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Calibration of a Super Small-Scale Cookoff Bomb (SSCB) for Predicting Severity of the Cookoff Reaction

by
Jack M. Pakulak, Jr.
and
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JULY 1983

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

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FOREWORD

The tragic fire aboard the carrier USS *Forrestal* resulted in substantial loss in life and material and put the ship out of commission for a long period of time. Subsequent investigation of the incident indicated that the fire was started by the inadvertent ignition of an ordnance item which, in turn, ignited aviation jet fuel. Early suppression of the fire was inhibited by the explosive behavior of other ordnance items that were on aircraft parked on the deck near the scene and subjected to fire from the burning jet fuel.

Actions resulting from the investigating commission suggested that an effort be made to modify the behavior of ordnance items of missile systems to preclude explosive behavior and/or extend the time to a reaction from the fire. Since then, a formal requirement has been imposed on air-launched ordnance, namely, "Criteria for Test Procedures for Ordnance Exposed to an Aircraft Fuel Fire," MIL-STD-1648(AS).

The Naval Weapons Center's Propulsion Systems Division, China Lake, California, has been assigned the responsibility for developing and demonstrating techniques for meeting the requirements of the specification for new missile systems and for supporting the Pacific Missile Test Center in the development of retrofit concepts for in-service ordnance. The former responsibility requires that the techniques should be suitable for incorporation into the basic design of new ordnance components. This report is in support of the assigned responsibility.

Work on the subtask was accomplished during fiscal years 1982 and 1983. The subtask is in partial fulfillment of the Advanced Development Task of the Naval Weapons Cookoff Program sponsored by the Naval Air Systems Command under AIRTASK A03P-03PA/054-C/1W0592-001. The line item number is 63262N W0592-SL.

This report was reviewed for technical accuracy by Edward Kuletz.

Approved by
C. L. SCHANIEL, *Head*
Ordnance Systems Department
24 June 1983

Under authority of
K. A. DICKERSON
Capt., U.S. Navy
Commander

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(U) The Super Small-Scale Cookoff Bomb (SSCB), like the Small-Scale Cookoff Bomb (SCB), was developed to provide a means for predicting the response of an ordnance item to a fast or slow cookoff by comparing an empirical relationship to the severity of cookoff reaction in a laboratory level explosive sample and the same explosive in an ordnance item during a field test. Whereas the SCB utilizes 600 grams, the SSCB requires only 20 grams. The SSCB will test any explosive whose critical diameter for steady-state detonation is less than 0.6 inch.

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INTRODUCTION

Methods and techniques are needed for predicting the time to cookoff and the severity of the cookoff reaction of explosives for munition use. Work documented in this report involves a small-scale cookoff fixture (Figure 1) for studying the thermal behavior of explosives under confined conditions. An earlier and larger version of this fixture called the Small-Scale Cookoff Bomb (SCB) is described by Pakulak and Anderson.[1] There is a need for testing on a smaller scale, for those explosives which can be scaled down. This allows a cost savings and a reduction in test equipment and size of the test facility. The SCB uses about 600 grams of explosive per test and can be heated at the same rate as a General Purpose (GP) bomb in a fuel fire. The cookoff fixture described in this report is a scaled-down version of the SCB called the Super Small-Scale Cookoff Bomb (SSCB). The SSCB uses about 20 grams of explosive and can be heated at the same rate as the SCB.

A method was developed to measure the thermal profile of the explosive surface and predict time to cookoff from a set of kinetic parameters on a given explosive[1] and then develop an empirical relationship to the severity of the cookoff reaction. This technique was used in a limited manner in this report. The SSCB, like the SCB, can provide a means for predicting the response of an ordnance item to a fast or slow cookoff and, thereby, have an empirical relationship to the severity of cookoff reaction between a laboratory level explosive sample and the same explosive in an ordnance item during a field test.

TEST EQUIPMENT DESCRIPTION

PROTOTYPE TEST FIXTURE

The SSCB fixture used in this series consisted of a 3-inch-long steel pipe (0.9-inch ID, 1.25-inch OD) welded at one end to a 0.375-inch-thick steel plate (5-inch diameter). The tube had a slot on the

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[1] Naval Weapons Center. *NWC Standard Methods for Determining Thermal Properties for Propellants and Explosives*, by Jack M. Pakulak, Jr. and Carl M. Anderson. China Lake, Calif., NWC, March 1980. 42 pp. (NWC TP 6118, publication UNCLASSIFIED.)

inside wall (0.0625-inch wide, 0.051-inch deep) for the insertion of a thermocouple. The top steel plate was also 0.375-inch thick and 5 inches in diameter with a center hole for pressure or additional temperature readings. An off center hole was drilled in this top plate for the placement of the thermocouple; the top and bottom plates were bolted together with four bolts. Two steel tubes (1.25-inch long, 0.6-inch ID, and 0.8-inch OD) housed the explosive which was either cast or pressed into them. An aluminum sleeve was located between the inner tubes and the outer steel tube (Figure 2). This aluminum sleeve acted as a heat sink to even out the heat delivered to the explosive sample. Two 125-watt electric heaters were fastened to the outside of the steel tube as shown in Figures 1 and 3.

This test fixture can be used for both fast and slow cookoff tests by varying the amount of line voltage applied. For fast cookoff, 208 VAC are required and 110 VAC are needed for the slow cookoff. The heating rates are non-linear as would be found in the actual cookoff environment.

TEST METHOD

The fixture has a thermocouple between the aluminum sleeve and the SSCB body, but does not have a thermocouple at the explosive interface to the steel tube. In order to get an approximate value of this interface temperature, two sand-filled SSCBs were tested, one at a line voltage of 110 VAC and one at 208 VAC to give a "slow" and a "fast" heating rate. The inert test was made with a thermocouple welded to the inside surface of the sample tube. A plot of the temperature time data at each heating rate is shown in Figures 5 and 6. The slower heating rate data showed an almost constant temperature difference of 22-23°C between the inner and outer steel tubes. At the higher heating rate, the temperature difference was about 82-84°C. The heating rates are non-linear just as a bomb or warhead in a fuel fire is heated non-linearly. The calibration data can be used to determine the approximate surface temperature of the explosive.

A series of tests was then made to calibrate this fixture in regard to severity of the cookoff reaction. Table 1 presents data gathered from sixteen tests conducted at the 65B Test Facility at the Thermal Research Laboratory, NAVWPNCEN. These tests are numbered non-sequentially because they represent the number of the test being performed at the facility, not the number of the SSCB calibration test in this particular study. Tests were performed with decreasing percentages of RDX in the explosives. Samples of explosives used in these calibration tests were formulated from standard explosive mixtures of RDX, TATB and a wax, in varying amounts of each ingredient. The composition of each formulation is given in Table 1.

The explosive samples used in this calibration test varied in RDX level from 96% to 20% by weight, in TATB level from 0% to 75%, and maintained a constant wax level of 4 to 5%. The only formulation that did not detonate or have a violent explosion was the 20/75/5 (RDX/TATB/wax) composition. The results are summarized for each formulation in Table 1. There were six separate formulations studied in this series of calibration tests. There were differences in cookoff reactions between each set of formulations and also differences between the low and high heating rates. Like an actual munition in a fire, the SSCB did not have linear heating rates. The low heating rate was about 0.1C°/second and the high heating rate was about 1°C/second. These rates are similar to those of munition boosters in fuel fires. The low heating rate is similar to a thermally-protected munition which can cook off in a time period from about 8 to 20 minutes. The non-thermally-protected munitions usually will cook off in 5 to 15 minutes. The cookoff time will vary with test conditions and the type of explosive used in the munition and, also, in the case of the thermally-protected munitions, with the effectiveness of the thermal coating on the munition case.

The effect of the explosive composition on the cookoff reaction is described below.

CALIBRATION TESTS

Figures 7 through 22 show the damage to the witness plates and the fragmentation resulting from each of the tests. The first composition listed in Table 1 is 96/0/4 (RDX/TATB/wax), a booster explosive called CH-6. This explosive is known to detonate on cookoff when used as a booster in a munition. Although each sample tested had a diameter of only 0.6 inch, the CH-6 in Test #10 left a 1.5-inch hole in the witness plate. Figure 7 is a photo of the post test results. The CH-6 did detonate in this test and the cookoff time was 932 seconds or about 15.5 minutes. This time frame for cookoff of a booster in a munition has been observed before. The munition itself tends to thermally protect the booster from the heat of the fuel fire, thereby increasing the time to cookoff.

The remainder of the explosives used in this calibration test were supplied by the Naval Surface Weapons Center, Code R11, Silver Spring, MD. The 85/10/5 (RDX/TATB/wax) composition was called PBXW-7, Mod A by the supplier. The results of Test #8 with this composition are shown in Figure 8. The sample detonated leaving a very ragged hole of about 0.5 inch in diameter. The next test, #15, also detonated leaving a less ragged hole than in Test #8, but a little larger at about 1 inch in diameter. The two tests (#8 and #15) used the low heat rate.

The next sample (Test #22) was heated at the high rate. Although no hole was punched in the witness plate of Test #22, the plate was bent about 0.2 inch and had a plate dent of another 0.4 inch (Figure 10). This reaction was listed as a violent explosion, since no hole was punched. According to Reference NOLTL 74-40, to indicate a detonation in the large scale gap test, the hole punched in the witness plate must be neat. The pressure needed to punch a neat hole in a witness plate (3/8-inch thickness) is about 75 kBar for the average voidless propellant or explosive. Although not measured, the pressure output from the above tests, even the dent (Test #22), would have initiated most main charge explosives.

The next series of tests, with the 70/25/5 (PBXW-7, Mod B) composition, resulted in holes punched in all the witness plates, two with ragged holes of about one inch and one (Test #23) with a neat hole of 1.4 inch (Figures 11, 12 and 13). Test #23 was very similar to Test #10 with the neat hole made by the CH-6. Again, any of the PBXW-7, Mod B compositions would have initiated a main charge explosion in a munition.

The next series of tests used the 45/50/5 composition (PBXW-7, Mod C). This composition at the low heating rate punched the witness plates with holes of 0.8-inch and 1.1-inch diameters. The test at the high heating rate produced a plate dent very similar to that of Test #22 which was also tested at the high heating rate. The results for testing with this composition are shown in Figures 14, 15 and 16.

The next composition, 35/60/5 (PBXW-7, Mod D), is the standard formulation for the booster explosive, PBXW-7. At the low heating rate, there was one detonation with a slightly ragged hole of one inch in diameter. The other two tests produced violent explosions with plate dents. The plate dent produced under the low heating rate had about twice the depth of the dent formed at the high heating rate (Figures 17, 18 and 19). This composition in Tests #13, 18 and 25 could have initiated a main charge explosive (i.e., H-6).

The last composition to be tested, 20/75/5 (PBXW-7, Mod E), had very mild cookoff reactions. The two tests at the slow heating rate were listed as mild deflagrations and the test at the high heating rate was listed as a burning reaction. The results are shown in Figures 20, 21 and 22.

TEST ANALYSIS

This portion of the study deals with predicting the time to cookoff using laboratory data on an explosive and determining the peak temperature at a given heating rate. The two explosives used in this calibration were RDX and TATB. A plot of the DSC thermal pattern data on these two explosives is shown in Figure 23. A DTA/TGA/DTG thermal pattern is shown in Figure 24 for general reference in the thermal documentation of PBXW-7, Mod D. The DSC data indicate a peak thermal temperature of about 230°C (0.1°C/second) to about 260°C (1°C/second) for the RDX explosive. The DTA/DTG peaks are at about 223°C (3°C/minute) for the RDX portion of the thermal pattern in Figure 23. The TATB portion of the thermal pattern shows two exothermic peaks, one at about 356°C and another at about 365°C. The DSC pattern on TATB (in PBXW-7, Mod D) also indicates two exothermic peaks which range in temperature from 367° to 386°C. The data in Table 1 show an explosive surface temperature range from about 208°C (RDX-rich) to about 255°C (TATB-rich). These data would indicate that in all of these tests, the RDX portion of the composition controlled the time to cookoff. Typical thermal patterns (tube temperature vs time, Figure 3) on Tests #8, 13, 22, and 25 are shown in Figures 25, 26, 27, and 28.

CONCLUSIONS

The SSCB test fixture presents a technique that can be used to empirically predict the time to cookoff and the severity of the cookoff reaction for a given explosive. The booster explosive CH-6 detonates in the SCB test fixture at about 600 grams, in the SSCB without the metal inserts at about 60 grams, and in the SSCB with the metal inserts at about 20 grams. This indicates that the technique is scaleable with at least the CH-6 explosive. The technique can be applied to other explosives that have a critical diameter less than 0.6 inch, as the "thermal run-up distance" appears to be about 0.1 inch, from examination of the witness plates.

Examination of the test fixture after completion of tests showed that when a cookoff reaction was a mild explosion, the thermocouple slot in the outer housing became a weak spot. The weak spot was eliminated with modification of the SSCB.

With the completion of the calibration series of tests with the SSCB, the need for modifications was apparent. The modified design eliminates the slot on the inside wall for the thermocouple. This slot presented a weak spot in the case of a mild explosion and has been relocated in the aluminum sleeve. Other minor design changes were made to facilitate the ease of manufacture and assembly.

The outer housing tube is still 3 inches long but now the ID is 1.112 inches and the OD is 1.3125 inches. The top and bottom plate diameter has been reduced to 3.5 inches. Also, the two 1.25-inch-long explosive housing cylinders now have IDs of 0.625 inch and ODs of 0.875 inch (Figure 4).

The apparent cookoff temperature of the explosive can indicate which explosive is controlling the cookoff time from the DSC and DTA/TGA/DTG thermal pattern data generated in the laboratory.

Some explosives will not scale down because of the small diameter of the SSCB, which may be below the critical diameter of the explosive to maintain a steady-state detonation. The new Air Force explosive, EAK, for example, falls into this category. The SCB must be used to test this explosive. For most explosives, however, the SSCB is applicable, and thus has a wide application at greatly reduced cost and test requirements.

TABLE 1. SSCB Calibration Tests for Cookoff Reaction Severity.

