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PRELIMINARY RESULTS OF CSTF AEROSOL BEHAVIOR TEST, AB-1

R. K. Hilliard
J. D. McCormack
J. A. Hassberger
L. D. Muhlestein

MAS

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Hanford Engineering Development Laboratory
Westinghouse Hanford Company
Richland, Washington 99352

1.0 INTRODUCTION

A large-scale aerosol behavior test (AB-1) was performed in the Containment Systems Test Facility (CSTF) containment vessel using sodium oxide aerosol generated by a pool of sodium burning in air. The purpose was to characterize the aerosol properties and compare the experimental results with computer code predictions. The 20-meter high CSTF vessel is by far the largest ever used in aerosol agglomeration studies and is approximately half-scale of large commercial reactor containment buildings for the parameters affecting particle agglomeration and settling.

Information derived from this test will be utilized in follow-on air cleaning development tests. Two additional aerosol behavior tests are planned before the air cleaning tests are started.

Although the test results are incomplete and only partially evaluated, sufficient information is available for making some important preliminary conclusions. A complete reporting of the test details and results will be made as soon as possible.

2.0 TEST CONDITIONS

2.1 Experimental Arrangement

A view of the top half of the containment vessel (CV) is shown in Figure 1. Figure 2 is a schematic diagram showing the key test features. Figure 3 is a photograph of the sodium burn pan and 2-in. spill pipe. Ten clusters of filter samplers were hung at various locations throughout the CV atmosphere, as can be seen in Figure 4. Each cluster contained 12 filters, each independently controlled by a solenoid valve so that samples could be taken at twelve different times from ten different locations.

Four "thief" sample stations were provided, as shown in Figure 2. A photograph of one of the stations is shown in Figure 5. These thief stations permit taking a large number and variety of types of samples without the use of sample lines. The sampler was thrust through the air lock and large ball valve directly into the containment atmosphere. Types of samples taken at the thief stations included filter samples (for mass concentration), samples for chemical species identification, deposition coupons, and cascade impactors for particle size measurements. Two gas sample systems were provided, one taking gas from high in the vessel (+20 ft. elevation) and one from low in the vessel (-22 ft.). Each system provided on-line analysis of oxygen, moisture, and hydrogen concentration.

Sodium was spilled into the burn pan by pressurizing with argon the sodium supply tank and opening the pneumatic operated valve. Sodium flowed at approximately 100 gal/min through the preheated 2-in. diameter spill pipe. Splashing was minimized by baffles in the pan.

The burn pan had a hinged lid which was in the vertical position during the spill. The lid was closed 62 minutes after the initiation of the spill, effectively stopping release of aerosol particles. In discussing the results of this test, time zero (t_0) is defined as the beginning of the sodium spill.

2.2 Initial Test Conditions

The initial conditions are summarized in Figure 6.

3.0 RESULTS

3.1 Temperature, Pressure, and Oxygen Concentration

The containment atmosphere reached a maximum temperature of 190°F, considerably less than the 280°F predicted by the SOFIRE-2 code(1). Figure 7 shows the comparison. As soon as the fire was extinguished, the gas temperature dropped rapidly to approximately 140°F.

The CV pressure increased from 17.9 psia to a maximum of 20.9 psia at the end of the sodium burning period. This was significantly less increase in pressure than predicted by SOFIRE, as shown by Figure 8.

Figure 9 compares the experimental oxygen concentration with SOFIRE. The assumption was made for SOFIRE input that the sodium combustion product would be 50% Na_2O, 50% Na_2O_2.

3.2 Aerosol Mass Concentration

The suspended aerosol mass concentration is shown as a function of time in Figure 10. The experimental points are the mean values for the four thief stations. The standard deviation among the results from the four locations averaged ± 20% throughout the test, indicating that mixing was good and experimental technique was adequate. At six minutes after beginning the spill the standard deviation was 16%.

The filter samples were analyzed for total sodium by either acid titration or flame spectrophotometry, with suitable blank corrections applied. For the purpose of plotting the data in Figure 10, a gravimetric factor of 2 grams of aerosol per gram of sodium was applied. Analyses now in progress will provide a refined value for this factor. However, based on balance weighing and chemical analyses, the factor is believed to be approximately 2 - 3.

The pre-test predictions of mass concentration using HAA-3B(2) and HAARM-3 are plotted in Figure 10. Fair agreement with the experimental results is seen, with HAARM being significantly high, especially at early times.

After the aerosol source was stopped, the concentration decreased with a 15-minute half time for approximately 40 minutes. This is equivalent to the stirred settling of 15-micron diameter spherical particles with unit density.

After 24 hr, the concentration was 0.005 g/m^3 and at 48 hr. it was 0.0015 g/m^3.

3.3 Particle Size Distribution

Twenty-two cascade impactor samples were taken at eleven different times. Samples were taken concurrently from the top and bottom thief stations (T-1 and T-4). No significant difference was detected between particle size from these two locations. Two types of impactors were used——the Andersen Mark III* and the Sierra Model 226**. The former is an eight-stage multi-circular jet sampler, the latter is a six-stage sampler with four slits per stage.

A typical distribution obtained from the Andersen impactor is shown in Figure 11. Figure 12 gives the same type of data provided by the Sierra instrument. The aerodynamic mass mean diameter (AMMD) and geometric standard deviation for the eleven sampling times are listed in Figure 13. The data of Figure 13 are plotted as a function of time in Figure 14. Also shown in Figure 14 are the pre-test predictions by the HAA-3B and HAARM-3 codes.

Calculations of particle size based on material deposited on coupons inserted into the atmosphere for brief periods of time give an effective diameter of 14 microns during the initial two hours, assuming unit density spheres. This is in close agreement with the size calculated from the rate of change of suspended mass concentration immediately after stopping the aerosol source.

* Andersen 2000, Inc., Atlanta, Georgia

** Sierra Instruments, Inc., St. Paul, Minnesota

3.4 Electron Microscopy

Electron microscope grids were exposed to the CV atmosphere at four different times. Typical views of particles which deposited on the grids by gravitational settling are shown in Figure 15 - 18. The particles were protected from ambient air by withdrawing the grids into O-ring sealed containers while they were in the CV atmosphere, transferring them to an inert atmosphere glove box, loading them into the electron microscope holder in the glove box, double bagging in plastic, flooding the electron microscope chamber with dry Freon, and inserting the holder into the Freon-filled chamber. The particles seen in Figures 15 - 18 have, of course, been subjected to vacuum during the microscopic examination. The clear trend is seen from small (1 - 5 μm) particles to large (30 μm) gas-filled spheres, to large crystalline skeletons to smaller particles at the later times. An optical microscope showed the gas bubbles being omitted, probably oxygen as a result of the reaction of sodium peroxide with water:

$$Na_2O_2 + H_2O \rightarrow 2\ NaOH + 1/2\ O_2$$

3.5 Humidity

Dew point meters in the gas analysis systems were judged to be unreliable. Gravimetric samples were taken directly from the containment atmosphere by using a thief station with a filter to remove the aerosol particles and collecting the water in a magnesium perchlorate drying tube. Figure 19 shows that the humidity decreased to -40°C dew point during the test.

3.6 Chemical Composition of Aerosol Particles

The chemical composition of the suspended aerosol particles at several different times was determined by a combination of infrared analysis and wet chemistry. The results are tabulated in Figure 20. At early times the particles contained more water (as hydroxide), with most of the balance sodium peroxide. At later times the hydroxide content decreased and the peroxide increased.

3.7 Extent of Mixing in the Atmosphere

Motion pictures of the spill showed great turbulence and billowing smoke clouds immediately as the sodium entered the burn pan. The concentration of aerosol particles six minutes after the beginning of the spill was uniform throughout the CV atmosphere, as shown by the low value of the standard deviation in Figure 21.

Additional evidence of good mixing in the atmosphere is given by Figure 22, which shows that the oxygen concentration was nearly identical at the top and bottom of the vessel.

The good mixing is believed to be caused by the convection currents induced by the rising hot gas plume over the sodium surface and the temperature gradient at the relatively cold vertical walls. The temperature gradient near the vessel midplane is shown in Figure 23.

3.8 Post-Test Observations

When the vessel was first opened, the deposited pale yellow aerosol covered all horizontal surfaces to a depth of 0.6 to 1.0 cm. The material was very dry and was easily swept up. As time passed, moisture was absorbed and the material formed a froth nearly 2 cm deep. At still longer times, the froth had solidified to a thin crust which easily crushed to a very thin layer.

Figure 24 gives a view of the vessel bottom head taken from the vessel midplane. A close-up view of the wall is shown in Figure 25. Figure 26 shows the operators retrieving the filter clusters, and Figure 27 shows a cluster after removal from the burn pan.

Cleanup operations are in progress, including washing the vessel walls and removal of the partially reacted sodium from the burn pan.

4.0 CONCLUSIONS

The chief conclusions are listed in Figure 28. Undoubtedly, other conclusions can be drawn from the large amount of data obtained from this test, and further evaluation may necessitate modifying some of these preliminary conclusions. A final detailed topical report will be prepared.

5.0 ACKNOWLEDGEMENTS

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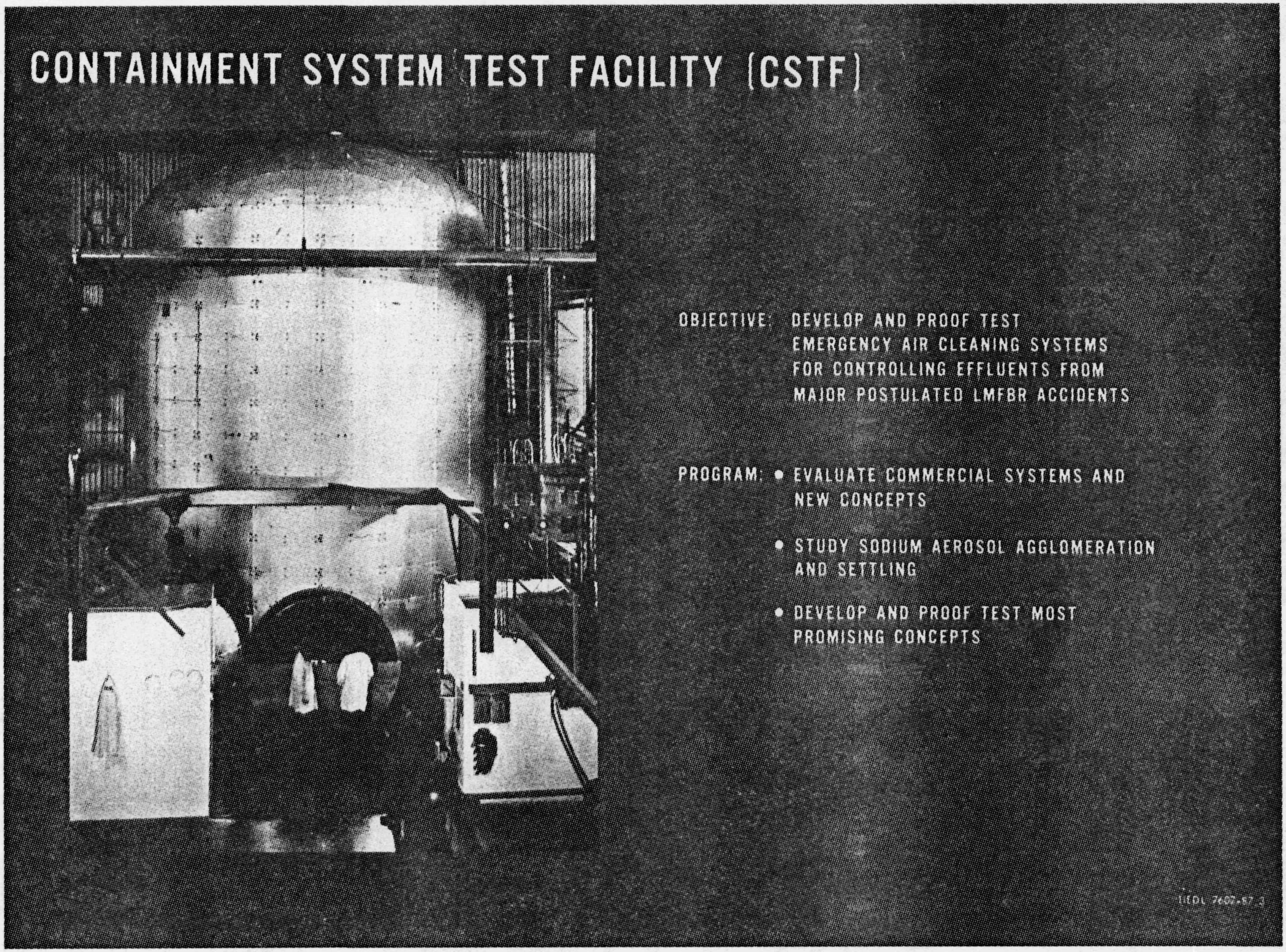
6.0 REFERENCES

(1) P. Beiringer et. al., "SOFIRE II User Report," AI-AEC-13055, Atomic International, Canoga Park, California, March 31, 1973.

