EXHAUST CLOUD EFFLUENTS FROM SOLID ROCKET
MOTOR (SRM) DURING DEMONSTRATION MODEL
(DM-2) STATIC TEST FIRING (NASA) 26 p HC Unclas
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ELECTRETS USED TO MEASURE EXHAUST CLOUD EFFLUENTS FROM SOLID ROCKET MOTOR (SRM) DURING DEMONSTRATION MODEL (DM-2) STATIC TEST FIRING

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16. Abstract

The purpose of this experimental research was to compare Marshall Space Flight Center's (MSFC) electrets with Thiokol's fixed flow samplers during the Demonstration Model (DM-2) static test firing at Thiokol's static test site, January 18, 1978, near Brigham City, Utah.

The measurement of the rocket exhaust effluents by Thiokol's samplers and MSFC's electrets indicated that the Solid Rocket Motor (SRM) had no significant effect on the air quality in the area sampled. Thiokol had only one significant measurement. At Plant 78 (Site 12), approximately 6.43 km at a 330 deg heading from the static test stand, the fixed flow air sampler obtained a trace of contamination of 0.0017 mg/m^3 (background) and 0.094 mg/m^3 (test). Of this total weight, 0.0017 mg/m^3 was of chlorine. Converting this to parts/million (ppm) gives 0.0006 ppm. At this site, from X-ray spectroscopy, the electret had a background count of 1667 and a test count of 2409, resulting in an increase of 742 counts. One of the additional electrets, E13, was closer to the static test site, approximately 585 m at a heading of 325 deg. The chlorine count from the X-ray spectroscopy analysis on this electret was 3576, an increase of 1909 counts. Equating the counts of 742 to 0.0006 ppm, 1909 counts equals 0.0015 ppm. Again, there was no measurement of significant rocket exhaust effluents at the test site.

The results show that the electrets (a passive device which needs no power) can be used effectively alongside existing measuring devices (which need power).

By placing electrets in areas where no power is available, measurements may be obtained. Consequently, it is a valuable complementary instrument in measuring rocket exhaust effluents in areas where other measuring devices may not be able to assess the contaminants.

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The use of electrets in the studies of rocket exhaust effluents was made possible through collaboration with the inventor, Dr. P. K. C. Pillai of the Physics Department, Indian Institute of Technology, New Delhi, India, who was a National Research Council postdoctoral research associate at NASA/Marshall Space Flight Center.

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ELECTRETS USED TO MEASURE EXHAUST CLOUD EFFLUENTS FROM SOLID ROCKET MOTOR (SRM) DURING DEMONSTRATION MODEL (DM-2) STATIC TEST FIRING

I. INTRODUCTION

The Space Shuttle Solid Rocket Motor (SRM) was static test fired at the Utah desert on January 18, 1978. The 38.1 m (125 ft) long motor fired for approximately 2 min, reaching a thrust level of 12 596 736 N (2 832 000 lb). During the firing, 500 279 kg (1 102 926 lb) of propellant were burned.

To measure the amount of effluents released by the firing of the Demonstration Model-2 (DM-2) rocket, fixed flow air samples were taken by Thiokol at eleven locations extending from the immediate test area to as far away as Brigham City. Alongside each of Thiokol's fixed flow samplers were MSFC's electrets. In addition, four near field and five far field measurements were obtained.

Section II of this report discusses the instruments, background, preparation, and use of electrets to measure effluents from Solid Rocket Boosters (SRB) and Thiokol's fixed flow samplers. Section III presents the meteorological conditions during the DM-2 static test firing at Utah, Section IV reports the test results obtained, and Section V presents the conclusions.

II. INSTRUMENTS

A. Electrets

Electrets have been known since the latter part of the 19th century. A substantial amount of work has been done on electrets, and a few practical applications, particularly in the area of communications, have been made.

In general, however, only qualitative descriptions of the various processes are known. Electrets are dielectrics, usually polymers, with a permanent surface charge that gives them properties analogous to those of magnets.

