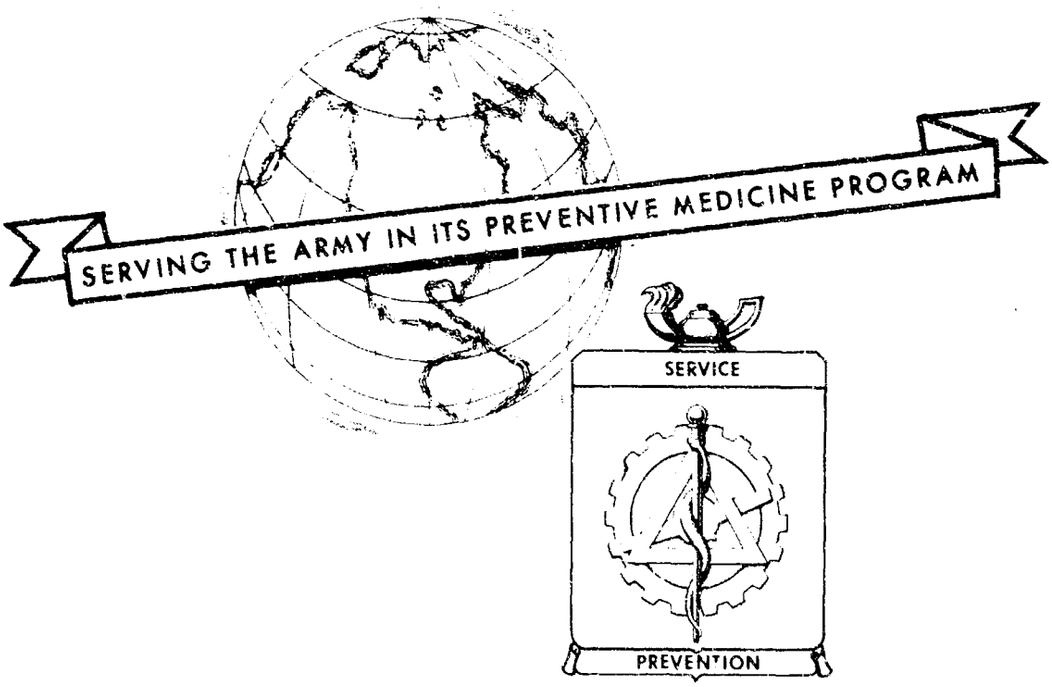
AIR POLLUTION ENGINEERING STUDY NO. 99-003-69/70
ATMOSPHERIC SAMPLING STUDY OF NF ROCKET PROPELLANT
REDSTONE ARSENAL
HUNTSVILLE, ALABAMA
26 MAY - 26 JUNE 1969



US ARMY
ENVIRONMENTAL HYGIENE AGENCY
EDGEWOOD ARSENAL, MD. 21010

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IN REPLY REFER TO:
USAEHA-EA

14 NOV 1969

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ABSTRACT

A field study was conducted at Redstone Arsenal, Huntsville, Alabama to measure the concentration of and determine areas of exposure to total fluorides in the exhaust cloud of statically fired six pound motors utilizing a developmental Rohm and Haas NF propellant. Results of the study gave strong indications that only areas exposed to the visible exhaust would be contaminated by fluorides. The study results also indicated that all fluorides in the exhaust were predominantly in the gaseous state. Areas of greatest exhaust cloud total fluoride concentration were found to be at the approximate location where the cloud was initially formed. In the firing tests conducted, exposure to the cloud at any point within its path was determined to be less than one minute in all cases observed. It was estimated that areas at distances greater than 150 meters from the firing point of the six-pound motors would not be significantly exposed to fluorides from the exhaust.

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ATMOSPHERIC SAMPLING STUDY OF NF ROCKET PROPELLANT
REDSTONE ARSENAL
HUNTSVILLE, ALABAMA
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1. REFERENCES.

a. Letter, AMSMI-ON, Headquarters, US Army Missile Command, 8 July 1966, subject: Toxicity of Exhaust Gases in Rocket Exhaust and indorsements thereto.

b. Letter, USAEHA-EA, US Army Environmental Hygiene Agency, 16 January 1969, subject: NF Propellant Project Progress Evaluation and Proposed Action, Headquarters Project No. 10-8-67/69 and indorsements thereto.

c. Programmed Services, FY 69 (US Army Environmental Hygiene Agency, Edgewood Arsenal, Maryland).

2. OBJECTIVE.

a. To measure the concentration of total fluorides in the exhaust cloud of a statically fired motor utilizing developmental Rohm and Haas NF propellant (RH-U-105).

b. To provide fluoride concentration information for subsequent use in the investigation of possible health hazards of the combustion products.

3. BACKGROUND.

a. NF Propellant.

(1) The Rohm and Haas Company, Redstone Research Laboratories have been working on the development of a NF Propellant for about 20 years. The present composition is proprietarily designated as RH-U-105. As yet the propellant has not been selected for any specific weapons system.