Test No.	Composition (by wt). %RDX/%TATB/%wax	Temperature, °C Bomb[1]	Expl.[2]	Heating rate	Cookoff time, sec.	Cookoff Reaction [3]
10	96/0/4	241	219	slow	932	Detonation; hole + no dent
8	85/10/5	230	208	slow	1126	Detonation; hole + 0.5-in dent
15	85/10/5	237	215	slow	900	Detonation; hole + 0.4-in dent
22	85/10/5	315	233	fast	228	Violent Explosion; no hole + 0.6-in dent
11	70/25/5	210	187	slow	1030	Detonation; hole + 0.4-in dent
16	70/25/5	241	219	slow	1023	Detonation; hole + 0.4-in dent
23	70/25/5	346	264	fast	230	Detonation; hole + 0.1-in dent
12	45/50/5	235	213	slow	1150	Detonation; hole + 0.5-in dent
17	45/50/5	241	219	slow	1070	Detonation; hole + 0.2-in dent
24	45/50/5	305	221	fast	283	Violent Explosion; no hole + 0.6-in dent
13	35/60/5	234	212	slow	924	Violent Explosion; no hole + .08-in dent
18	35/60/5	241	219	slow	991	Detonation; hole + 0.2-in dent
25	35/60/5	307	223	fast	279	Violent Explosion; no hole + .04-in dent
14	20/75/5	261	240	slow	909	Deflagration; no dent
19	20/75/5	267	246	slow	899	Deflagration; no dent
26	20/75/5	337	255	fast	278	Burning

1/Temperature of outer bomb. 2/Temperature of explosive-aluminum interface estimated from inert sand filled SSCB bomb tests. 3/Detonation = a neat hole punched in a 3/8-inch witness plate; plate dent = distance of distortion from normal plane of the witness plate at center of plate.

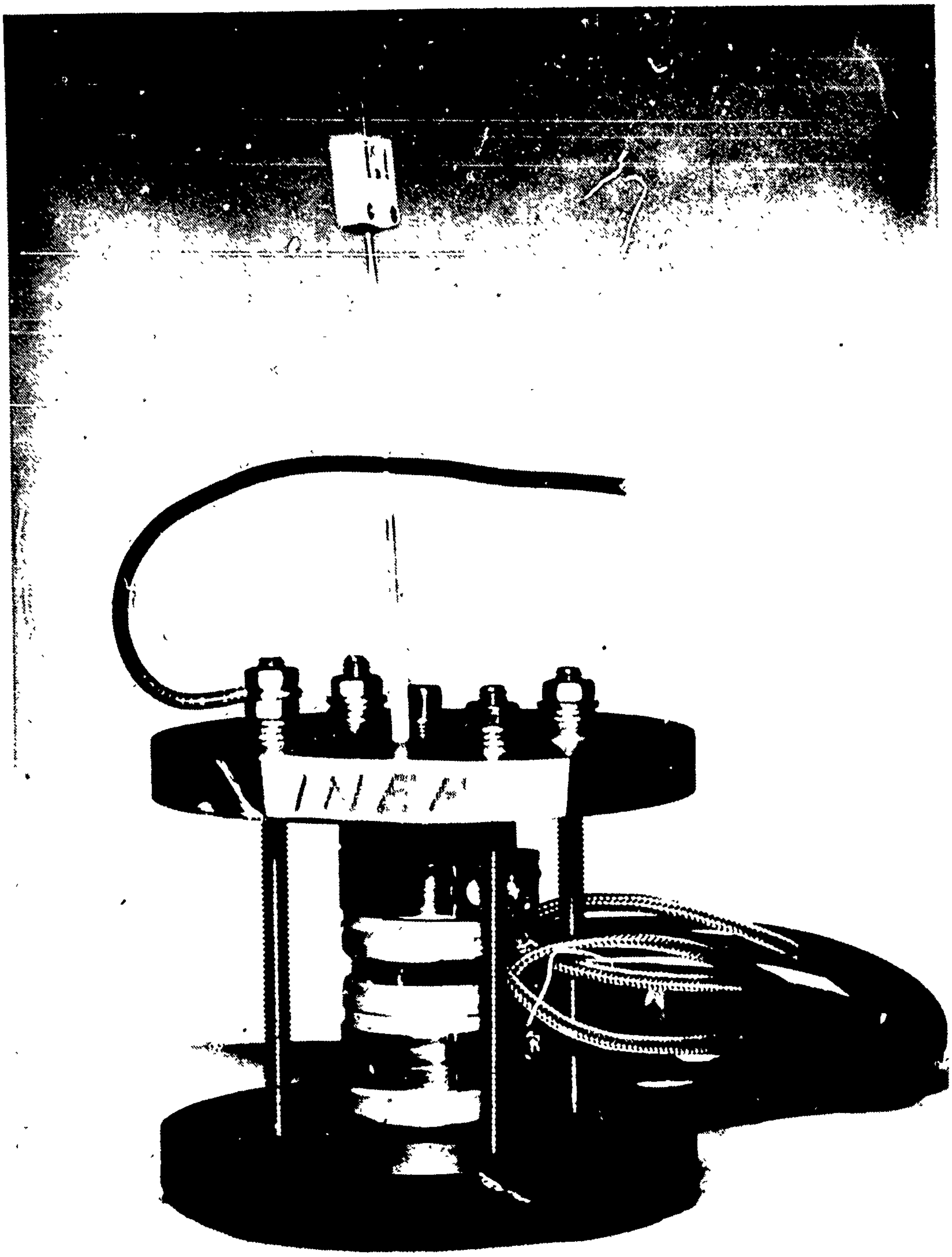


FIGURE 1. SSCB Test Fixture. (Neg. LHL 222474)

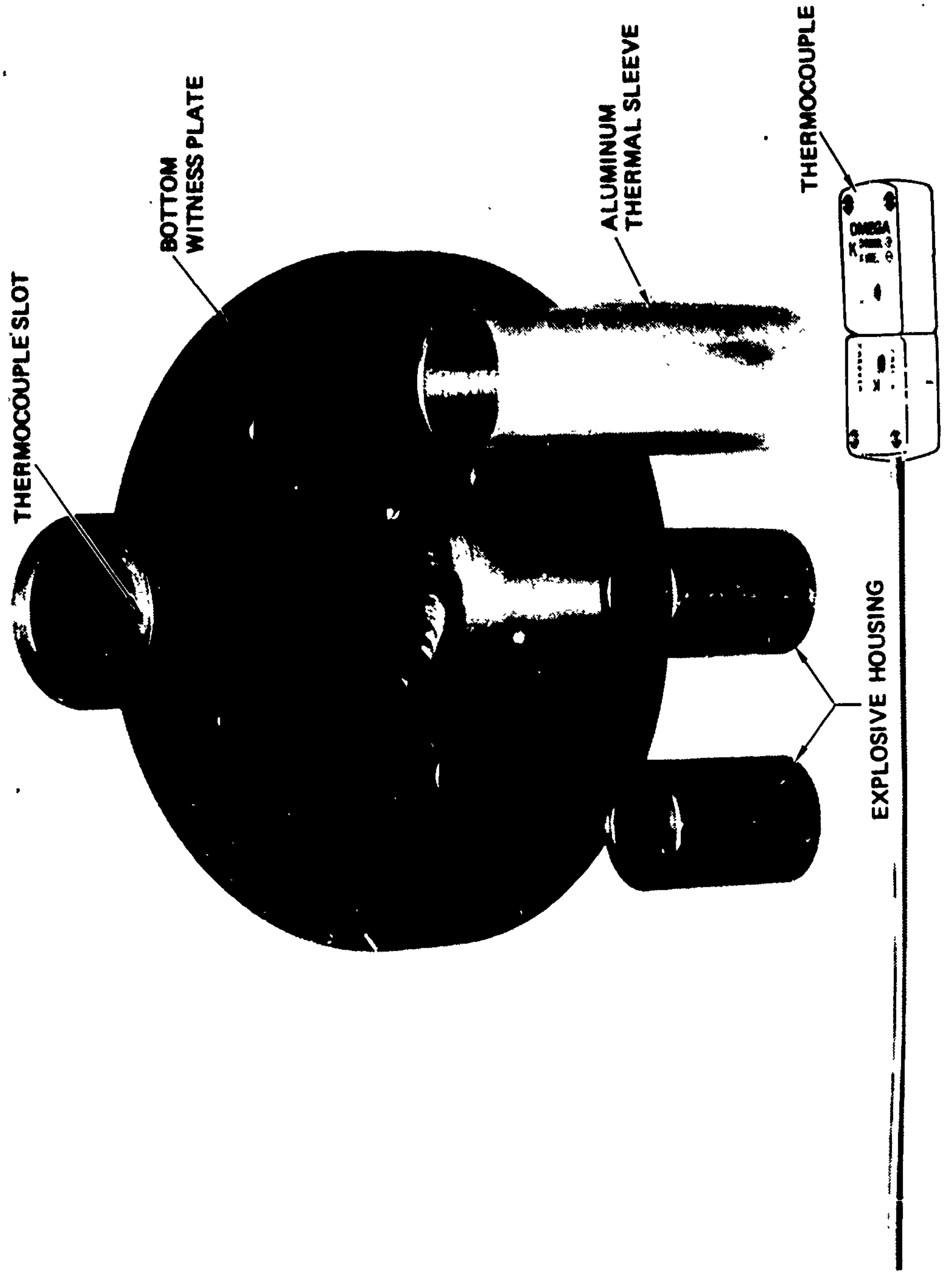
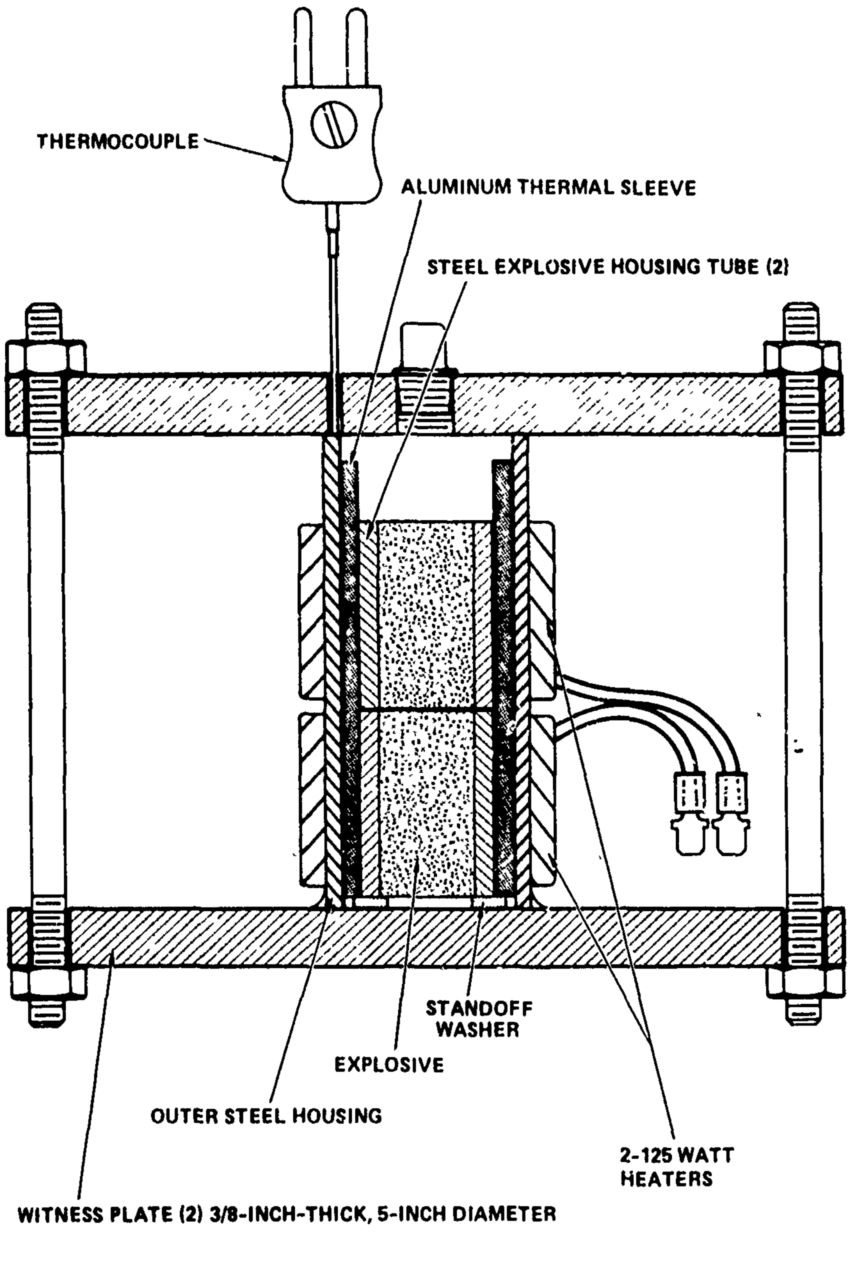


FIGURE 2. SSCB Components. (Neg. LHL 224310)



SSCB TEST FIXTURE

FIGURE 3. Prototype SSCB.