(2) R. S. Hubner, et. at., "HAA-3 User Report," AI-AEC-13088, Atomics International, March 30, 1973.

APPENDIX

FIGURES AND TABLES



CONTAINMENT SYSTEM TEST FACILITY (CSTF)

OBJECTIVE: DEVELOP AND PROOF TEST EMERGENCY AIR CLEANING SYSTEMS FOR CONTROLLING EFFLUENTS FROM MAJOR POSTULATED LMFBR ACCIDENTS

PROGRAM:
- EVALUATE COMMERCIAL SYSTEMS AND NEW CONCEPTS
- STUDY SODIUM AEROSOL AGGLOMERATION AND SETTLING
- DEVELOP AND PROOF TEST MOST PROMISING CONCEPTS

HEDL 7607-87.3

FIGURE 1.

CSTF AEROSOL BEHAVIOR TEST ARRANGEMENT WITH SODIUM POOL FIRE

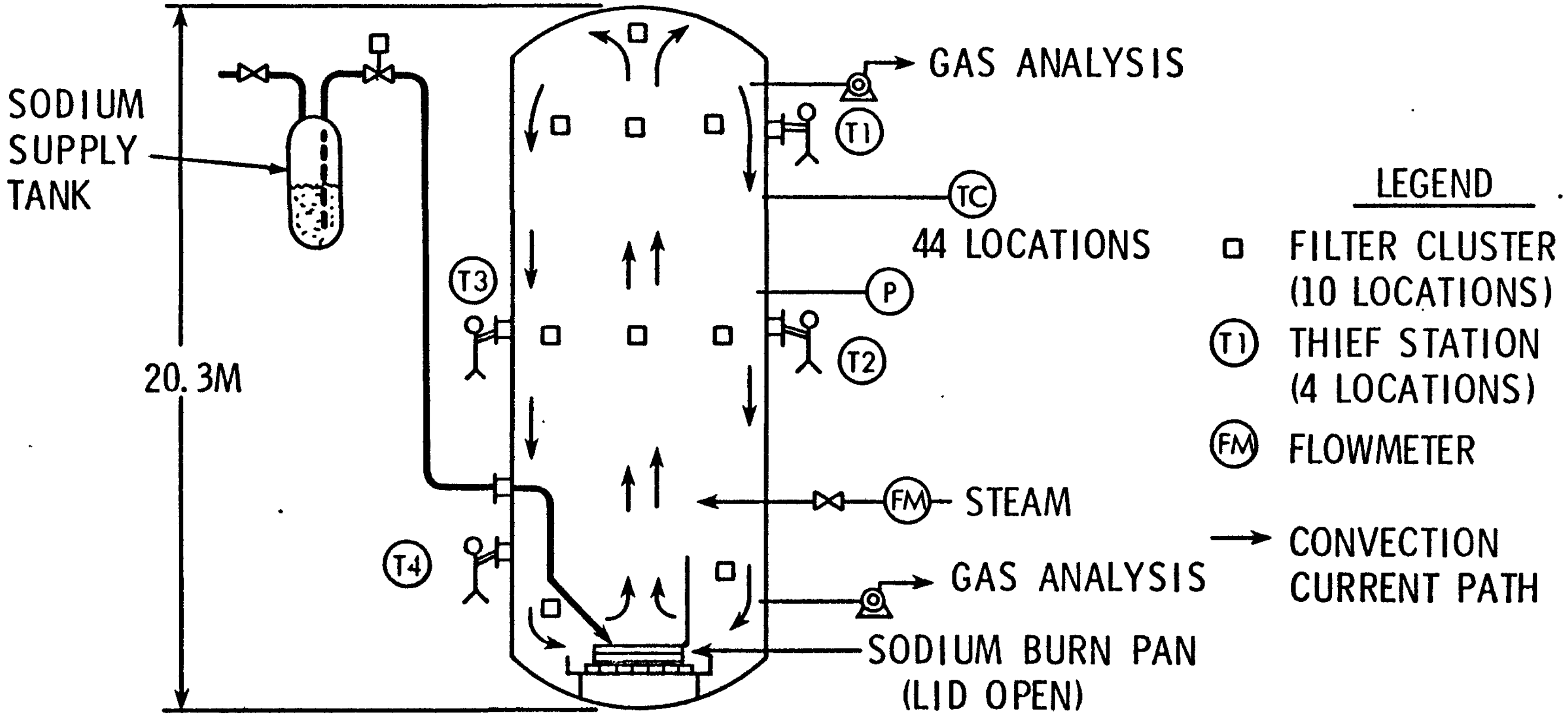


FIGURE 2.

HEDL 7710-38.1

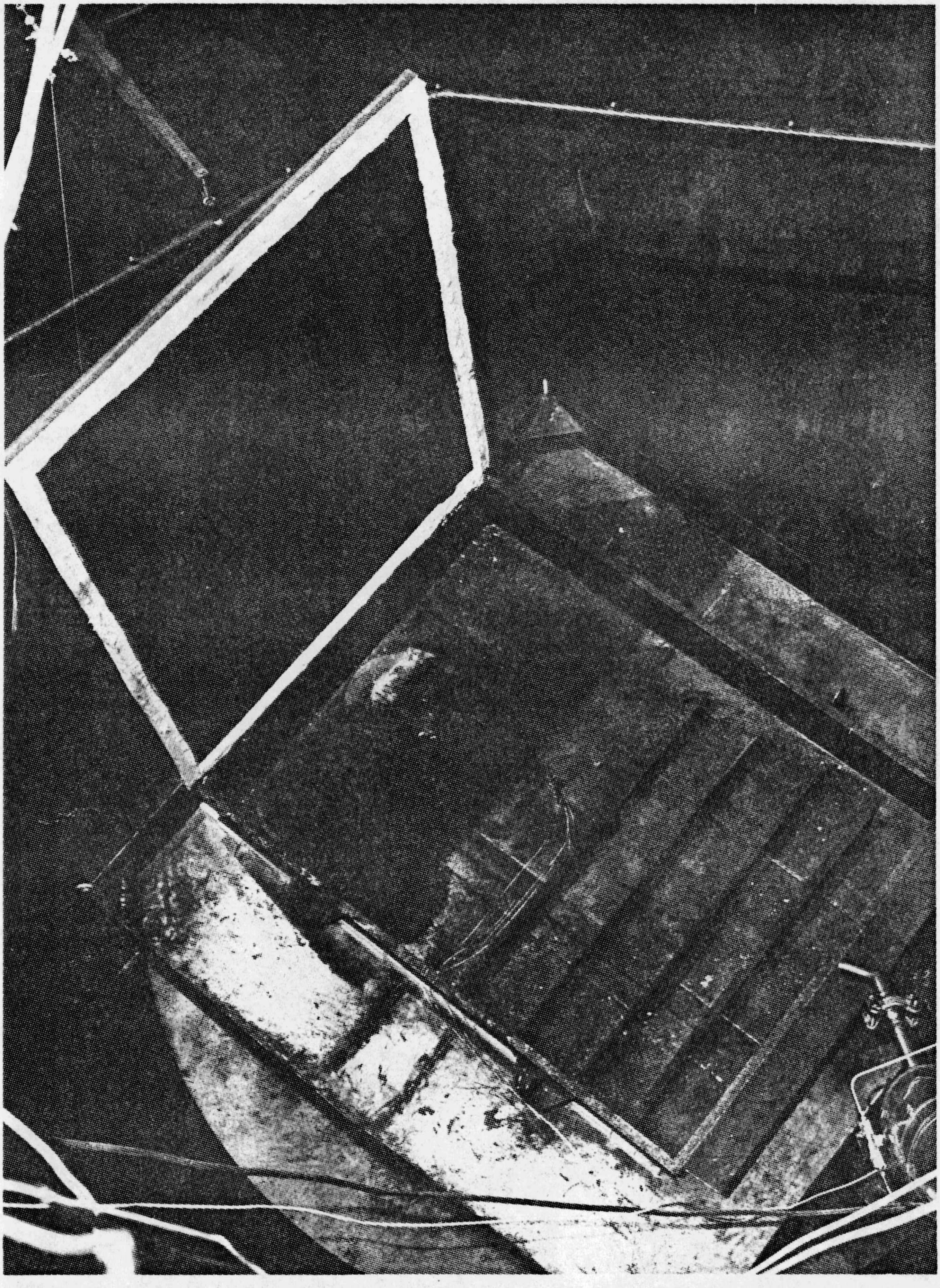


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FIGURE 3. View of Sodium Burn Pan and Spill Pipe in Containment Vessel.

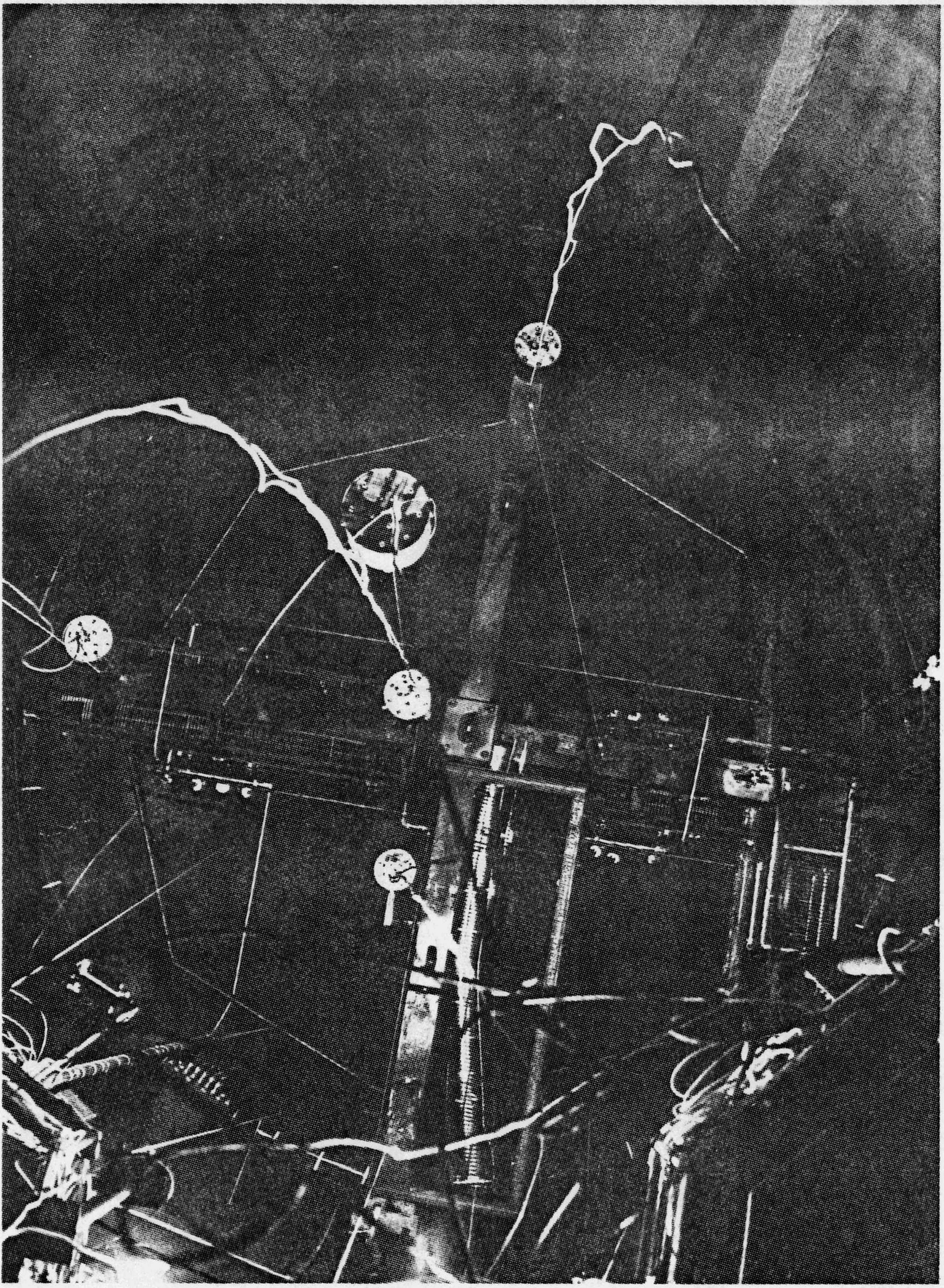

FIGURE 4. Pre-Test View of Containment Vessel Showing Filter Clusters.