(2) Theoretically, the RH-U-105 formulation produces the exhaust products, at the motor nozzle, listed in Appendix A, Table A-1.

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b. Previous US Army Environmental Hygiene Agency (USAEHA) NF Propellant Air Pollution Studies.

(1) The NF propellant studies conducted by the Air Pollution Engineering Division, this Agency, were separated into phases (I, II and III). Phases I and II were completed in October 1968 and April 1969 respectively. The primary objective of these studies was to determine the feasibility and reliability of analytical methods and sampling techniques developed in the laboratory for use in the field. Phase III, conducted from 26 May 1969 to 26 June 1969 is reported herein.

(2) All field tests were conducted at the "hybrid" test stand in the Rohm and Haas Redstone Research Laboratory complex. This test stand was open at both ends and the exhaust expelled into a large, open, level field. Six inch diameter motors, each containing from about 6.1 to 6.2 pounds of RH-U-105 propellant, were used throughout the study. Two motors were fired during Phase I and another two during Phase II. Seven were fired during Phase III. These were fired horizontally at a height of 27 inches above the ground.

4. RESULTS.

a. Total fluoride concentration measurements ranged from 1.0 to approximately 300 micrograms per liter of air.

b. Average exhaust cloud fluoride concentrations for motors fired against the wind, i.e., the wind blowing in the same general direction as the exhaust thrust, are presented in Appendix B, Figure B-1.

c. Fluoride concentration was found to decrease as the distance from the point of firing increased, for motors fired against the wind. The relationship of average measured fluoride concentration with distance from the firing point is presented in Appendix B, Figure B-2.

d. The exhaust cloud fluoride concentrations for a motor fired with the wind, i.e., the wind blowing in the opposite direction as the exhaust thrust, are presented in Appendix B, Figure B-3.

e. Observations of exhaust cloud passages and sampling results indicated that total fluorides could not be detected at points in the sampling grid that were not encompassed or contacted by any visible portion of the exhaust cloud.

f. Times of exposure to the visible exhaust were determined for points in the path of the cloud at various distances from the firing point. The results of these observations are presented in Appendix A, Table A-2.

g. Combined laboratory and field investigations indicated that the fluorides measured and reported herein were essentially all in the gaseous state.

3. DISCUSSION.

a. Selected Variables and their Measurement.

(1) Dependent variables measured in this study were the exhaust cloud fluoride concentration and the time of exposure to the exhaust at various locations in the path of the exhaust cloud. Independent variables measured for correlation with the above were distance from the rocket motor firing point, wind speed and wind direction. As mentioned in para 3b(2), the amount and type of propellant in each motor fired was held constant.

(2) A sampling grid was designed for measurement of fluoride concentration, wind speed and wind direction at distances of 30, 60 and 90 meters from the firing point. A composite sampling method was employed utilizing bubblers and membrane filters. The samples obtained were analyzed colorimetrically for total fluorides by the alizarin complexone tri-hydrate - cerous nitrate method. These methods and procedures are described in detail in Appendix C.

(3) Exposure times for points in the path of the exhaust cloud were determined by studies of high speed movies taken of each firing. Exposure time was defined as that in which a given, marked point, from ground level to about five feet, was encompassed in any visible portion of the exhaust cloud. Movies of firings taken during all study phases have been retained by this Agency for future references.

(4) In addition to a total fluoride analysis, it was also desired to analyze the samples obtained for HF, specifically. However, due to the fact that neither a feasible sampling technique nor a suitable method of analysis could be made available, this was not done. In preparing for the subject field study, literature searches and contacts with sources external to this Agency were made in an attempt to devise a satisfactory method. No published method for discriminately detecting HF in a mixture of fluorides could be found; nor could commercial instrumentation or previous, proven techniques be found to be available.

b. Measured Fluoride Concentrations.

(1) Samples obtained during the firings were analyzed to determine the quantity of total fluorides collected. The minimum detectable quantity of total fluorides, for the analytical method used, was 1.0 microgram. Results of the individual sample analyses for six of the seven findings are presented in Appendix D, Tables D-1 through D-6. (Due to equipment malfunction, sampling for Firing No. 6 was incomplete and the partial results were determined to be invalid. However, movies were taken of that Firing to at least allow exposure time determinations.) Calculated exhaust cloud total fluoride concentrations for Firings No. 1 through 5 (conducted with the wind blowing in the same direction as the exhaust thrust) are presented in Appendix E, Figures E-1 through E-5. The values for Firing No. 7 are discussed and presented in para 4c above.

(2) Observations of exhaust cloud passages and sampling results indicated that total fluorides could not be detected at points in the sampling grid that were not encompassed or contacted by any visible portion of the exhaust cloud. It was also apparent from observations and sampling results, that all sampling points contacted by the visible portion of the exhaust did produce detectable total fluoride quantities. This is felt to be a significant finding. Based on these results, it is very likely that observation of the exhaust can be used as a simple indicator of areas exposed (or not significantly exposed) to total fluorides.