Electrets have been made in a variety of ways, but the method used at MSFC's Space Sciences Laboratory is the charge injection method [1]. A dielectric sheet is passed over a plate and, as it emerges, a corona discharge is induced over the surface by applying a high-voltage current to a metal wire brush that is kept a short distance from the dielectric. Charges are injected on the dielectric, polarizing it. The sheet then passes through a grounded, air-cooled plate to freeze in the injected and polarized charge. Usually, charges of opposite polarity are produced on opposite sides of the sheet. The polarizing voltage is 15 kV, the temperature is 200°C, and the sample is stroked 10 times. Teflon [polytetrafluoroethylene $(C_2F_4)_n$] electrets have shown the best stability and charge retention up to 200°C. Using the charge injection technique, a surface charge of 10^{-8} C/cm^2 is easily attained.

It has been found that electrets of polymers with stable surface charges on either side are suitable devices for attracting charged particles and ions to their surface. Therefore, it was decided to use these electrets for effectively measuring charged gases, vapors, or particles in the atmosphere.

Electrets are being used to measure the effluents from the propellants in SRB's. The most widely used propellant in SRB's is ammonium perchlorate as the oxidizer with powdered aluminum filler that acts in part as a fuel and partially as a stabilizer to control the burning rate. The exhaust products from this type of fuel contain hydrogen chloride (HCl), aluminum oxide (Al_2C_3), and water (H_2O). To assess the impact of these products in the atmosphere, it is necessary to know not only their quantity but also their distribution in the ground cloud that develops at the launch site after a rocket firing [2].

Electrets of polymers were used successfully in measuring rocket exhaust effluents. The particles in tests that have been conducted have either a positive or negative charge and are attracted to the electret's surface. These collected particles or ions on the electrets are then analyzed by taking an X-ray spectrograph of the sample. The electrets were evaluated by taking the total chlorine counts obtained from the surface of the electret after exposure to pollution as a measure of the quantity of material collected by the dispersive X-ray analyses. The counts were converted to parts/million (ppm) and compared with HCl measuring equipment and computed values from the NASA/MSFC Multilayer Diffusion Model [2,3]. From these studies, it was possible to identify the various effluents coming from the rockets at the time of firing. Direct comparisons of values obtained with electrets were made with the results. A comparison of measured values of HCl during 18 static tests at MSFC with the envelope of the upper and lower bounds obtained from the NASA/MSFC Multilayer Diffusion Model is presented in Reference 2.

B. Thiokol's Fixed Flow Samplers

The linear flow is obtained by use of a wind tunnel to which the air sampler is attached. The tunnel consists of a pipe whose length [177.8 cm (70 in.)] is ten times its diameter [17.78 cm (7 in.)]. The air flow rate is calculated from the linear velocity plus the area swept out through the wind tunnel. The sampling rate was 4.88 m^3 (16 ft^3) of air/minute with Whatman No. 41 paper filters. The MSA samples aluminum (Al), silica (Si), sulfur (S), and chlorine (Cl).

The Whatman No. 41 filters trap 98 percent of the 20-25 μ particles at very rapid flow. X-ray fluorescence was used to determine Cl, S, Si, and Al content. Figure 1 shows Thiokol's fixed flow samplers and MSFC's electrets during the DM-2 static test.

III. METEOROLOGICAL DATA

A. General Synoptic Conditions

From a meteorological standpoint, unstable atmospheric conditions existed during the two-day period immediately preceding the SRB test firing on Wednesday, January 18. At 0500 MST, Monday January 16, synoptic scale analysis depicted an occluded frontal system, emanating from a surface low off the Oregon coast, swinging southward along the northern California shoreline. In addition, a stationary front stretched from extreme southeastern British Columbia, south-southeastward across western sections of Montana and Wyoming to northern Colorado. The Salt Lake City (SLC) area lay under overcast skies with scattered snow showers occurring in the vicinity and light southerly winds at the surface. Precipitation [0.81 cm (0.32 in.)] had fallen during the 24-hr period ending at 2300 MST Sunday night. Only a trace of precipitation occurred during the subsequent 24-hr period.

