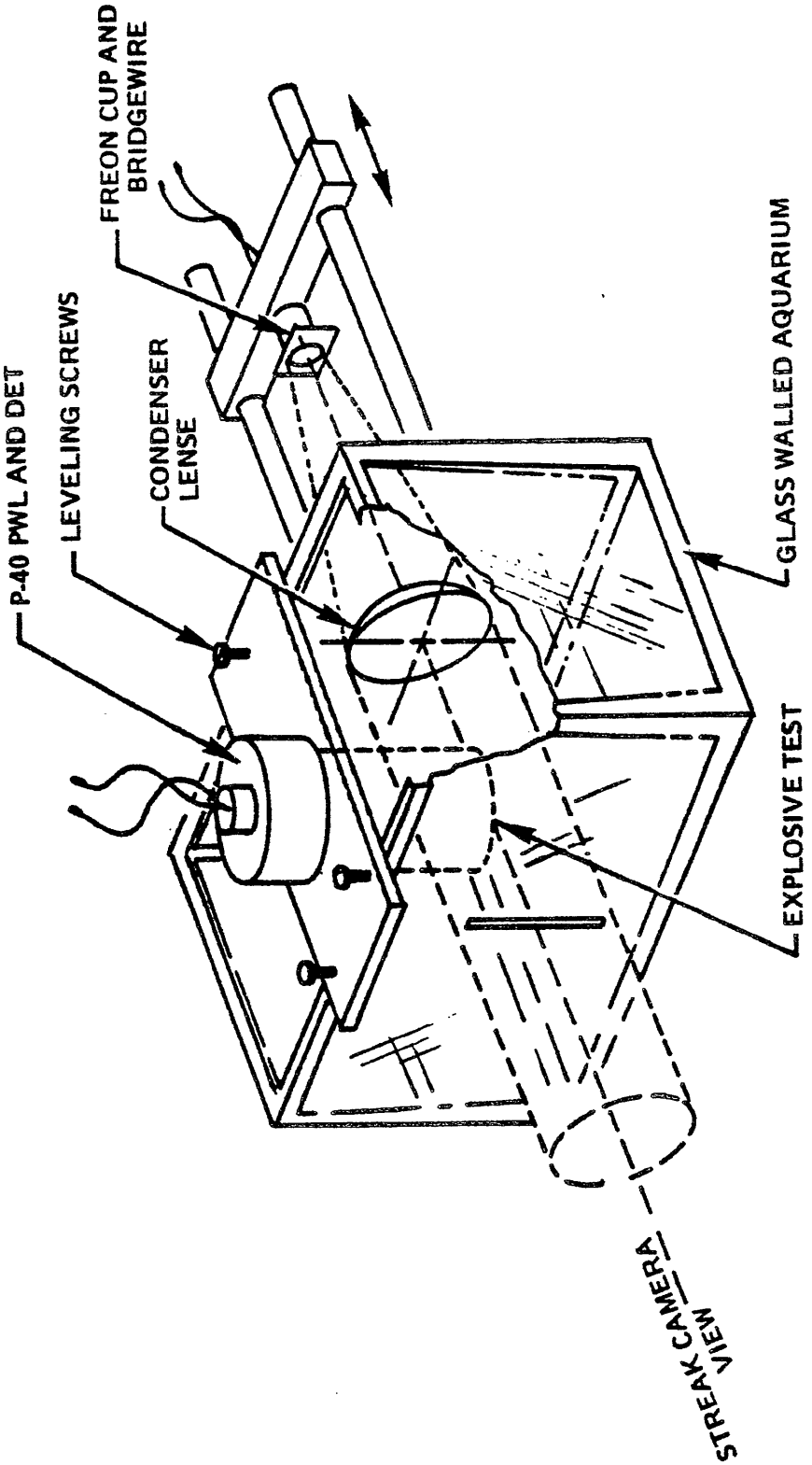

Figure 1 - Typical aquarium test setup for measuring detonation pressure.