(3) A review and comparison of all firing results (Appendix B, Figures B-1 and B-3; and Appendix E, Figures E-1 through E-5) indicate that they all show the same general relationship. Shifting of curve maximum values and relative locations can be attributed to meteorological factors, as discussed in para 5d. It is apparent from all of the results that the area of greatest total fluoride concentration is that closest to the initial point of exhaust cloud formation.

(4) The relationship of concentration and distance is a measure of diffusion and is primarily affected by meteorological factors.

(5) All samples were taken at a height of five feet above ground. This height was chosen because it approximated the breathing zone of a standing man. Visible observations made in Phases I and II also indicated that the exhaust cloud density at this height was at least equal to and normally greater than that at ground level.

c. Time of Exposure.

(1) The estimated accuracy of exposure time determinations reported in para 4d and Appendix A, Table A-2 is approximately ± 35 percent. Deter-

mination of the time that the last visible portion of the exhaust passed any given point on the film was difficult. Human judgement was primarily required for this evaluation.

(2) All of the determined exposure times were extremely short in duration. As discussed in para 5b(2), it is doubtful that any significant exposure to fluorides at any given point occurred after passage of the visible cloud.

d. Meteorological Effects.

(1) The motors tested burned for approximately 0.6 seconds. Initial cloud formation was observed during this period. This cloud formation was primarily influenced by motor size, motor type, nozzle configuration, burning time, propellant mass discharge rate and the amount of air entrained during firing. After the burning time, diffusion of the initial cloud formation was primarily controlled by meteorological conditions.

(2) The most important factor affecting exhaust diffusion is atmospheric stability. Atmospheric stability is basically a function of the vertical temperature profile of the atmosphere. The greater the temperature decrease with height, the greater the instability of the atmosphere will be. As the atmosphere becomes less stable, the rate of mixing of the exhaust and the surrounding air can be expected to increase. Lateral movement of the exhaust cloud is a function of wind speed and wind direction.

(3) Meteorological measurements and observations made during the firings in this study are presented in Appendix F, Tables F-1 through F-2. AN/GMQ-12 wind measuring sets were placed at one end of each arc in the sampling grid and in the immediate area of the firing site. Their relative locations are shown in Appendix C, Figure C-1. Details of this equipment capability and accuracy can be found in the reference cited in Appendix G, para 1.

(4) An appreciably greater number of firings would be required over a wider range of weather conditions before firm conclusions could be reached regarding the specific effects of the meteorological parameters. However, the relatively limited study that this Agency performed did allow general conclusions to be made. Areas of exposure to the exhaust in terms of distance from the firing point were defined. The effect of wind direction on the path of the exhaust cloud was indicated. Assuming that the point of maximum concentration is the cloud center, a review and comparison of Appendix F, Table F-2 with Appendix E, Figures E-1 through E-5 will show the wind direction effects.

e. Chemical and Physical State of Measured Fluorides.

(1) Combined field study and laboratory results indicated that the fluorides measured were predominantly in the gaseous state. Sampling and analytical development studies were conducted in the laboratory using pure, gaseous HF and a NaF aerosol. The gaseous samples were prepared by introducing HF from a cylinder into a Mylar bag. A direct connection was made from the bag to the sampling apparatus with Tygon tubing. The NaF aerosol was generated using a pneumatic nozzle (Spraying Systems Co., fluid nozzle No. 2050, air nozzle No. 70) and a five percent NaF solution. This aerosol was generated directly into a chamber containing the sampling equipment under development and an impaction type sampling device for determining particulate size. The aerosol was found to have a mass median diameter of 1.2 microns.

(2) Two sampling train configurations were used in the above studies. Both contained the same components as the assembly illustrated in Appendix C, Figure C-2. However, both had three of the bubblers described in Appendix C, Figure C-2, in series. In one of the configurations studied, the assembly consisted of three bubblers, filter holder and filter and critical flow orifice, in that sequence. In the other configuration, the sequence consisted of the filter holder and filter, three bubblers in series and the critical flow orifice. Thus, the laboratory study essentially consisted of the following four different tests:

(a) No. 1 - gaseous HF introduced into the sampling assembly having the bubblers first in the train sequence.

(b) No. 2 - gaseous HF introduced into the sampling assembly having the filter first in the train sequence.

(c) No. 3 - NaF aerosol introduced into the sampling assembly having the bubblers first in the train sequence.

(d) No. 4 - NaF aerosol introduced into the sampling assembly having the filter first in the train sequence.

(3) Results of the tests, as described above, were as follows:

(a) No. 1 - total fluorides could only be detected in the first bubbler; none were found in either the second or the third bubbler in series or on the filter.

(b) No. 2 - total fluorides were detected on the filter and only in the first of three bubblers, in series.