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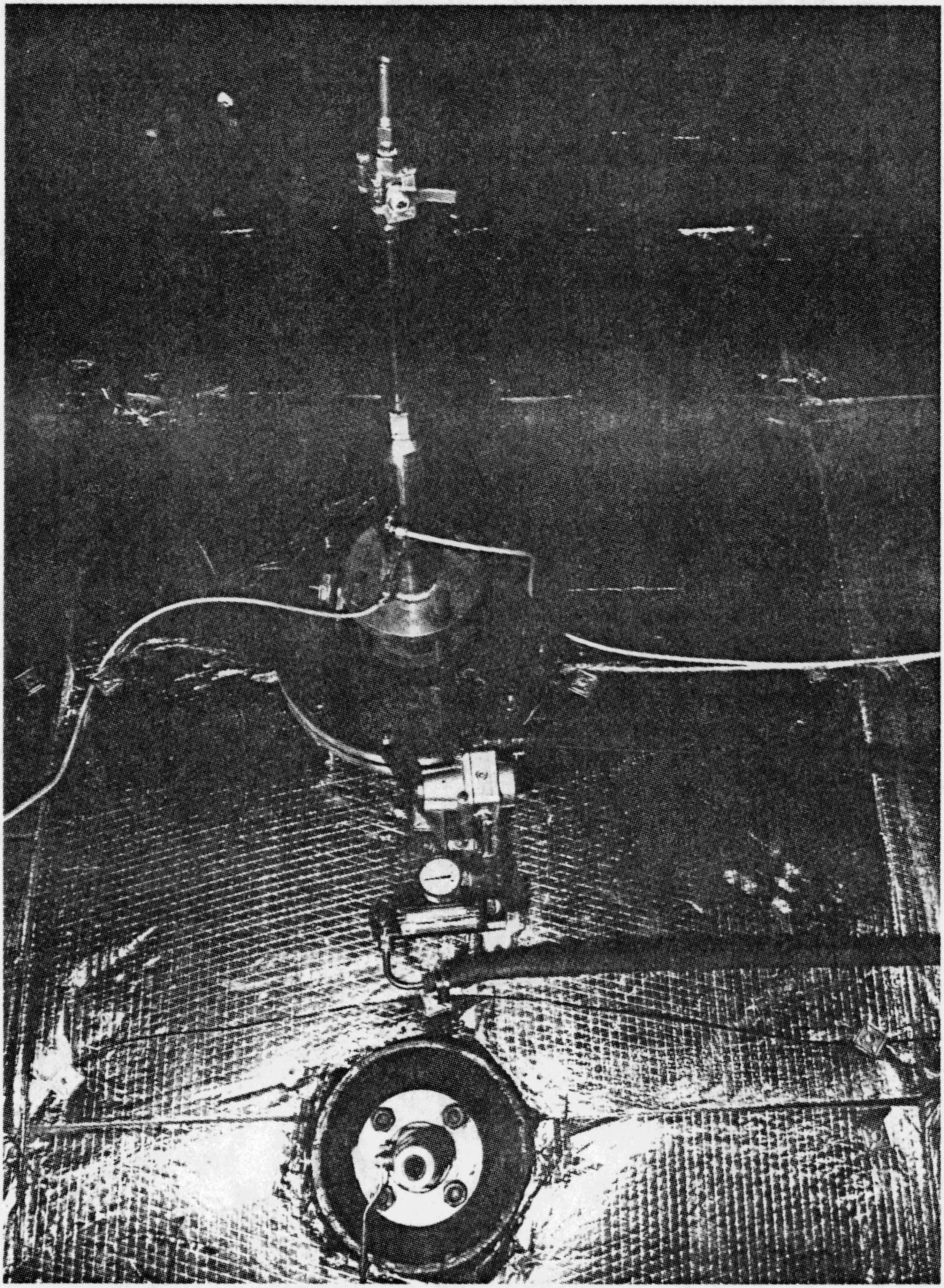


FIGURE 5. View of Thief Station No. 3.

INITIAL CONDITIONS - TEST AB-1

CONTAINMENT VESSEL

VOLUME, M^3	850
HORIZONTAL SECTION, M^2	45.6
TOTAL HORIZONTAL SURFACE, M^2	88
VESSEL STEEL MASS, KG	103,000
LEAKAGE RATE, %/D AT 10 PSIG	2.0

AEROSOL SOURCE

TYPE	SODIUM POOL FIRE
SOURCE DURATION, MINUTES	62

SODIUM BURN PAN

SURFACE, M^2	4.4

SODIUM SPILL

MASS NA SPILLED, KG	400
SPILL DURATION, MINUTES	1.3
TEMPERATURE OF NA, °C	500

CONTAINMENT ATMOSPHERE

OXYGEN, %	19.8
DEW POINT, °C	10.0
TEMPERATURE, °C	26.5
PRESSURE, M PA	0.123

FIGURE 6.

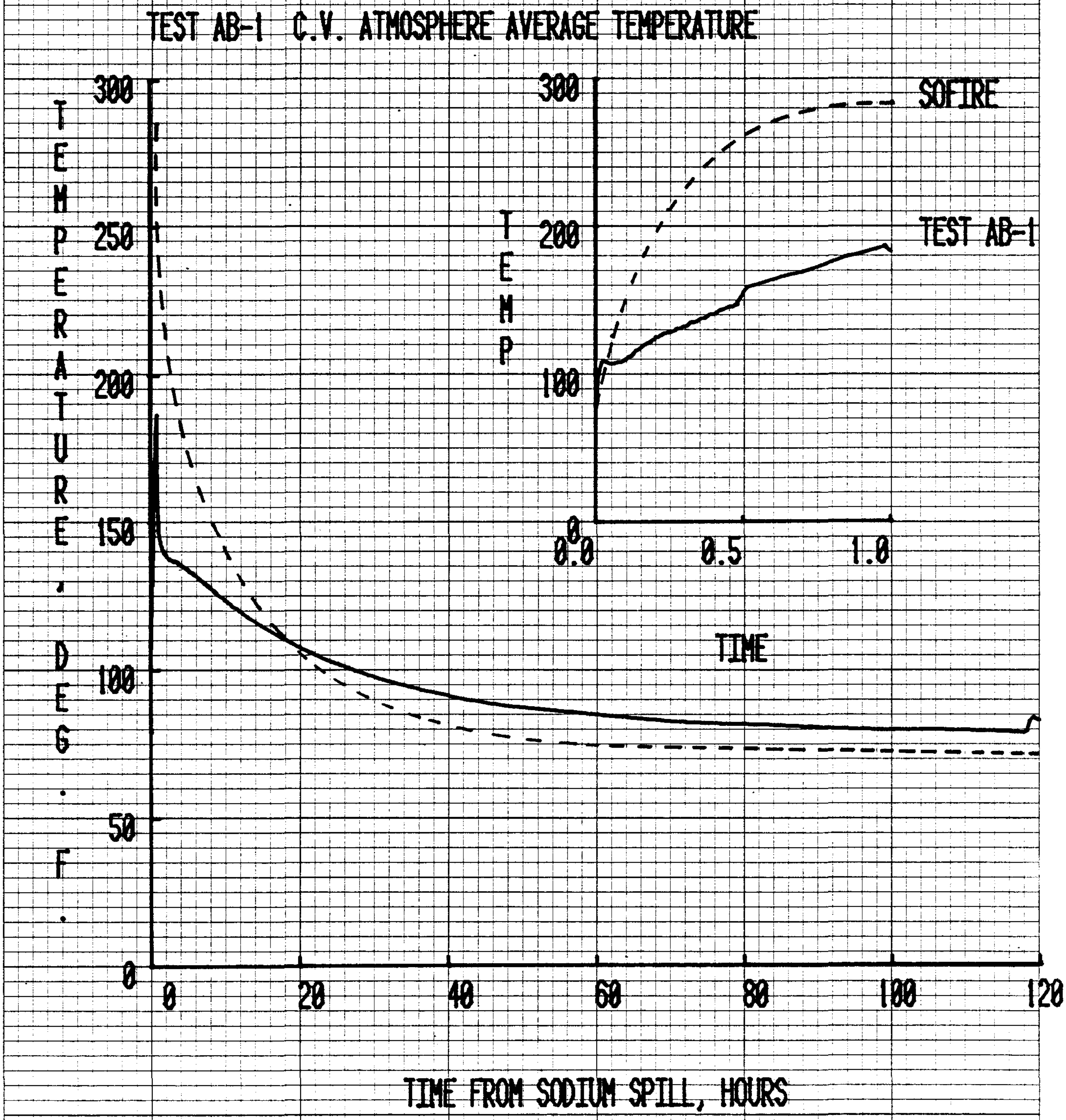

TEST AB-1 C.V. ATMOSPHERE AVERAGE TEMPERATURE
TEMPERATURE, DEG. F.
300
250
200
150
100
50
0
0
20
40
60
80
100
120
TIME FROM SODIUM SPILL, HOURS
TEMP
300
200
100
0
0.0
0.5
1.0
TIME
SOFIRE
TEST AB-1

FIGURE 7.

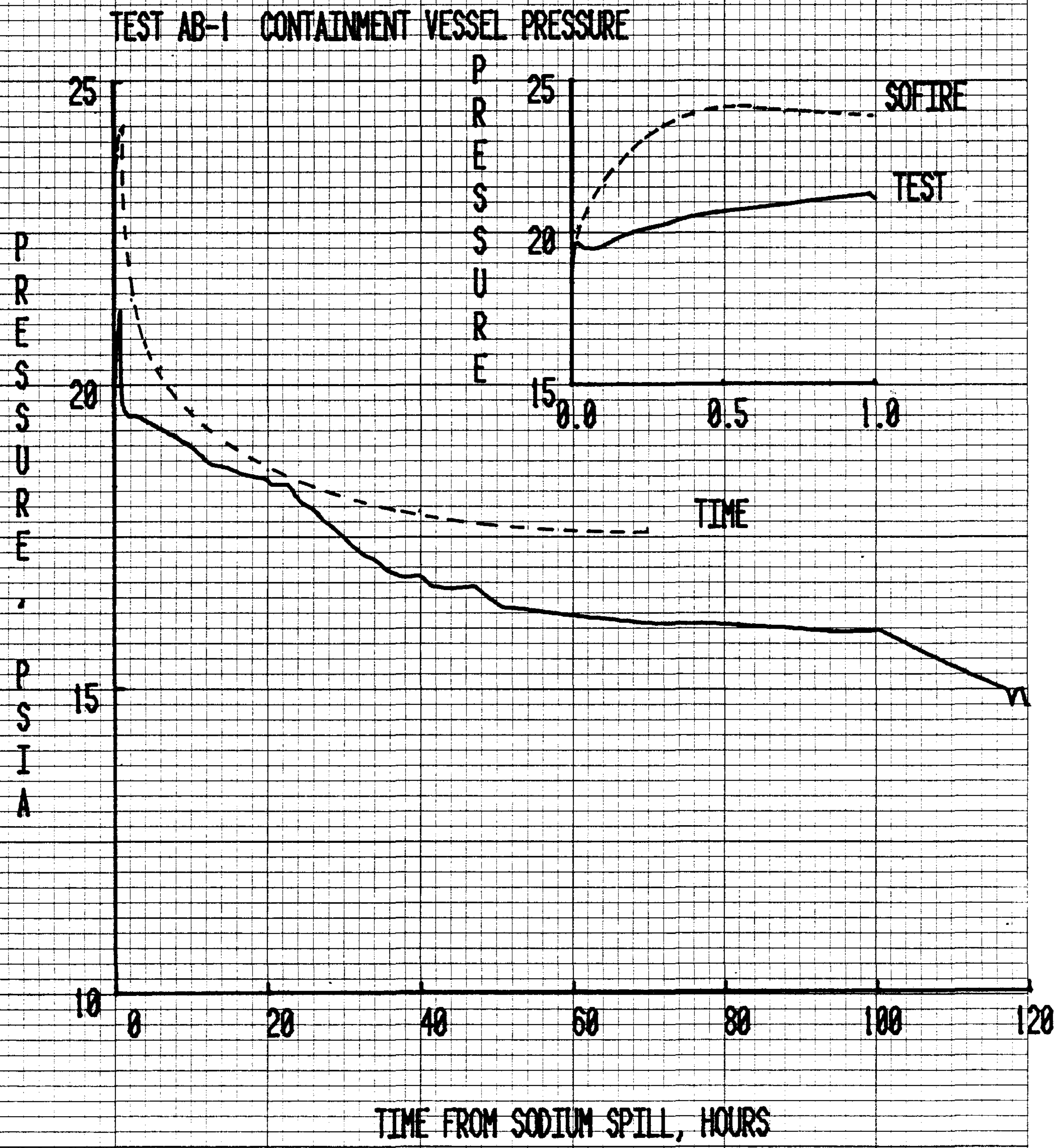

TEST AB-1 CONTAINMENT VESSEL PRESSURE
PRESSURE, PSIA
25
20
15
10
0
20
40
60
80
100
120
TIME FROM SODIUM SPILL, HOURS
PRESSURE
25
20
15
0.0
0.5
1.0
TIME
SOFIRE
TEST

FIGURE 8.

