Cm 102-4

# DEBRIS DISTRIBUTION IN UNDERWATER EXPLOSIONS



ANNUAL SUMMARY REPORT

CONTRACT NO. NOnr 3095(00)

JANUARY 1964



Prepared for
DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
WASHINGTON 25, D. C.

Malaker Laboratories, Inc.

HIGH BRIDGE, N. J.

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EARL F. BRYANT

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APPROVED BY [signature]
Dr. S. F. Malaker

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## *INTRODUCTION*

*Malaker Laboratories has been engaged in explosion simulation studies for the Office of Naval Research under Contract No. NOnr 3095(00) for three years. Previous reports issued include Numbers CM 102-1, CM 102-2 and CM 102-3.*

*During this reporting period (January 1, 1963, to January 1, 1964), above and below surface effects of underwater explosions have been investigated through use of exploding wire equipment. A correlation between bubble phases and deposition of debris has been sought and a means has been devised to measure debris concentration in certain water column areas. This report includes data obtained from underwater bubble studies and a description of the apparatus being prepared for the above surface investigation. Data from more than sixty underwater bubble experiments has been obtained. The results of shots not reported here are being reduced and will be submitted in a supplementary report along with data on above surface tests in progress at the time of this writing.*

*Underwater debris deposition was studied by means of high speed motion pictures of wires exploded in light mineral oil. Above surface effects of radioactive exploding wires submerged* in scintillation solution are being investigated by means of a sensitive photoelectric scanner.

UNDERWATER BUBBLE STUDIES

A 10 joule wire exploder was constructed and arranged to explode silver ribbon material in a beaker filled with light mineral oil (see Fig. 2). Mineral oil was used to eliminate the electrical losses associated with water. The low energy system was selected to minimize the problems of lighting and photography. The effects of gravity on bubble migration have been shown to be a function of hydrostatic pressure[1]. Thus, if scale model experiments such as these are to produce significant prototype information, the surface pressure must be reduced below atmospheric. Experiments were conducted, therefore, under an evacuated bell jar. Strong backlighting was used and during the violent phases of the event a high speed motion analysis camera (Fairchild HS401) recorded the action. In many cases the movie camera was run until cessation of violence, to record character and position of the debris cloud. In other instances, a still camera was set up immediately after the shot to photograph this cloud. Fig. 2 is such a photograph obtained subsequent to

[1] Cole, R. H., UNDERWATER EXPLOSIONS, Princeton University Press, 1948, pp. 291, 292.

the firing depicted in Fig. 1 (Fig. 1 and similar figures were prepared by enlarging individual frames selected from the 16 mm movie film--in general, selected frames show early bubble maxima and minima and enough later frames to establish migration direction). Figs. 1 through 9 present the results obtained from eight experiments.

SCALING

The results of the eight experiments reported here are compiled in Table I. Event violence is obviously a function of the physical size of the exploding wire and of the electrical energy actually converted in the event. Direct measurement of the energy is not practical. Therefore, recourse is made to measurement of the optical records and use of accepted hydrodynamical theory for derivation of the desired energy release. A reliable first approximation to the energy involved in producing a bubble (that is, total event yield less both shock wave and bubble internal energy) is given by:

$$Y = \frac{4\pi}{3} P_o a_m^3$$ [2]

where $Y$ = fraction of total yield involved in bubble expansion

$P_o$ = hydrostatic pressure

$a_m$ = maximum bubble radius

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[2] Op. Cit. Equation 8.6, p. 275

*Measurements of maximum bubble radius listed in the table were scaled from high speed motion picture film. The vertical bubble dimension was selected as being the least distorted by refraction due to the cylindrical, oil-filled chamber. Partition of explosion energy between shock wave and gas sphere has been determined with some care by experimenters working with various chemical explosives. The shock wave fraction has been shown to be a definite attribute of the explosive chemical composition and physical form. Buntzen[3] has investigated the energy partition with underwater exploding wires and concludes that 31.0% of explosion yield is involved in bubble formation. No transient pressure measurements were made in the series reported here so that independent determination of partition values is not possible. Therefore, the 31% figure will be used as an acceptable estimate. Total yield figures listed in the table are not unreasonable since 9.1 joules was stored in the capacitor for each shot (10 microfarads at 1350 volts).*

*The oscillation period of bubbles formed by chemical explosives is given by:*

$$T = k \frac{Y^{1/3}}{P^{5/6}} \qquad 4$$

---

[3] *R. R. Buntzen, "The Use of Exploding Wires in The Study of Small-Scale Explosions," Hydra Program, Technical Memorandum No. 133, March, 1962.*

[4] *Op. Cit., P. 280, Equation 8.11*

where $T$ is bubble oscillation period

$k$ is a coefficient determined by the explosive

$Y$ is the energy available for bubble formation

$P$ is the hydrostatic pressure

No value for $k$ is known for the underwater exploding wire. Therefore, the equation is solved for $k$:

$$k = \frac{T\,P^{5/6}}{Y^{1/3}}$$

And values are found for each of the reported cases (see table column headed "Period Expression Coefficient k"). The resulting figures are far from constant so a graph relating the values of $k$ with bubble energies was prepared. A linear relationship between $k$ and $Y$ is revealed by this graph. This definite departure from chemical explosion behavior is reported as a matter of interest but without attempt at explanation at this time.

## BUBBLE STUDY RESULTS

Figs. 1 through 9 are photographs of the principal apparent explosion features for eight experiments. For instance, Fig. 1 shows the bubble phases obtained from motion pictures of one shot while Fig. 2 is a still photograph of the resulting debris cloud. The still photograph is omitted in subsequent figures but considerable debris disposition can be detected in later movie frames. Several bubble migration directions occur and, in fact, these particular experiments were selected from over sixty shots for this preliminary report on the basis of the variety of migration directions.

BUBBLE STUDY CONCLUSIONS

It is quite apparent from every film record obtained to date that little or no metallic debris is deposited in the medium during early bubble oscillations. Further, it is clear that the debris is transported by the bubble and released in a relatively well defined cloud upon cessation of oscillation. The conclusion is fortified by the complete lack of debris cloud observed in Fig. 8 which depicts a bubble venting before cessation of oscillations.

The functional relation found between total yield and the period formula coefficient should make accurate scaling of the bubble behavior resulting from any type explosive device possible with the exploding wire equipment used in this study.

ABOVE SURFACE STUDY

No actual data has been obtained to date in this phase. The equipment has been fabricated and some initial calibrations performed. This work will continue and be reported fully in the supplementary report.

Figs. 11 and 13 are photographs of the equipment to be used in this phase. Very small radioactive gold wires are exploded in a small open vessel placed inside the large evacuated steel chamber. The fluid medium is xylene solution of diphenyloxazole which produces scintillations in the presence of radioactive material. Four small objective lenses focus images of the explosion scene on related photomultiplier tubes and an interposed scanning disc breaks the image down into a sequential scan pattern by means of the spiral hole patterns visible in Fig. 13. A synchronous motor turns this scanning disc through a long belt to minimize the effects of the motor field on the sensitive photomultiplier tubes. A small incandescent lamp is used to illuminate a silicon solar cell through the hole pattern thus providing a disc position reference signal. "Video" signals from the photomultiplier tubes and the disc position reference signal are displayed on a dual beam oscilloscope through use of a 4-trace preamplifier. Fig. 12 is a photograph of two calibration tests performed on one scanning channel. In the upper oscilloscope view the top trace displays the photomultiplier output obtained with the bottom hole of the "calibration *scene" illuminated. In the lower oscilloscope view the upper trace was obtained with the next to bottom calibration scene aperture illuminated. In both oscilloscope photos the lower trace was produced by the reference lamp. Horizontal sweep rate was 50 milliseconds per centimeter.*

## TABLE I

| Shot | Ref. Fig. | Surface Pressure In. Hg. | Hydrostatic Pressure psi | Max. Bubble Radius in. | Derived Bubble Energy Joules | Observed Oscillation Period Seconds | Period Expression Coefficient k | Total Explosion Yield @31% to Bubble Joules |
|---|---|---|---|---|---|---|---|---|
| 8 | 1<br>2 | 6 | 3.14 | 0.88 | 1.01 | .009 | 0.92 | 2.3 |
| R5S1 | 3 | 2 | 1.16 | 0.99 | 0.54 | .018 | 0.87 | 1.7 |
| R6S1 | 4 | 0.5 | 0.44 | 1.2 | 0.36 | .017 | 0.37 | 1.2 |
| R7S1 | 5 | 0 | 0.203 | 1.7 | 0.47 | .033 | 0.41 | 1.5 |
| R9S1 | 6 | 0.3 | 0.35 | 2.1 | 1.55 | .082 | 1.2 | 5.0 |
| R10S2 | 7 | 10 | 5.1 | 0.88 | 1.6 | .0045 | 0.39 | 5.2 |
| R13S1 | 8 | 0 | 0.203 | 2.9 | 2.1 | .163 | 1.4 | 6.8 |
| R13S2 | 9 | 2 | 1.18 | 1.2 | 0.97 | .021 | 0.96 | 3.1 |

