AD701373

RDTR NO. 160
3 DECEMBER 1969

# SAFETY TEST OF FLARE EXTRUSION FACILITY





PREPARED BY

RESEARCH AND DEVELOPMENT DEPARTMENT
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# SAFETY TEST OF FLARE EXTRUSION FACILITY

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# SAFETY TEST OF FLARE EXTRUSION FACILITY

I. Summary. During manufacture of MK 46 Flare grains for a pre-production lot, an accidental ignition occurred in the extrusion press. The press operator was fatally burned. Similar incidents had occurred at other plants.

The facility was restored with several additional safety interlocks, shields, and a new blowout window. The operating procedures were critically reviewed and personnel and material limits significantly reduced. Also a remote viewing system (closed circuit TV) was added. These changes were considered to be more than adequate to protect our personnel during future operations; however, a controlled instrumented test of the press cell would provide tangible evidence to support these judgments.

On September 29, 1969, the test was conducted with the press loaded with seven pounds of flare composition so as to simulate a point in the extrusion cycle at which an accidental ignition could occur. If an operator had been standing in front of the controls during the test, the greatest hazard he would have endured would have been toxic smoke inhalation. Flame inside the cell was visible from outside the cell within 0.15 seconds and smoke clouded the press control area in approximately two seconds. The temperature under the press rose high enough to melt aluminum; however, not all of the newspaper burned that was taped to the inside of the cell door. The temperature in the operator area peaked at 330°F for approximately one second. The polycarbonate shield between the bottom press platen and the floor did a fantastic job of shielding the front half of the cell

in the door area.

The pressure rise in the cell of approximately three psi was not great enough to blow the windows. The window should be replaced with one that blows at a lower pressure.

The results of the test increased our confidence that the restored extrusion facility can be operated safely. The test provided the type of information that is desperately needed for many other operations, which re-emphasizes the need for a duplicate cell in a remote area for such tests.

II. Introduction. On December 18, 1968, the operator of an extrusion press was fatally burned in Building 198 at NAD Crane. IR flare grains were being extruded for NAVAIRSYSCOM Project Order 8-0426. The investigation revealed that at least three major safety practices were being violated: pyrotechnic materials had accumulated to an unsafe quantity, the facility did not permit adequate separation of the various operations being conducted that day, and adequate personnel protection had not been provided. Similar situations have occurred far too many times at other plants where IR flares were being manufactured.

2. During restoration of the facility, the safety of the operation was very critically reviewed. Material and personnel limits were reduced, and new blowout windows and shields were installed. Also additional safety interlocks were installed in the press control circuits and a remote viewing system (closed circuit TV) added.

3. Ignition at the extrusion press on December 18 could have resulted from friction between the ram and charge cylinder, adiabatic

compression of air not evacuated from the charge cylinder, broken extrusion die, or static electricity. The exact cause was not established; however, several opinions strongly favored a broken extrusion die. After the extrusion facility was restored, an extrusion die for the MK 46 flare grain with a crown made of material that had twice the tensile strength of the crown being used in December was installed in the press. Several inert extrusions were made at a line pressure of 1000 psi and at 130°F charge cylinder temperature. In order to increase the stress on the die, additional inert extrusions were made at a line pressure of 1500 psi and with the charge cylinder at ambient temperature. During the second run, the die crown collapsed as can be seen in Figure 1. Die collapse with only 50% over stress adds strength to the opinions that the die crown broke and caused ignition in the press on December 18.

4. Because of our recent accident, the fact that other manufacturers have had similar accidents, and because of the low factor of safety in the strength of the die crown, the degree of safety for personnel operating the newly restored extrusion facility had to be known. We were confident that the changes made to the facility were more than adequate, but this was our best judgment. In order to obtain some tangible evidence to support our judgment, permission to conduct an instrumented, controlled burn test of the facility was requested and granted. The test was conducted on September 29, 1969.

## III. Description of Test

1. The extrusion press is located in cell number 109 Building 198. The material limit for cell 109 has been established at eight pounds. This limit allows extrusion of approximately 30 inches of MK 46 type flare

grain. The press was loaded with seven pounds of MK 46 flare composition, so as to simulate a point in the extrusion cycle at which an accidental ignition might occur. Figure 2 is an illustration of the press as loaded for the test.

2. Several inert extrusions had been made to checkout press operation which left the press blocked. The press was then charged with 2700 grams of flare composition and cycled, which produced a 37-inch length of flare grain. The grain was the same as the MK 46 grain except without the center hole. The last increment consisted of an additional 454 grams consolidated with one-half the pressure required to extrude the 37 inch grain. The purpose of the partially consolidated increment was to simulate the condition under which a compression ignition might occur. Since ignition would take place inside the press, a simulation of an accidental ignition caused by a die breaking would also be achieved. An igniter was placed through the side of the charge cylinder 2.4 inches below the face of the ram and 5.5 inches into the charge cylinder.

3. Figure 3 shows the press before the test and the shield which was installed to help deflect flame away from the loose-fitting cell door and to provide more protection for personnel entering the cell to remove extrusions.

Instrumentation was set up in and around the press cell to collect temperature, pressure, toxicity, audio, and photographic information. Four 16mm movie cameras, running at 24 frames per second, were used. Figure 4a shows a camera aimed at the press cell from the left side. Figure 4b shows one camera aimed at the cell from the right side and another aimed at the top of the cell. It also shows the TV camera used to monitor the test. Figure 5a shows the blowout windows before the test and the location of the outside camera which was aimed toward the bottom of the press. Two of the polyethylene panes were replaced with clear polystyrene panes. Figure 5b shows the location of two photocells mounted on tripods and thermocouples, T1, T2, and T3. The photocell on the left detected visible energy and the photocell on the right detected infrared energy. Figure 6a shows the location of T4 and a pressure transducer. T5 was located on the press as shown by Figure 6b. Figure 3 also shows small pieces of newspaper taped to the doorway. Paper was also taped to the walls inside the cell at various locations. A book[1] by the AEC provides information with which a relationship can be made between the radiation energy level required to ignite newspaper and the radiation energy level that causes skin burns. From tables 7.45 and 7.65, it can be seen that the energy required to ignite newspaper would at least cause first degree burns and probably second degree burns. Flash time was also considered when making the relationship.

4. Three air samplers were placed outside the cell near the door and samples collected for toxicity analysis. Total particulate matter concentration and particle size distribution were to be determined.

5. Also a pressure transducer was placed in the hydraulic line on the high pressure side of the cylinder which operates the press. The investigation of the December accident had indicated a significant pressure build-up inside the charge cylinder.

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[1]The Effects of Nuclear Weapons (abridged), a reprint of the non-technical sections of the book published by United States Atomic Energy Commission, June, 1957.

6. A list of the recording equipment used is included as Appendix A.

IV. Discussion of Test Results

1. On September 29, 1969, the test was conducted from the test wing of Building 198. A remote TV monitor located at the firing station was used to verify that the composition did ignite and burn. The TV showed a large cloud of smoke coming around the cell door one or two seconds after initiation. A review of the highlights shown by the four movie cameras is presented in Figure 7.