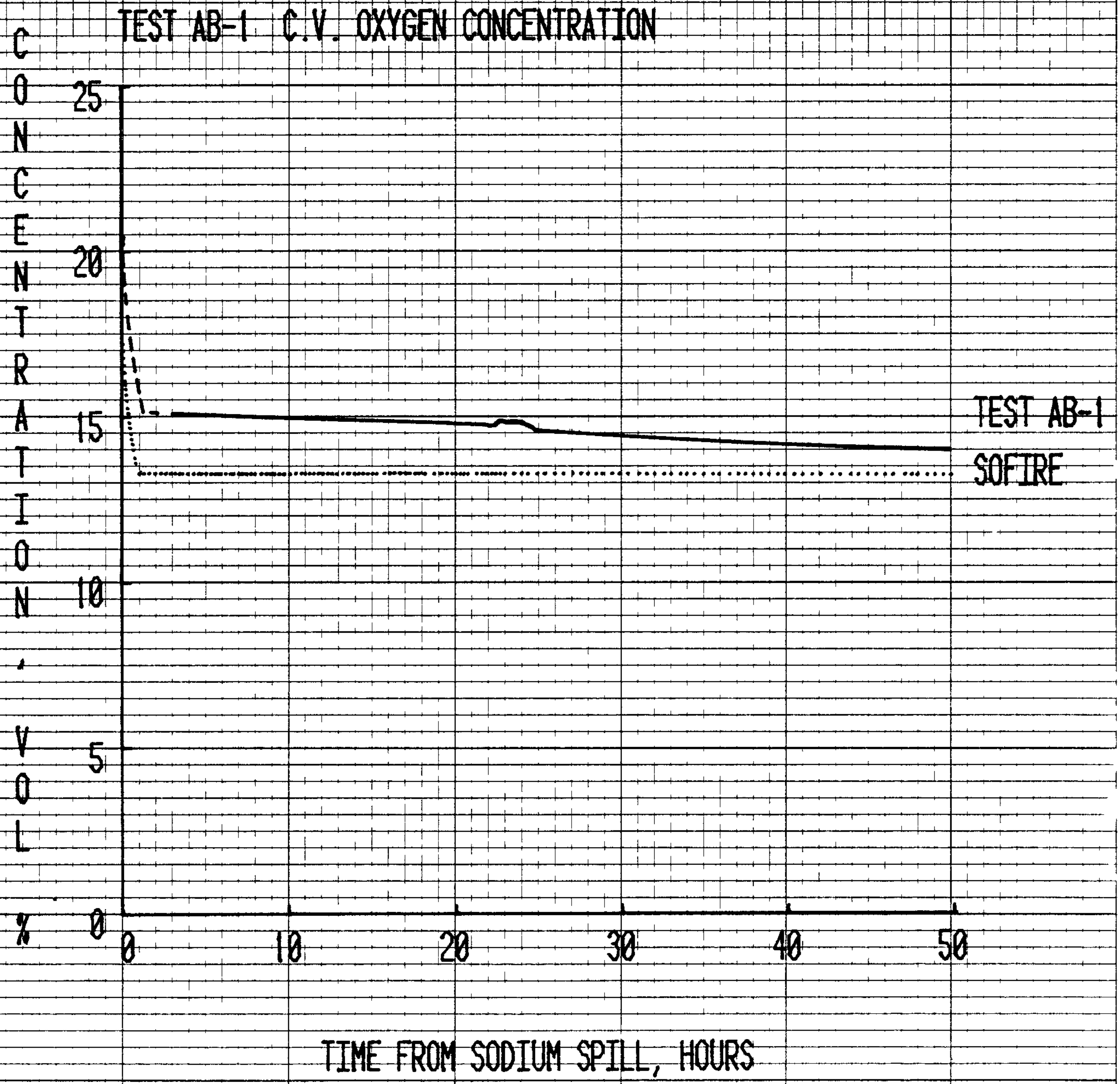

TEST AB-1 C.V. OXYGEN CONCENTRATION
CONCENTRATION, VOL %
25
20
15
10
5
0
0
10
20
30
40
50
TIME FROM SODIUM SPILL, HOURS
TEST AB-1
SOFIRE

FIGURE 9.

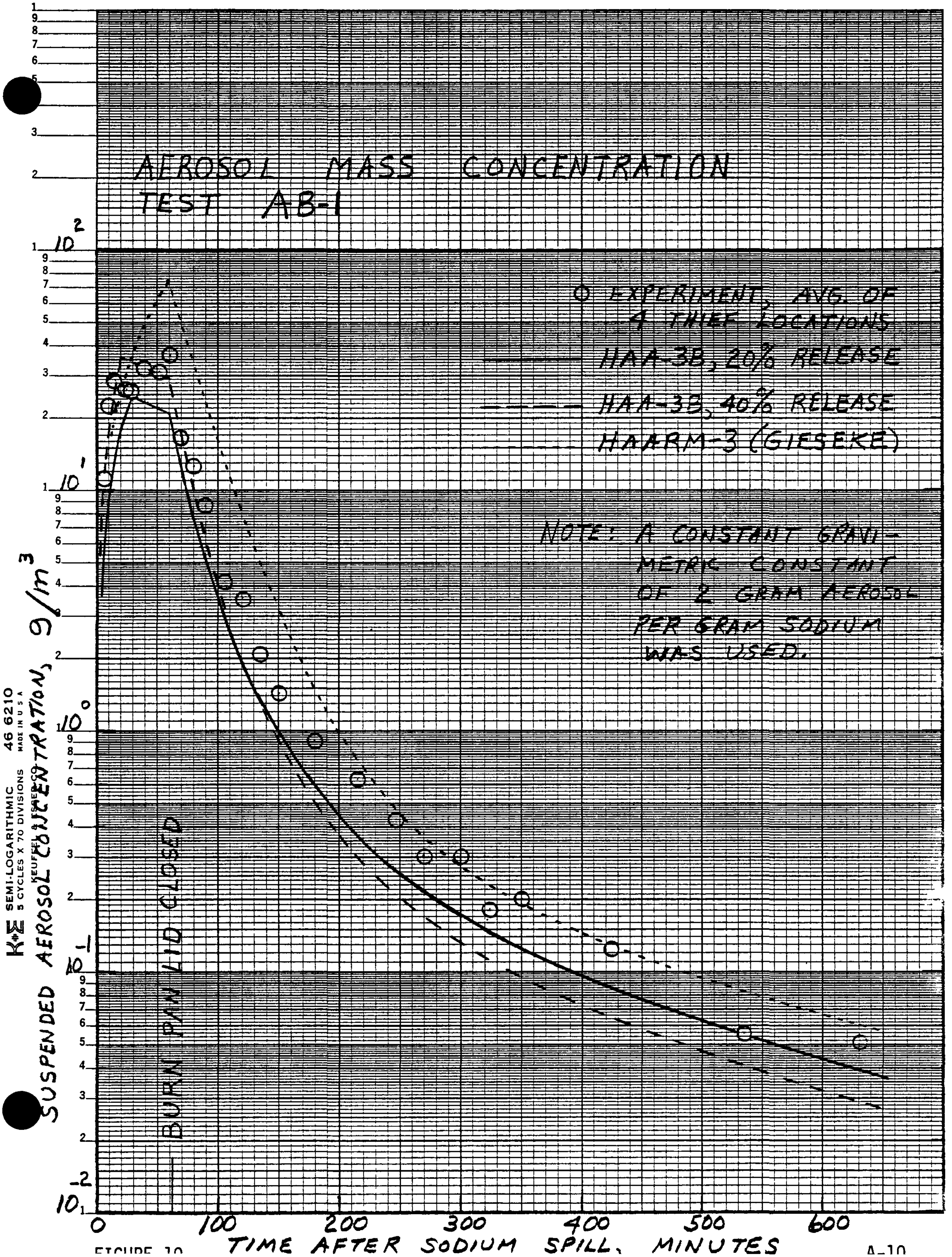

AEROSOL MASS CONCENTRATION
TEST AB-1
○ EXPERIMENT, AVG. OF 4 THIEF LOCATIONS
HAA-3B, 20% RELEASE
HAA-3B, 40% RELEASE
HAARM-3 (GIESEKE)
NOTE: A CONSTANT GRAVIMETRIC CONSTANT OF 2 GRAM AEROSOL PER GRAM SODIUM WAS USED.
BURN PAN LID CLOSED
SUSPENDED AEROSOL CONCENTRATION, g/m³
10^2
10^1
10^0
10^{-1}
10^{-2}
0
100
200
300
400
500
600
TIME AFTER SODIUM SPILL, MINUTES
K+E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.
46 6210
MADE IN U.S.A.