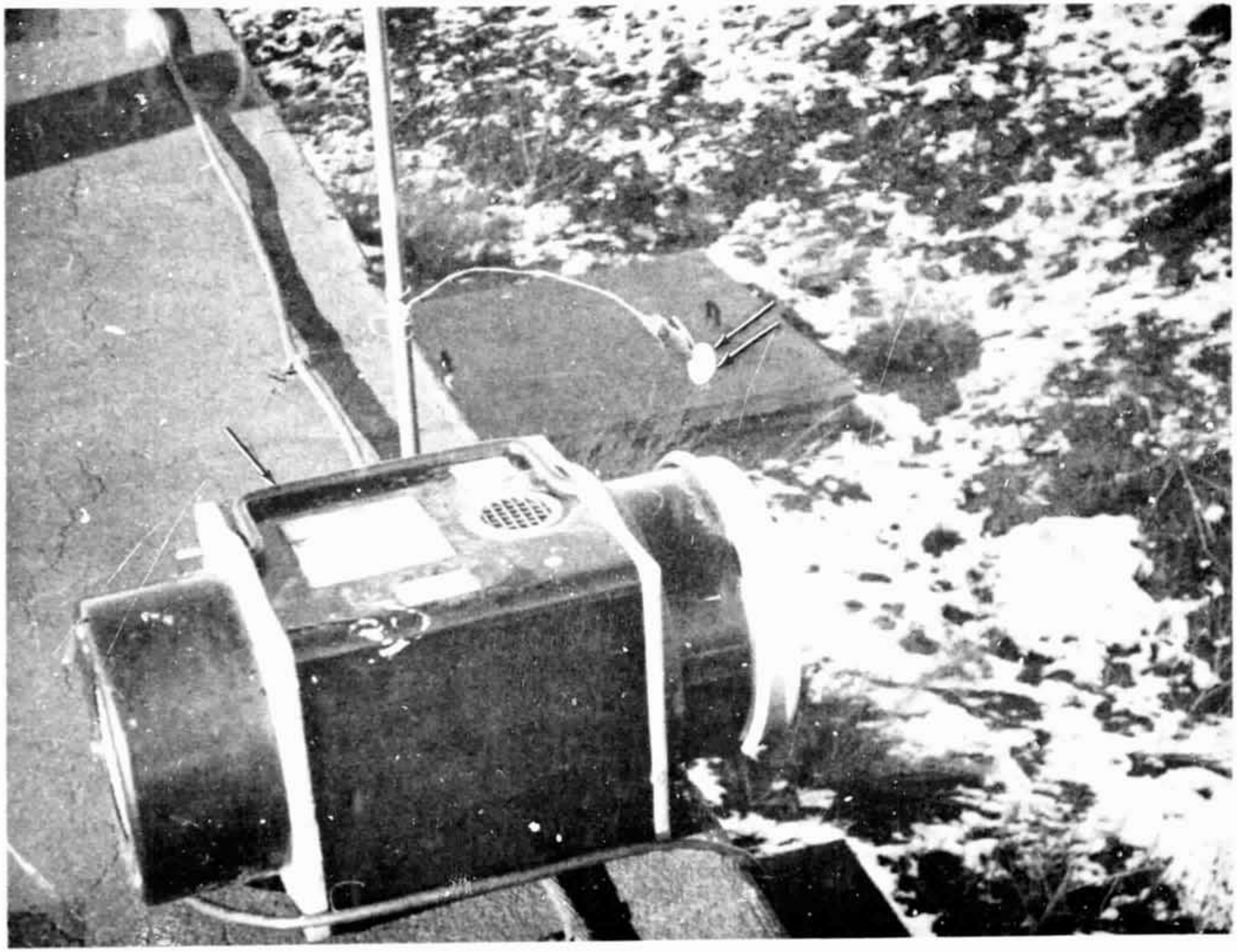

Figure 1. Thiokol's fixed flow sampler (single arrow) and MSFC's electret (double arrow).

A 500-mb ridge extended southward from western Canada along the Rocky Mountain chain, separating two upper level troughs, one located off the northwest U.S. coast and the other over the Central Plains. 1200 GMT radiosonde data from SLC indicated westerly winds of 15.43 m/s (30 kn).