2. Figure 8a shows the cell after the test. The shield deflected much of the heat away from the front of the cell. None of the newspaper in the doorway burned. Figure 8b shows the blowout window from the outside. The lower two rows of window sections were badly distorted. One section fell to the inside of the cell after the composition had burned out. The temperature under the press rose high enough to melt aluminum, as can be seen by figures 9a and 9b, but was insufficient at the front of the cell to burn all the newspaper on the inside of the cell door, figure 10a. Figure 10b shows the top part of the door where two pieces of newspaper scorched and the third piece mostly burned.

3. Burning inside the press was very vigorous and hot, as was expected. A total time of nine seconds of audible burning was indicated by the audio tape. The combustion pressure in the charge cylinder vented in two directions, up through the vacuum passage in the ram and down through the die. Flame venting through the ram melted steel pipe fittings as shown in Figure 11a. These fittings were originally located at the top of the ram--figure 11b. The beryllium copper ram was eroded as shown in figure 12a.

The O ring on the ram (not shown) was not damaged significantly. The stainless steel die, figure 12b, was eroded in a spiraling pattern. The vacuum pump was pumping during the test which definitely promoted venting through the ram. Venting through the ram began at approximately 0.15 seconds from test initiation.

4. The temperatures indicated by six thermocouples are shown in figure 13. T1 and T2 were located so as to record temperatures that would be endured by operating personnel. T1, on the right side of the cell door where the cutoff control is located, indicated a negligible temperature rise. T2, near the press controls, indicated 330°F for one second. The temperature rise and fall was fast, above 200°F for two seconds, and probably would not have burned a person seriously. The 16mm movie showed a large cloud of smoke coming through the gap on the right side of the door into the area where the highest outside temperature was recorded. The duration and location of the smoke cloud was quite similar to the duration and location of the highest temperatures, which indicates that closing the gaps around the cell door would further reduce hazards to operating personnel. T3, in the doorway on the left side, indicated a significantly higher temperature than T2. Since T3 was somewhat closer to the heat source, the higher temperature was expected. The high temperature recorded by T4 (inside cell at upper corner of door) of almost 1200°F is relatively short lived, showing a rapid decay of intensity as the combustion pressure inside the charge cylinder relieved. T5, near the top of the press, and T6, on the bottom platen, show overall intensity and duration of burning inside the cell.

5. Two photocells were directed towards the cell door, PC 1 to the left side and PC 2 to the right side. An IR filter was used on PC 1. An amplitude of four inches is equivalent to the output of a 1000 watt projection lamp, one foot from the photocell. At this distance it is uncomfortably hot to bare skin. The photocell was located about four feet from the cell door and sensed about 1/12th of that level. The level at the door would have been approximately equal to that of the lamp at one foot, since the radiation is inversely proportional to the square of the distance. The output of the photocells is summarized as follows:

| | PC 1 | PC 2 |
|---|---|---|
| Time to first rise | 0.15 sec. | 0.15 sec. |
| Time to peak | 0.19 sec. | 0.19 sec. |
| Peak amplitude | 0.32 in. | 0.24 in. |
| Pulse width | 0.10 sec. | 0.10 sec. |

Both sensors indicated light very soon after initiation (0.15 seconds) with a duration of 0.10 seconds. The movie film verifies the duration of this initial flush. All subsequent light was obscured from the sensors by smoke.

6. The output of the pressure transducer (P1) in the hydraulic line and the two transducers (P2 and P3) in the cell, to record over pressure, is shown below:

| | P1 | P2 | P3 |
|---|---|---|---|
| Time to rise | --- | 2 sec. | 1 sec. |
| Time to peak | 0.16 | No Peak | 2.5 sec. |
| Peak Amplitude | 120 psig | | 3.2* psig |
| Duration | | | 2.5 sec. |

*One psig thermal shift

Peak pressure in the charge cylinder, as indicated by P1, verifies that the visible flash did occur at .15 seconds and as venting increased the internal pressure decreased. The peak pressure inside the charge cylinder of 1900 psi was much lower than anticipated. Rapid burning through the partially consolidated composition and venting through the ram prevented a greater pressure build up.

7. P3 indicated a maximum overpressure in the cell of 3.2, however, the blowout windows did not blow. If the window had blown as it should have, most of the smoke and heat that went around the cell door into the building would have exhausted to the outside.

8. An analysis of air samples taken during the test showed the following particle size distribution:

| Particle Size (Microns) | | Concentration (Milligrams/$m^3$) |
|---|---|---|
| 9.2 and larger | | 8.75 |
| 5.5 to 9.2 | | 11.00 |
| 3.3 to 5.5 | | 14.50 |
| 2.0 to 3.3 | | 19.00 |
| 1.0 to 3.3 | | 27.80 |
| Up to 1.0 | | 22.20 |
| | TOTAL | 103.25 |

Three air samples were analyzed for water soluble fluorides. Two samples showed approximately .025 mg/$m^3$ of water soluble fluorides. The third showed no detectable quantity. Due to the large percentage of particulates in the respirable size range, it could be expected that a significant amount of inhaled particles containing fluorides would be retained in the lungs.

Due to the low water solubility of these particles, it would take a long period of time for these particles to be absorbed and excreted from the body.

9. Prior to test firing, nineteen persons with varying degrees of knowledge about pyrotechnics predicted how the test would go by answering a short questionnaire. In answer to the first question, 13 persons predicted vigorous burning rather than detonation. Also, 13 persons predicted that the blowout window in the cell would go, which was correct. One window section fell out after burning in the cell had ended. The only question answered wrong by the majority was concerning detectable flame past the cell door. Twelve persons predicted detectable flame and seven predicted no detectable flame. A few more questions of less overall importance were answered correctly by the majority. The significance of these predictions is that there were many more correct predictions than incorrect. This adds confidence to the one shot test.

V. Conclusions

1. The following conclusions were either made or supported as a result of the test:

a. The extrusion facility has been restored so as to afford adequate safety protection to the press operating personnel. None of the newspaper in the doorway to the press cell burned, indicating that the press operators would not have received serious burns.

b. The polycarbonate shield between the press and floor deflected heat from the cell door much better than anticipated. We now have greater confidence in polycarbonate shielding used in other operations.

c. Blowout window improvement is needed. If the window had blown, as it should have, much less smoke and heat would have been forced past the door.

d. The 1" to 1 1/2" gaps around the cell door should be sealed so as to increase the resistance to smoke being blown into the operator area.

e. Anyone entering an area within the first five minutes after a MK 46 fire starts should wear respiratory protection (a minimum of an organic vapor respirator and preferably an air supplied mask).

f. This test was considered to be very successful; however, several reruns would be required to establish statistical confidence in all details of the test. This is not practical in an operational building, which emphasizes the need for a duplicate cell. A duplicate cell located in a remote area would be invaluable for intentionally duplicating fires in operations using large quantities of materials or especially hazardous materials and for testing blowout windows, doors, etc. Such a test facility would allow conducting of tests free of conflict with other operations and free of risk to operational facilities.