FIGURE 10

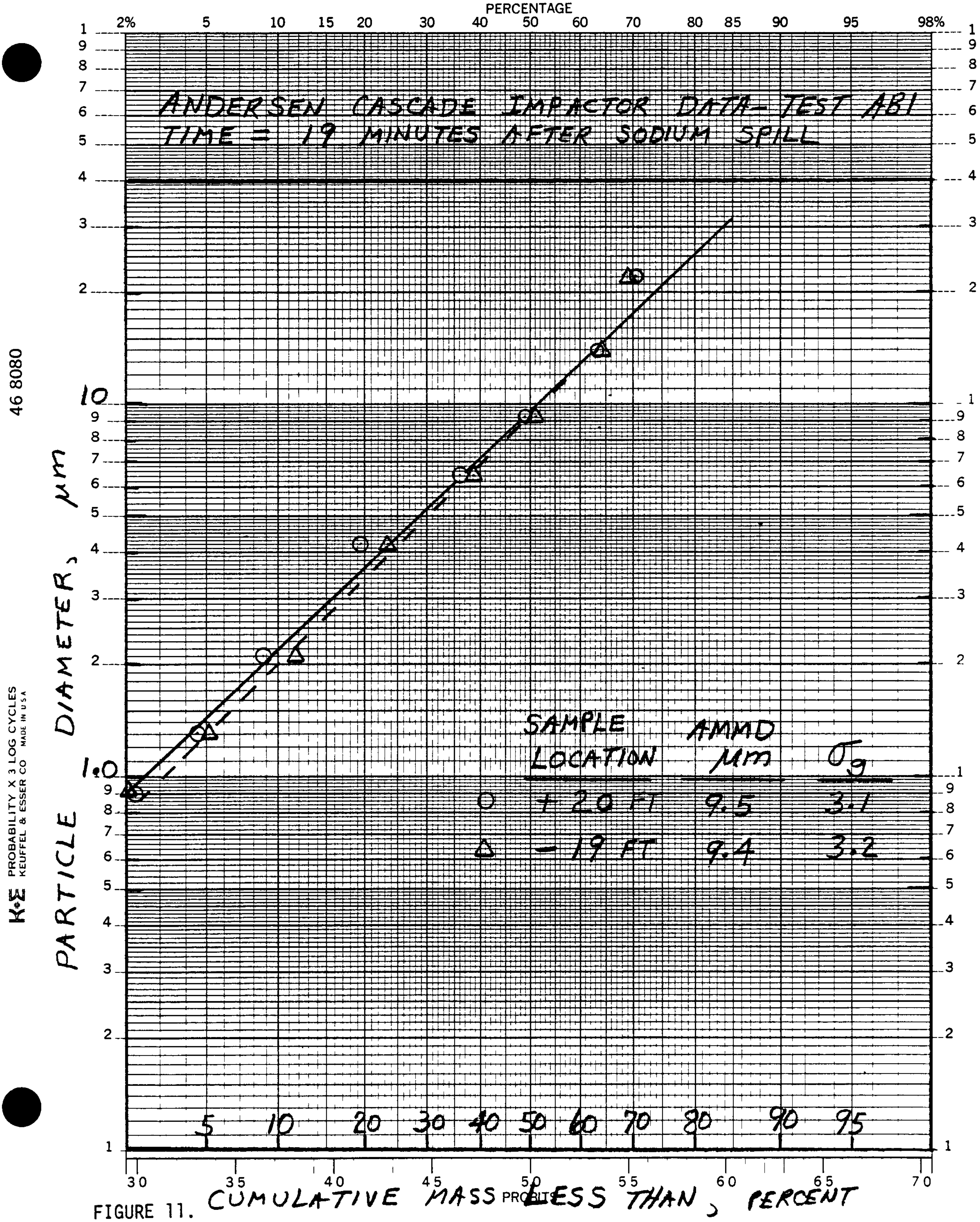

ANDERSEN CASCADE IMPACTOR DATA- TEST AB1
TIME = 19 MINUTES AFTER SODIUM SPILL
PERCENTAGE
2%
5
10
15
20
30
40
50
60
70
80
85
90
95
98%
PARTICLE DIAMETER, μm
10
1.0
SAMPLE LOCATION
AMMD μm
σ_g
○ +20 FT 9.5 3.1
△ -19 FT 9.4 3.2
5 10 20 30 40 50 60 70 80 90 95
30 35 40 45 50 55 60 65 70
PROBITS
CUMULATIVE MASS LESS THAN, PERCENT
46 8080
K+E PROBABILITY X 3 LOG CYCLES
KEUFFEL & ESSER CO MADE IN U.S.A.

FIGURE 11.

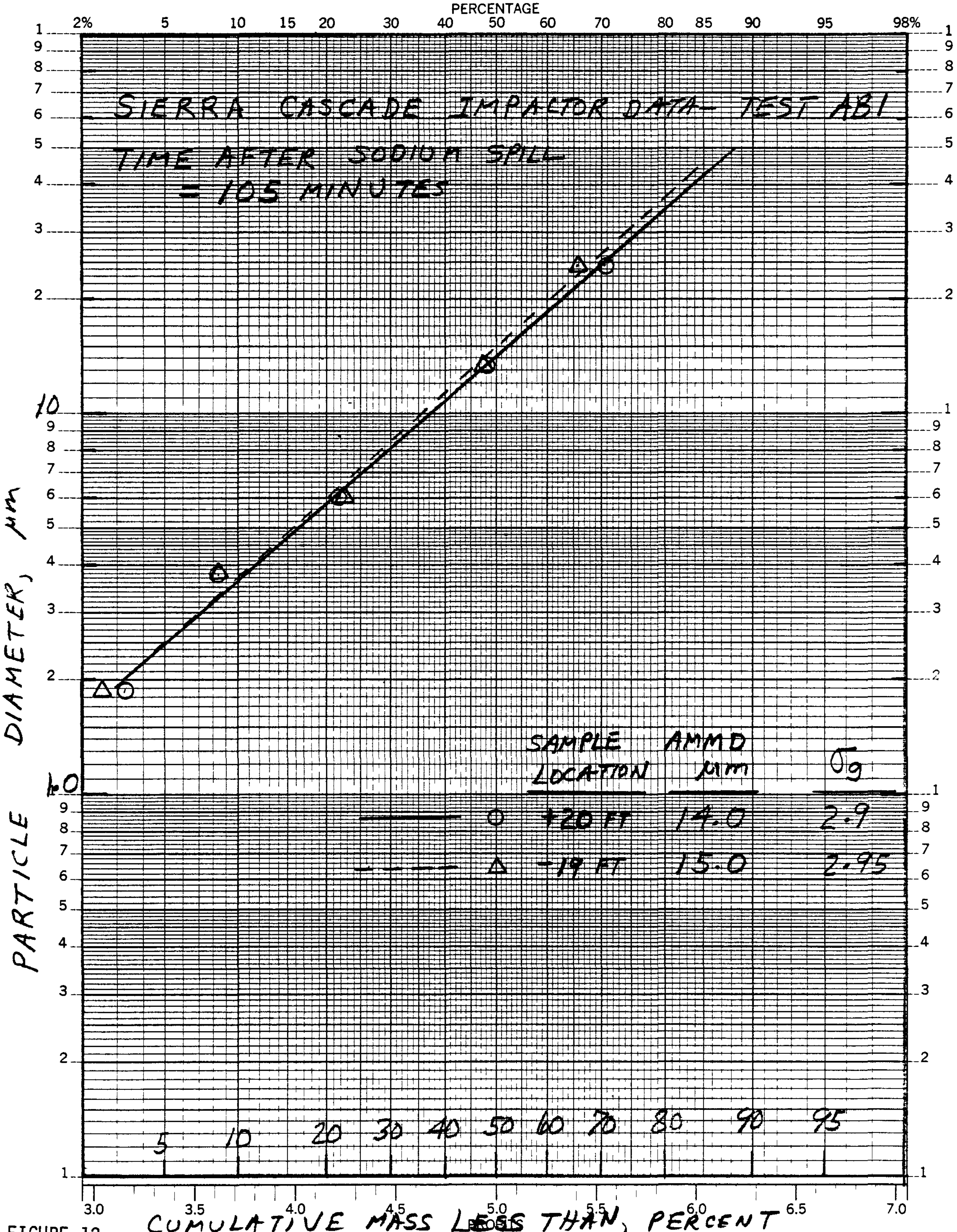

SIERRA CASCADE IMPACTOR DATA - TEST AB1
TIME AFTER SODIUM SPILL
= 105 MINUTES
PERCENTAGE
2%
5
10
15
20
30
40
50
60
70
80
85
90
95
98%
PARTICLE DIAMETER, μm
10
1.0
SAMPLE LOCATION
AMMD μm
σ_g
○ +20 FT 14.0 2.9
△ -19 FT 15.0 2.95
5
10
20
30
40
50
60
70
80
90
95
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
PROBITS
CUMULATIVE MASS LESS THAN, PERCENT
46 8080
K+E PROBABILITY X 3 LOG CYCLES
KEUFFEL & ESSER CO MADE IN U.S.A.

FIGURE 12.

CASCADE IMPACTOR DATA - TEST AB-1

TIME, MINUTES AFTER NA SPILL	ANDERSEN MARK III AMMD µM	ANDERSEN MARK III σ_G	SIERRA 226 AMMD µM	SIERRA 226 σ_G
19	9.5	3.1	--	--
30	--	--	13.7	5.3
70	9.0	2.4	--	--
105	--	--	14.5	2.9
190	6.7	2.5	--	--
200	--	--	9.3	2.8
640	2.4	3.2	--	--
665	--	--	2.5	3.0
1540	1.8	3.0	--	--
1635	--	--	2.1	3.2
2940	1.5	3.2	--	--

FIGURE 13.