(c) No. 3 - total fluorides were detected in each of the bubblers and on the filter.

(d) No. 4 - total fluorides were detected only on the filter; none were found in any of the three bubblers.

(4) The following conclusions were made from the above tests:

(a) Gaseous HF was partially entrapped on the filter due to either adsorption, absorption, reaction with the filter medium or a combination of these effects.

(b) Absorption of the gaseous HF in the bubblers used was so efficient that all detectable quantities of the gas could be recovered in a single bubbler.

(c) Bubbler efficiency for recovery of NaF aerosol was less than 50 percent.

(d) All detectable quantities of the NaF aerosol introduced on the filter could be recovered on it.

(5) In this study (Phase III) total fluorides could only be detected in the single bubbler of the sampling assembly. Thus, it was concluded that the total fluorides measured were predominantly present in the gaseous state.

(6) As discussed in para 5a(4), a feasible method for specific determination of HF in the exhaust under the field test conditions, was not available. It is felt that specific determination of HF concentration in the exhaust could best be made in laboratory chamber firing tests. In doing so, burning time, propellant mass discharge rate and the amount of air entrained during firing would have to be controlled in order to provide valid results. Immediate sample analysis would be required to eliminate any error attributable to the effect of time on the percentage of HF in the total fluoride mixture.

(7) The best guidance known to exist with regard to the percentage of HF in the total fluorides of the exhaust cloud is that presented in Appendix A, Table A-1. Based on that information, 81 percent (by weight) of the total fluorides is attributable to HF. Ninety-one percent of the volume occupied by fluorine compounds is attributable to HF.

f. Study Limitations.

(1) Determination of the potential toxic effects of exposure to the total fluorides measured and reported herein are beyond the scope of this study.

(2) Due to a lack of funding for propellant manufacture, it was not possible to test firings with different sized motors or burning times. Consequently, indications of the effects of these variables could not be determined.

6. CONCLUSIONS.

a. It is doubtful that any area not exposed to visible exhaust from the HF propellant firing will be contaminated by fluorides from the exhaust.

b. Fluorides present in the exhaust cloud are predominantly in the gaseous state.

c. The area of greatest total fluoride concentration in the exhaust cloud is at the approximate point where the exhaust cloud is initially formed.

d. It can be expected that there will be no exposure to fluorides at the firing point if the wind is blowing in the same direction as the propellant exhaust thrust.

e. Specifically, with regard to nominal six inch (six pound) RH-U-105 propellant motors:

(1) It can be expected that there will be no significant exposure to fluorides from the motor exhaust at any location greater than about 150 meters from the firing point.

(2) The time of exposure to the exhaust cloud at any point within the above area can be expected to be less than one minute.

7. RECOMMENDATION. When a specific formulation and system application has been selected, further studies should be conducted on the actual system. The propellant should be fired under field conditions and measurements similar to those of this study should be made. Particular attention should be directed towards breathing zones and other areas around which personnel utilizing the system will be located.

USAEHA-EA Air Pollution Engr Study No. 99-003-69/70, Redstone Arsenal, Huntsville, Alabama, 26 May-26 Jun 69

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APPENDIX A
TABLE A-1

THEORETICAL EXHAUST COMPOSITION; RH-U-105 PROPELLANT*

Compound**	Mole Fraction	Volume Percent†
CO	0.2544	27.24
H_2	.2320	24.84
HF	.1788	19.15
N_2	.1064	11.39
HCl	.0973	10.42
Al_2O_3	.0661	--
H_2O	.0365	3.91
AlF_3	.0107	1.15
CO_2	.0076	.81
H	.0030	.32
$AlClF_2$	.0021	.22
AlF_2	.0017	.18
AlClF	.0010	.11
Cl	.0009	.10
AlF	.0007	.07
AlOF	.0004	.04
$AlCl_2F$	.0003	.03
Miscellaneous§	--	.02

* Provided by Dr. T. H. Pratt, Rohm and Haas Co., Redstone Research Laboratories

** All compounds reported to be in the gaseous state, except Al_2O_3.

† Volume percent calculated using theoretical exhaust composition expressed in mole fractions. The volume of the only solid compound (Al_2O_3) is negligible in comparison to the other compounds.

§ Consisting principally of AlCl, OH, and AlOCl, all of which are theoretically present in quantities of less than 0.01 percent by volume.

APPENDIX A
TABLE A-2

TIMES OF EXPOSURE TO VISIBLE EXHAUST AT POINTS IN THE PATH OF THE EXHAUST CLOUD

Wind Direction	Point No.	Distance From Firing Point (meters)	Times of Exposure to Visible Exhaust (seconds) Average	Range
*Same as the direction of the exhaust thrust	0	0	0	--
	1	30	8	5-11
	2	60	20	14-26
	3	90	30	20-40
**In the opposite direction of the exhaust thrust	0	0	30	20-40
	1	30	19	13-25
	2	60	0	--
	3	90	0	--

* With this wind direction, the exhaust cloud formed in the immediate vicinity of point 1 and subsequently expanded in volume and traveled through points 2 and 3. This condition prevailed during Firings 1 through 5.