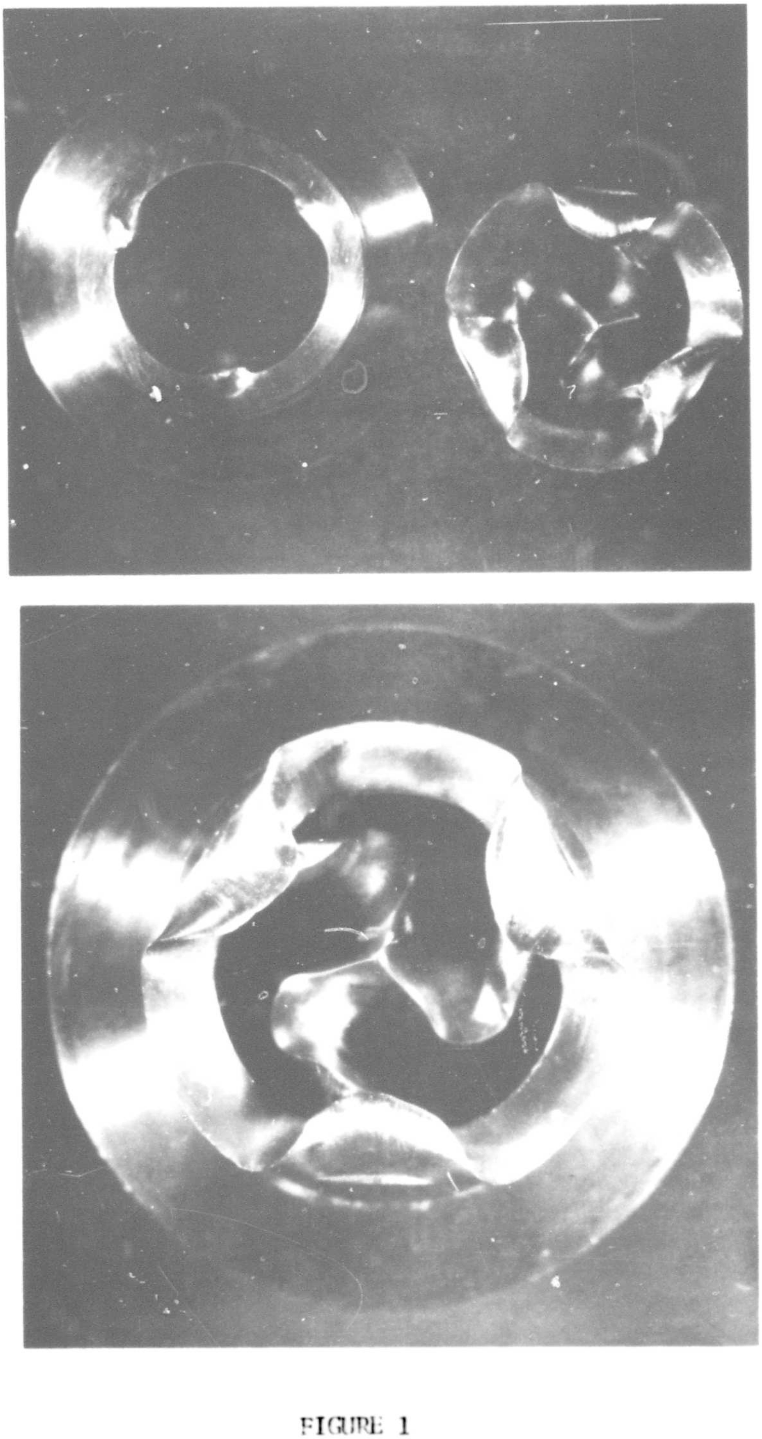

FIGURE 1
COLLAPSED DIE CROWN

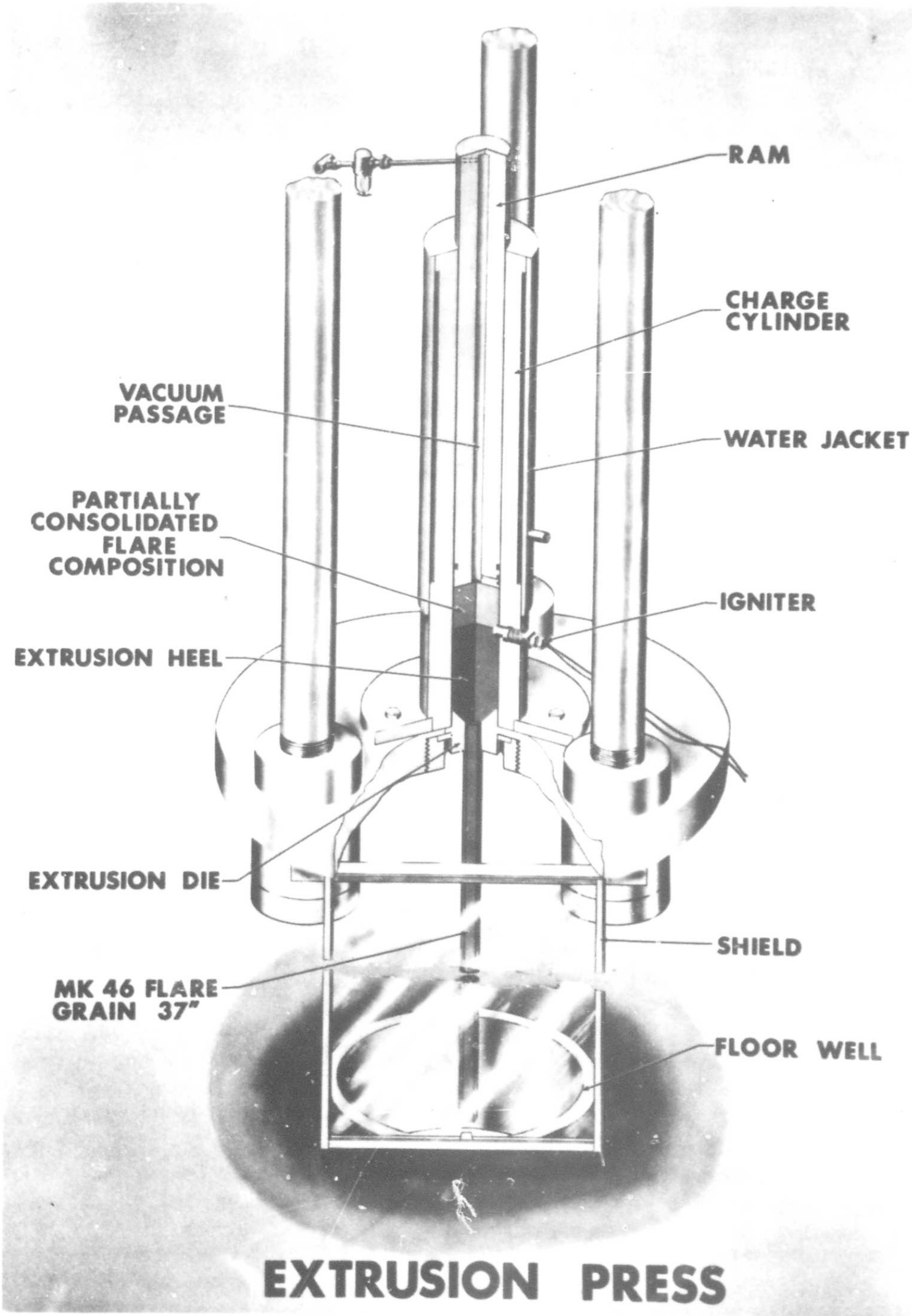
RAM
CHARGE CYLINDER
VACUUM PASSAGE
WATER JACKET
PARTIALLY CONSOLIDATED FLARE COMPOSITION
IGNITER
EXTRUSION HEEL
EXTRUSION DIE
SHIELD
MK 46 FLARE GRAIN 37"
FLOOR WELL
EXTRUSION PRESS