## *LIST OF ILLUSTRATIONS*

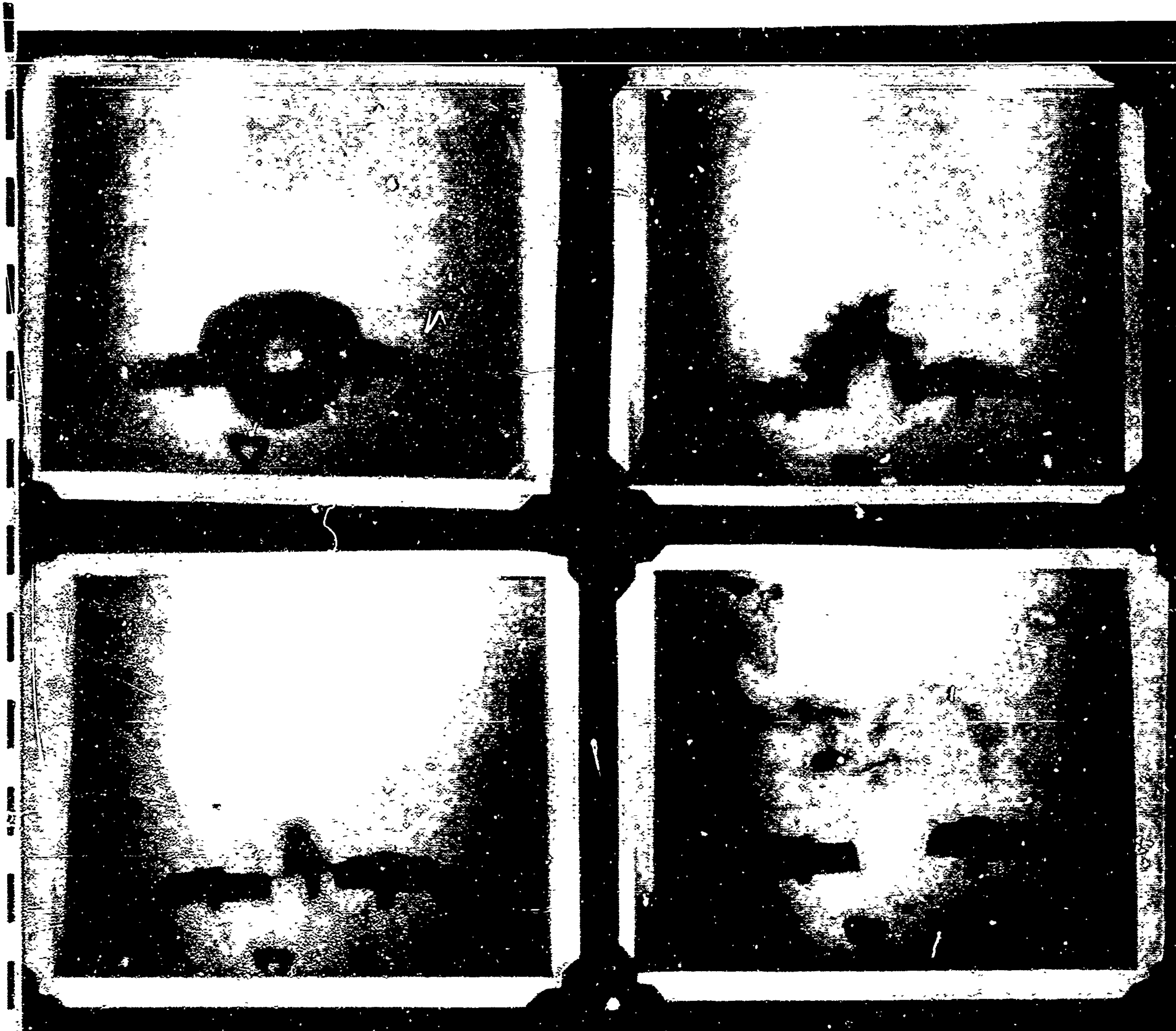


FIGURE 1

SURFACE PRESSURE 6" [illegible]

DEPTH 6ft, 3" [illegible]

| | | |
|---|---|---|
| UPPER LEFT | FIRST MAX. | [illegible] |
| CENTER LEFT | FIRST MIN. | [illegible] |
| LOWER LEFT | SECOND MAX. | [illegible] |
| UPPER RIGHT | BUBBLE [illegible] | |
| LOWER RIGHT | BUBBLE [illegible] | |

(a)