By Tuesday morning, the 17th, the Pacific low and associated frontal system had tracked eastward, well inland. The front stretched southward from the low, now positioned over Idaho, to a point just west of SLC, then through Arizona, continuing southwestward as a cold front to Baja California. A stationary front was still visible to the east, running from southeastern British Columbia to a low over central Wyoming, then southward across Colorado and New Mexico to extreme western Texas. Skies were still overcast over northern Utah, with a mixture of rain and snow being reported by SLC at 0500 MST along with light east-southeast surface winds. Another 0.86 cm (0.34 in.) of precipitation fell during the 24-hr period ending at 2300 MST. The 500-mb ridge had progressed eastward into the Plains with a weak trough now influencing the intermountain region of the western U.S. SLC was reporting west-southwest winds at 7.72 m/s (15 kn).

By early Wednesday morning, a weak zone of high pressure had been established over the Great Basin area of Nevada on the surface and a massive Arctic air mass, centered over central Saskatchewan, had already plunged southward into Montana, Wyoming, and the Dakotas. The persistent stationary front, which remained east of the test area for the duration, had moved little. SLC was experiencing partly cloudy skies and light northwest surface winds. Precipitation [0.51 to 0.66 cm (0.20 to 0.26 in.)] had fallen in the 6-hr period through 0500 MST. No further precipitation was recorded during the day. SLC indicated a 7.72 m/s (15 kn) north-northwest circulation at 500 mb on the east side of a sharp north-south upper level ridge which had just moved onshore along the entire Pacific coast. The trough, located over the Rockies the day before, was now aligned with Nebraska south-southwestward to eastern New Mexico.

B. Localized Atmospheric Conditions

During the hours immediately preceding the 1400 MST firing, personnel from the Astro-met Plant and Wasatch Engineering Department conducted wind measurements in the static test site area.

Runs made at 0915 and 0955 MST resulted in average wind speeds of less than 3.34 m/s (6.5 kn) through 1828 m (6000 ft) with maximum winds in the layer remaining under 5.40 m/s (10.5 kn).

A third calculation made at 1032 MST yielded an average speed of 2.16 m/s (4.2 kn) from the surface through 3108 m (10 200 ft) with maximum speeds never reaching 4.63 m/s (9 kn).

At 1418 MST, just minutes after conclusion of the test, a final balloon was released. Results indicated an average wind speed of 3.5 m/s (6.8 kn) through 3566 m (11 700 ft). Speeds remained below 3.09 m/s (6 kn) through the initial 1524 m (5000 ft) layer, and never exceeded 7.71 m/s (15 kn) above. Directions meandered between 175 to 245 deg within the first 2133 m (7000 ft) varying from 220 to 240 deg from that point through the top of the layer.

By 0500 MST Thursday, a cold low pressure trough was nestled in along the Pacific Coast at 500 mb, displacing the ridge conditions which had existed a day earlier.

The upper trough was reflected on the surface by a weak low over Nevada. An occluded front stretched northward from this low with a cold front trailing southward. This system brought another light precipitation episode to the SLC area on Thursday as it advanced eastward.

Temperatures over the period of record remained in the 1 to 4°C (30 to 40°F) range.

IV. TEST RESULTS

A. Thiokol's Fixed Flow Samplers

Because of the inclement weather before and after the firing, all sampling (including background sampling) was done in one day. The sampling time at each location varied from 5 to 8 hr and the background samples were taken at Promontory Well No. 1 (Fig. 2), T-35 No. 7, and T-24 No. 5, and Southwest Boundary No. 10 (Fig. 3). No samples were taken at Howell Well No. 4 because the electrical power was inaccessible. However, an electret was placed in that location. The sampler at Southwest Boundary No. 10 was powered by a gasoline generator which altered the background at this location.

Thiokol used the MSA fixed flow samplers during the static test. The sampling rate was 4.88 m^3 (16 ft^3) of air/minute with Whatman No. 41 paper filters. After sampling was completed, the following tests were run on each filter:

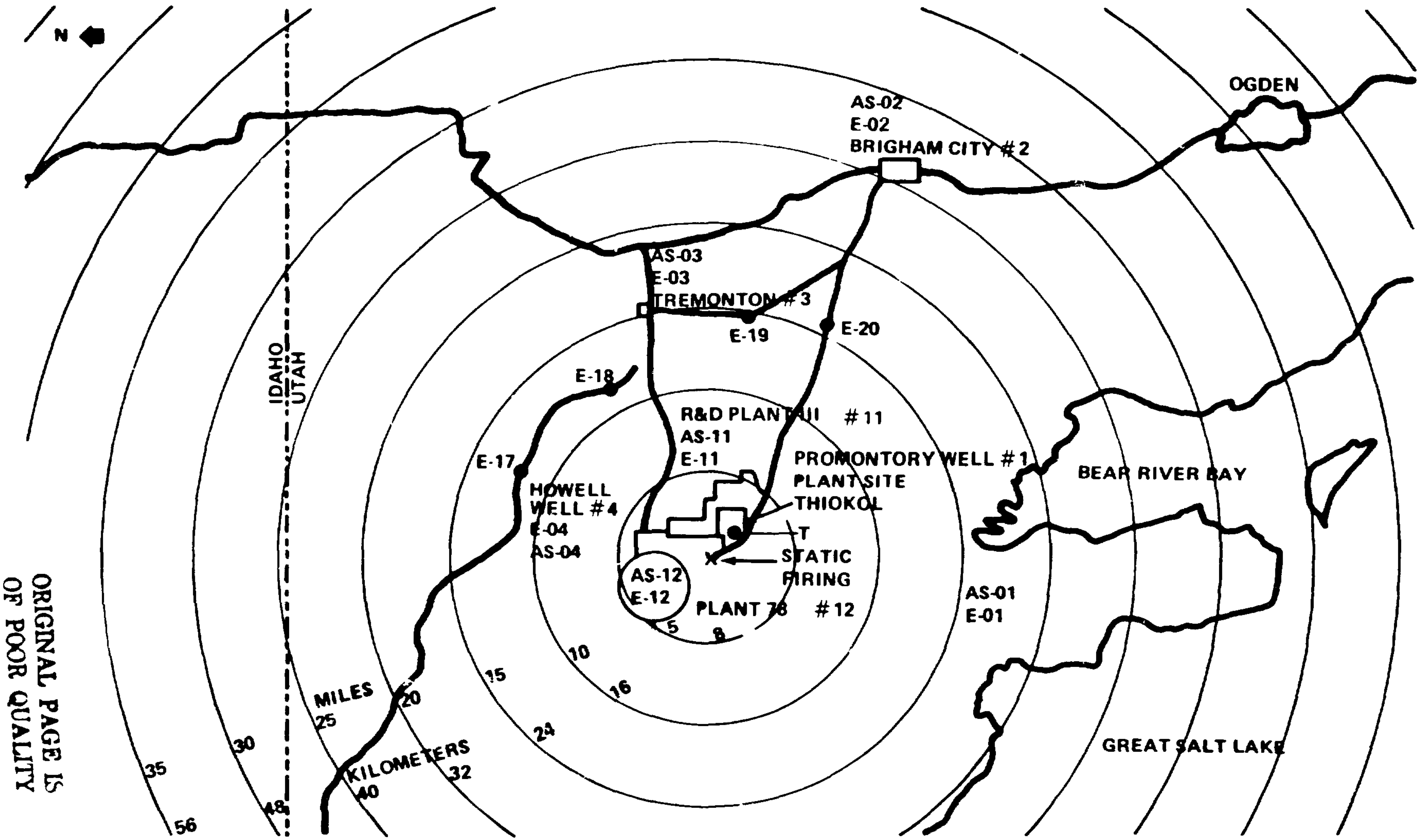

Figure 2. Measurements obtained at Site 12 (far field deployment of instrument~).