Figure 2

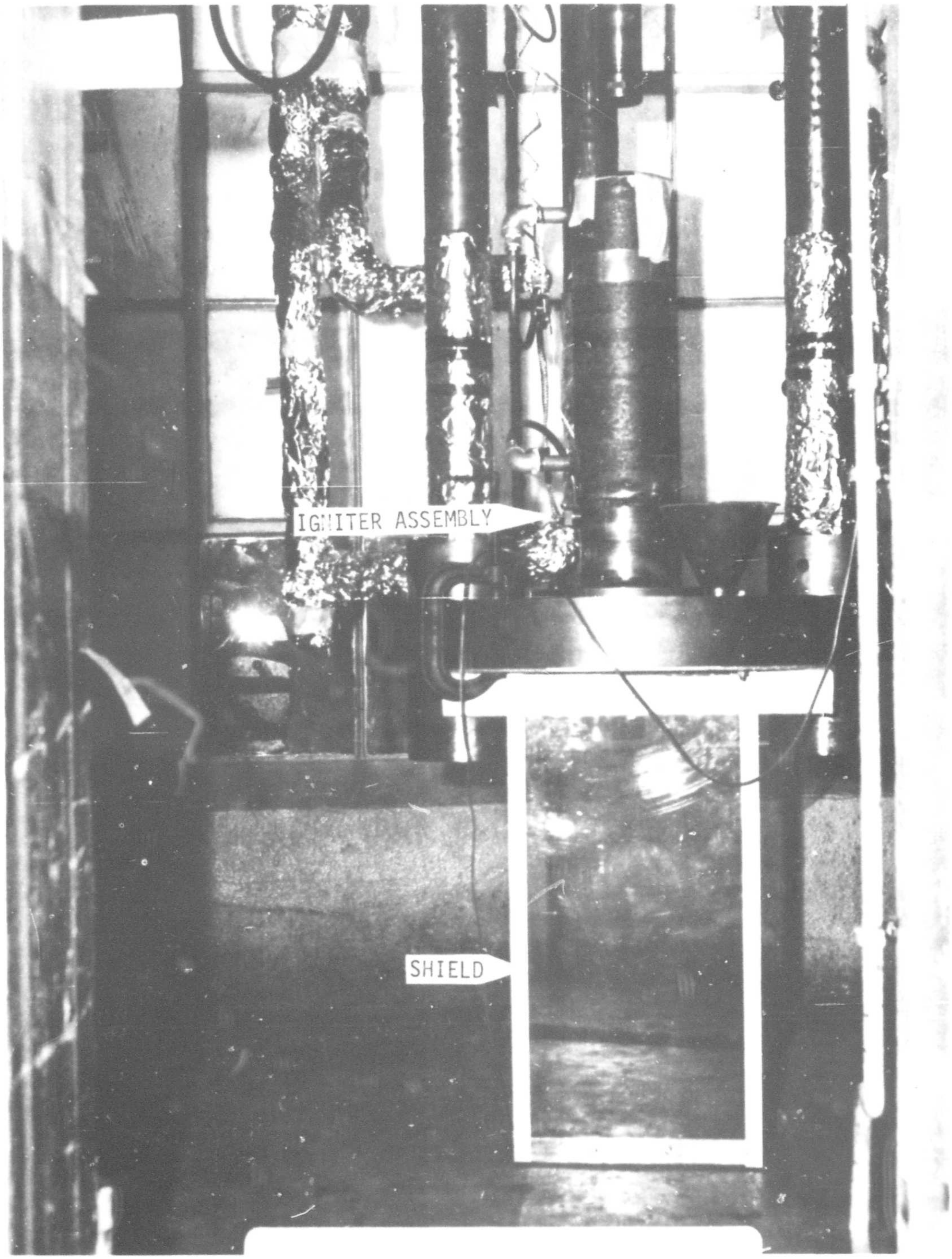


FIGURE 3
PRESS CELL BEFORE TEST

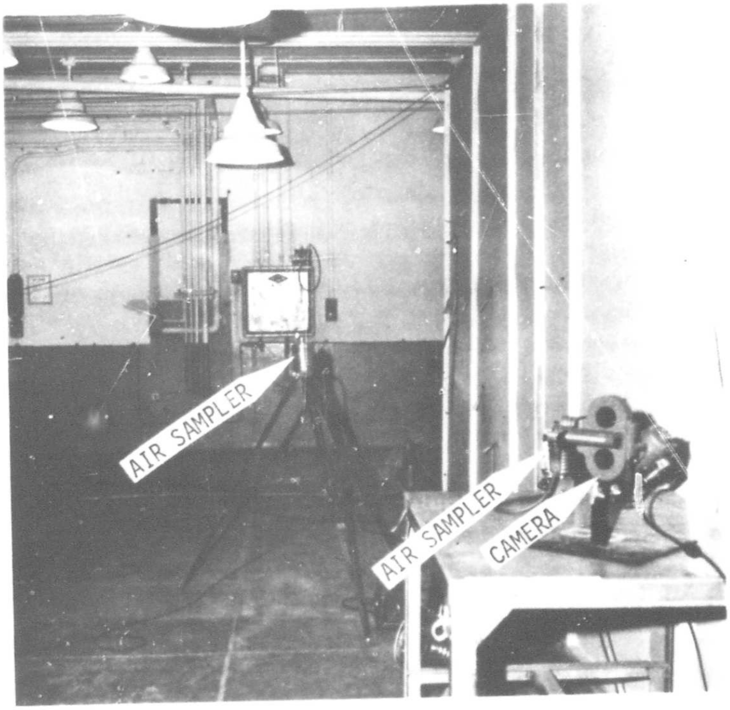


FIGURE 4a LEFT CAMERA

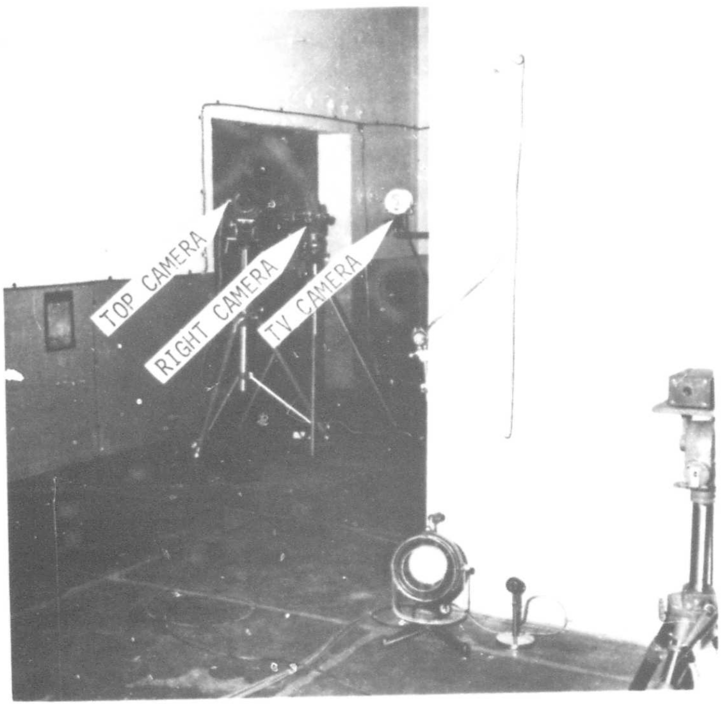


FIGURE 4b RIGHT AND TOP CAMERA

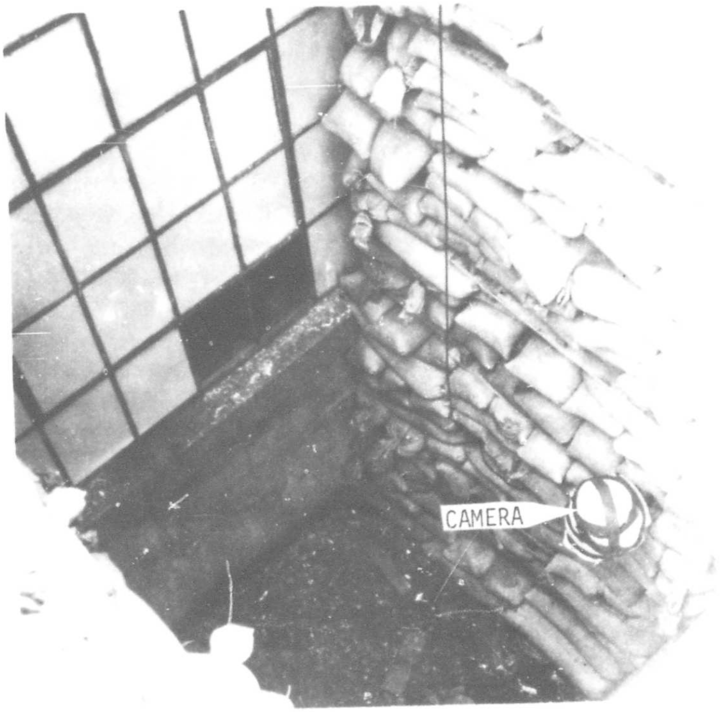


FIGURE 5a OUTSIDE CAMERA

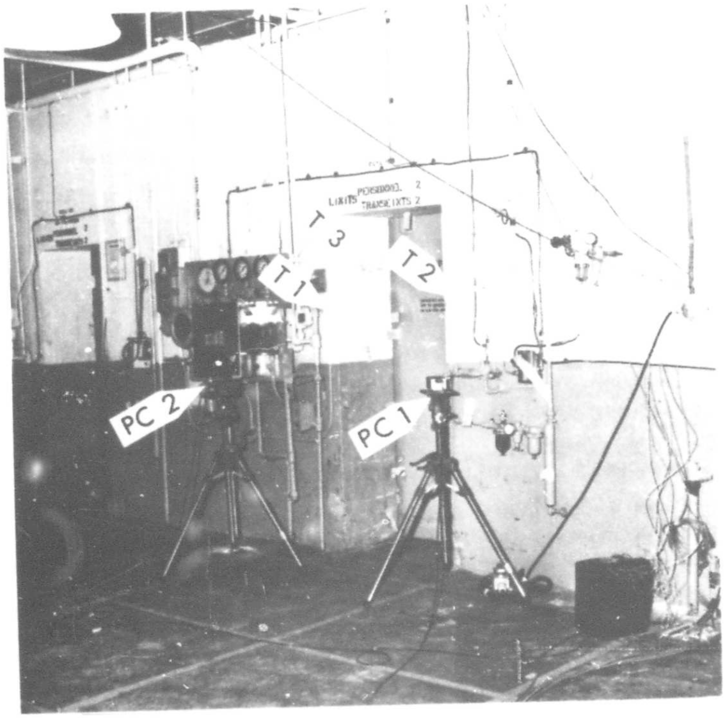


FIGURE 5b IR SENSORS AND THERMOCOUPLES

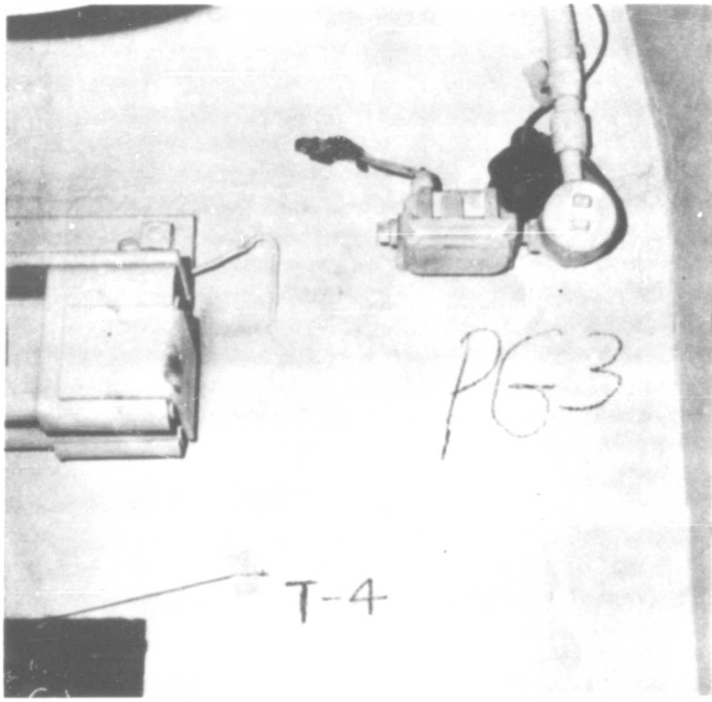


FIGURE 6a THERMOCOUPLE AND PRESSURE TRANSDUCERS

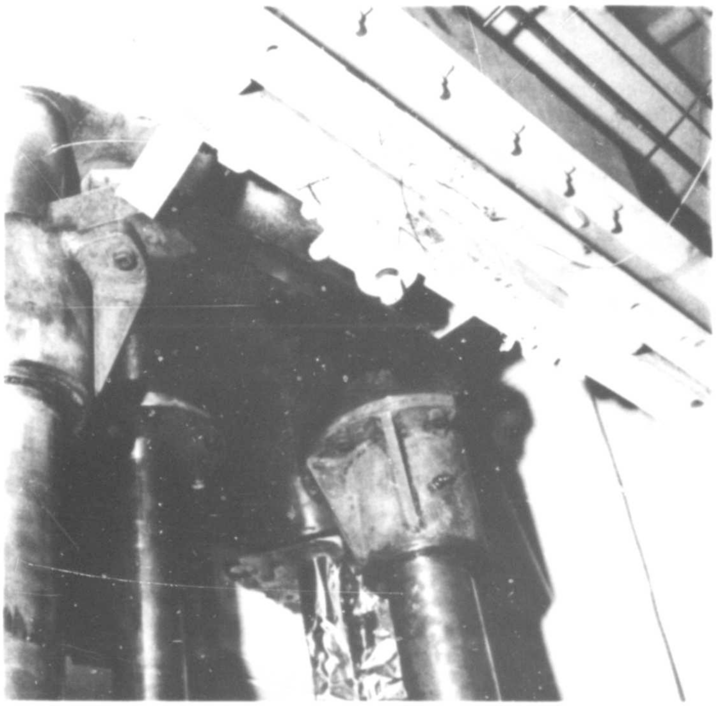

FIGURE 6b THERMOCOUPLE

MOVIE FILM ANALYSIS