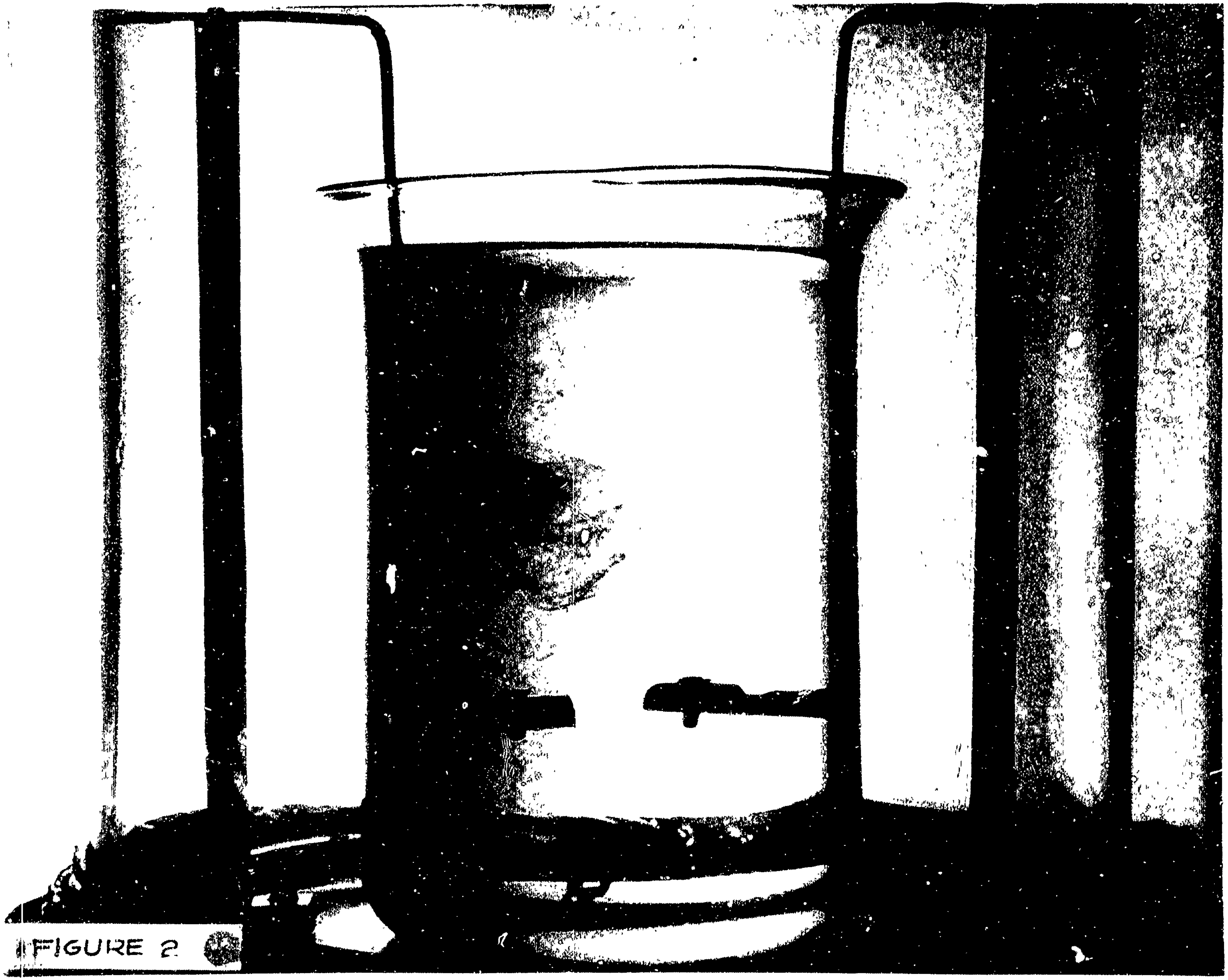


FIGURE 2

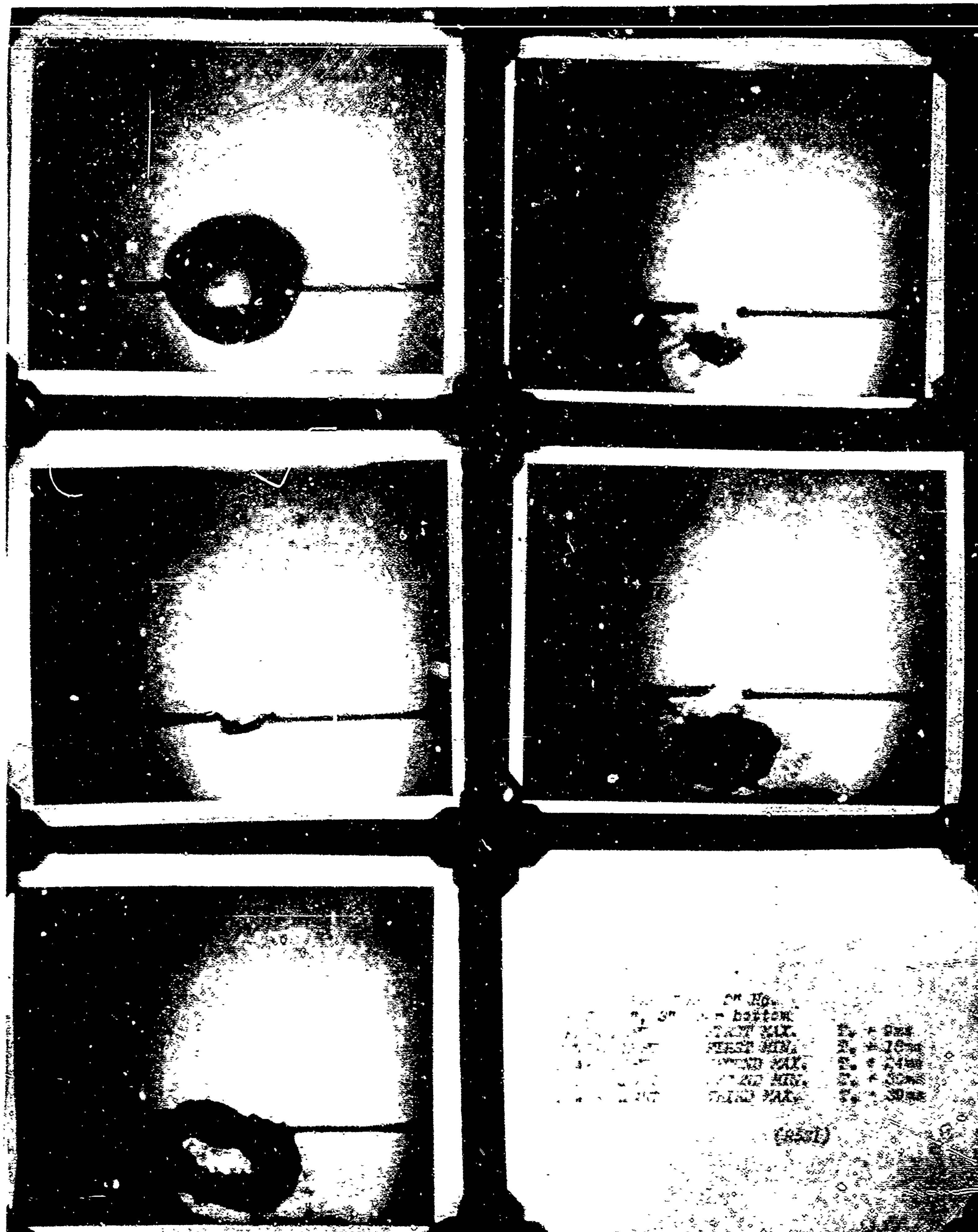


PLATE XV

[illegible]TION OF [illegible] BUBBLE [illegible] TOWARD [illegible] AND RE[illegible] [illegible] WALL SURFACE

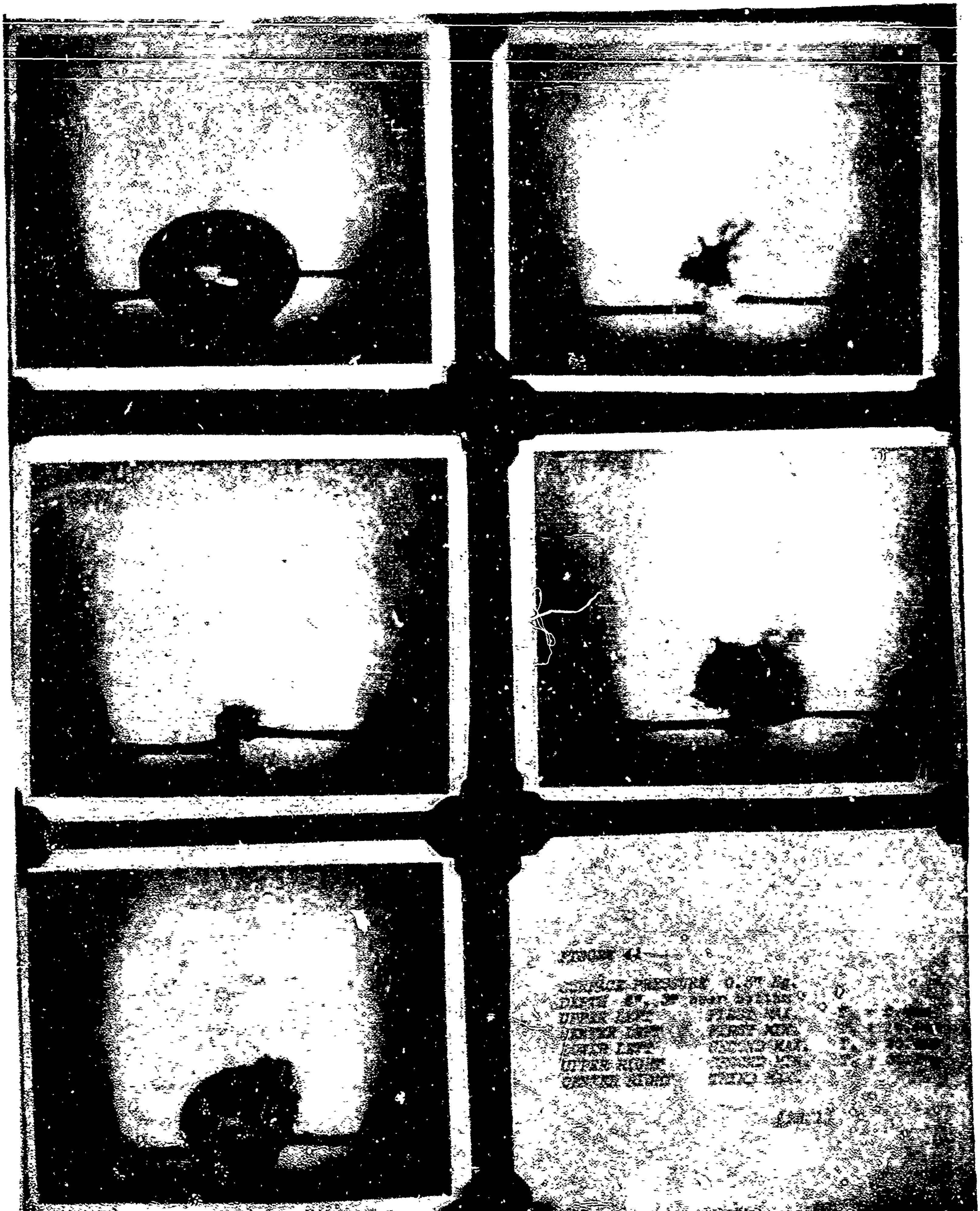


FIGURE 41

SURFACE PRESSURE 0.97 [illegible]
DEPTH [illegible]
UPPER LEFT FIRST MAX.
CENTER LEFT FIRST MIN.
LOWER LEFT SECOND MAX.
UPPER RIGHT SECOND MIN.
CENTER RIGHT THIRD MAX.