PARTICLE SIZE - TEST AB1

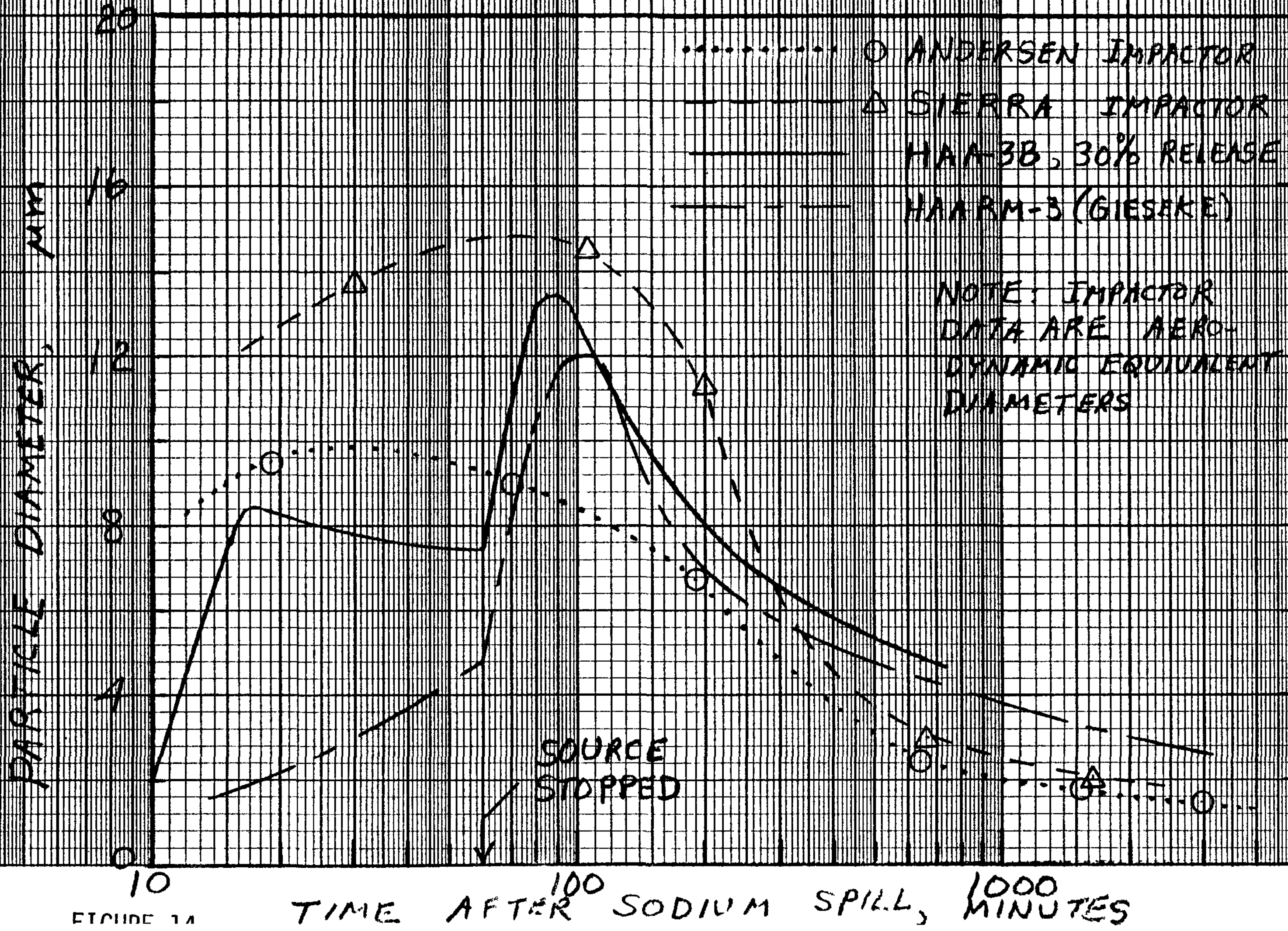
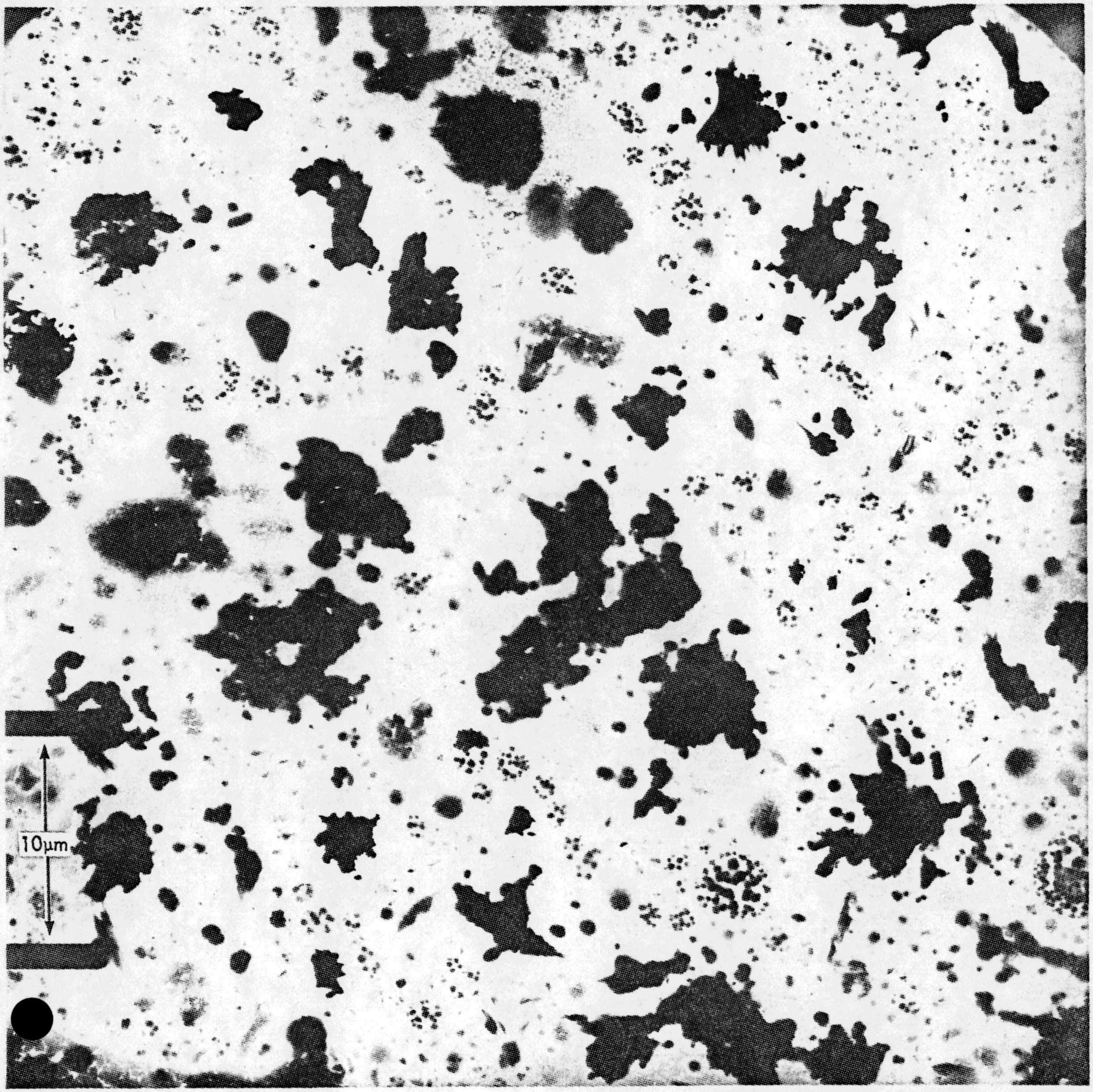
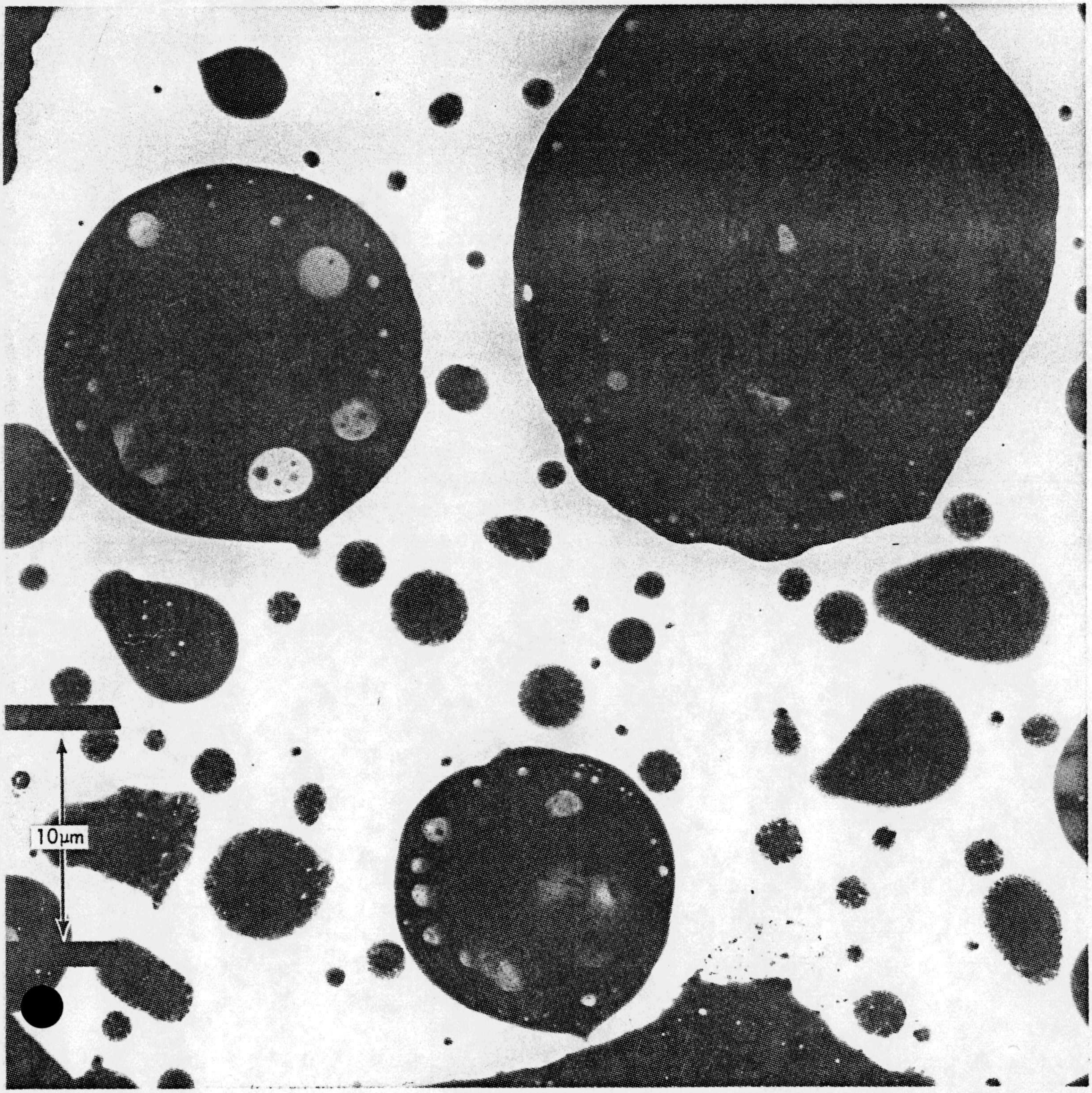


FIGURE 14

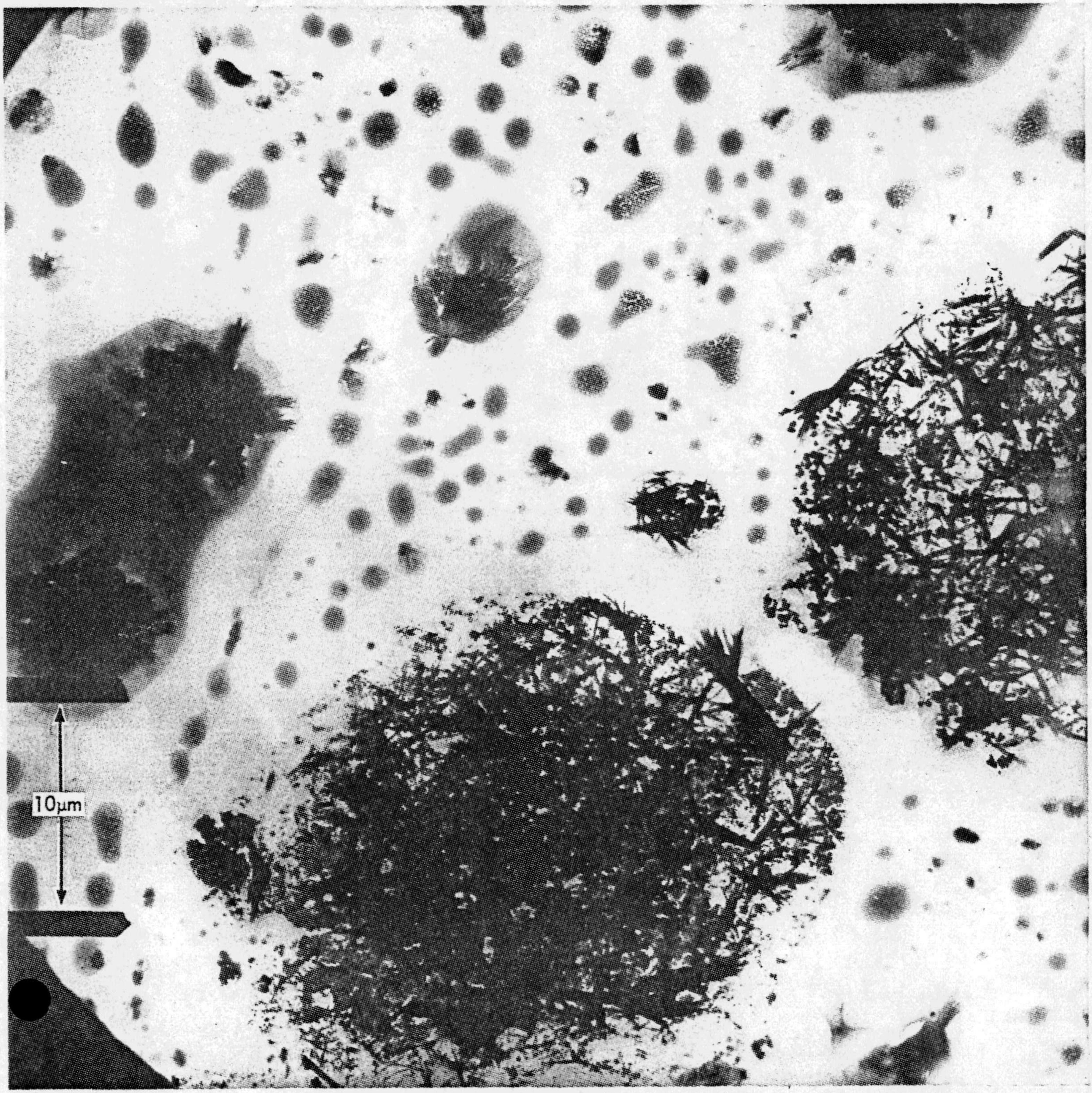
AEROSOL PARTICLES AT 8 MINUTES DURING TEST ABI



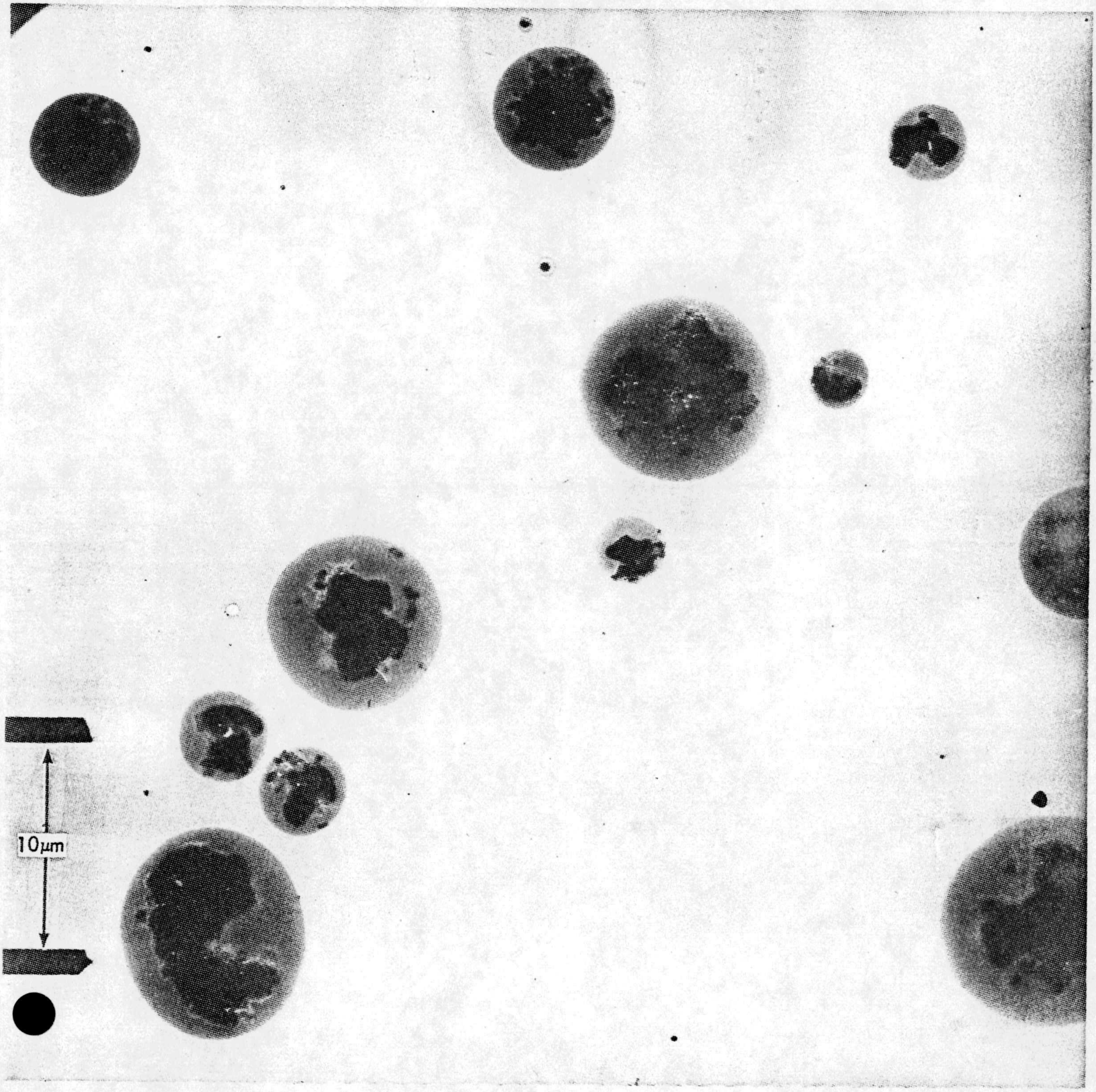
AEROSOL PARTICLES AT 56 MINUTES DURING TEST ABI