| | Right Side frames - sec. | Top frames-sec. | Left Side frames - sec. | Press frames-sec |
|---|---|---|---|---|
| First Light | 0* | 0* | 0* | 0* |
| Brightest Light | 1 - .04 | 0 | 0 | 0 |
| Significantly Decreased Light Level | 3 - .13 | 2 - .08 | 2 - .08 | 6 - .25 |
| First Smoke | 8 - .33 | 18 - .75 | 8 - .33 | --- |
| Doorway Filled with Smoke | 26 - 1.08 | 25 - 1.04 | 21 - .88 | --- |
| Press Controls not visible | 70 - 2.91 | --- | 60 - 2.50 | --- |
| Peak Smoke | 100 - 4.17 | 120 - 5.00 | --- | --- |
| Controls again visible | 200 - 8.33 | --- | 90 - 3.75 | --- |
| Major burning ends | --- | --- | --- | 220 - 9.17 |
| All burning ends | --- | --- | --- | 264 - 11.00 |
| Window section fell out | --- | --- | --- | 360 - 15.00 |

*First frame showing light (no firing pulse on film)

Figure 7

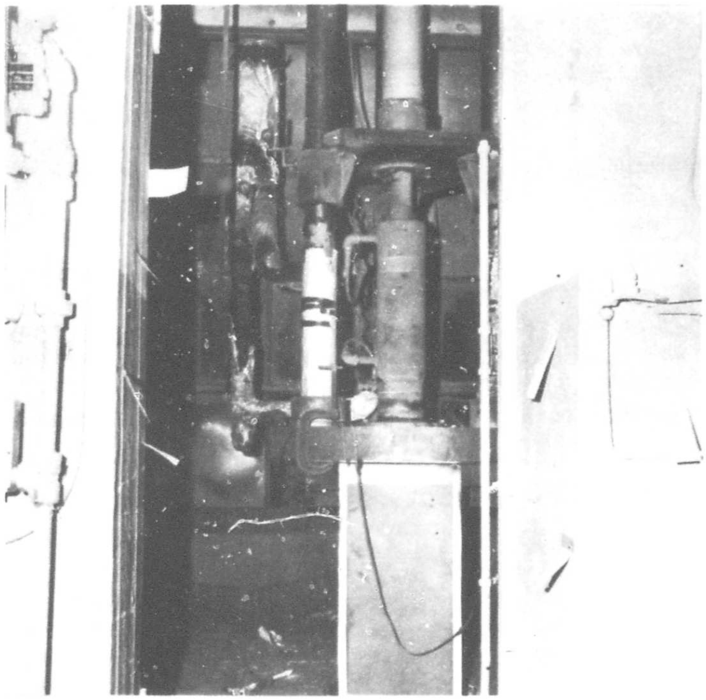

FIGURE 8a PRESS CELL AFTER TEST

FIGURE 8b BLOWOUT WINDOW AFTER TEST

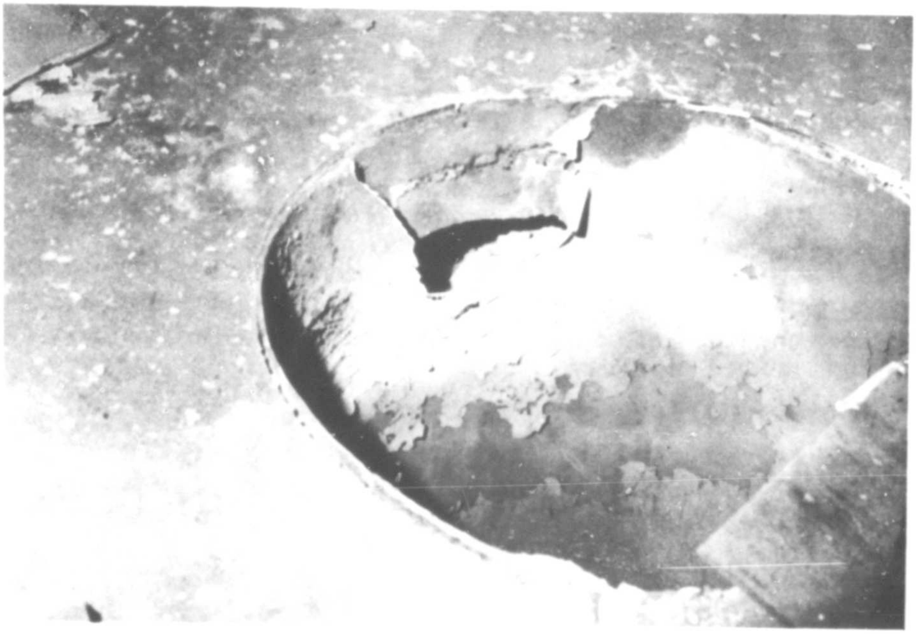

FIGURE 9a FLOOR WELL

FIGURE 9b BACK SIDE OF SHIELD

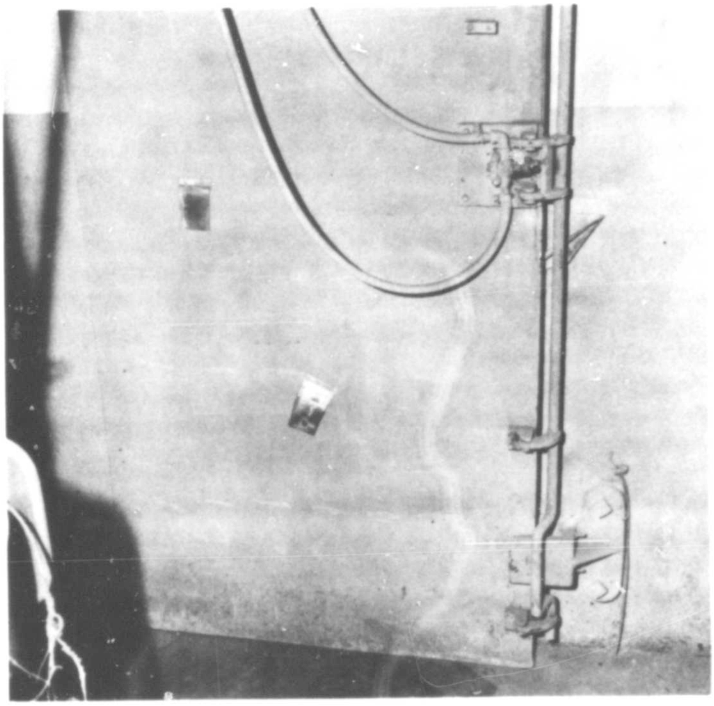

FIGURE 10a DOOR FROM INSIDE (BOTTOM)