** With this wind direction, the exhaust cloud formed in the immediate vicinity of point 1, expanded in volume at that location, and was borne by the wind in a direction opposing that of the thrust through the firing point (point 0). This condition prevailed for Firings 6 and 7.

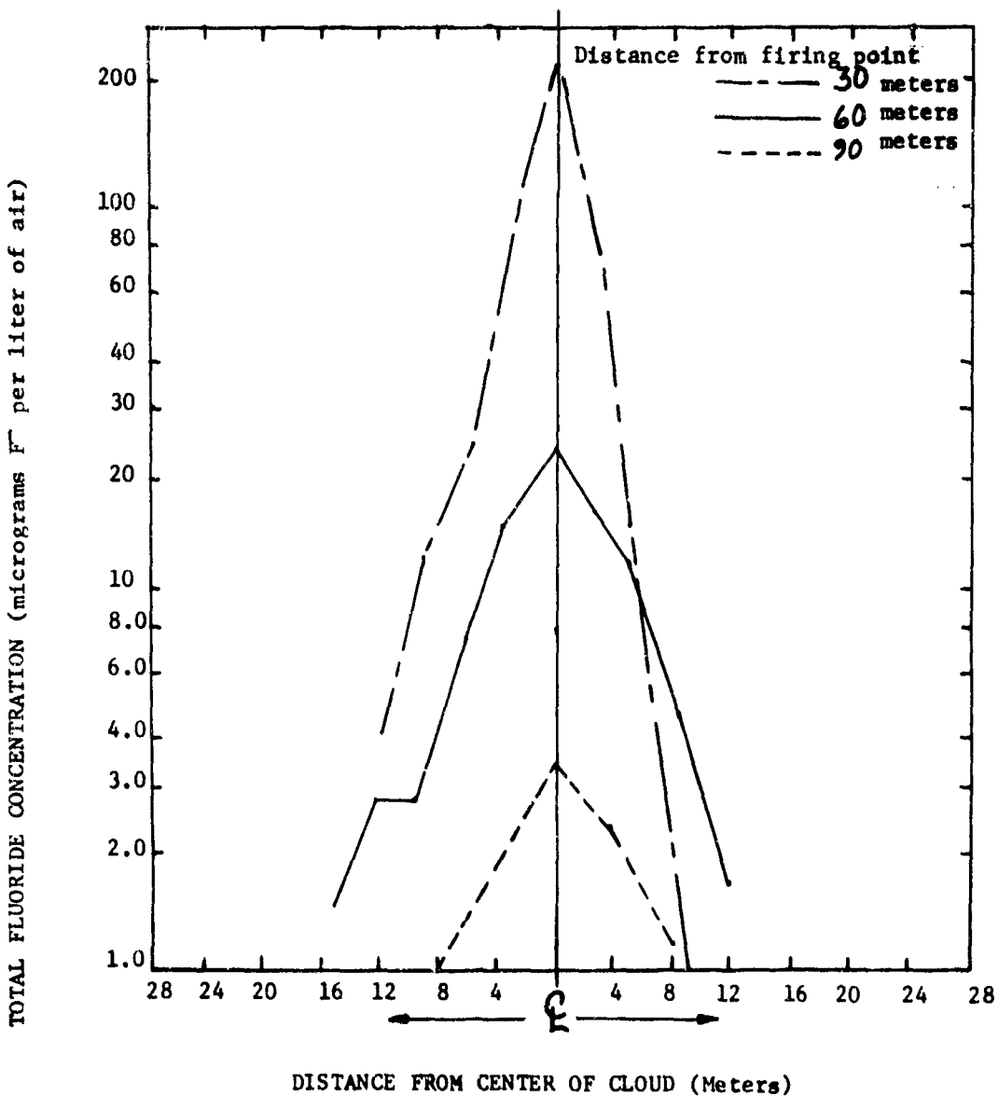


Figure B-1. Average Total Fluoride Concentrations; Firings 1 through 5

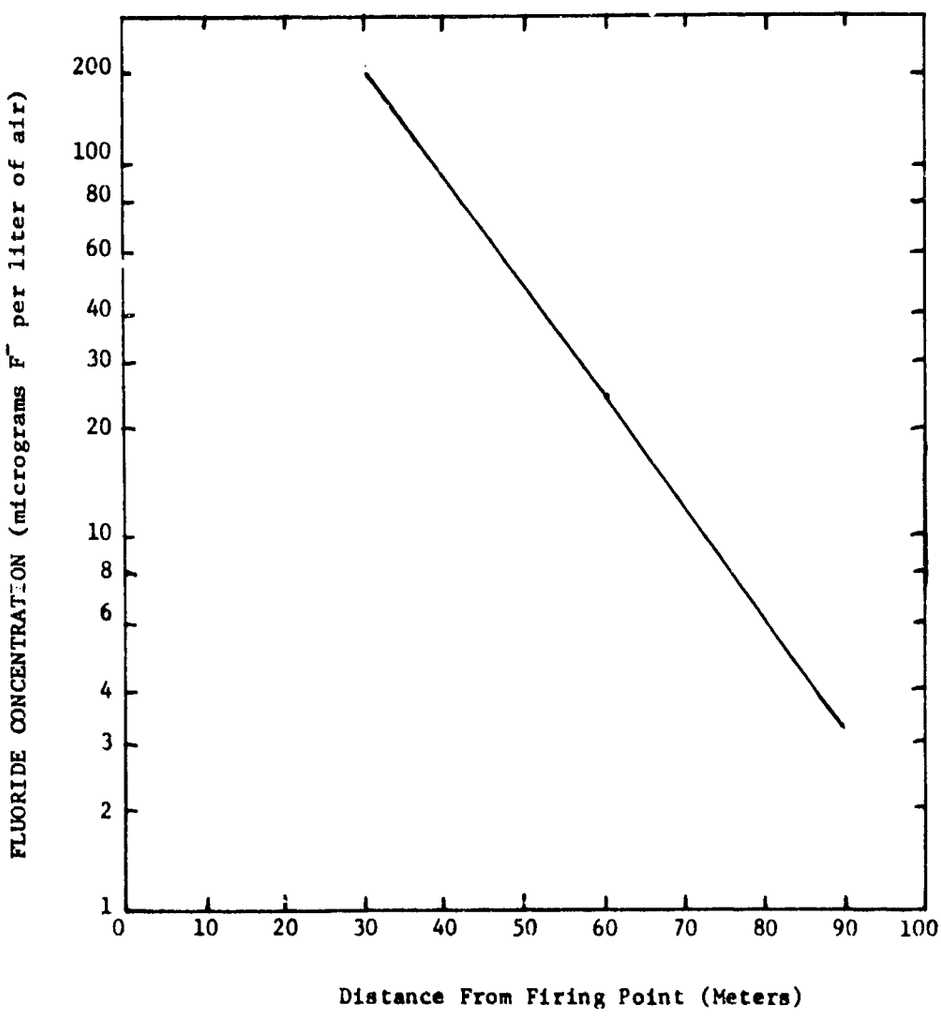
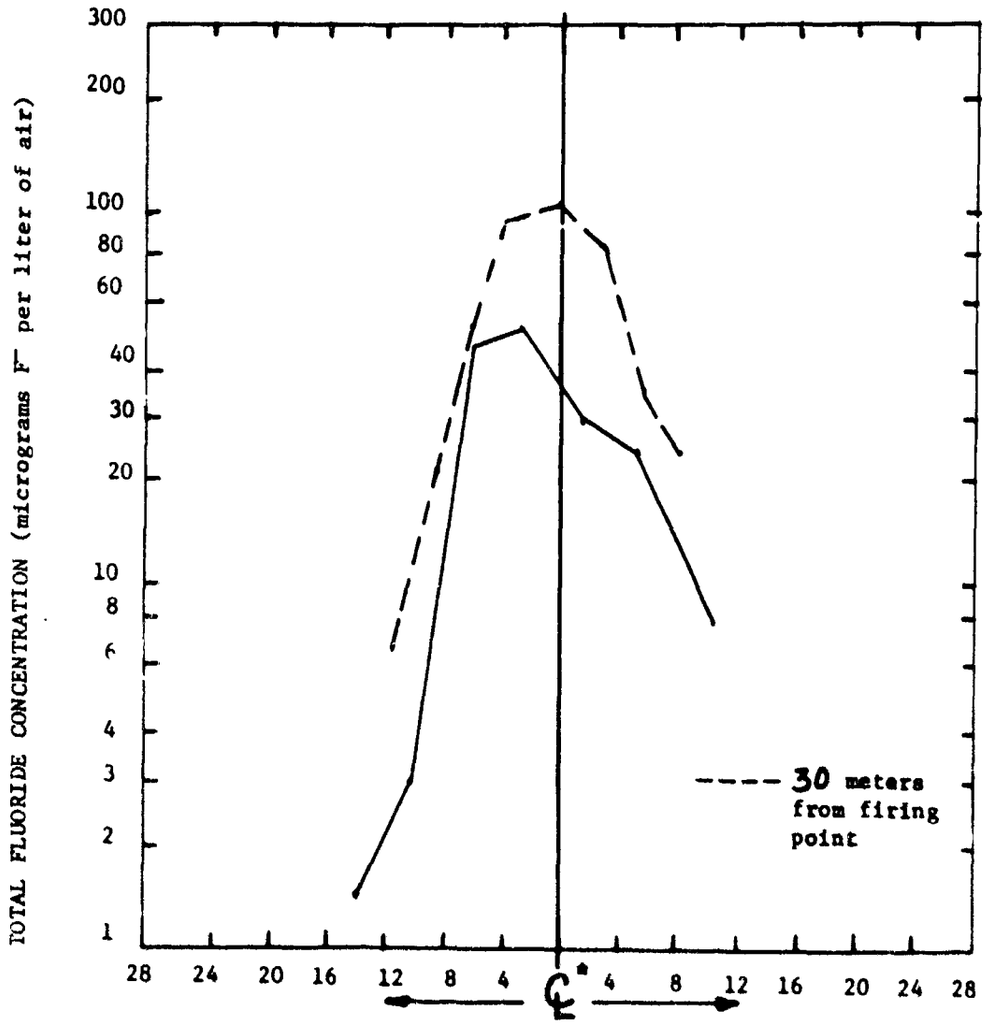