AEROSOL PARTICLES AT 190 MINUTES DURING TEST ABI



AEROSOL PARTICLES AT 25 HR DURING TEST ABI



HUMIDITY OF CONTAINMENT VESSEL ATMOSPHERE - TEST AB-1

TIME AFTER SODIUM SPILL	DEW POINT °C
- 2 HR	+ 10
+ 20 HR	- 40

FIGURE 19.

CHEMICAL COMPOSITION OF AEROSOL PARTICLES - TEST AB-1

	WEIGHT PERCENT			
TIME	16 MIN	46 MIN	190 MIN	610 MIN
Na_2O_2	15	56	43	35
NaOH	82	43	55	58
Na_2CO_3	2.9	0.4	1.8	6.1
NaH	0.01	0.7	0.11	1.1

FIGURE 20.

DEVIATION OF AEROSOL MASS CONCENTRATION - TEST AB-1

(A)

TIME MINUTES	$\overline{X}$ gNa/m³	σ_G gNa/m³	σ_G %
6	4.69	1.03	22
15	23.0	1.00	4.4
25	22.4	2.4	10.7
40	18.4	1.7	9.3
60	21.6	3.36	15.5

(A) MEAN OF 10 CLUSTER SAMPLES

FIGURE 21.

EXTENT OF MIXING AS INDICATED BY OXYGEN ANALYSIS - TEST AB-1

TIME MIN AFTER T_0	PERCENT OXYGEN (A)	
	+ 20 FT	-22 FT
10	19.2	19.1
30	17.8	17.8
60	15.8	15.7

(A) MASS SPECTROMETER ANALYSIS

FIGURE 22.

TEMPERATURE GRADIENT NEAR WALL - TEST AB1

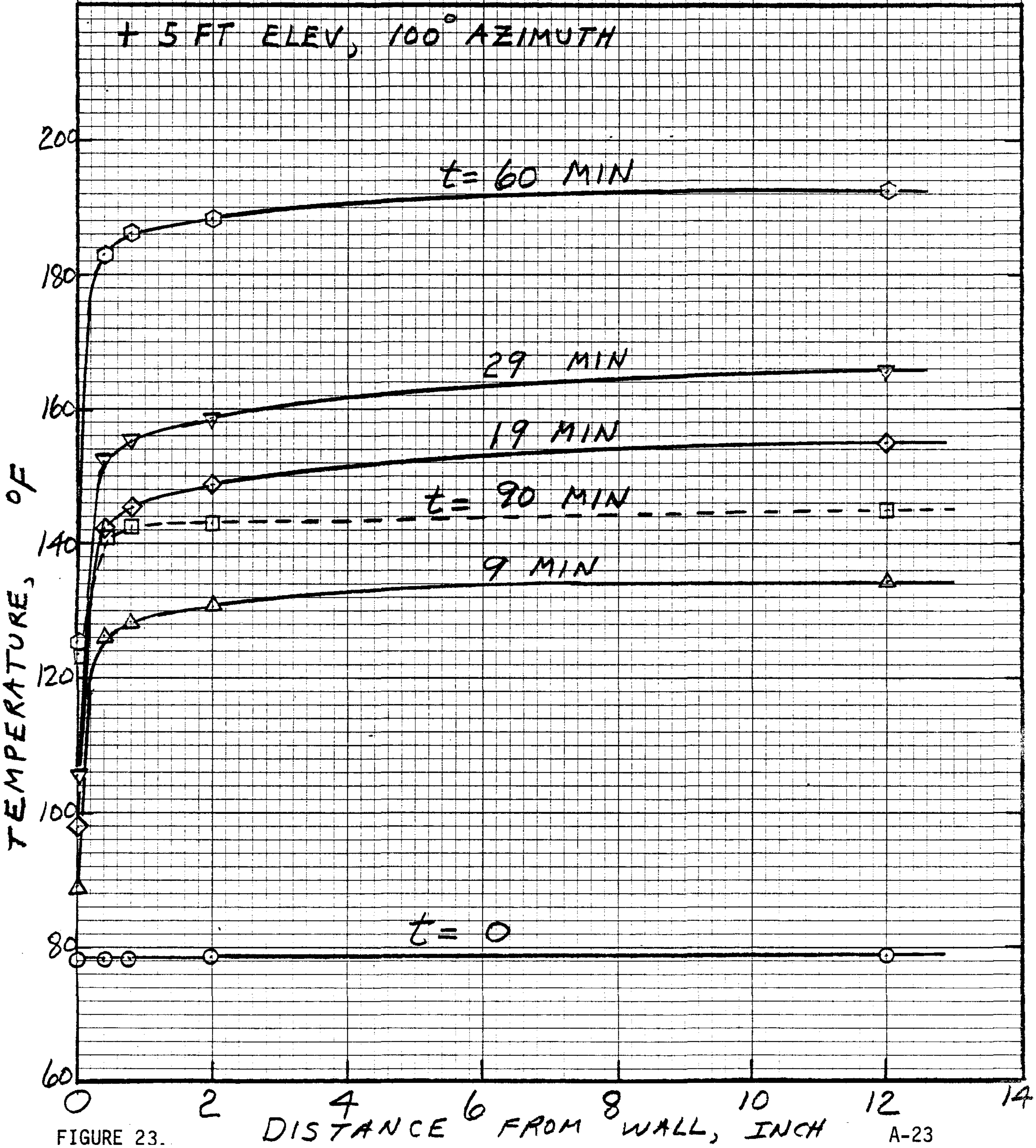


FIGURE 23.

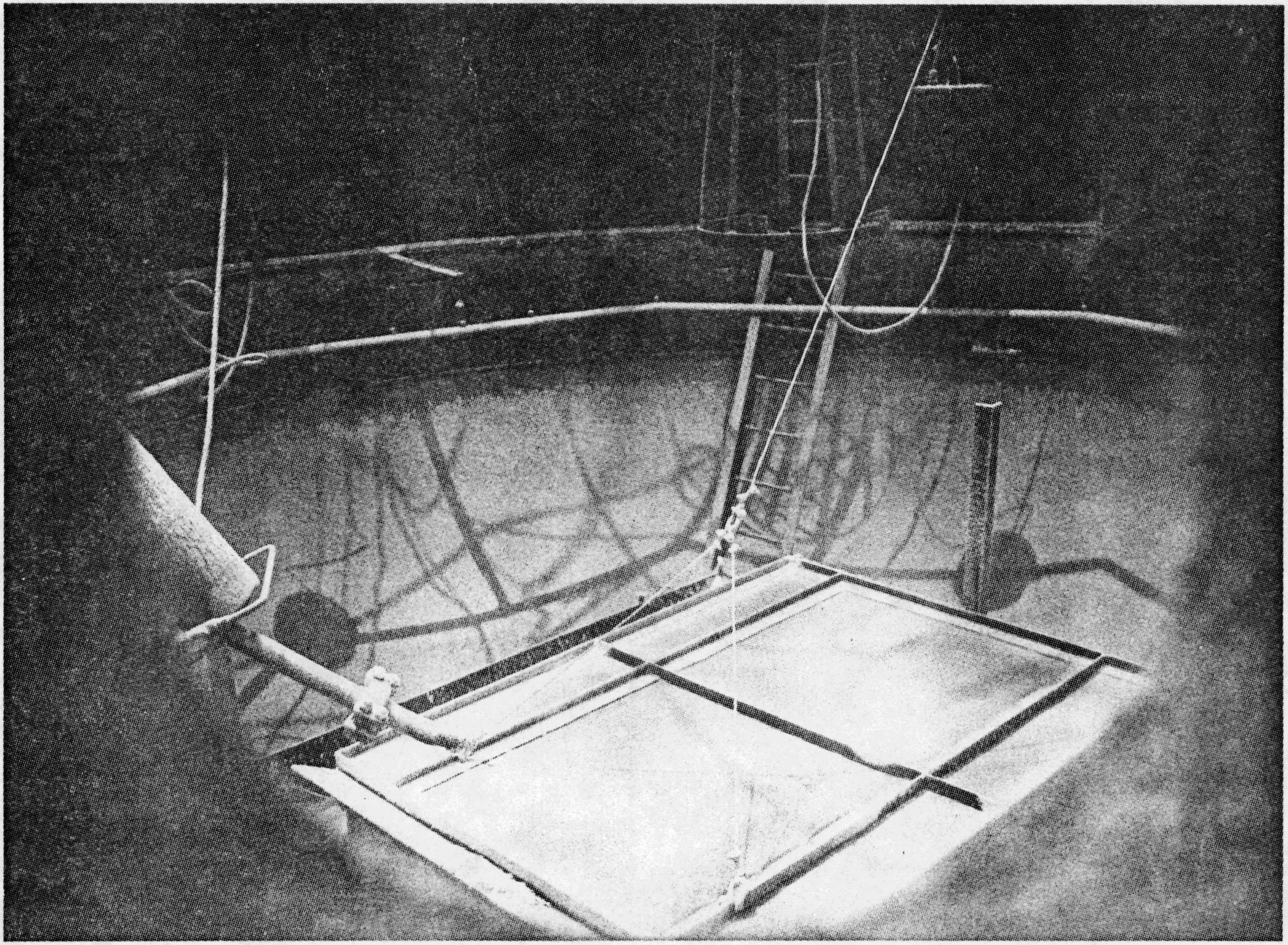


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FIGURE 24. Post-test View of Vessel Bottom Head.