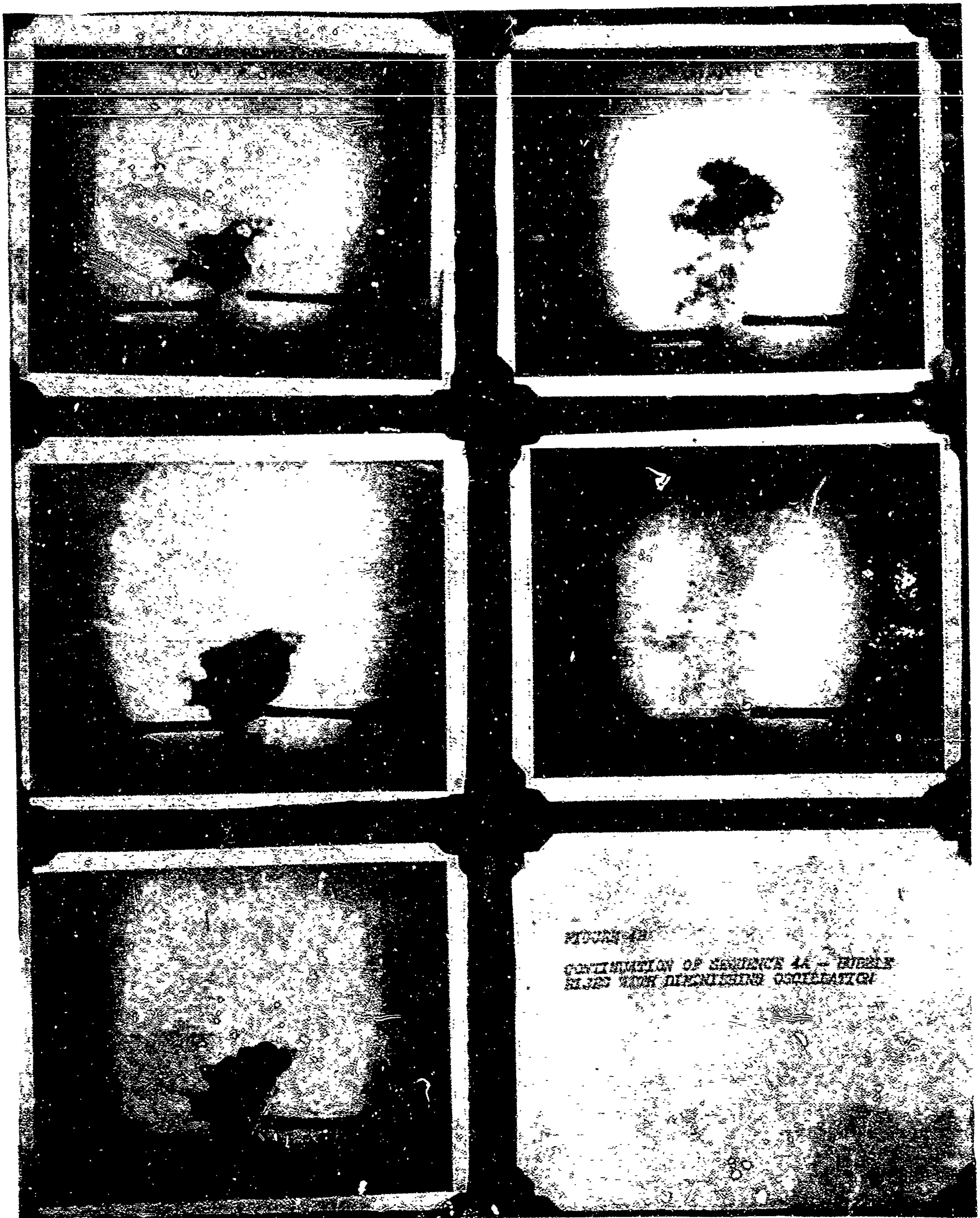


FIGURE 4B

CONTINUATION OF SEQUENCE 4A - BUBBLE RISES WITH DIMINISHING OSCILLATION