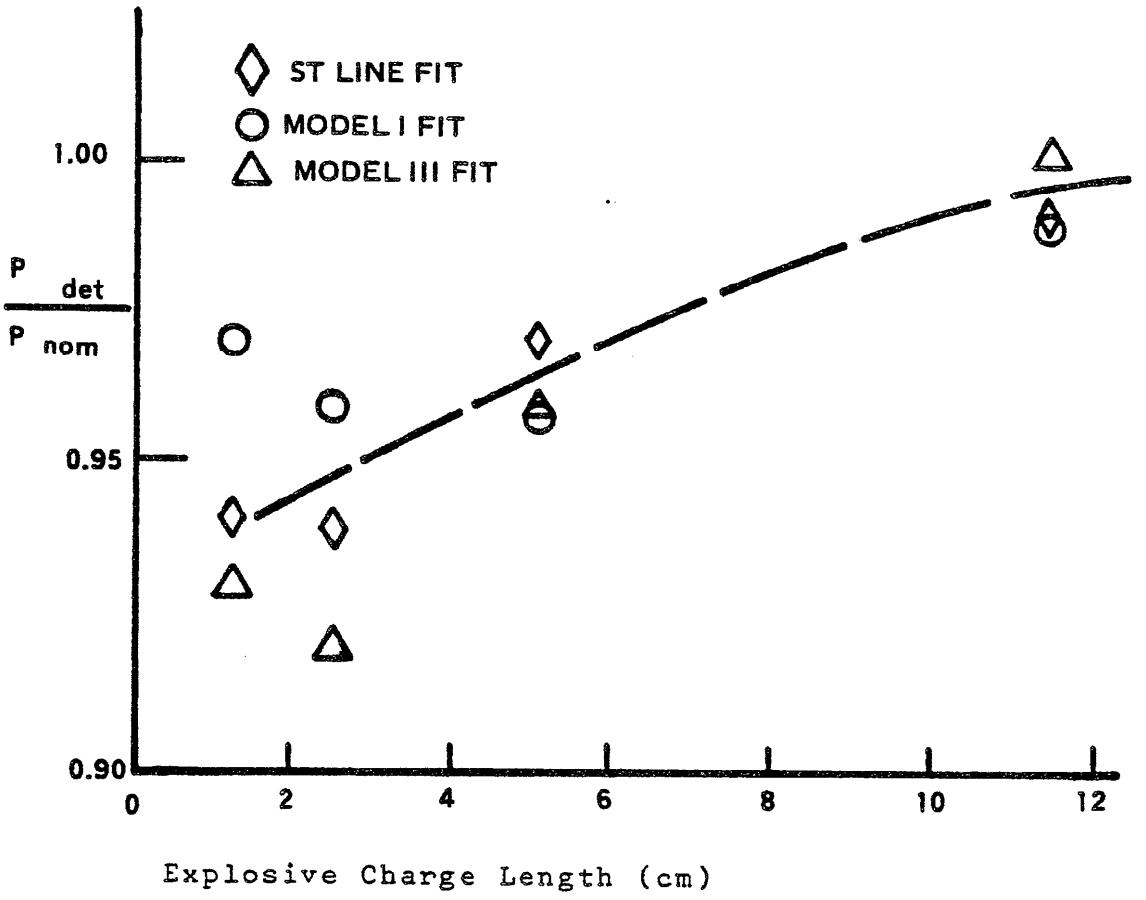

FIGURE 2 - RATIO OF EXPERIMENTALLY MEASURED PRESSURE TO NOMINAL DETONATION PRESSURE AS A FUNCTION OF CHARGE LENGTH.

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1. HAS ANY PART OF THE DOCUMENT CREATED PROBLEMS OR REQUIRED INTERPRETATION IN PROCUREMENT USE?
   A. GIVE PARAGRAPH NUMBER AND WORDING.

   B. RECOMMENDATIONS FOR CORRECTING THE DEFICIENCIES

2. COMMENTS ON ANY DOCUMENT REQUIREMENT CONSIDERED TOO RIGID

3. IS THE DOCUMENT RESTRICTIVE?
   [ ] YES [ ] NO *(If "Yes", in what way?)*

4. REMARKS

SUBMITTED BY *(Printed or typed name and address - Optional)*

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