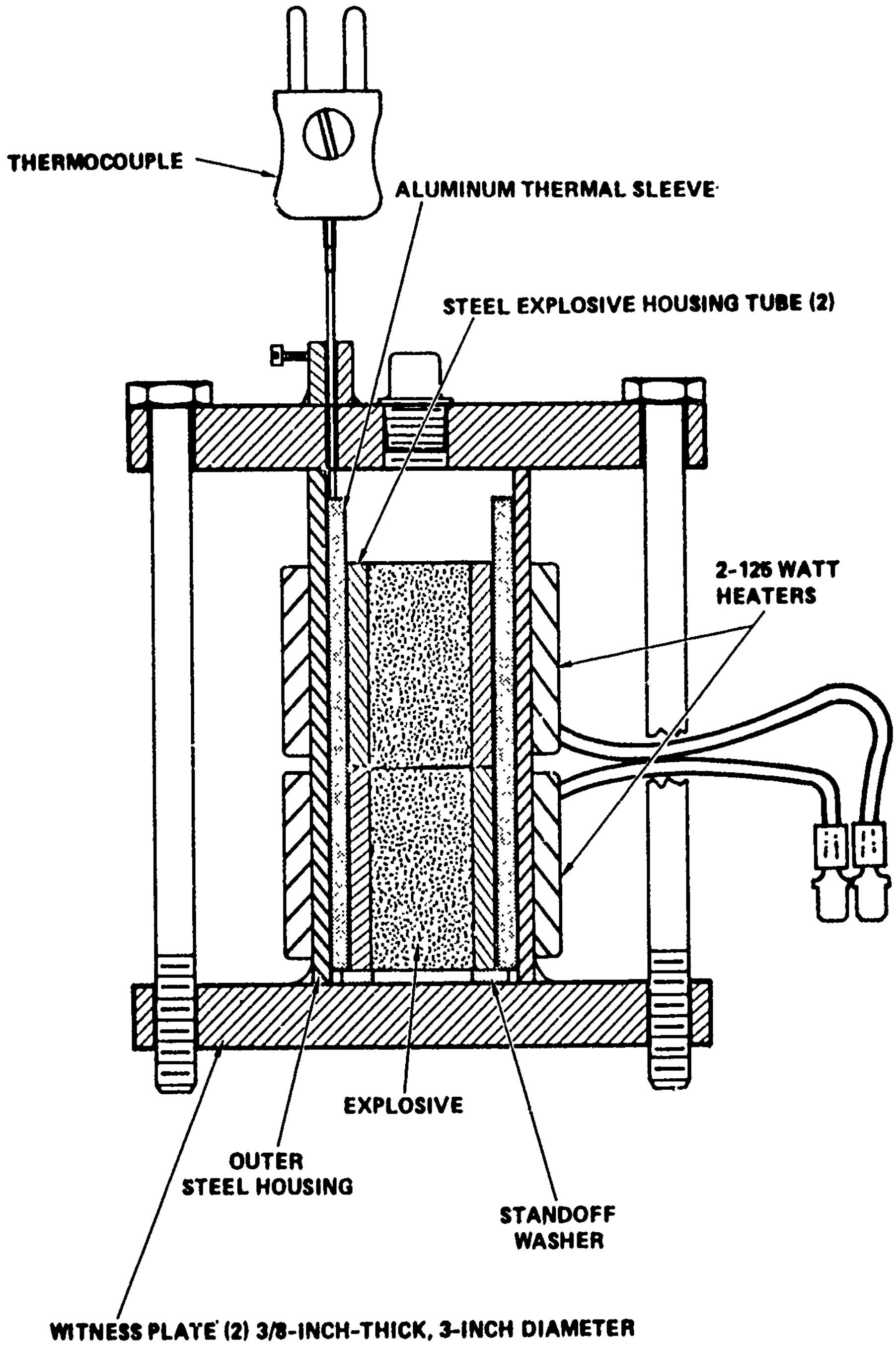


FIGURE 4. Modified SSCB.

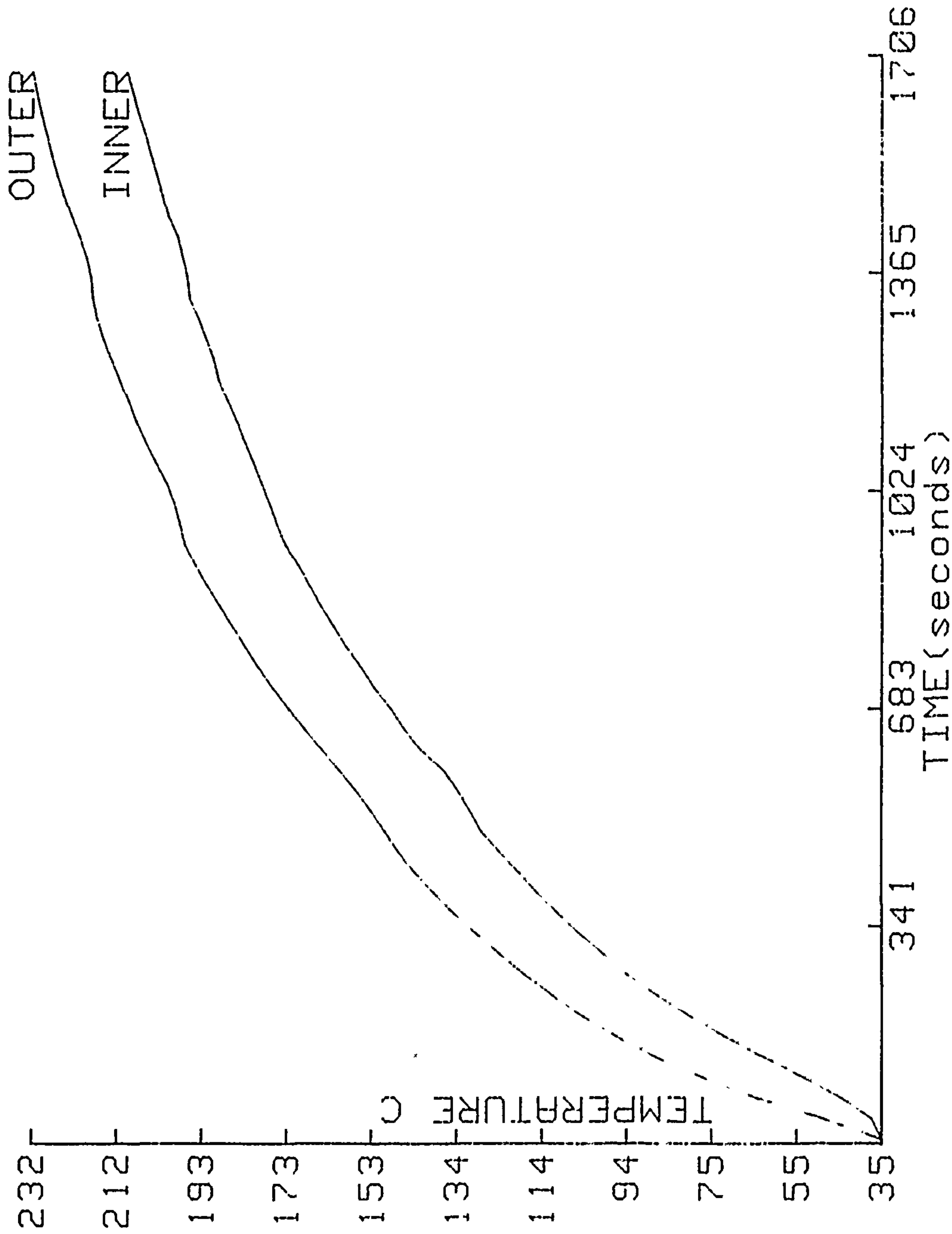


FIGURE 5. Slow Cookoff Temperature Range (Sand Filled).

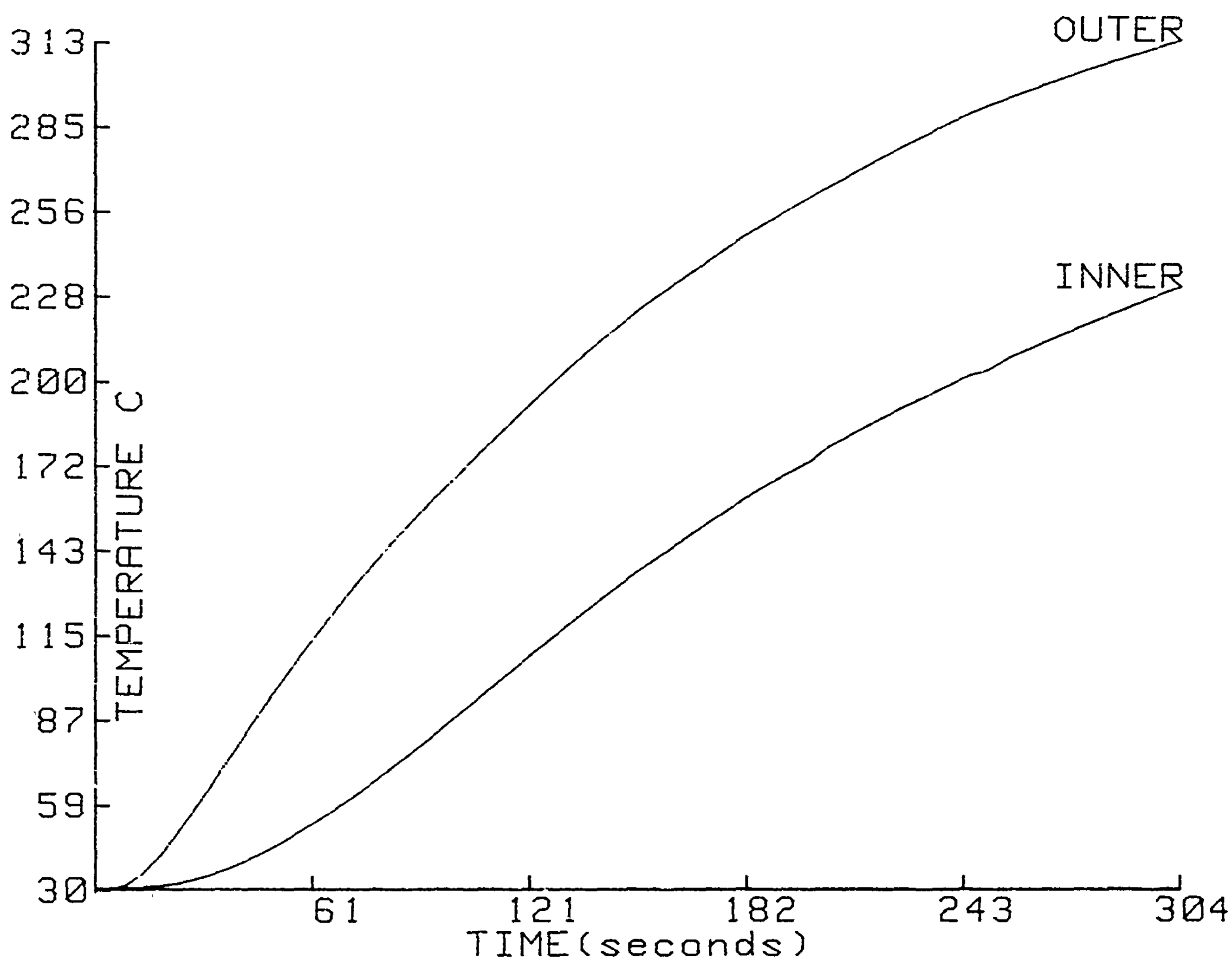


FIGURE 6. Fast Cookoff Temperature Range (Sand Filled).

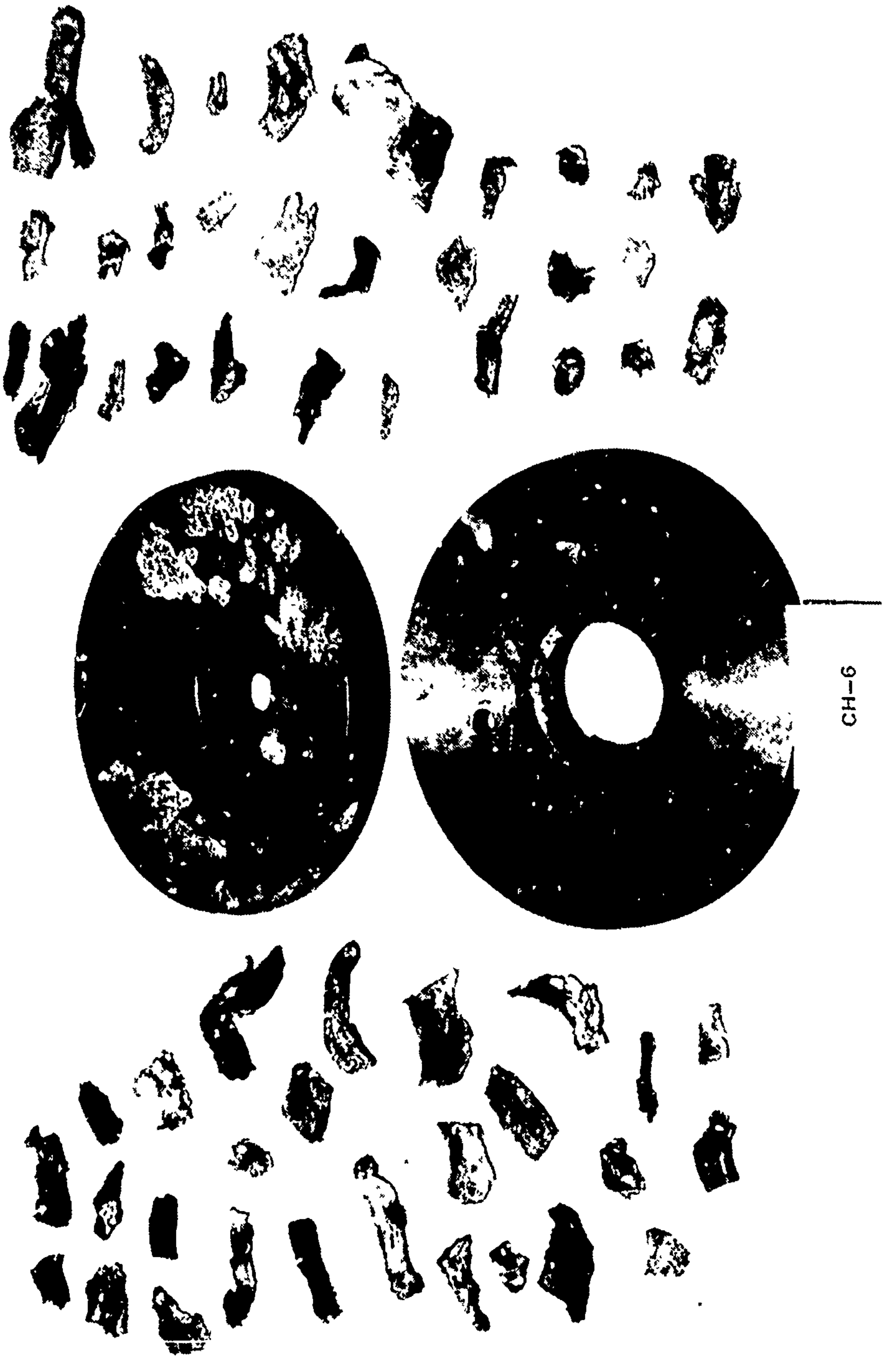


FIGURE 7. Results of SSCB Test Number 10. (Neg. LHL 224120)