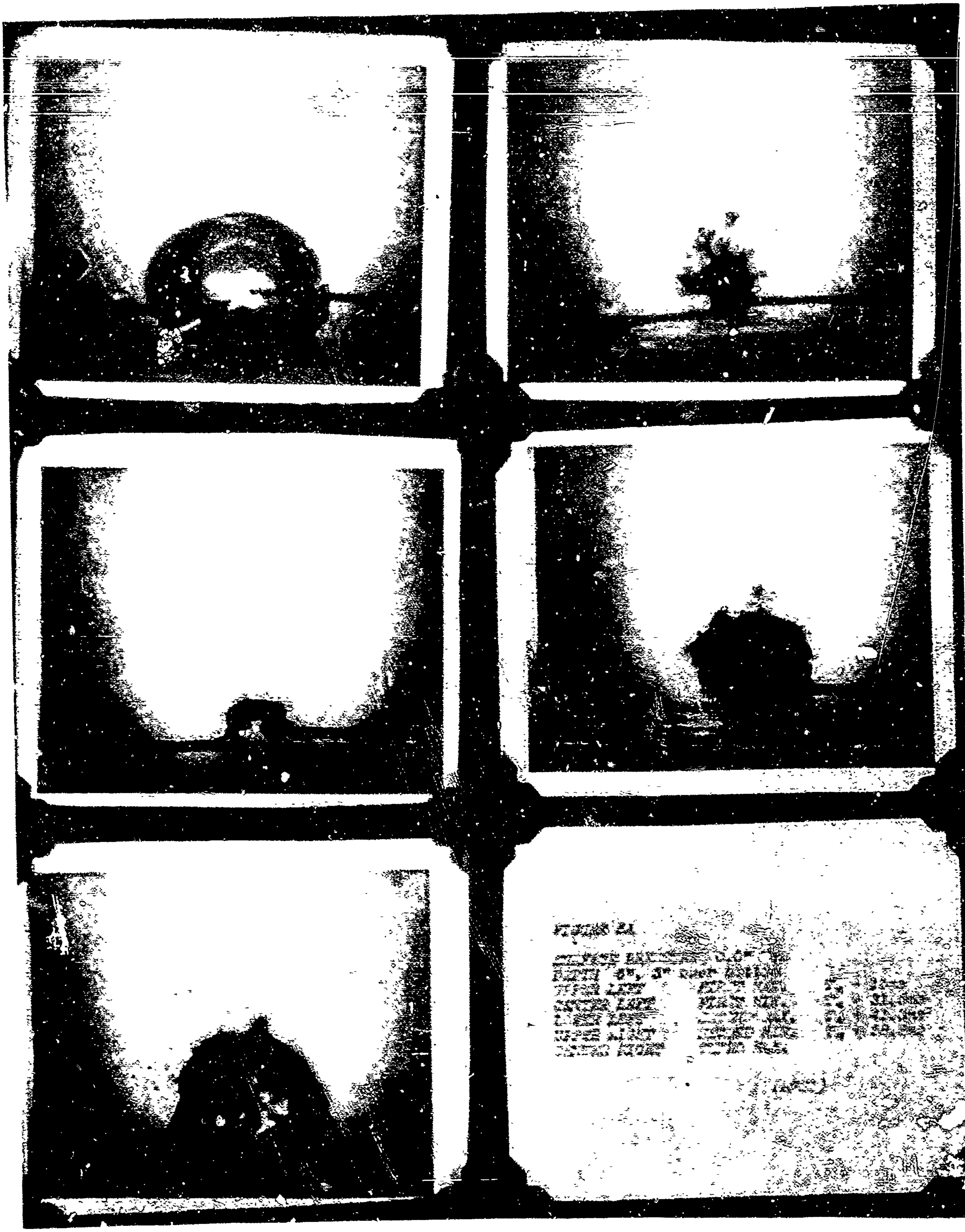
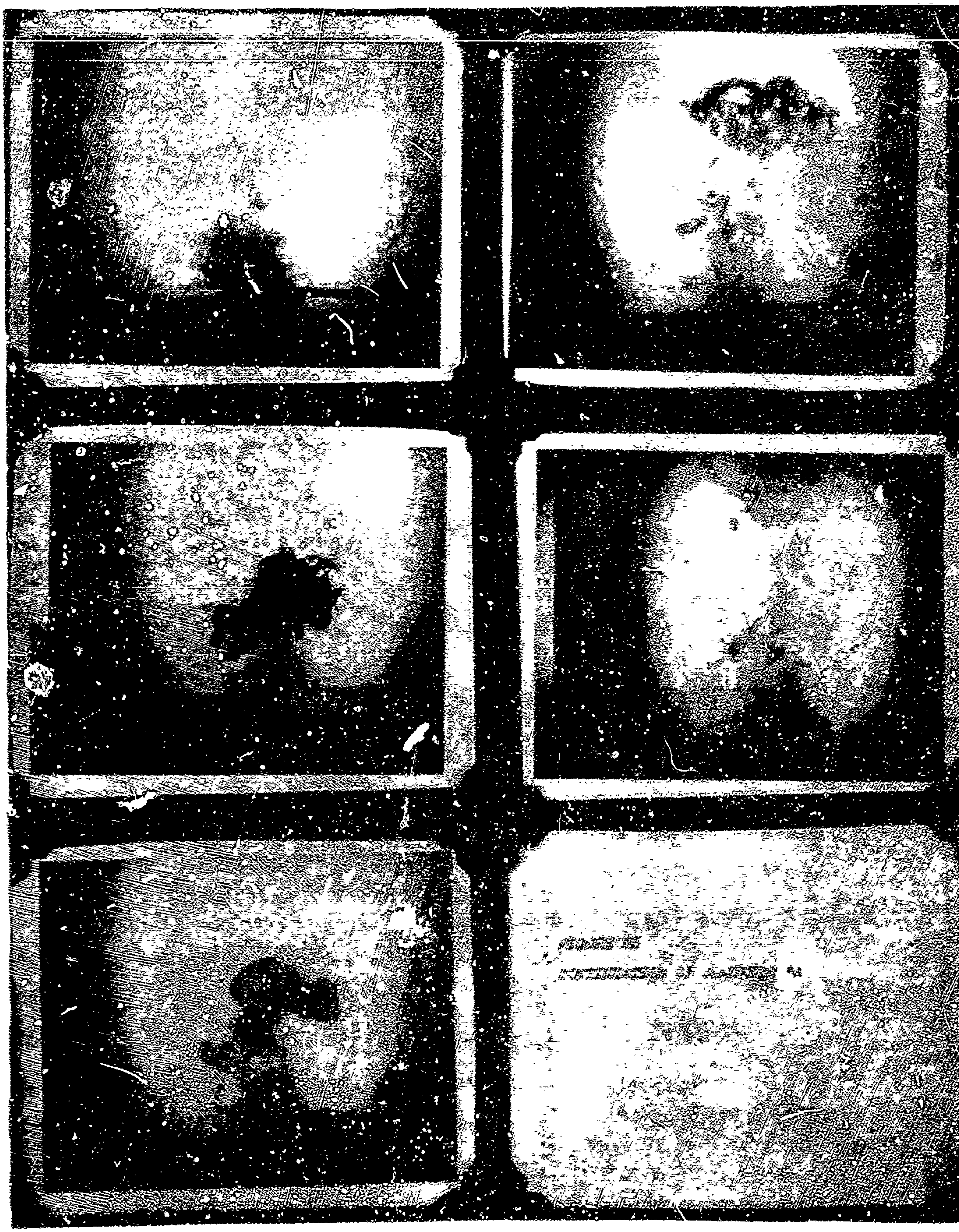