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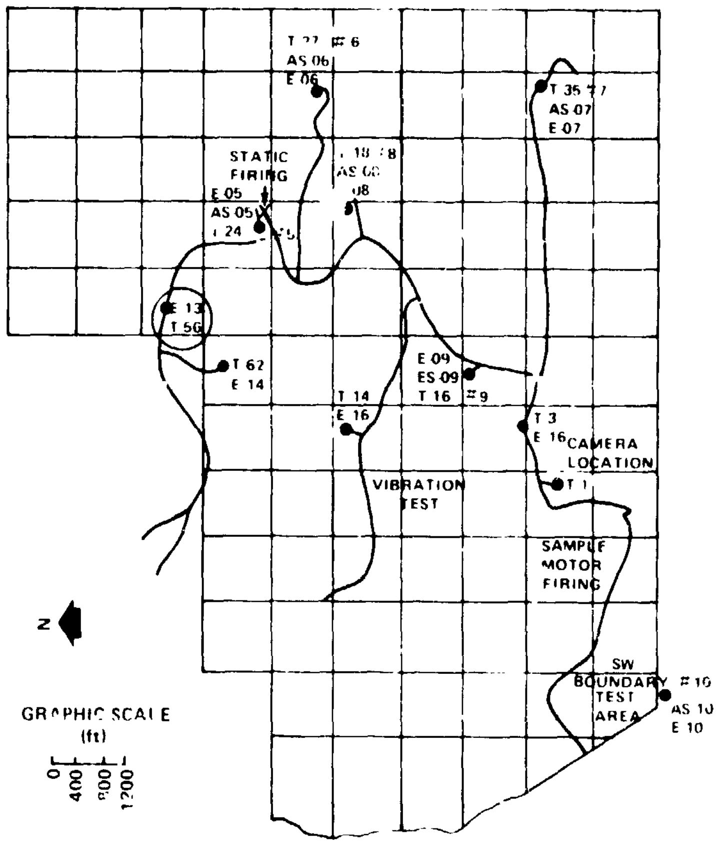

Figure 3. Measurements obtained at Site E-13 (near field deployment of instruments).

TABLE. DISPERSIVE X-RAY ANALYSIS OF ELECTRET AT SITE E-13 (585 m AT A 325 deg HEADING FROM STATIC TEST STAND)

X-RAY ENERGY (KeV)	TOTAL TEST COUNTS (1000 s)	SYMBOL	BACKGROUND COUNTS
0.685	6748	Fe	6547
1.489	72 069	Al	73 595
1.741	80 821	Si	56 240
2.629	3576	Cl	1667
3.329	1141	Sn α	1130
3.675	744	Sn β	–
4.500	157	Ti	–
5.413	3282	Cr α	2092
5.965	242	Cr β	–
6.412	9200	Fe α	5534
7.083	1049	F· β	106
7.462	1011	Ni	–
8.055	6275	Cu α	2105
8.925	700	Cu β	131

a. Filters were weighed (before and after).

b. X-ray fluorescence was used to determine Cl, S, Si, and Al content.

c. The filters were leached with water, and the pH of each solution was measured.

The results of these tests indicate that all of the weight and X-ray values are very low and are near the detection limits of the equipment and methods used. The pH measurements were taken because any HCl contamination should show a noticeable decrease in the pH. The only pH value showing any significant indication of acid was one from the Southwest Boundary No. 10. However, the background at this location showed the same pH, indicating that the acid was coming from the gasoline generator rather than the rocket motor. The largest pH changes occurred at higher elevations, which indicates that the samples picked up alkaline material rather than HCl from the motor. When the motor was fired, the wind velocity was approximately 3.5 m/s (6.8 kn) and its direction meandered between 175 to 245 deg. Consequently, the cloud rose straight up to approximately 5182 m (17 000 ft) and dispersed. Therefore, the samplers and electrets picked up very little, if any, fallout. The sampler at Plant No. 78 picked up more weight than any of the others, but again the amount was very small. (Figures A-1 through A-7 in the appendix illustrate the exhaust cloud during the DM-2 static test firing.)

The fixed flow samplers obtained a trace of contamination [0.094 mg/m^3 (test), 0.0017 mg/m^3 (background)]. Of this total weight, 0.0017 was Cl, 0.0007 was S, 0.015 was Si, and 0.041 was Al. Converting the 0.0017 mg/m^3 of Cl to ppm results in 0.0006 ppm [4].

B. MSFC's Electrets

At Site 12 (far field), from X-ray spectroscopy, the electret had a background count of 1667 and a test count of 2409, resulting in an increase of 742 counts (Fig. 4). As previously indicated, the fixed flow measurement was 0.0006 ppm of Cl. One of the electrets, E-13, was in closer to the static test site [585 m at a heading of 325 deg (Fig. 3)]. The Cl count on this electret (obtained from quantitative results of X-ray spectroscopy) was 3576, an increase of 1909 counts (Table). Equating the count of 742 to 0.0006 ppm, 1909 counts equals 0.0015 ppm. Again, there was no measurement of significant rocket exhaust effluents at the test site sampled.