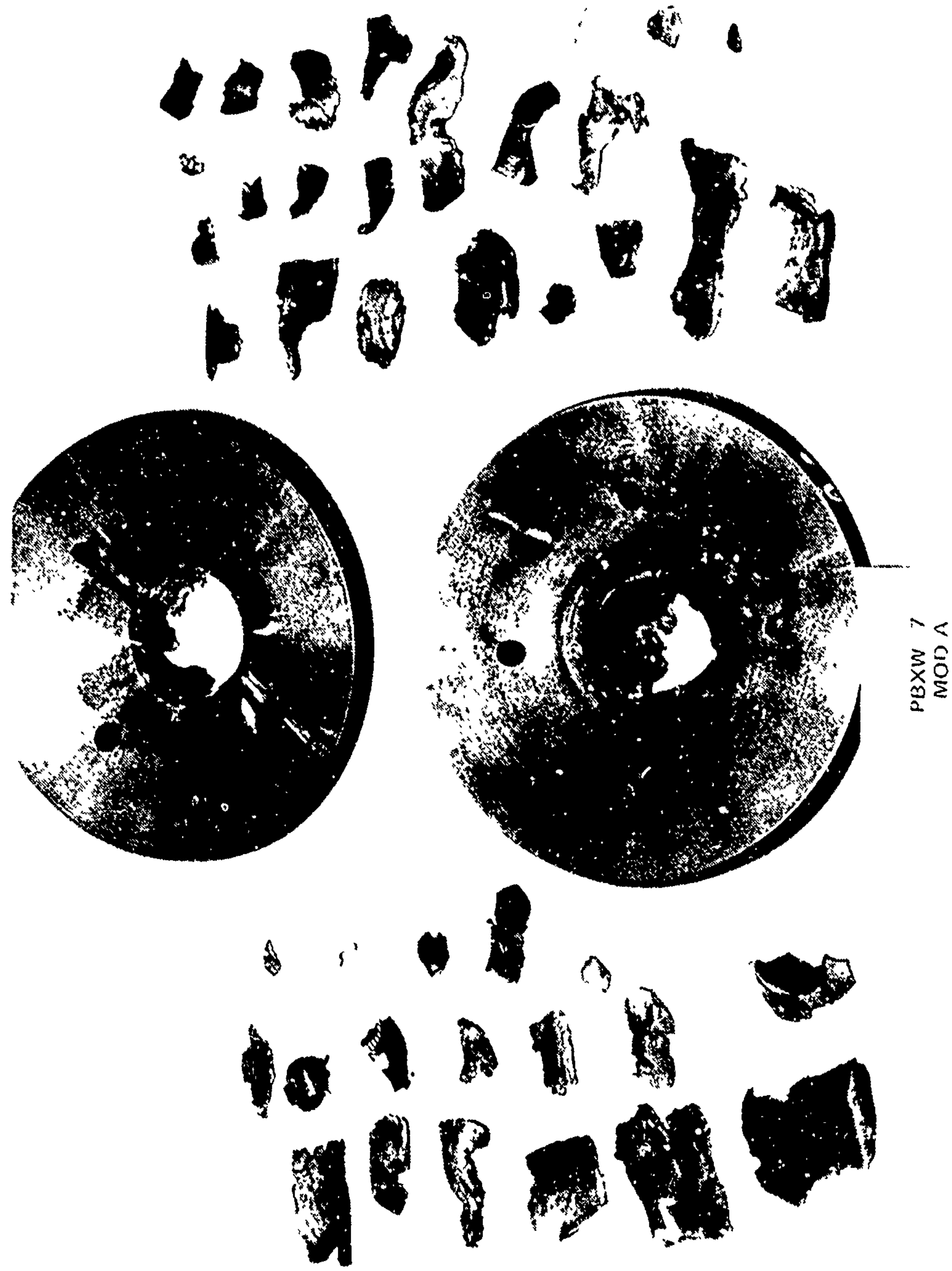


FIGURE 8. Results of SSCB Test Number 8. (Neg. LHL 224118)

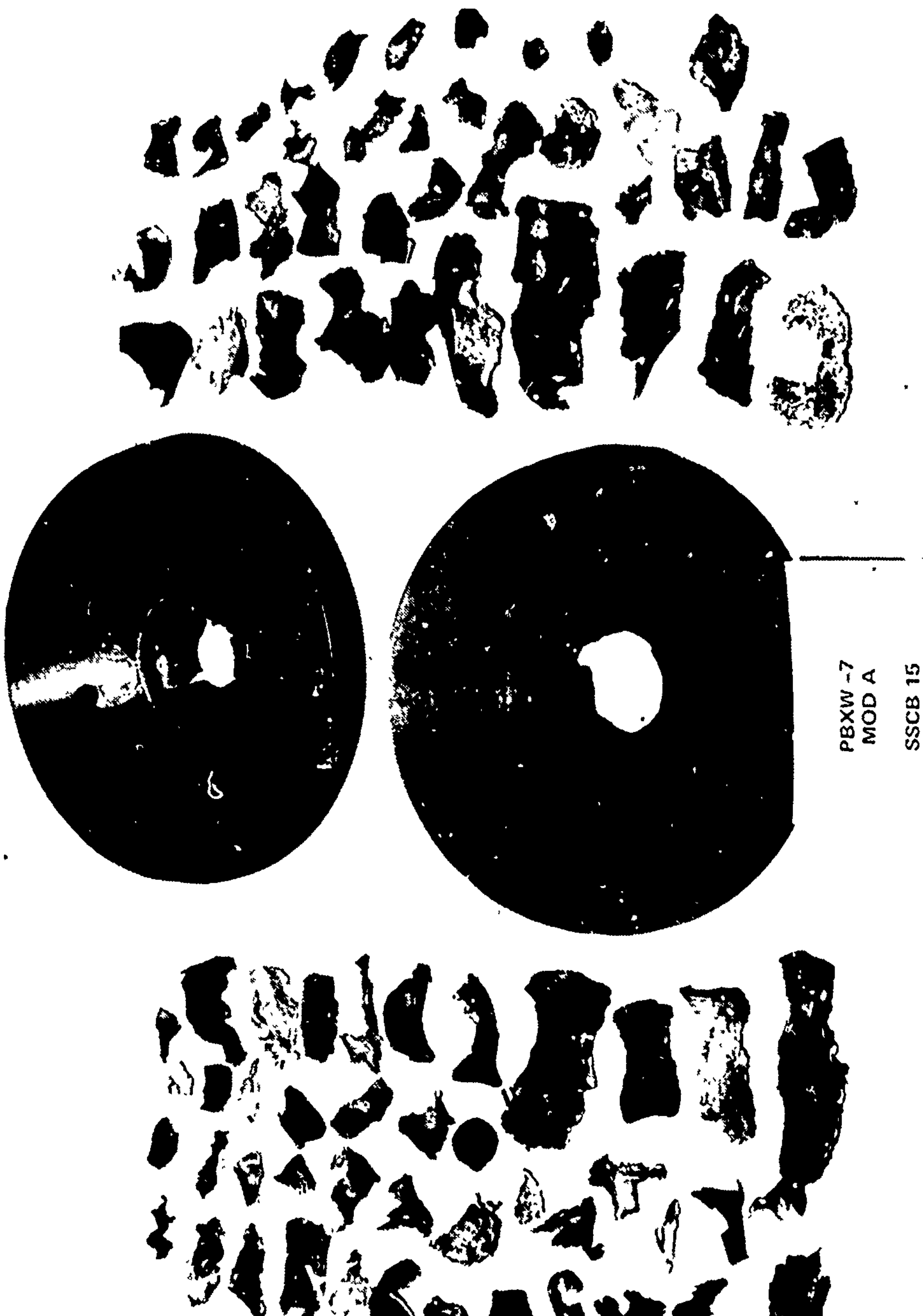


FIGURE 9. Results of SSCB Test Number 15. (Neg. LHL 224125)

FIGURE 10. Results of SSCB Test Number 22. (Neg. LHL 224133)

FIGURE 11. Results of SSCB Test Number 11. (Neg. LHL 224121)

FIGURE 12. Results of SSCB Test Number 16. (Neg. LHL 224126)

FIGURE 13. Results of SSCB Test Number 23. (Neg. LHL 224134)

FIGURE 14. Results of SSCB Test Number 12. (Neg. LHL 224122)

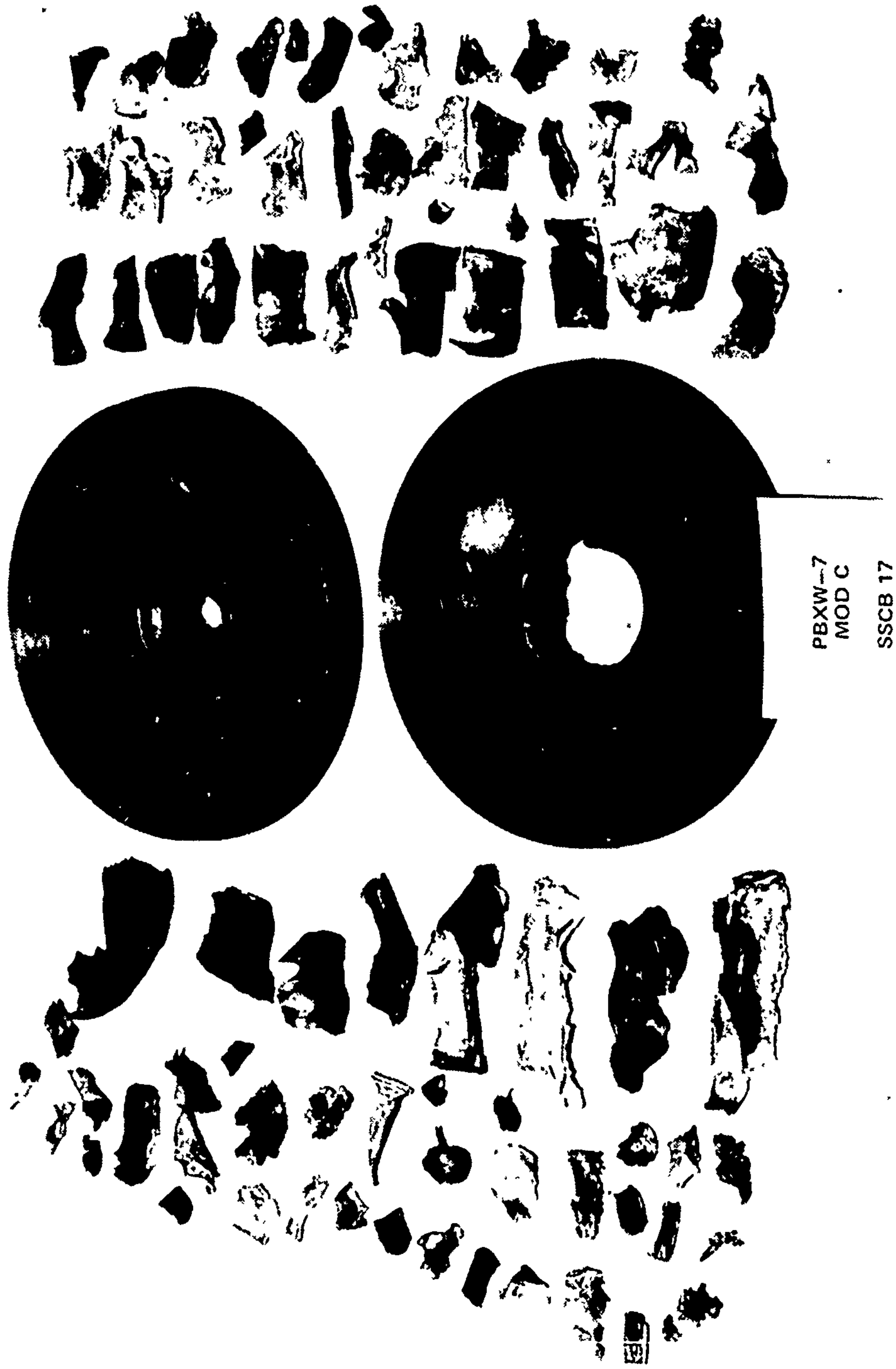


FIGURE 15. Results of SSCB Test Number 17. (Neg. LHL 224127)

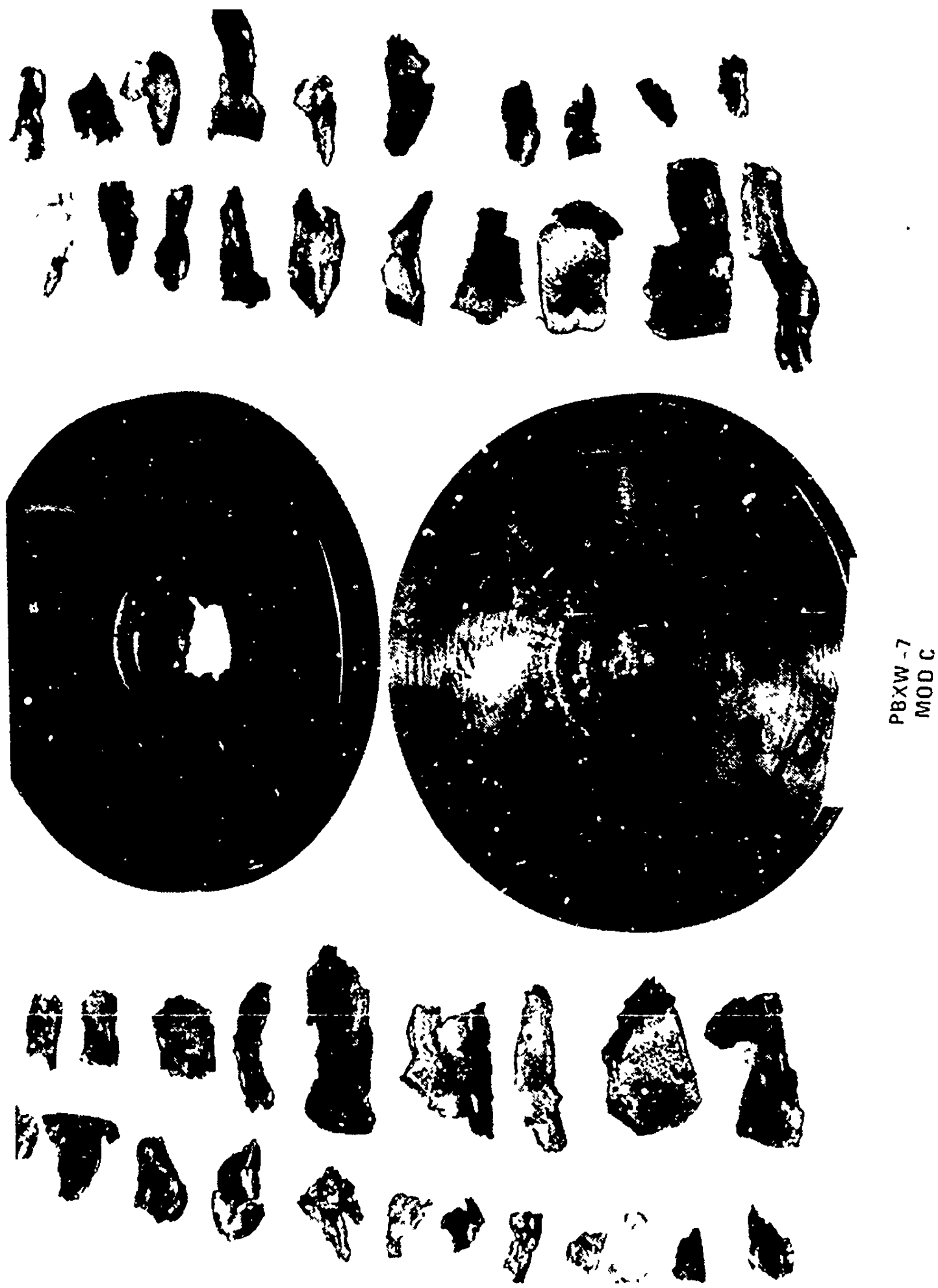


FIGURE 16. Results of SSCB Test Number 24. (Neg. LHL 224135)