Figure B-2. Relationship of Average Fluoride Concentration With Distance



* Relative location of motor firing 90 degrees to the right and left of the firing point centerline and at the distance from it as indicated by the abcissa.

Figure B-3. Total Fluoride Concentrations; Firing No. 7

APPENDIX C
SAMPLING AND ANALYTICAL METHODS AND PROCEDURES

1. Sampling Grid. Forty-one sampling stations were arranged in three arcs located 30, 60 and 90 meters from the firing point. Each of these arcs had eight, 17 and 16 equally spaced sampling stations, respectively. This layout faced the direction of the motor exhaust thrust. The sampling grid arcs were drawn from an imaginary point located 15 meters behind the motor. As observed in previous study phases, this point represented the approximate center of the initial cloud formation. Figure C-1 shows the sampling grid layout.

2. Sampling Apparatus and Procedure. All sampling stations were identical. Each station was mounted to obtain an ambient sample at a height of five feet above ground level. The sampling train of each station consisted of a bubbler, positive filter and critical flow orifice in that order. Figure C-2 is an illustration of an assembled sampling train with further information regarding the train components. The train outlets were manifolded to portable 1/3 hp vacuum pumps. Immediately before a firing, the vacuum was supplied for all sampling stations. After the visible exhaust passed the last sampling arc, it was shut off.

3. Method of Analysis. All samples were analyzed for total fluorides on the same day as the firing using a Technicon Autoanalyzer and the alizarin complexone trihydrate - cerous nitrate method, slightly modified. Refer to Appendix G, para 2. The sample analysis rate was 25 per hour. 1.0 micrograms was the minimum detectable amount of total fluorides in any sample.