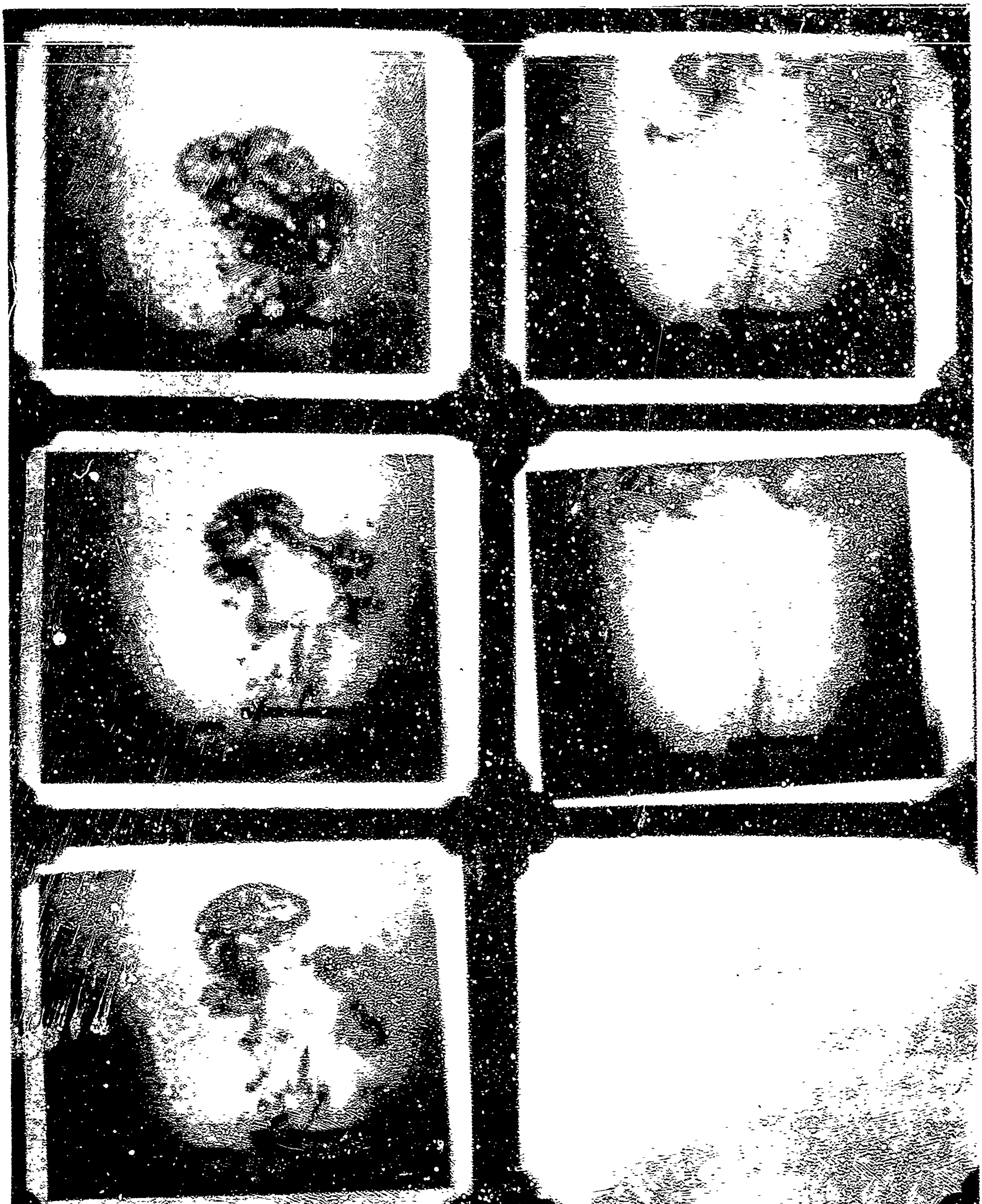
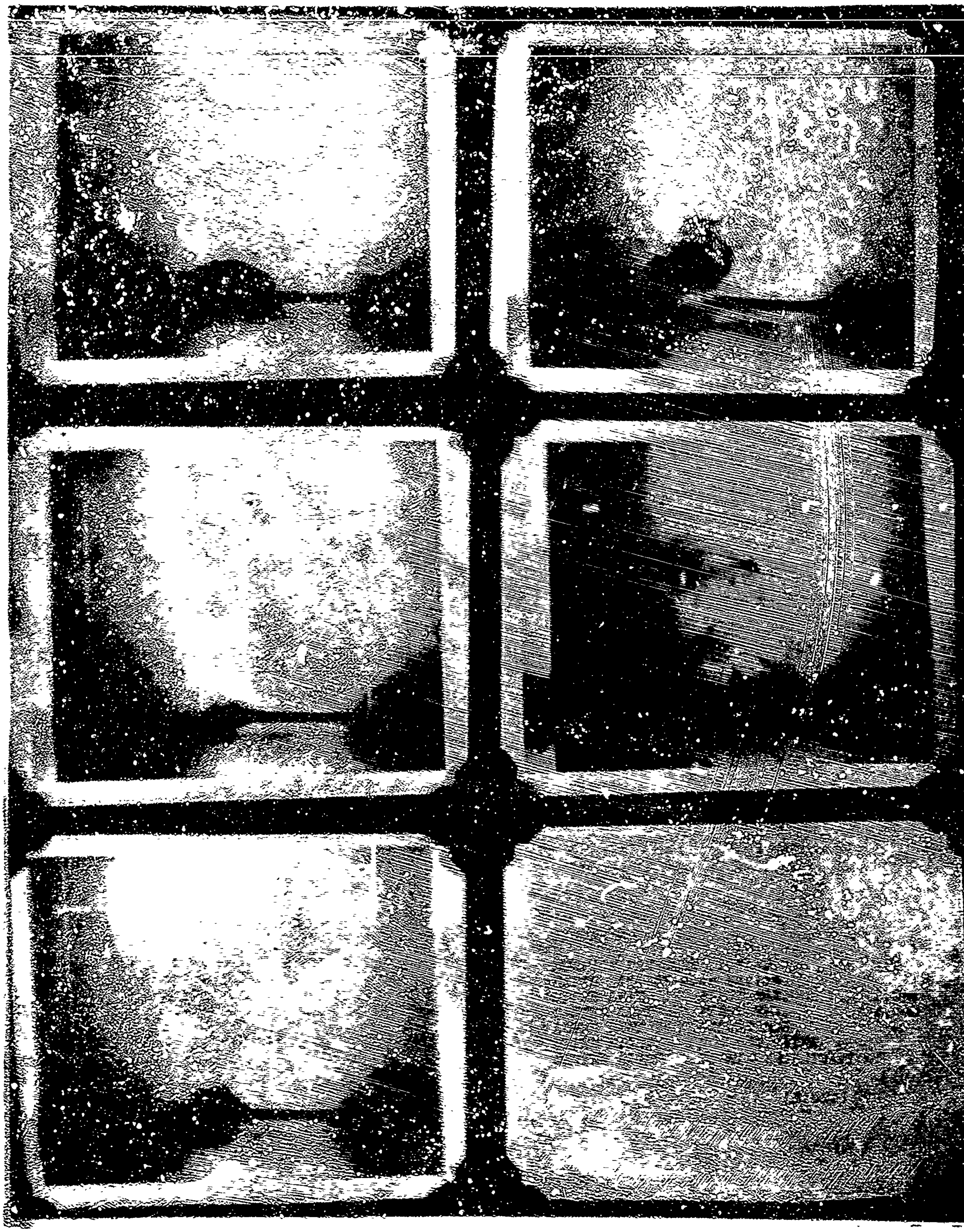
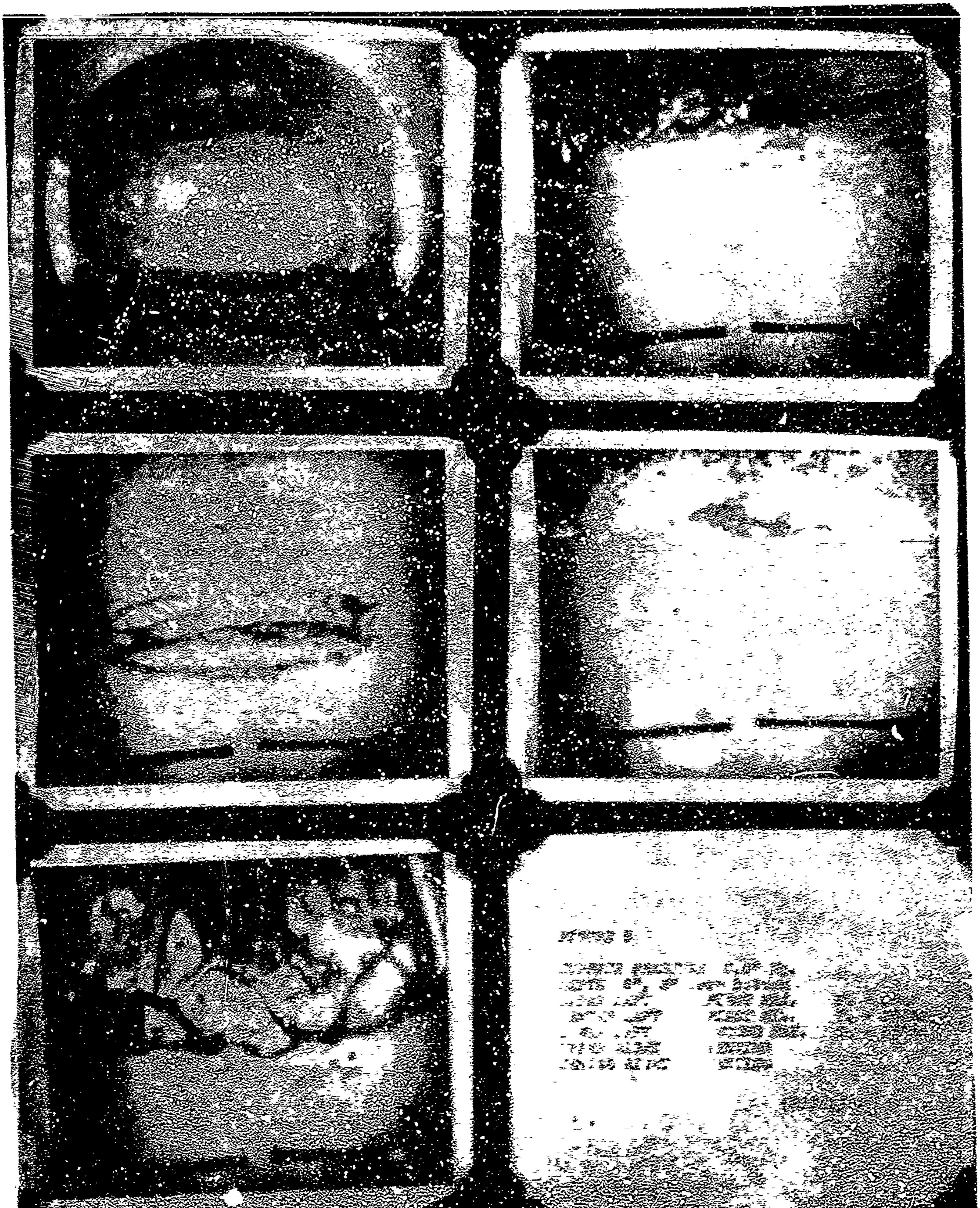