FIGURE 17. Results of SSCB Test Number 13. (Neg. LHL 224123)

FIGURE 18. Results of SSCB Test Number 18. (Neg. LHL 224128)

FIGURE 19. Results of SSCB Test Number 25. (Neg. LHL 224136)

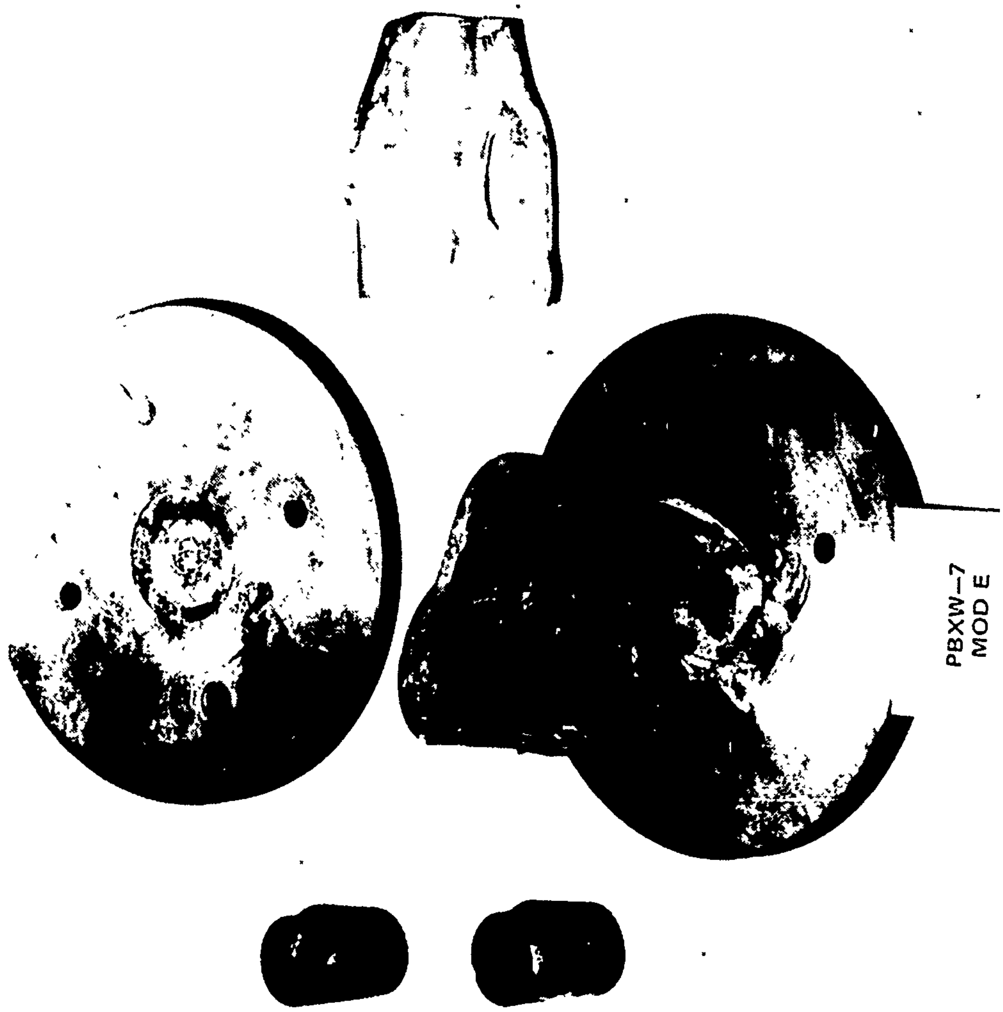


FIGURE 20. Results of SSCB Test Number 14. (Neg. LHL 224124)

FIGURE 21. Results of SSCB Test Number 19. (Neg. LHL 224129)

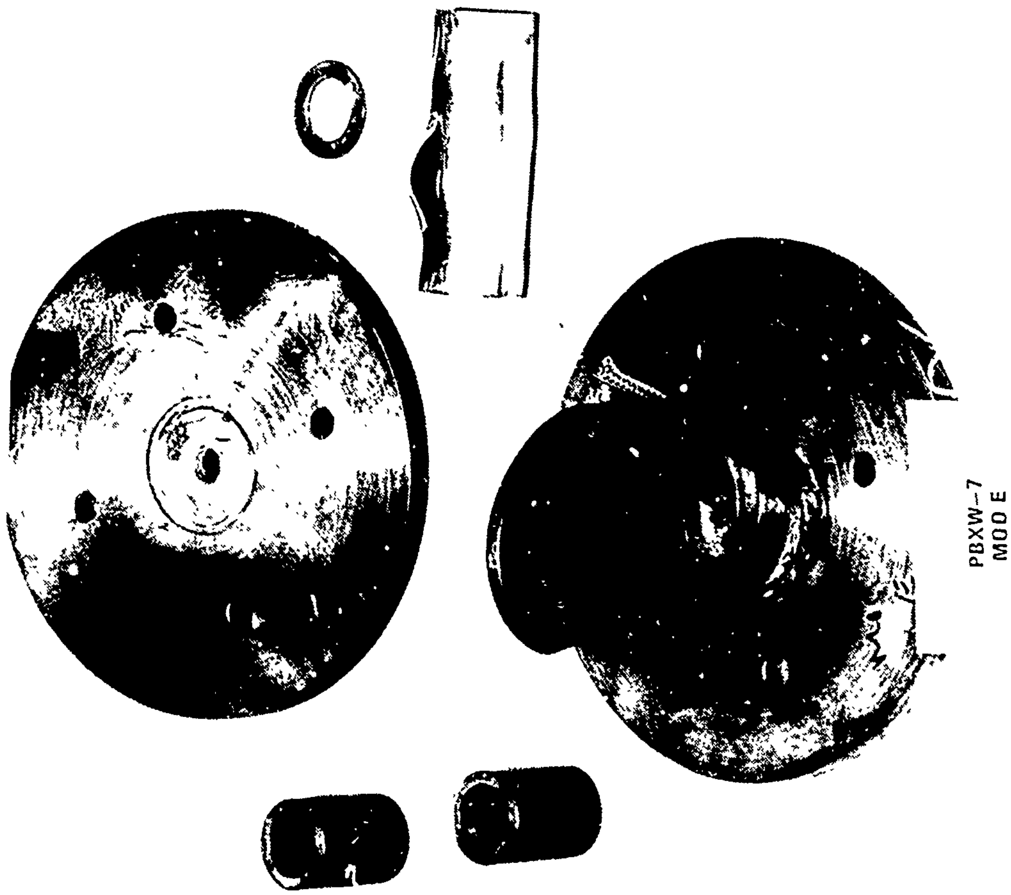


FIGURE 22. Results of SSCB Test Number 26. (Neg. LHL 224137)

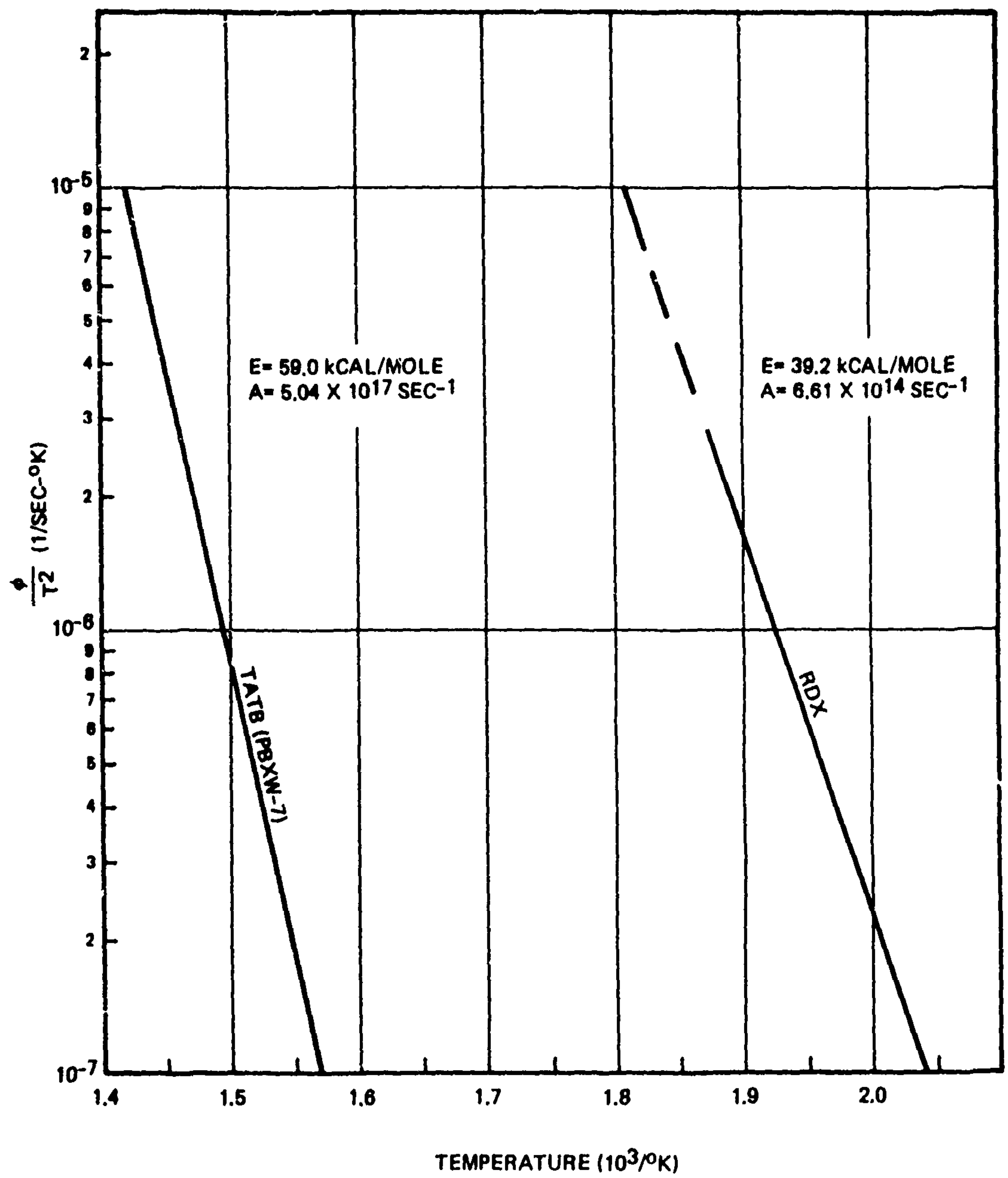


FIGURE 23. Data from DSC Thermal Peaks.

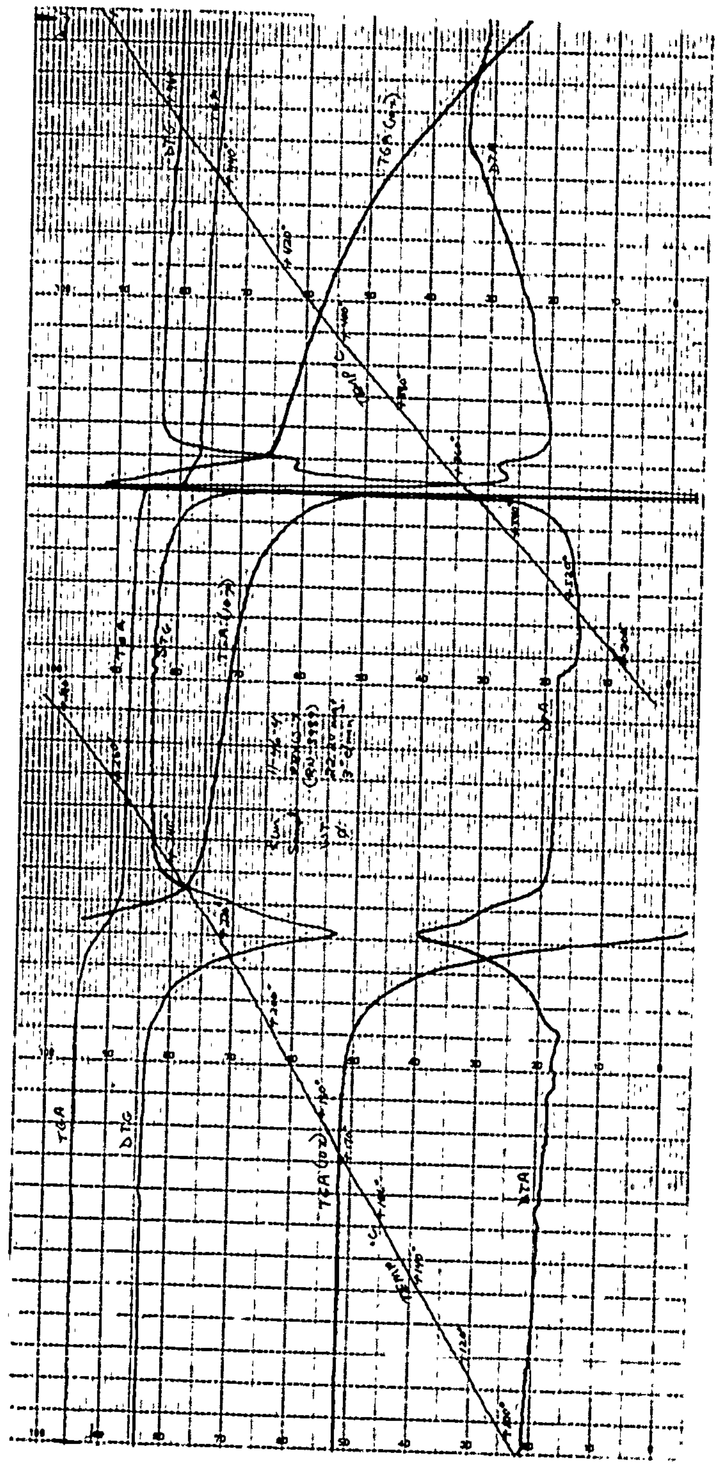


FIGURE 24. DTA/TGA/DTG Thermal Pattern.