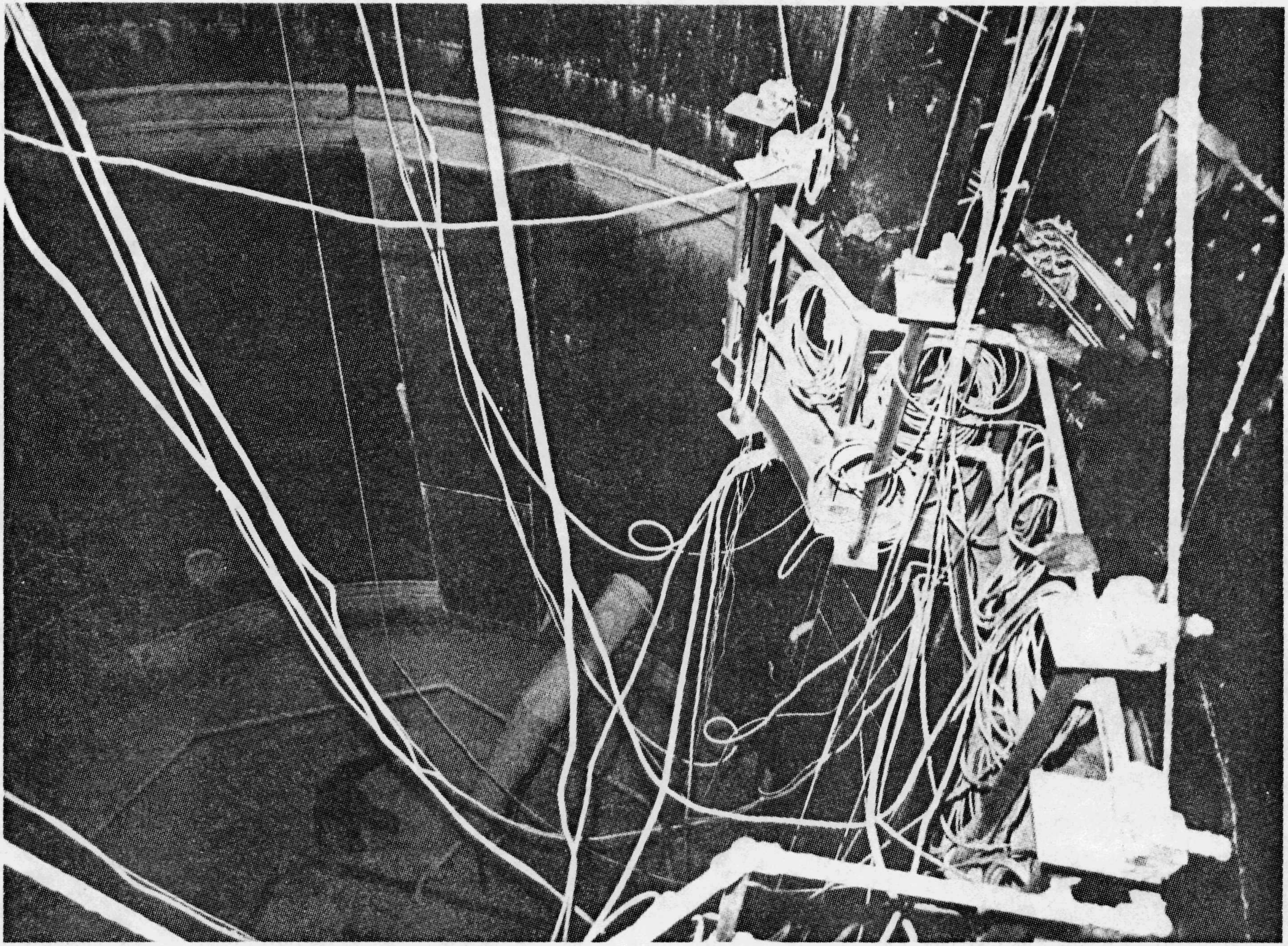


FIGURE 25. Post-test View of Vessel Wall.

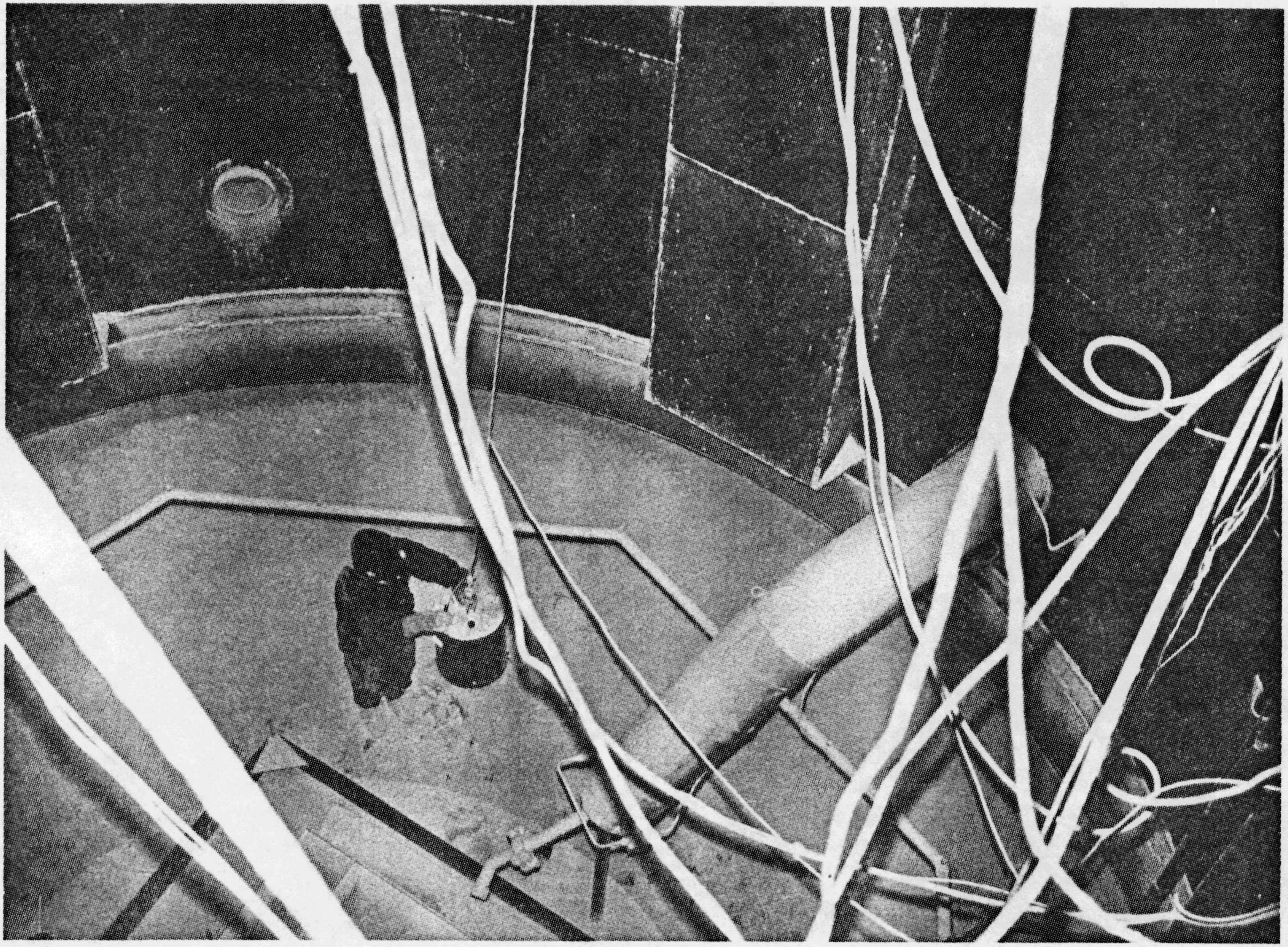
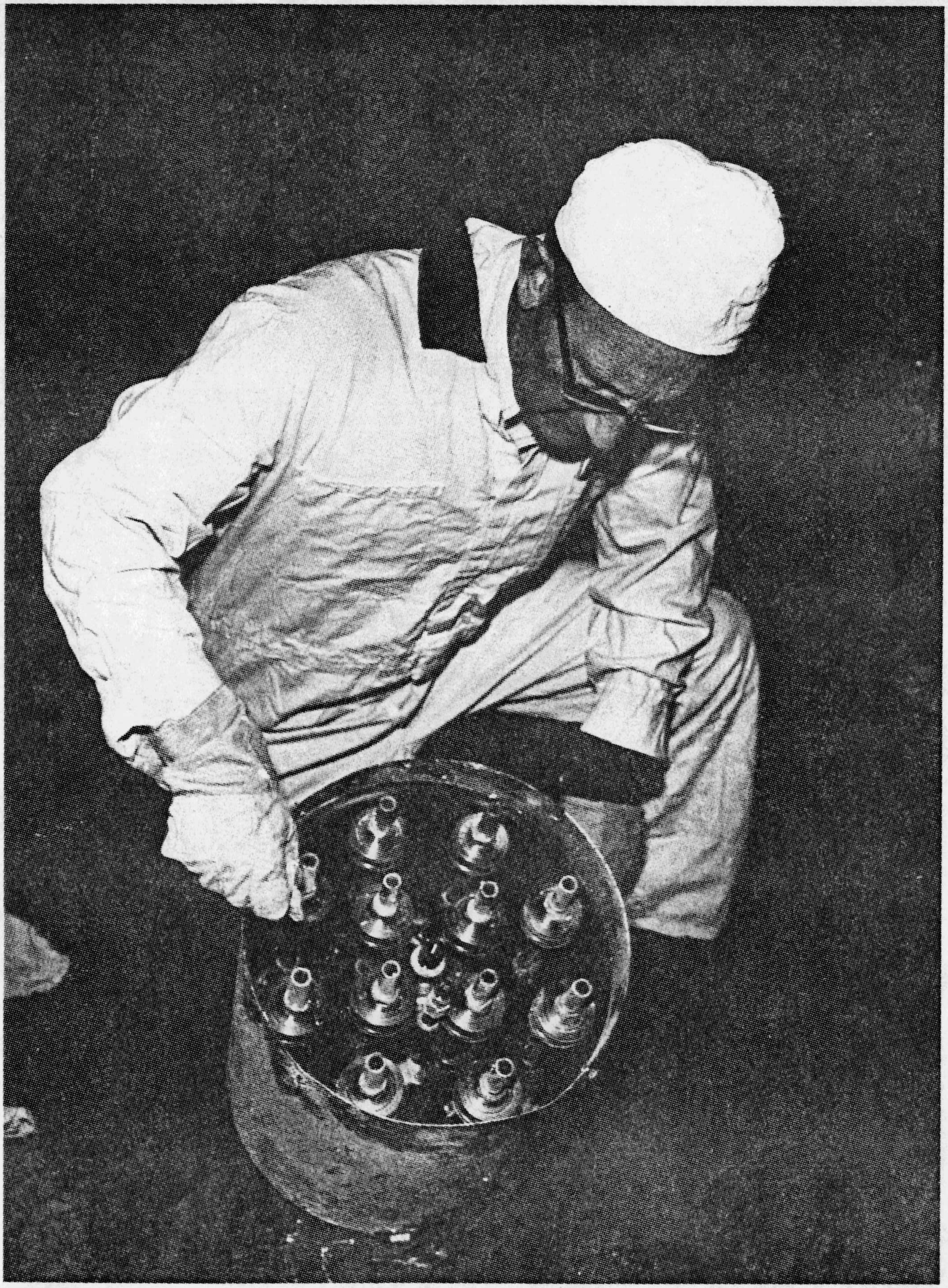


FIGURE 26. View of Operator Retrieving Filter Cluster.



779932-9cn

FIGURE 27. View of Cluster After Removal From Vessel.

TENTATIVE CONCLUSIONS - TEST AB-1

(1) THE CONTAINMENT ATMOSPHERE WAS WELL STIRRED AT ALL TIMES, BASED ON MEASUREMENTS OF AEROSOL AND OXYGEN CONCENTRATIONS AND VISUAL OBSERVATIONS.

(2) THE AEROSOL PARTICLES AGGLOMERATED RAPIDLY TO A MAXIMUM OF 14-MICRON AERODYNAMIC MASS MEAN DIAMETER. THE MEAN DIAMETER DECREASED TO 2-MICRON AFTER 24 HOURS.

(3) THE SUSPENDED MASS CONCENTRATION REACHED A MAXIMUM OF 40 G/M^3 DURING THE FIRE. IMMEDIATELY AFTER THE SOURCE STOPPED, THE CONCENTRATION DECREASED WITH A 15-MINUTE HALF TIME, WHICH IS EQUIVALENT TO SETTLING OF 15-MICRON DIAMETER SPHERICAL PARTICLES WITH UNIT DENSITY.

(4) PRE-TEST PREDICTIONS OF SUSPENDED CONCENTRATION USING HAA-3B AND HAARM-3 CODES WERE REASONABLY ACCURATE. FURTHER EVALUATION IS NEEDED, INCLUDING RE-RUNNING THE CODES USING EXACT EXPERIMENTAL CONDITIONS.

(5) THE FIRST PARTICLES GENERATED ABSORBED MOISTURE, RAPIDLY PLUGGING FILTERS, AND CONTAINED ONLY 0.1 GRAM Na PER GRAM AEROSOL. AFTER APPROXIMATELY 15 MINUTES THE PARTICLES WERE DRY AND FILTERABLE AND CONTAINED 0.3 - 0.5 GRAM Na PER GRAM AEROSOL. THE ATMOSPHERE HUMIDITY DECREASED FROM 10°C TO -40 C°DEW POINT.

FIGURE 23.