FIGURE 21









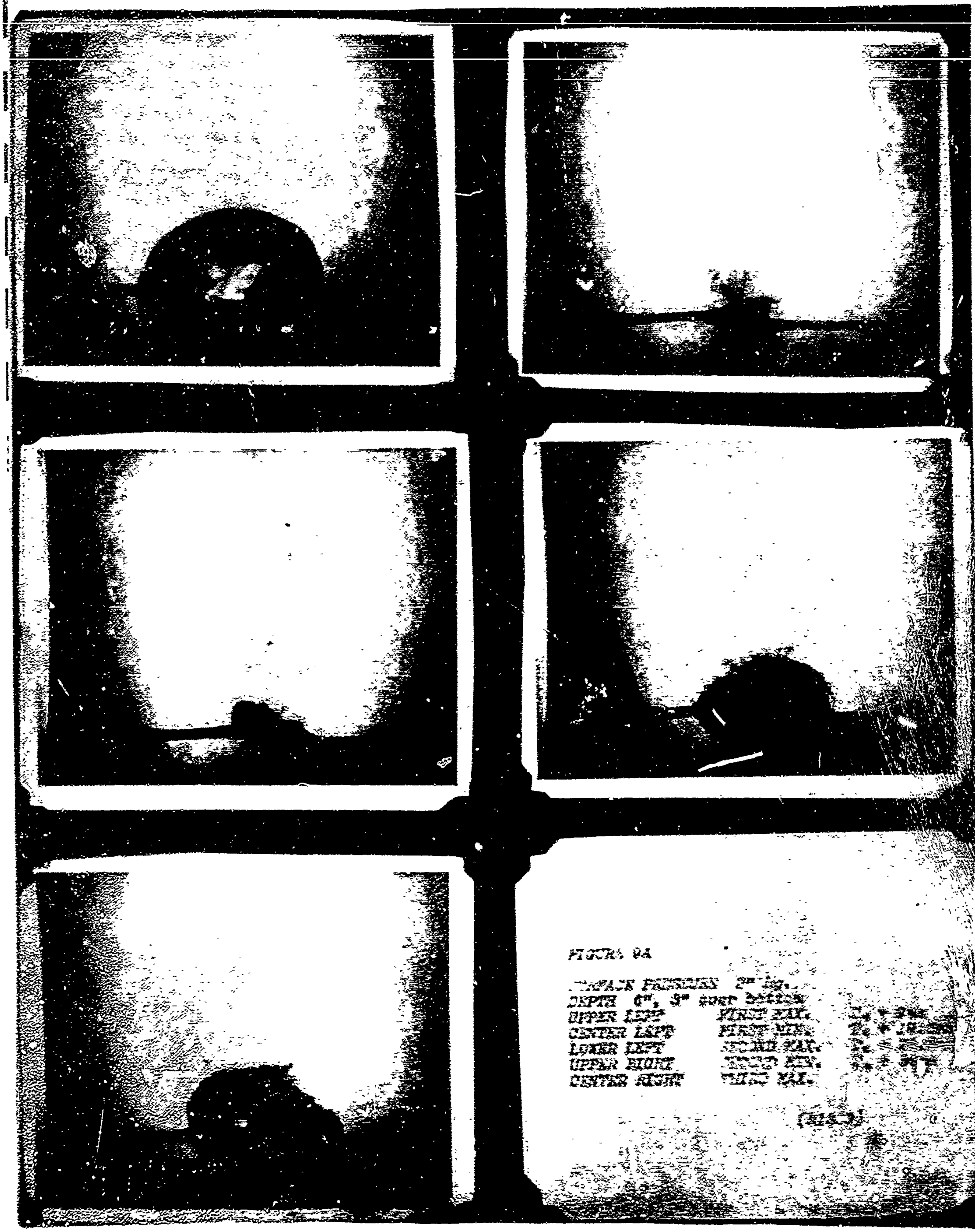
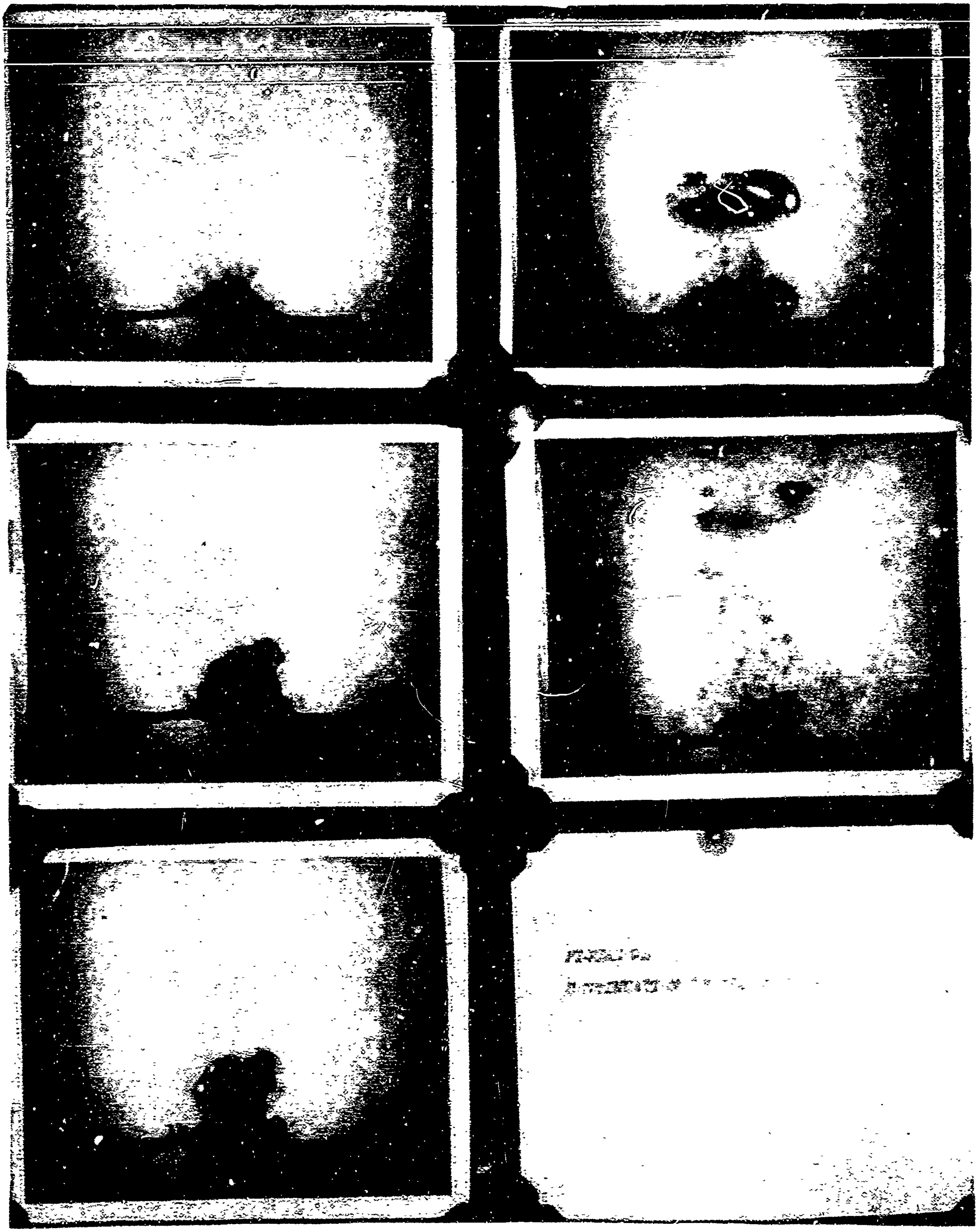


FIGURE 9A

SURFACE PRESSURES 2" [illegible]
DEPTH 6", 3" over bottom [illegible]

UPPER LEFT FIRST MAX. [illegible]
CENTER LEFT FIRST MIN. [illegible]
LOWER LEFT SECOND MAX. [illegible]
UPPER RIGHT SECOND MIN. [illegible]
CENTER RIGHT THIRD MAX.

[illegible]