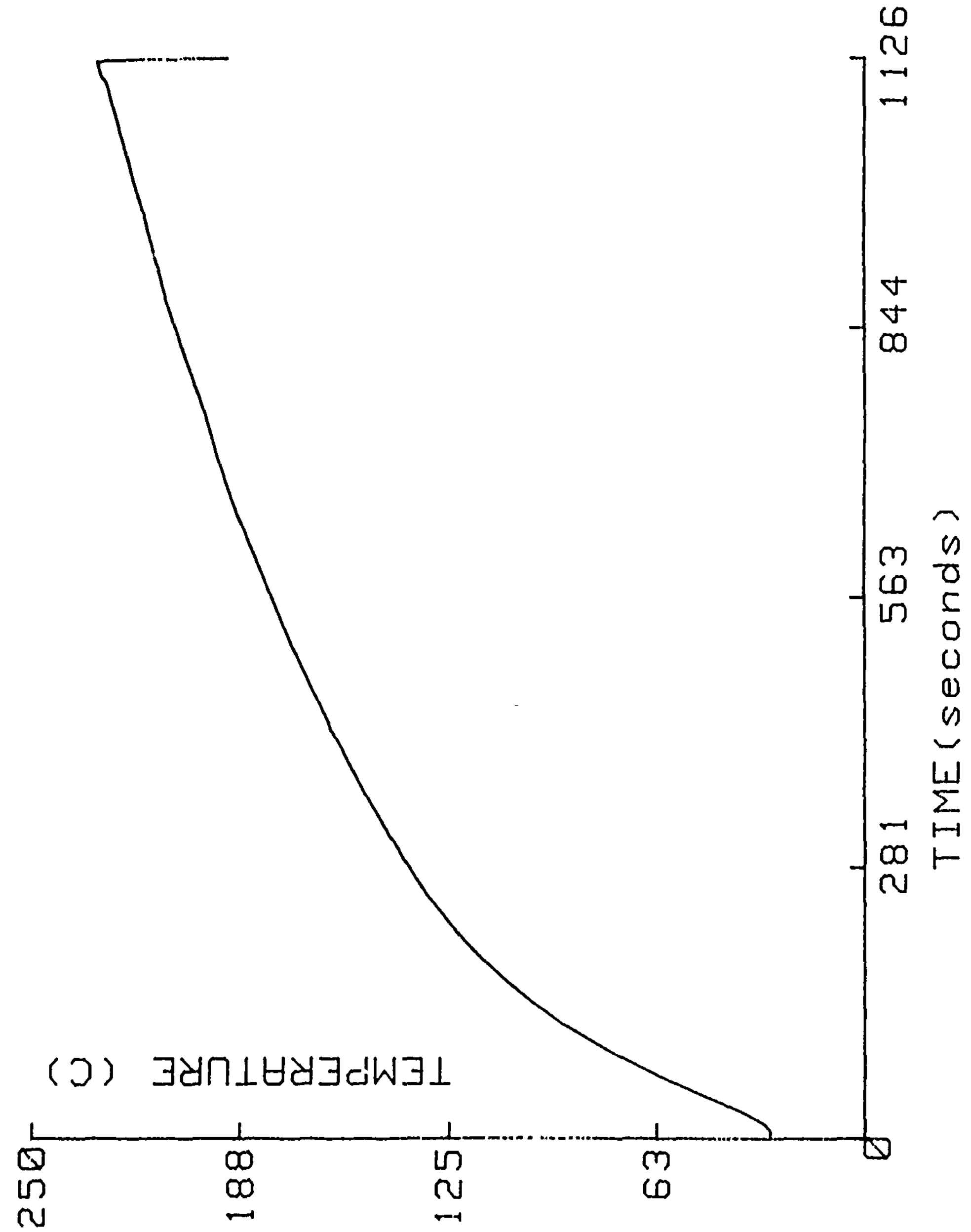


FIGURE 25. Thermal Pattern for SSCB Test Number 8.

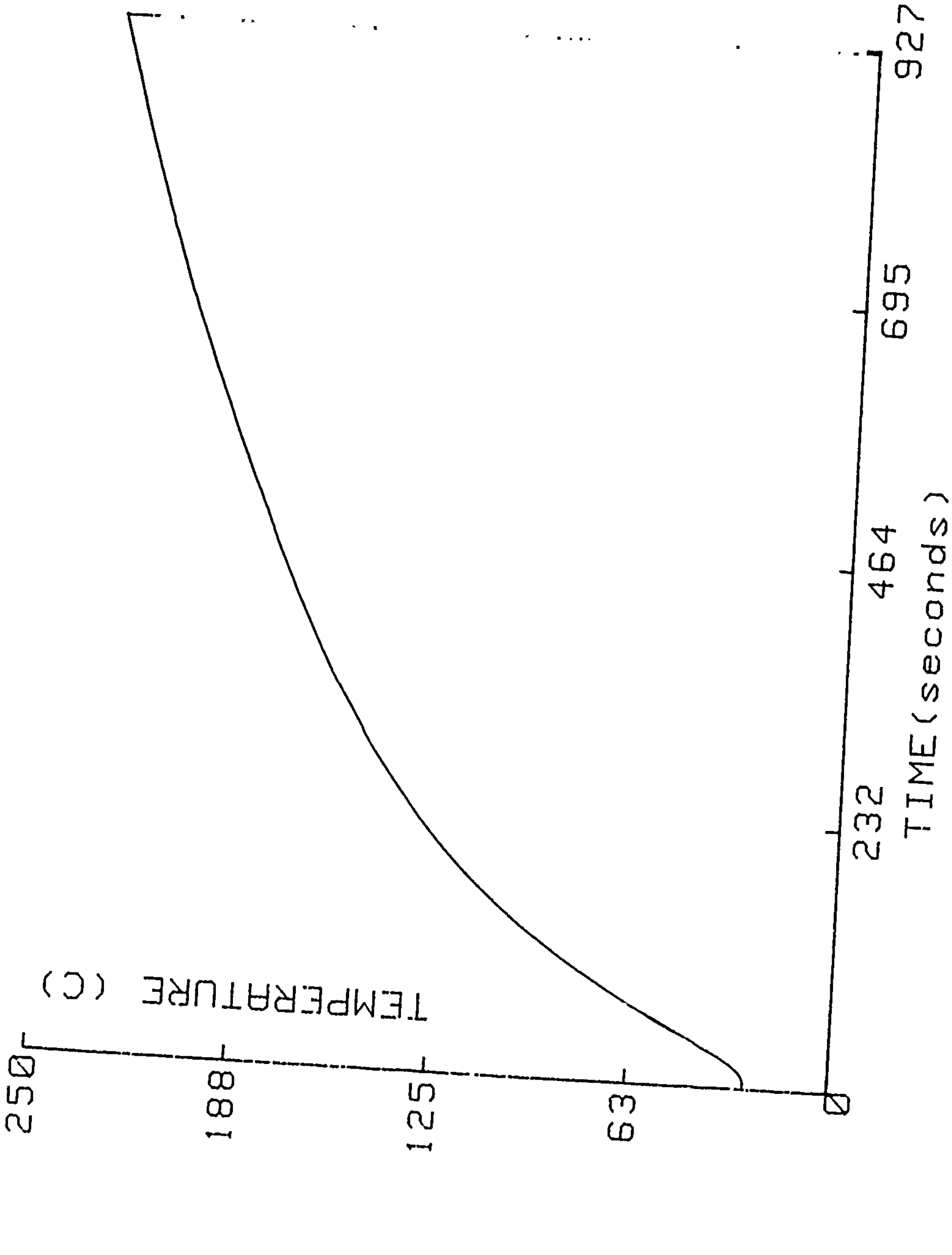


FIGURE 26. Thermal Pattern for SSCB Test Number 13.

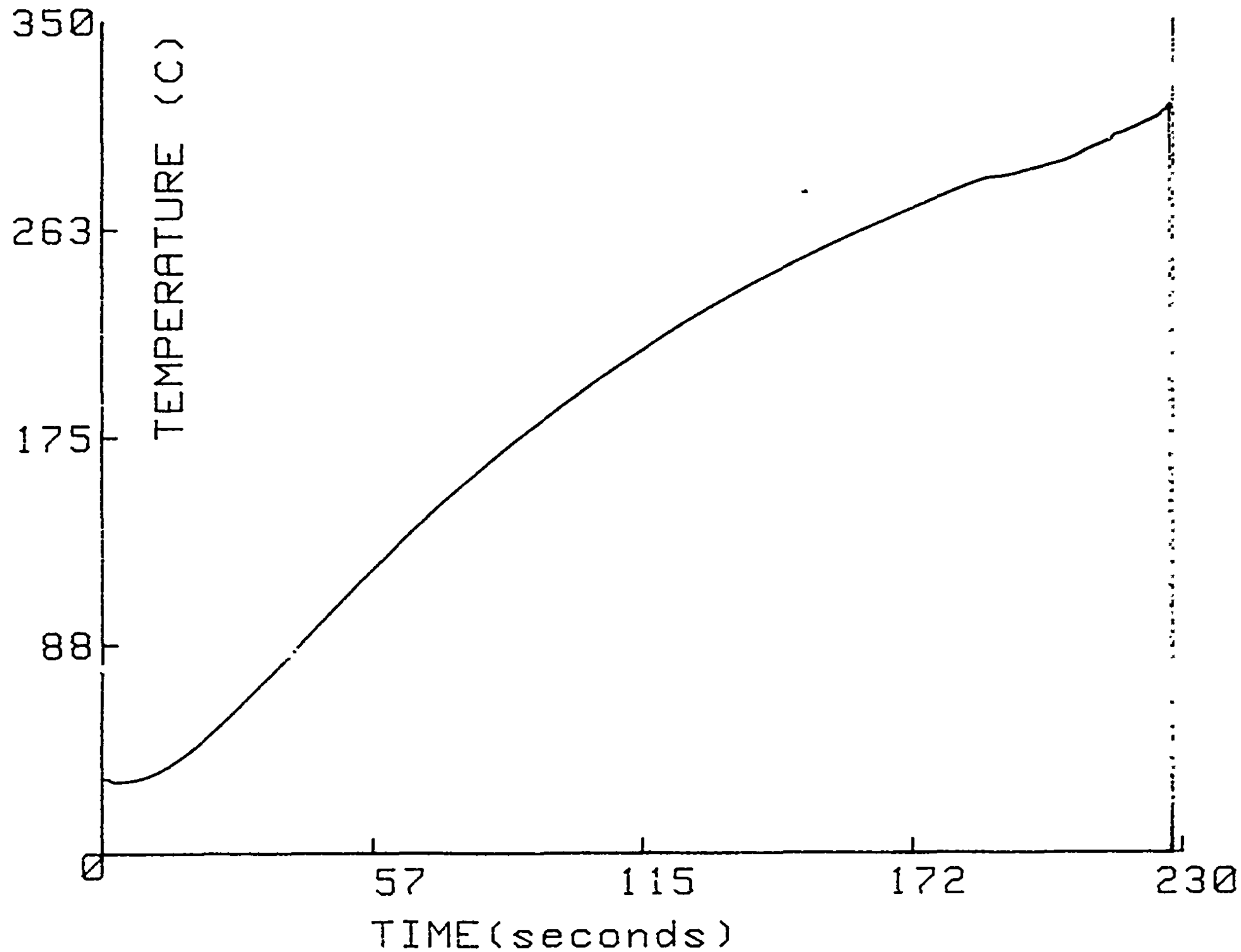


FIGURE 27. Thermal Pattern for SSCB Test Number 22.