ELECTRET'S QUANTITATIVE RESULTS OBTAINED FROM X–RAY SPECTROSCOPY – SITE 12

X–RAY ENERGY (KeV)	TOTAL TEST COUNTS (1000 s)	SYMBOL	BACKGROUND COUNTS
0.689	6953	Fe	6547
1.483	74888	Al	73595
1.748	68290	Si	56240
2.131	[illegible]445	Au	783
2.328	4061	S	4692
2.626	2409	Cl	1667
3.334	735	Sn α	1130
3.680	84	Sn β	–
5.436	2979	Cr α	2092
5.929	428	Cr β	–
6.418	8097	Fe α	5534
7.030	908	Fe β	106
7.502	483	Ni	–
8.050	2279	Cu α	2105
8.930	218	Cu β	131

THIOKOL'S FIXED FLOW SAMPLER # AS–12–RESULTS

0.0017 mg/m^3 (BACKGROUND) 0.094 mg/m^3 (TEST)

ELECTRET'S X-RAY SPECTROGRAPH–SITE 12

INTENSITY VS KILO ELECTRON VOLTS

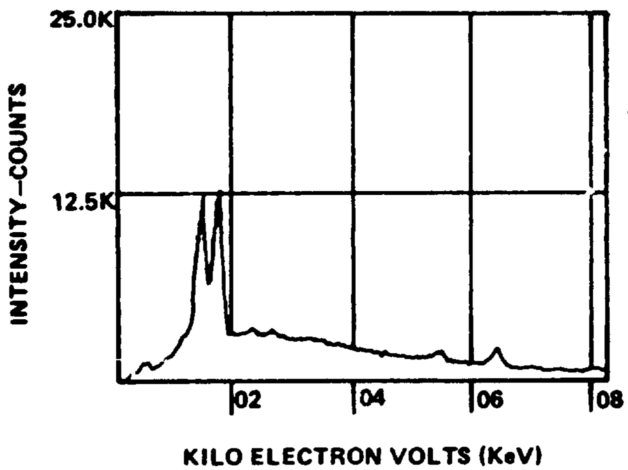

Figure 4. Comparison of measurements obtained from Thiokol's fixed flow samplers and MSFC's electrets.

V. CONCLUSIONS

The purpose of this research investigation was to evaluate the electret, a new detecting contamination device developed by MSFC, in conjunction with Thiokol's fixed flow sampler during the DM-2 static test firing in Utah.

In assessing the effectiveness of the electret, the following was concluded:

At Plant No. 78, 6.43 km at a 330 deg heading from the static test site, Thiokol's fixed flow samplers obtained the only trace of contamination — 0.0017 mg/m^3 or 0.0006 ppm Cl. At this site, the Cl count from the dispersive X-ray spectroscopy analysis was 1667 (background) and 2409 (test), an increase of 742 counts.

An additional electret was placed at Site 13 (586 m at a 325 deg heading from the static test firing). With no power available at this site, the electret was the only measurement device. The background count was 1667 and the test count was 3576, an increase of 1909 counts. Equating the 742 counts to 0.006 ppm, the 1909 counts obtained at the closer test site converts to 0.0015 ppm. Again there was no significant amount of rocket exhaust effluents measured. In addition, simplicity in deployment of the electrets (no power necessary) makes the electret a valuable complementary device in detecting rocket gas effluents.

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APPENDIX

PHOTOGRAPHS OF ROCKET PLUME/FIRE AT VARIOUS STAGES OF BURN

Figure A-1. Photograph of rocket plume/fire at time of ignition.

Figure A-2. Photograph of rocket plume/fire at 10 s after ignition.

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Figure A-3. Photograph of rocket plume/fire at 30 s after ignition.

Figure A-4. Photograph of rocket plume/fire at 50 s after ignition.

Figure A-5. Photograph of rocket plume/fire at 70 s after ignition.

Figure A-6. Photograph of rocket plume/fire at 90 s after ignition.

Figure A-7. Photograph of rocket plume/fire at 115 s after ignition.

APPROVAL

ELECTRETS USED TO MEASURE EXHAUST CLOUD EFFLUENTS FROM SOLID ROCKET MOTOR (SRM) DURING DEMONSTRATION MODEL (DM-2) STATIC TEST FIRING

By Michael Susko

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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