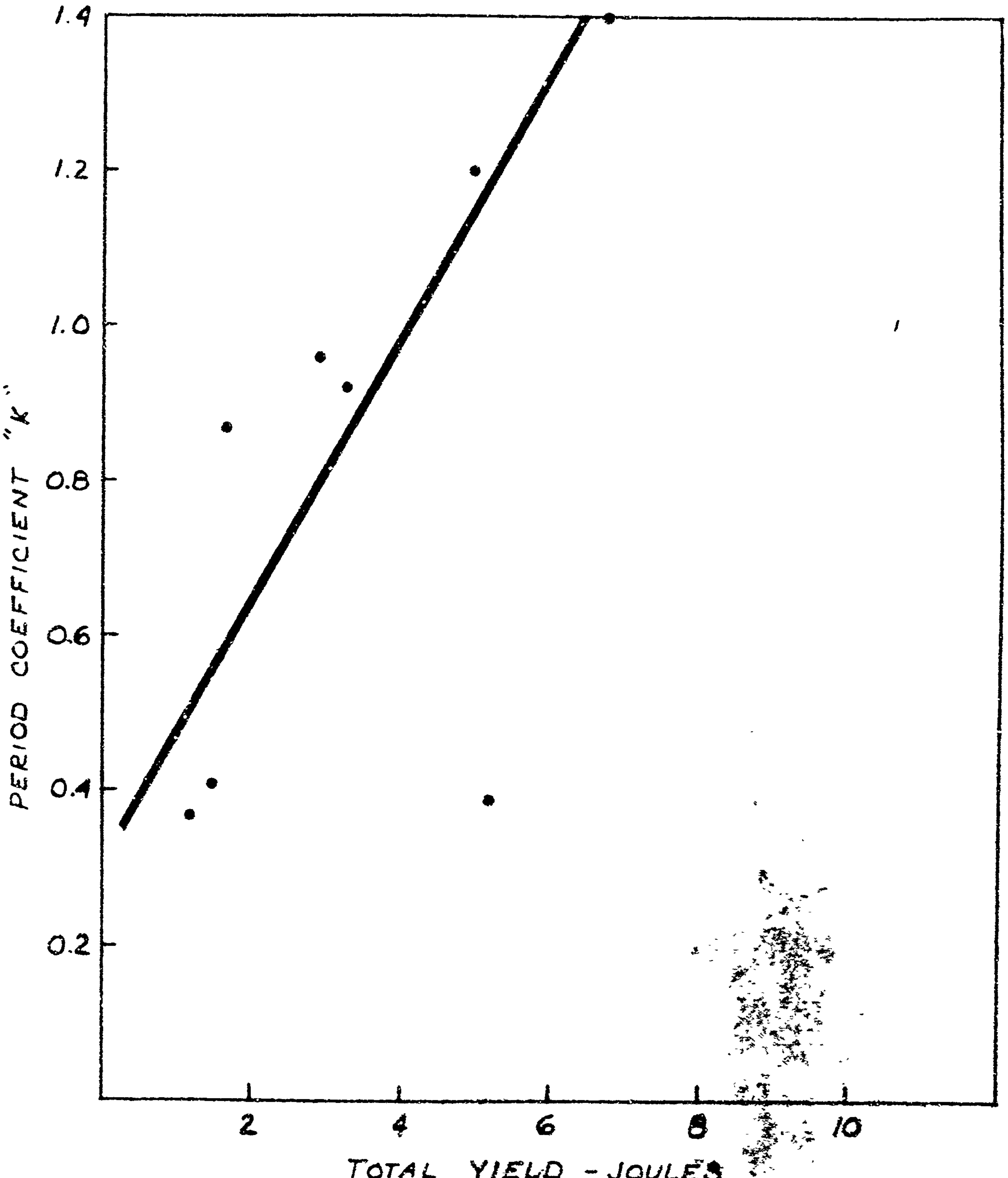

1.4
1.2
1.0
0.8
0.6
0.4
0.2
PERIOD COEFFICIENT "K"
2
4
6
8
10
TOTAL YIELD - JOULES

FIGURE 10

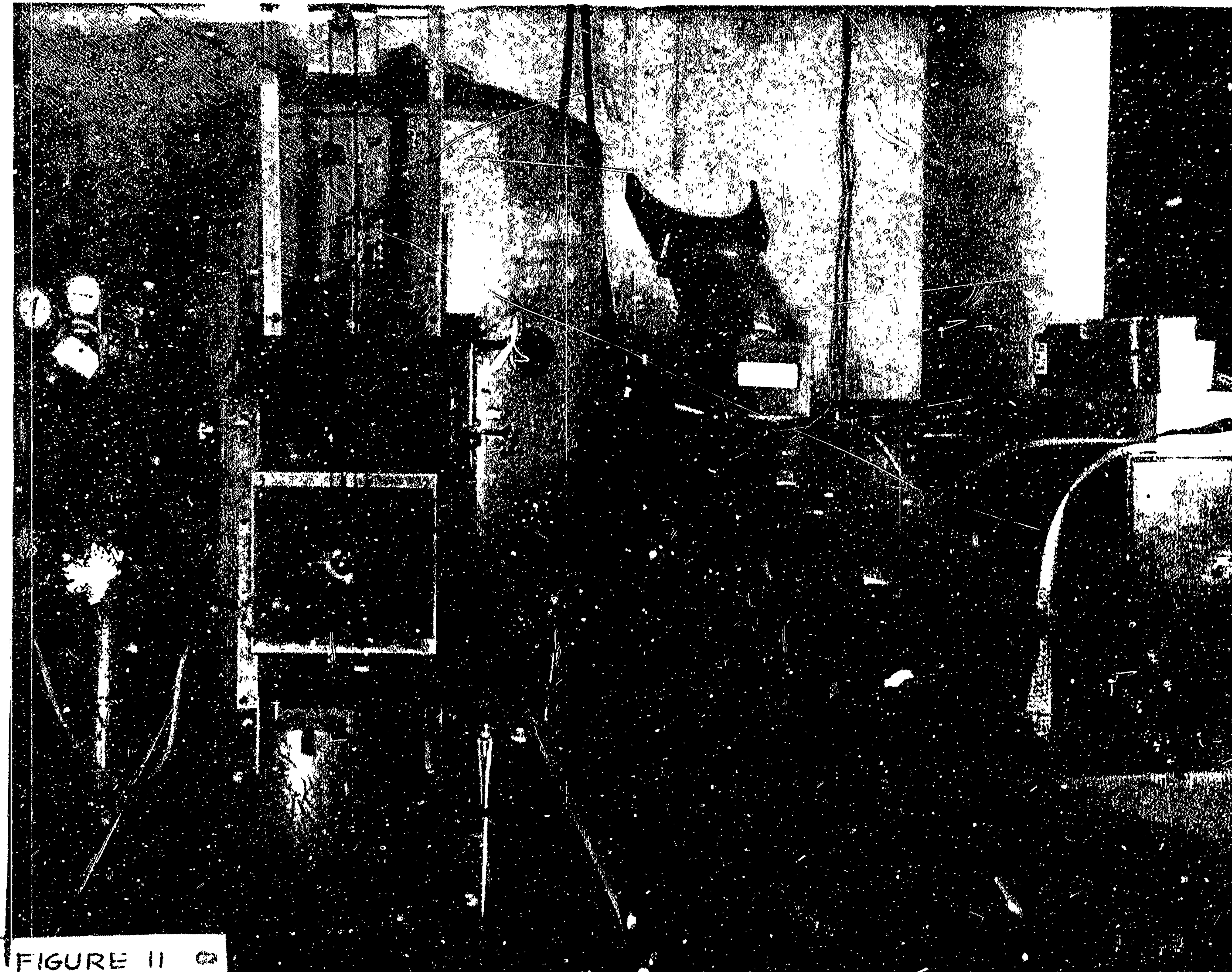


FIGURE 11

FIGURE [illegible]

Top - Inner Pole Illumination
Center - East Pole Illumination
Bottom - Calibration Lamp

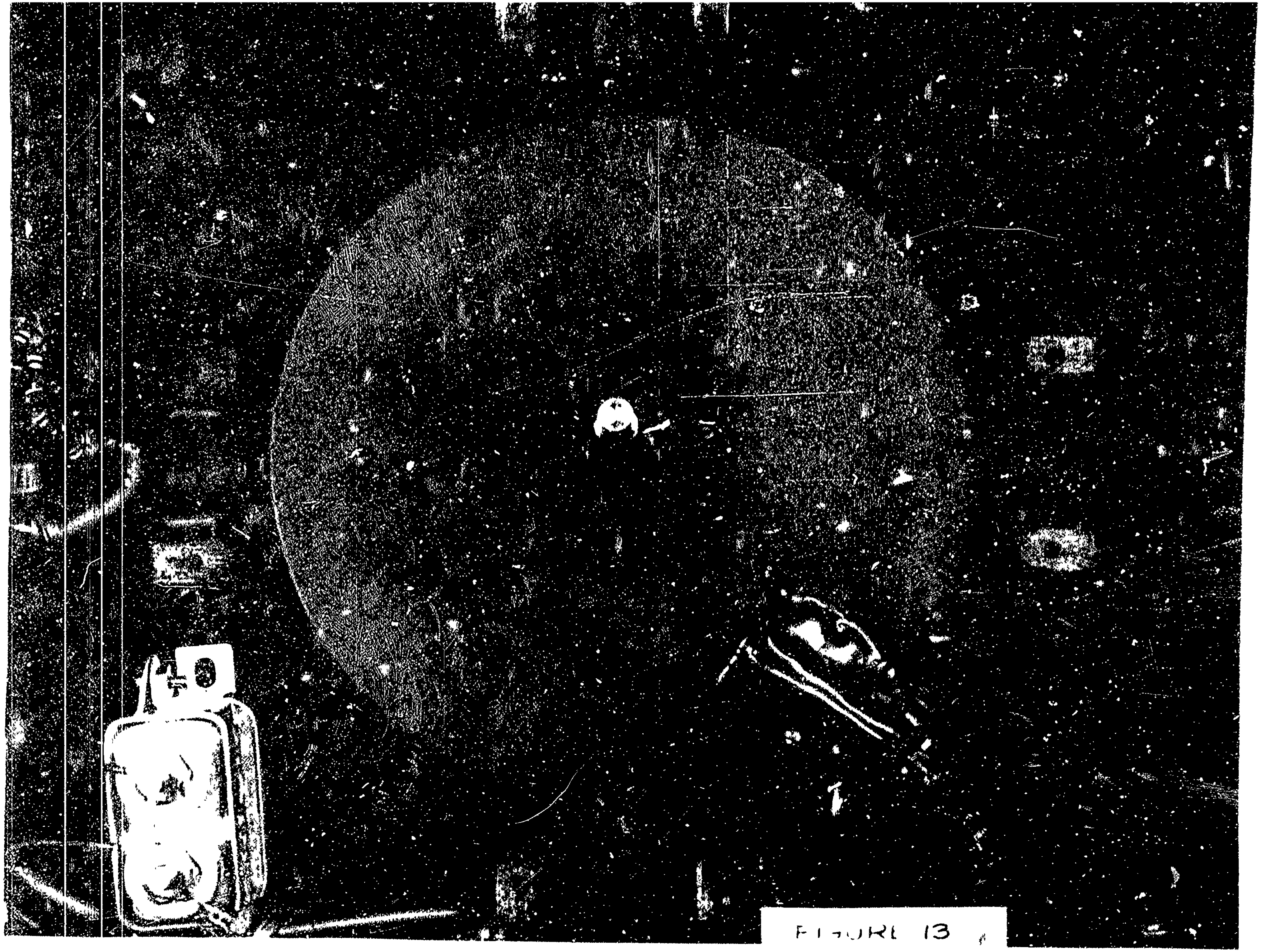


FIGURE 13