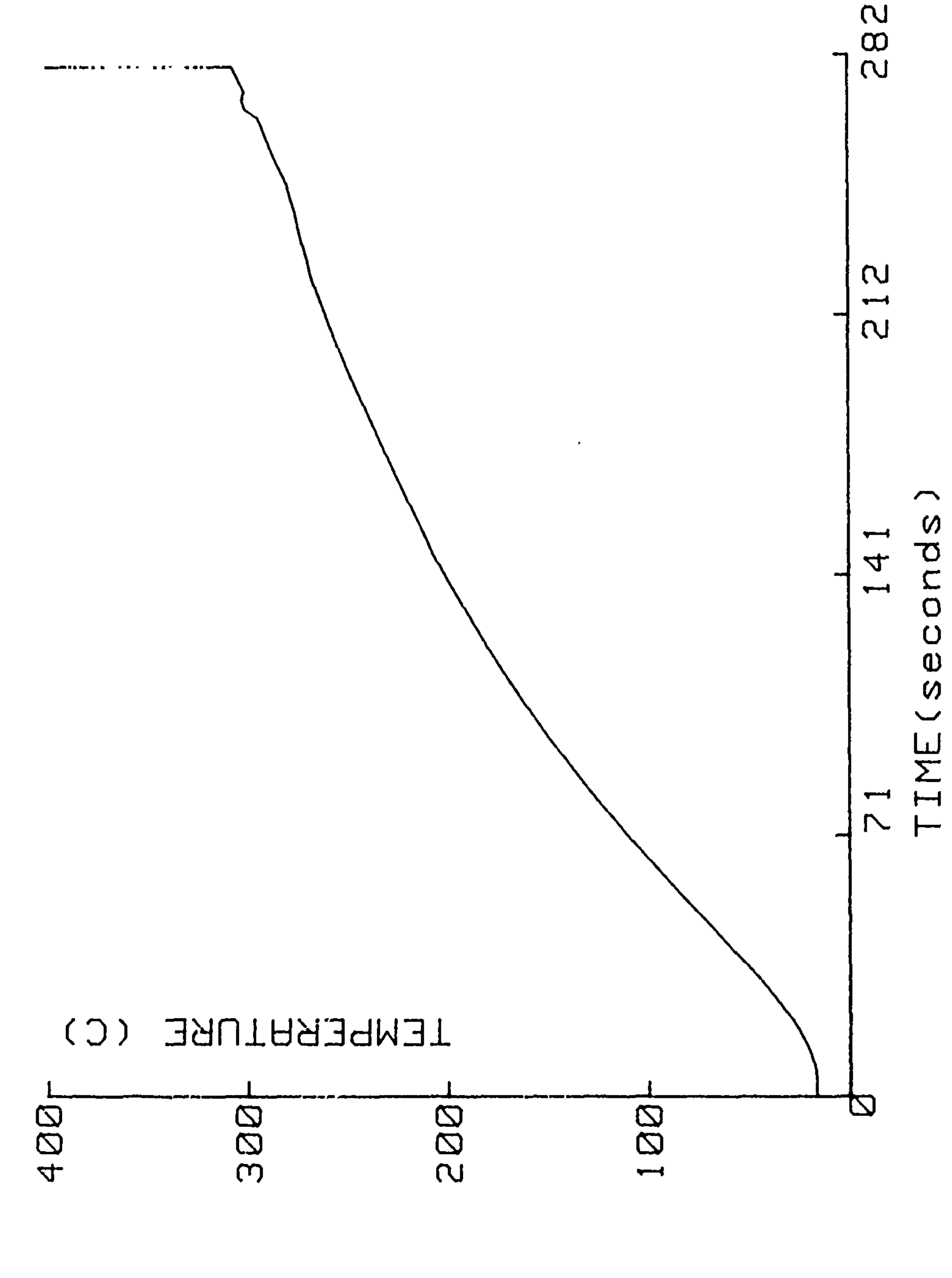


FIGURE 28. Thermal Pattern for SSCB Test Number 25.

APPENDIX A

MODIFIED SSCB PARTS LIST

MODIFIED SCCB PARTS LIST

Item Number	Nomenclature	Quantity	Part Number/ Identification No.	Specification
1	Bottom Witness Plate/ Outer Housing	1		1020 Steel Witness Plate 3.500" Dia. .375" Thick Housing 3.120" Long 1.312" OD 1.122" ID
2	Electric Heater	2	A 8334J 8144	120V 125W Type M, Type A Lead, Galvanized Metal Braid, Fiber Glass Insulation Suggested Sources: Watlow of St. Louis
3	Standoff Washer	1		Mild Steel Washer 11/16" OD 5/8" ID 1/16" Thick All dimensions ±.006"
4	Liner Sleeve	1		6061-T6 Aluminum 2.750" Long 1.112" OD .885" ID
5	Explosive	2		1020 Steel 1.250" Long .875" OD .635" ID Filled with explosive
6	Top Witness Plate	1		1020 Steel 3.500" Dia., .375" Thick
7	Thermocouple	1	SCASS-062G-6	Type K thermocouple probe assembly 304 Stainless steel-grounded junction Suggested Source: Omega Engineering, Stanford, Conn
8	Plug	1		1/8"-Pipe Plug
9	Assembly Bolt	4		1/4"-20 NC x 4" Long

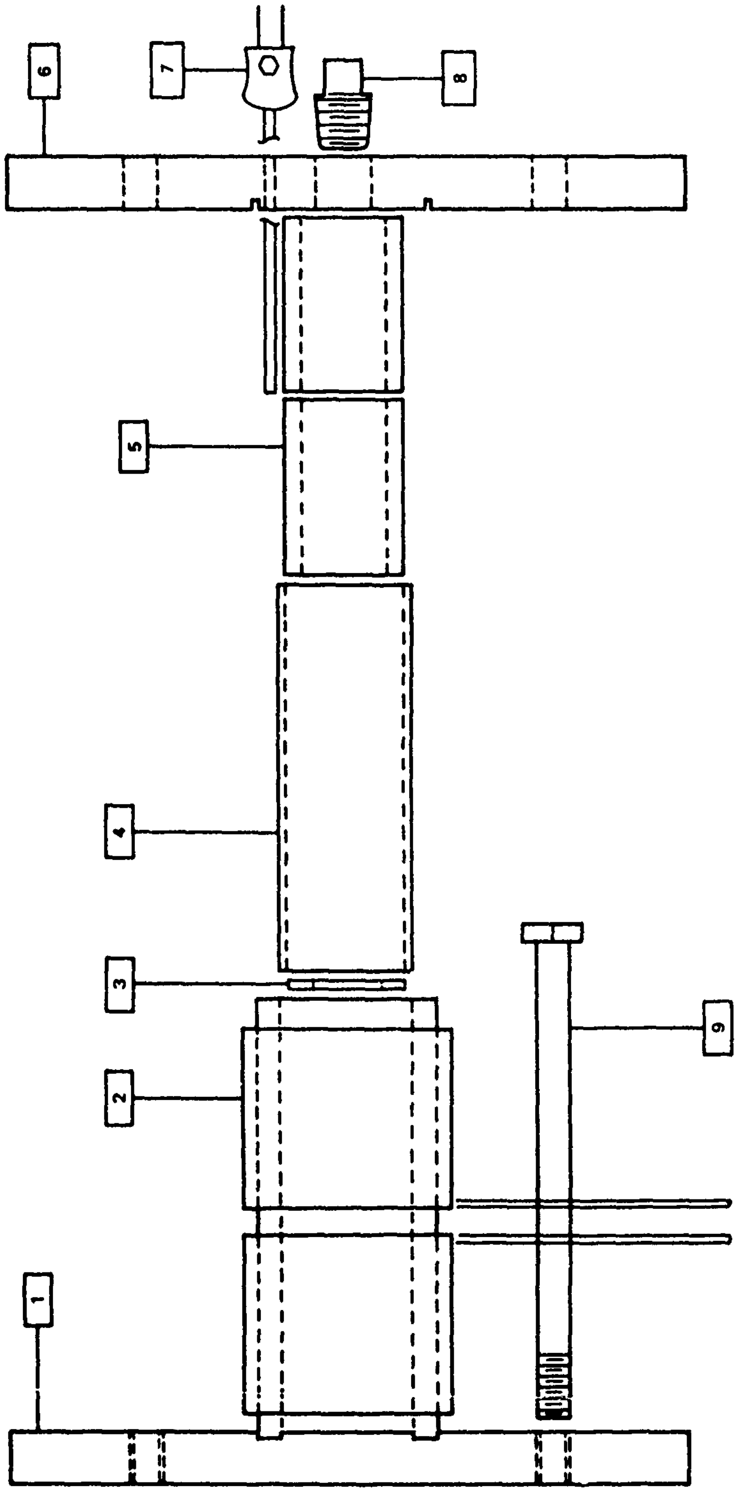


FIGURE A-1. Exploded View of the Modified SSCB.

APPENDIX B

MODIFIED SSCB DRAWING PACKAGE

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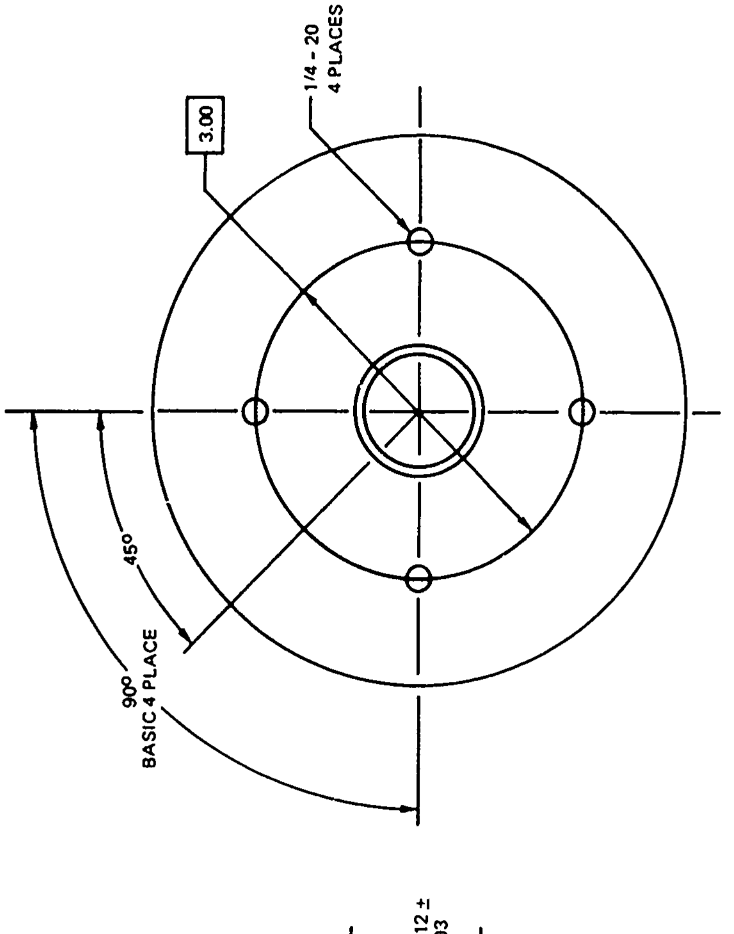

FIGURE B-1. Bottom Witness Plate/Outer Housing.

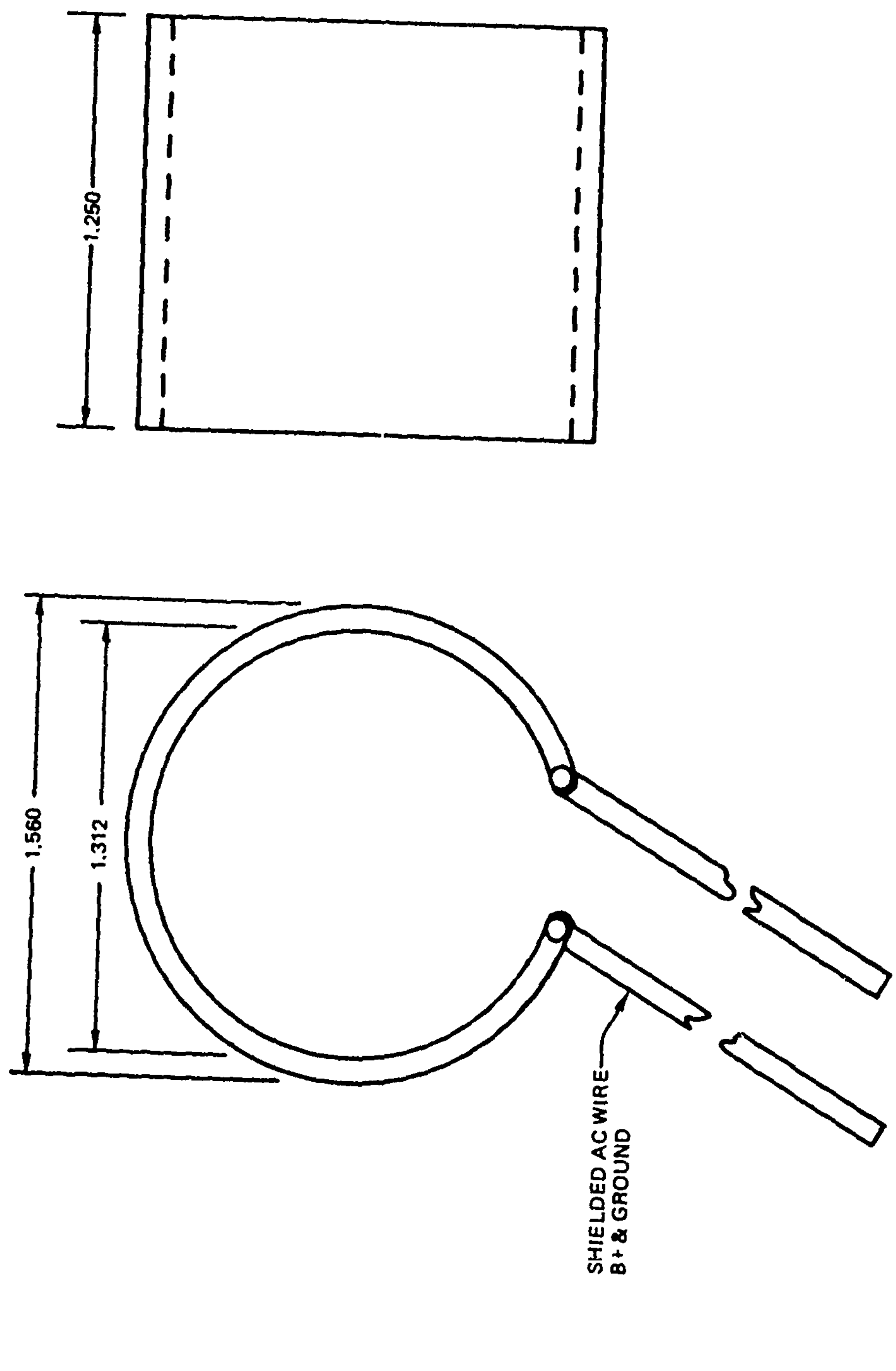

FIGURE B-2. Electric Heater.