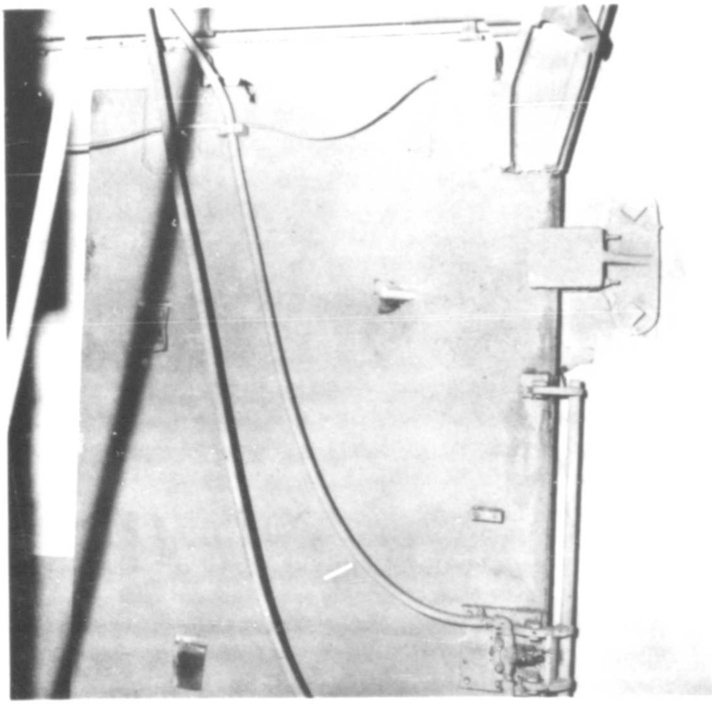

FIGURE 10b DOOR FROM INSIDE (TOP)