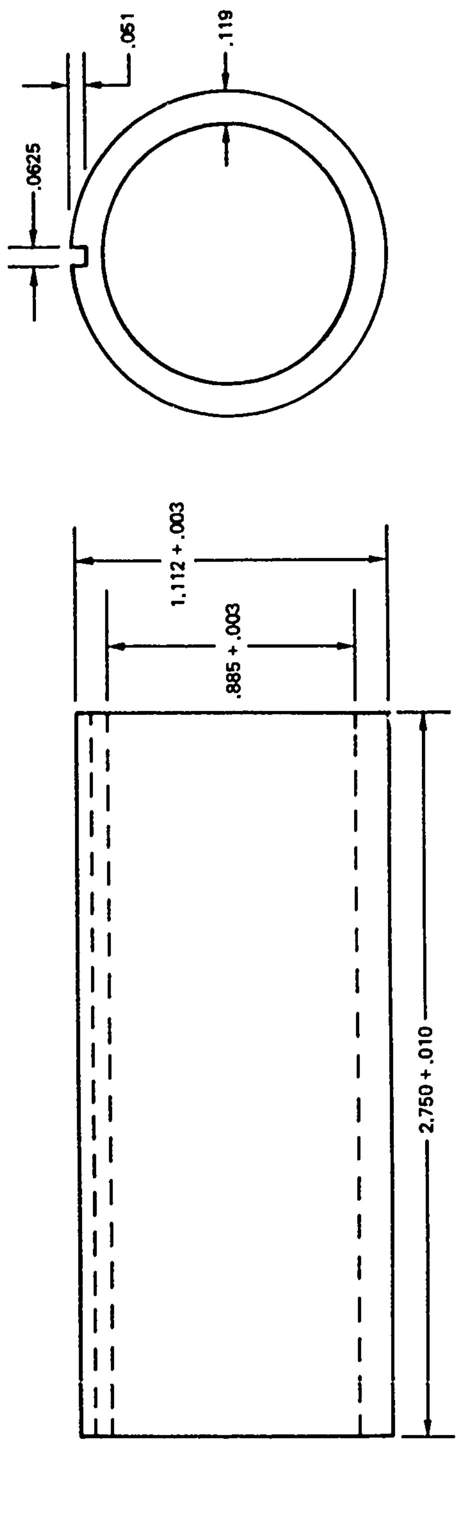

FIGURE B-3. Sleeve Liner.

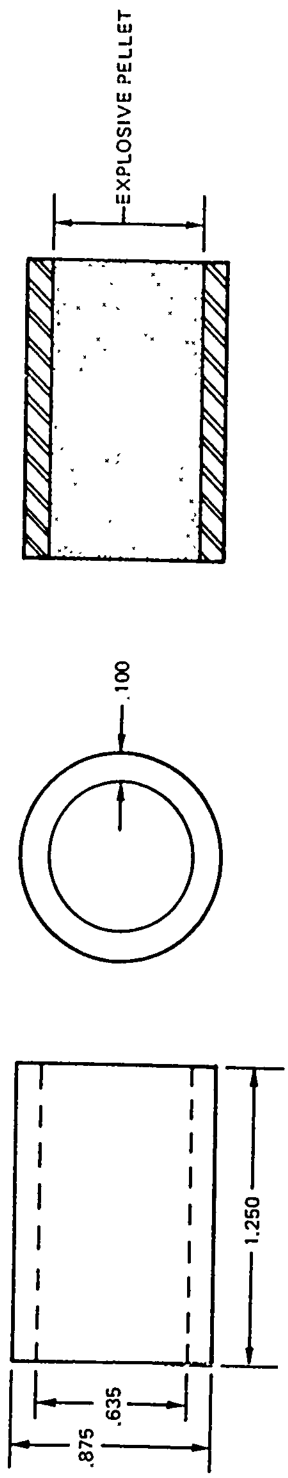

FIGURE B-4. Explosive.

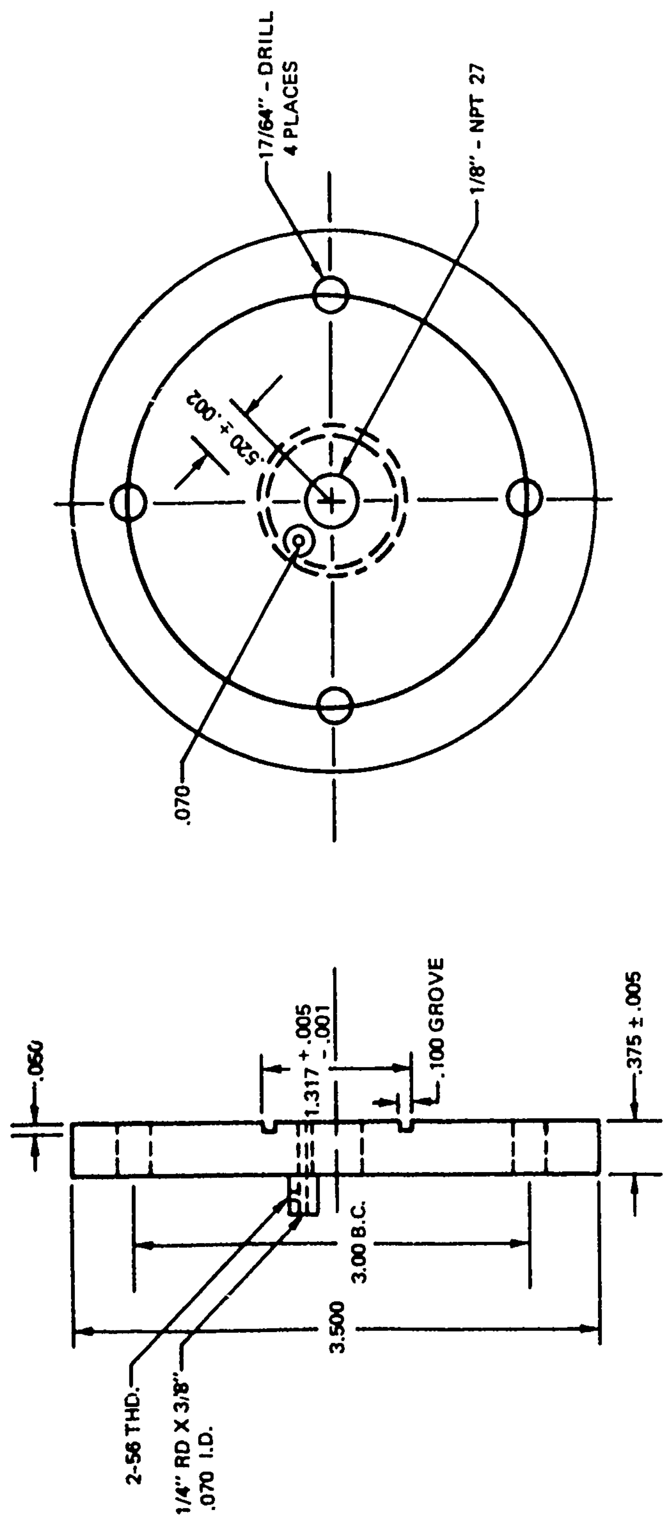

FIGURE B-5. Top Witness Plate.

APPENDIX C

MODIFIED SSCB ASSEMBLY PROCEDURE

ASSEMBLY OF SSCB TEST FIXTURE

Items referred to in the body of this document are numbered on attached sketch which are a part of this loading procedure.

Operations	Hazard	Precautions
1. Place bottom witness plate and outer housing (Item 1) on the assembly table.		1. Ground (Item 1) as per acceptable inhouse procedures
2. Install two 125-watt heater bands (Item 2) around housing as shown on attached sketch.		2. Position bottom heater as close as possible to base plate with leads up. Position upper heater level with, or slightly above explosive with leads down. Add heater band clamps and tighten.
3. Twist electrical leads from the heaters together using one upper right and one lower left lead for the first pair. Then twist the remaining two leads together. Attach the twisted pair securely to "zip-cord" for later attachment to firing line.		
4. Insert standoff washer (Item 9) into the outer housing (Item 1) then place thermal sleeve (Item 3) into outer housing, as shown on attached sketch.		

ASSEMBLY OF SSCB TEST FIXTURE

Items referred to in the body of this document are numbered on attached sketch which are a part of this loading procedure.

Operations	Hazard	Precautions
5. Hold bottom witness plate and outer housing (Item 1) at approximately a 45 degree angle insert (2) explosive charges (Item 4) into the assembly as shown on the attached sketch. Return assembly to verticle position on the assembly table.	5. Some explosives can be sensitive to impact or friction.	5. Keep the assembly grounded during this operation.
6. Place old thermocouple or aligning rod in hole "A" in top witness plate (Item 5) let thermocouple or rod extend approximately 1.5 inches from bottom surface of plate.		
7. Insert extended end of thermocouple or aligning rod into the thermocouple groove on the thermal sleeve (Item 3). Rotate assembly until bolt holes in the top and bottom witness plates are aligned. Lower top witness plate into position as shown on the attached sketch.	7. Make sure pipe plug is not in hole "B" in the top witness plate (Item 5) during assembly steps No. 7 and 8 to eliminate closed bomb effect in case of accidental ignition of charges.	7. Use no force during aligning operation of the assembly.
8. Insert the (4) bolts (Item 7) through top witness plate (Item 5) and thread into bottom witness plate (Item 1) and tighten to a snug fit.		
9. Remove old thermocouple or aligning rod from hold "A" in top witness plate (Item 5).		

ASSEMBLY OF SSCB TEST FIXTURE

Items referred to in the body of this document are numbered on attached sketch which are a part of this loading procedure.

Operations	Hazard	Precautions
10. Insert thermocouple to be used during test into hole "A" to desired depth. Tighten holding screw.		10. Caution do not over torque holding screw as damage to thermocouple could occur.
11. Insert pipe plug or second thermocouple into hole "B" in the top witness plate.		

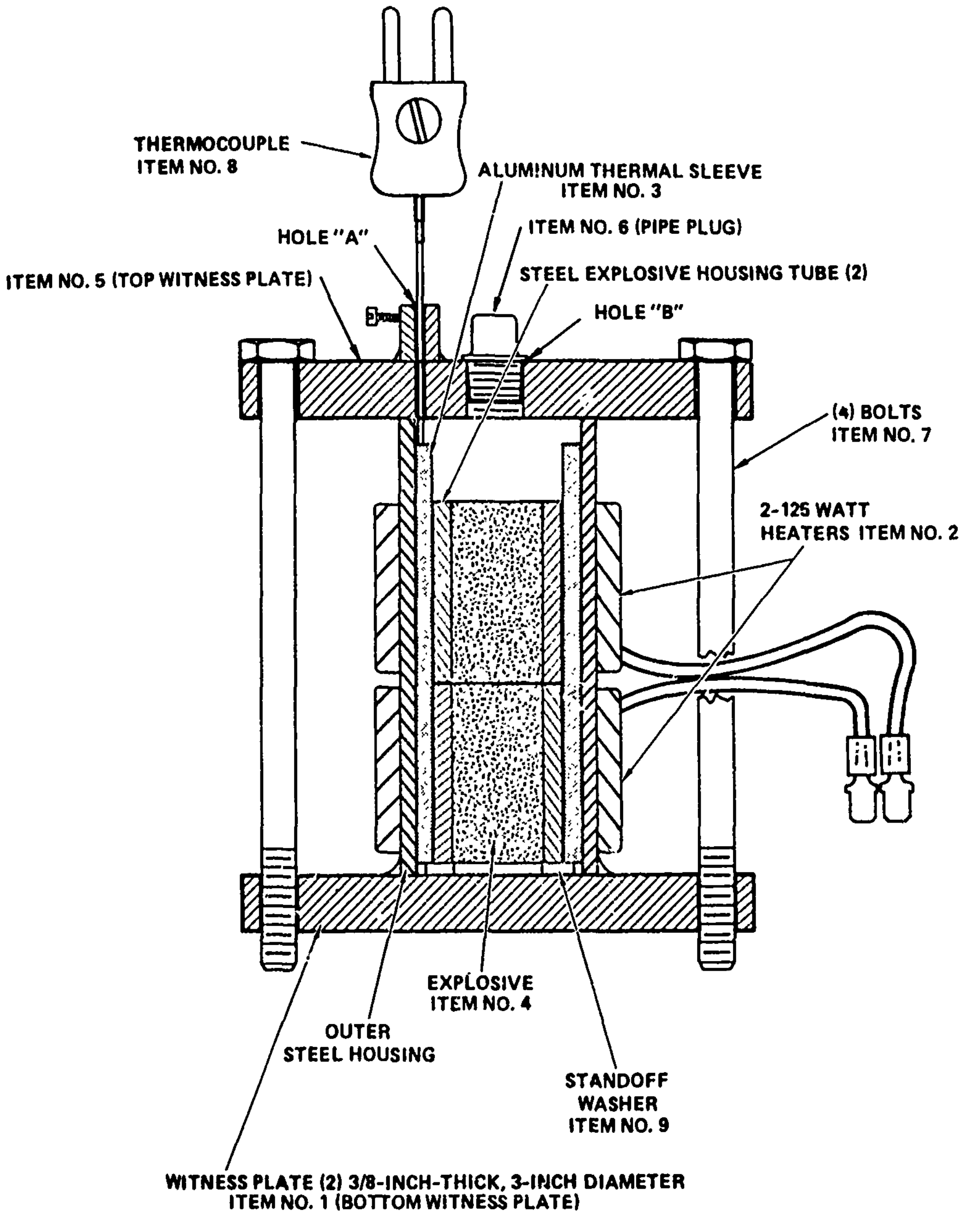

FIGURE C-1. SSCB Test Fixture Sketch No. 1.

NOMENCLATURE

CH-6	RDX-Calcium Stearate-Graphite-Polyisobutylene
DSC	Differential Scanning Calorimetry
DTA	Differential Thermal Analyzer
DTG	Derivative Thermogravimetry
EAK	Ethylene Diamine Dinitrate/Ammonium Nitrate/Potassium Nitrate
H-6	RDX-Trinitrotoulene/Aluminum/Wax
PBW-7	Plastic Bonded Explosive-White Oak
RDX	Cyclodimethylenetrinitramine
SCB	Small-Scale Cookoff Bomb
SSCB	Super Small-Scale Cookoff Bomb
TATB	2,4,6-Triamino-1,3,5-Trinitro Benzene
TGA	Thermogravimetric Analyzer

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