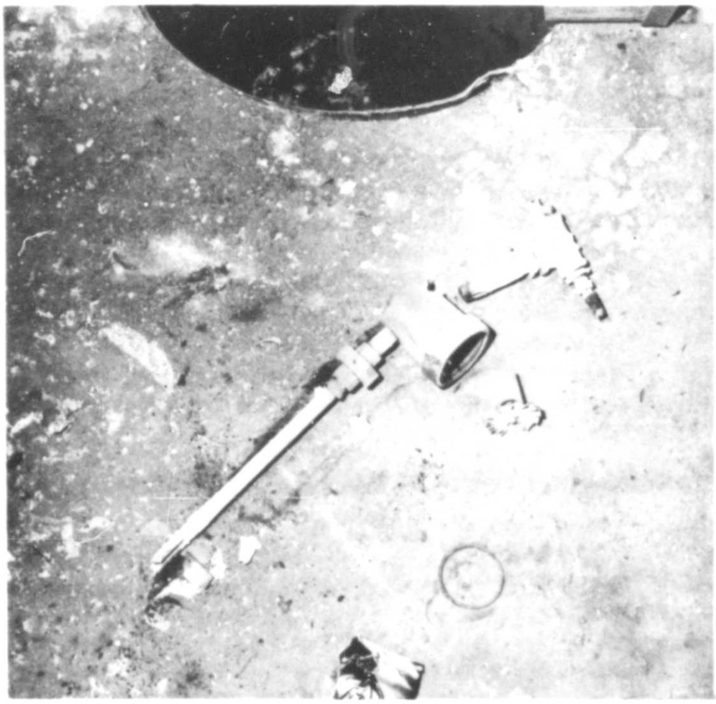

FIGURE 11a PLUMBING FROM TOP OF RAM

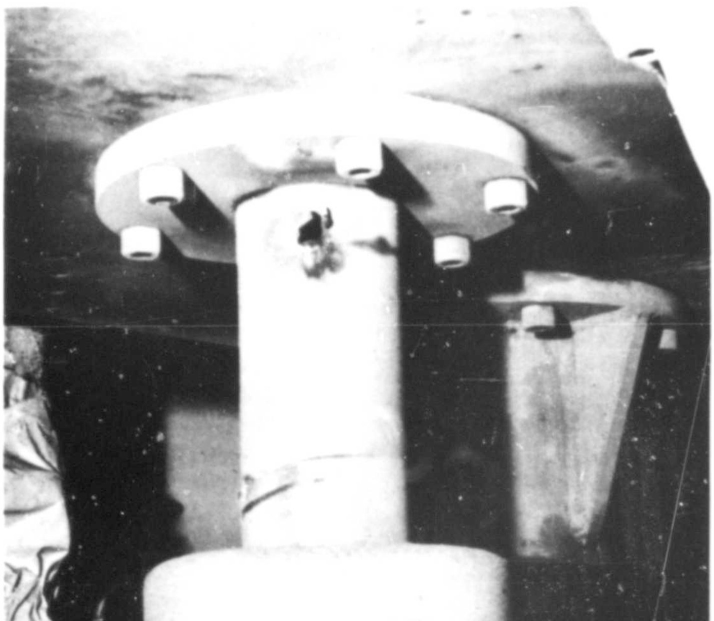

FIGURE 11b TOP OF RAM

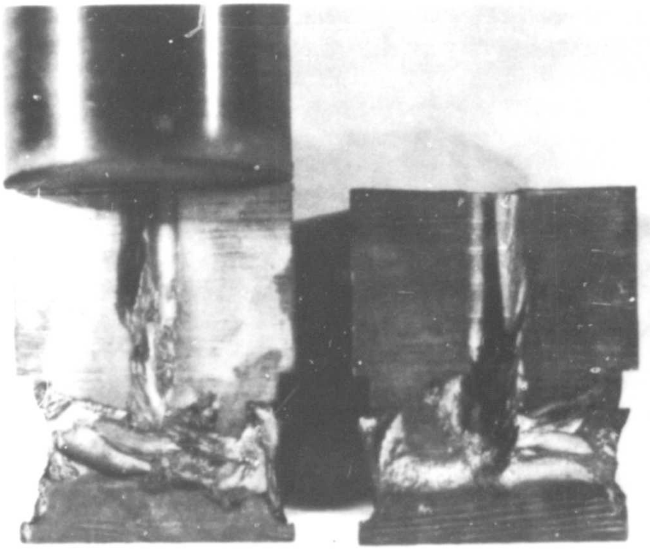

FIGURE 12a RAM EROSION

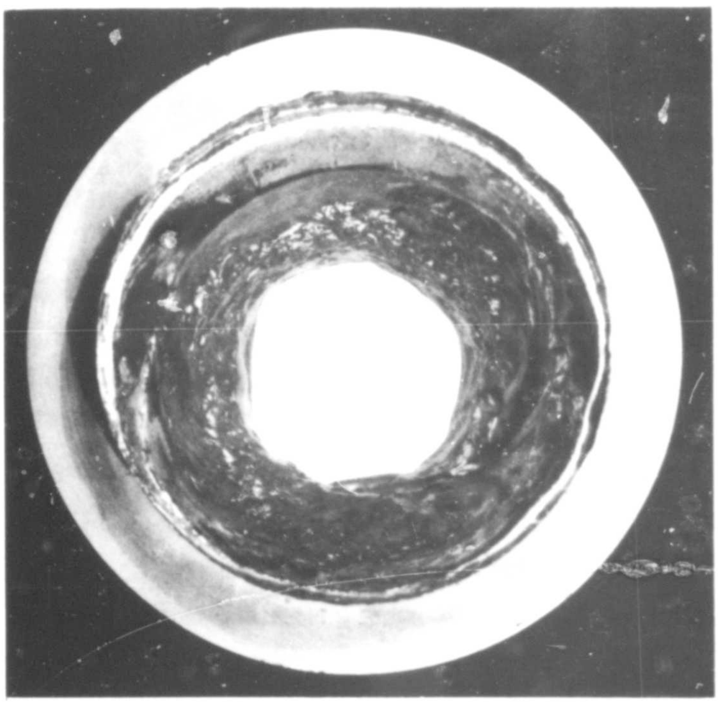

FIGURE 12b DIE EROSION

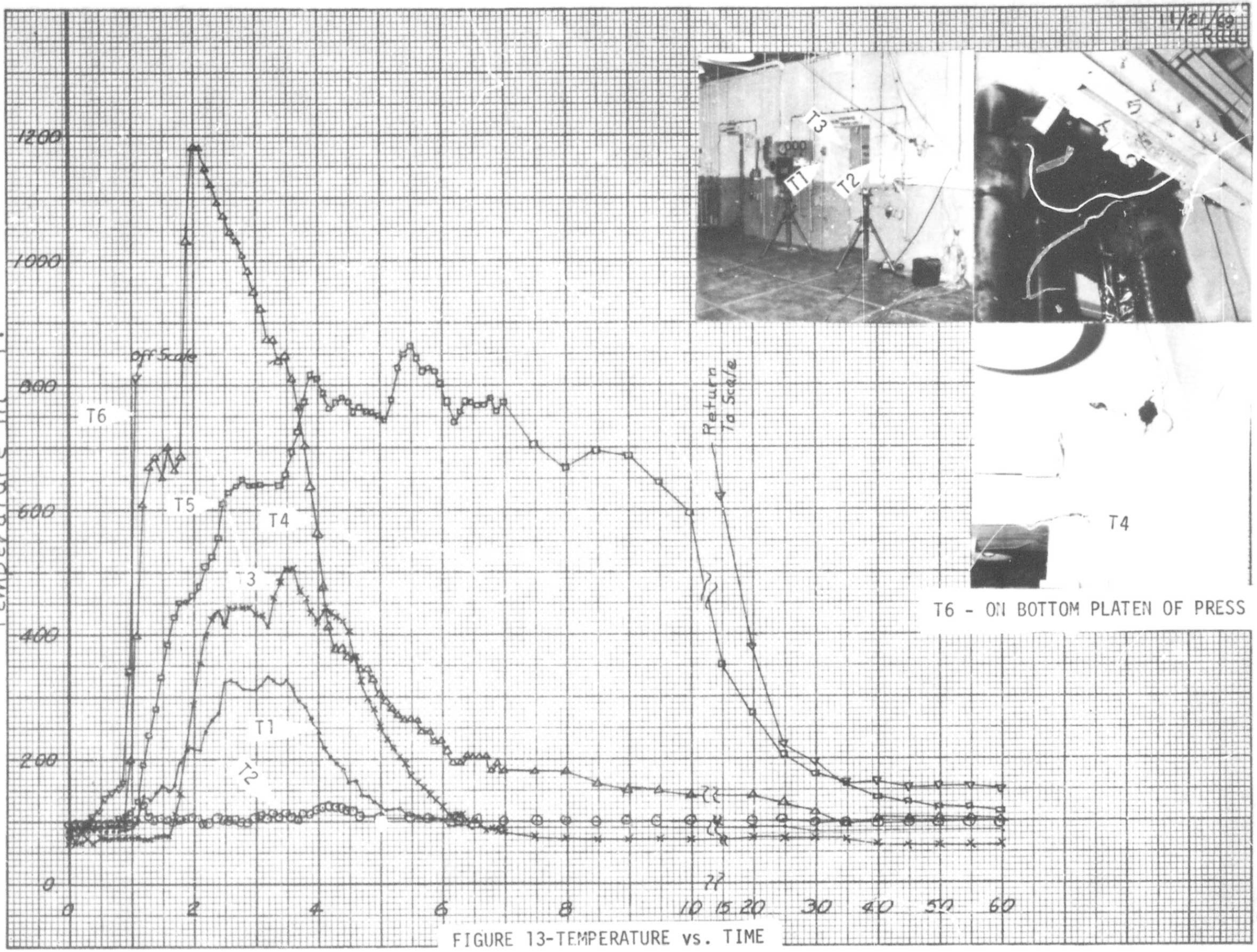


FIGURE 13-TEMPERATURE vs. TIME

# APPENDIX A

## List of Equipment

| Quantity | Item | Manufacturer | Model | Range Used |
|---|---|---|---|---|
| 3 | Air Samplers | Union Industrial Co. | Unnet | 0.1 $ft^3$/min. |
| 1 | Air Sampler | Medi-Comp R & D Corp. | Anderson 0670 | 1 $ft^3$/min |
| 1 | Thermocouple (T1) | Thermo Electric | ISA Type K, Chromel-Alumel #40 B & S | 0-830°F |
| 1 | Thermocouple (T2) | " | " " | 0-800°F |
| 1 | Thermocouple (T3) | " | " " | 0-1560°F |
| 1 | Thermocouple (T4) | " | " " | 0-2480°F |
| 1 | Thermocouple (T5) | " | " " | 0-1180°F |
| 1 | Thermocouple (T6) | " | " " | 0-590°F |
| 1 | Pressure Transducer (P1) | Advanced Technology Div., American Std. | 111-3-5000-G-36-10-61 | 0-1000 psig |
| 1 | Pressure Transducer (P2) | " | 111-3-100-G-36 10-61 | 0-100 psig |
| 1 | Pressure Transducer (P3) | " | " " | 0-100 psig |
| 1 | Silicon Photocell (PC-1) with Infrared Filter | International | S1020E4PL | For indication of rise time only |
| 1 | Silicon Photocell (PC-2) | " | " " | " " |
| 2 | Recorders | CEO | 5 - 124 | |
| 1 | 16mm Movie Camera | Paillard Bolex | | 24 fr/sec |
| 2 | " " | Bell & Howell | 70 BR | " |
| 1 | " " | Bach & Auricon | Auricon Pro 600 | " |

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UNCLASSIFIED
Security Classification

## DOCUMENT CONTROL DATA - R & D

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Research and Development Department<br>Naval Ammunition Depot<br>Crane, Indiana | 2a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED<br>2b. GROUP |

3. REPORT TITLE

Safety Test of Flare Extrusion Facility

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

RICHARDSON, JAMES

| 6. REPORT DATE | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS |
|---|---|---|
| 3 December 1969 | 25 | |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>RDTR No. 160 |
| b. PROJECT NO. | |
| c. | 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) |
| d. | |

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| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY |
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13. ABSTRACT

A recent accident in the flare extrusion facility fatally burned the press operator. During restoration of the facility, several additional safety features were incorporated. Tangible proof that the changes were adequate was desired. Permission to conduct a controlled burn test, with the press loaded so as to simulate a point in the extrusion cycle at which an accidental ignition might occur, was requested and granted. The test was conducted on September 29, 1969. The test was considered to be successful. Confidence in operator safety has increased. Similar tests on other operations would greatly improve personnel safety in pyrotechnics. ( )

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S/N 0101-807-6801

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Security Classification

| 14 KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| 1. Safety Test | | | | | | |
| 2. Flare Extrusion Facility | | | | | | |
| 3. Mk 46 Decoy Flare | | | | | | |