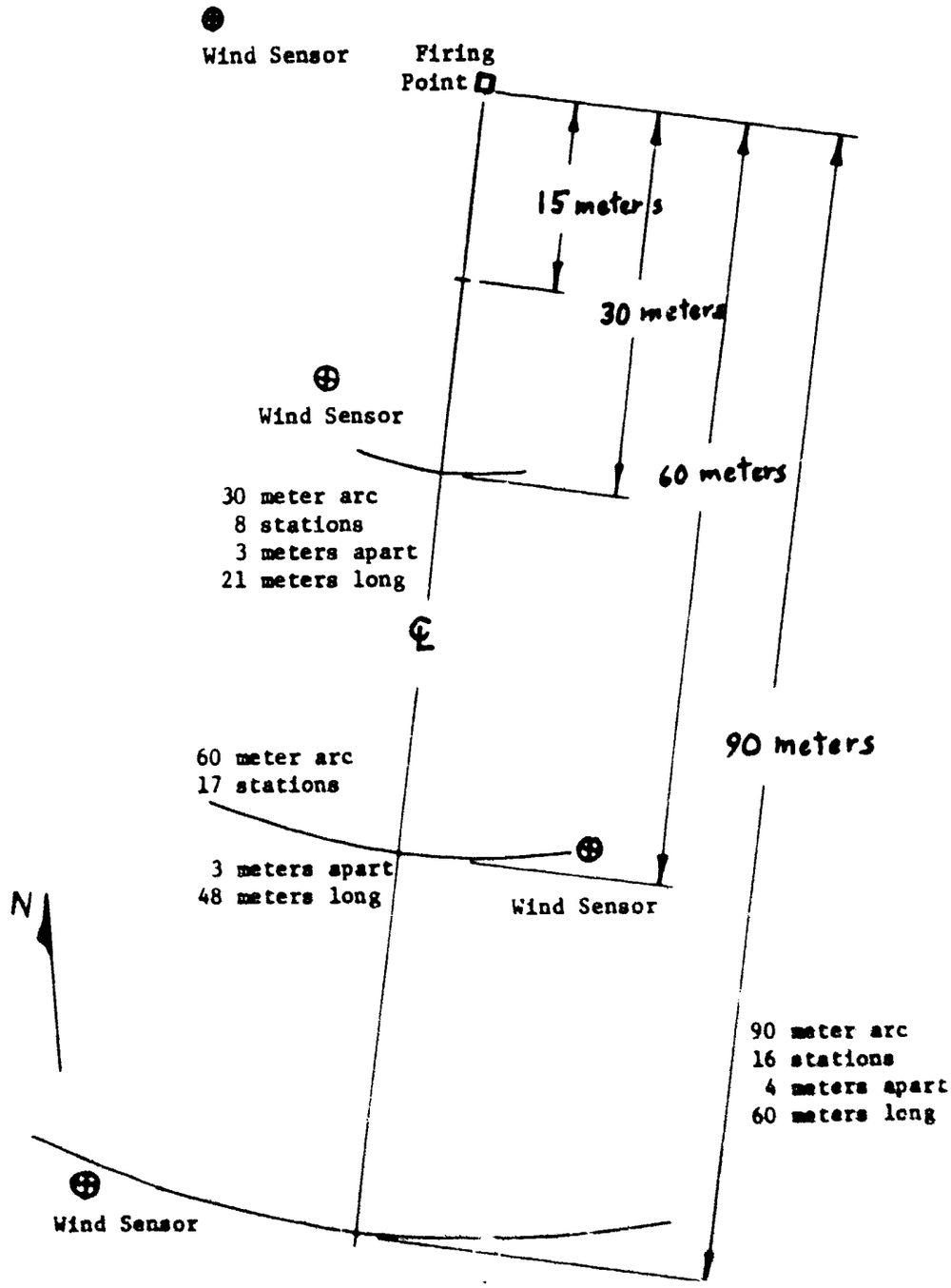
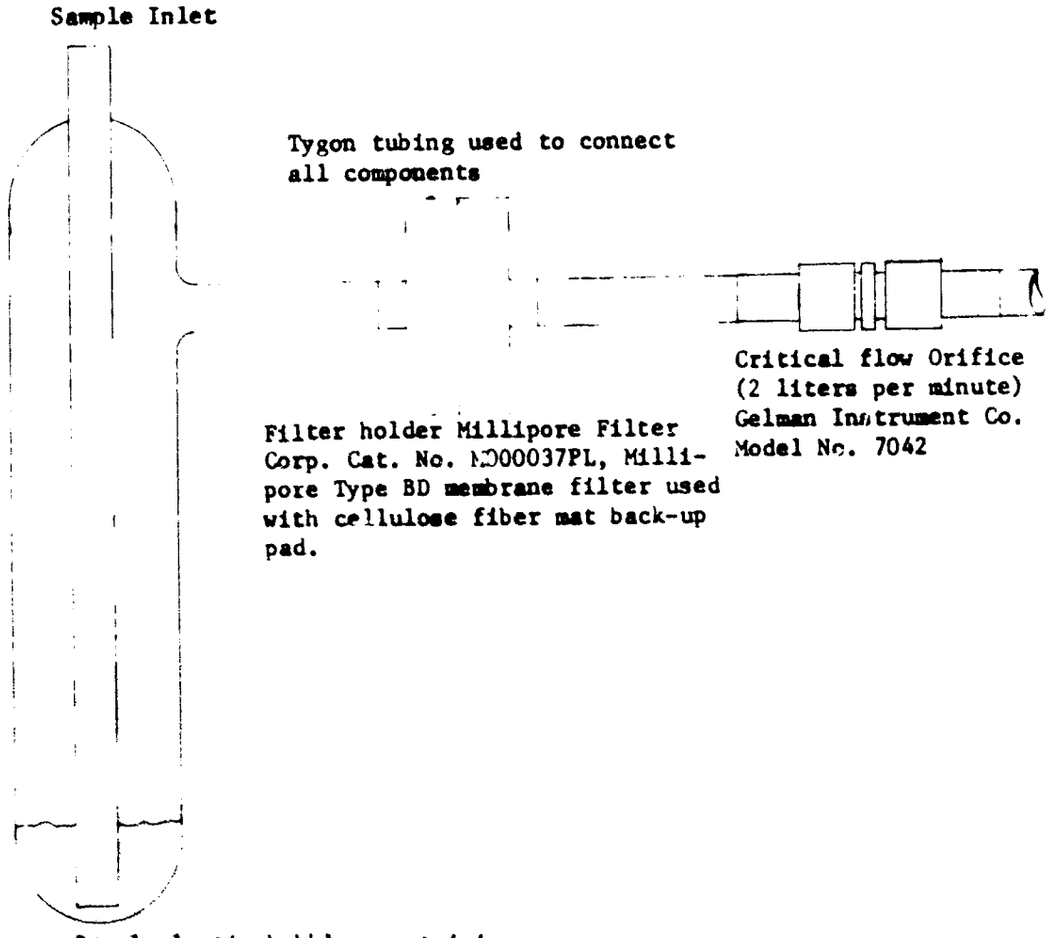


Figure C-1. Sampling Grid Layout



(Item was custom-made and obtained as surplus from Edgewood Arsenal)

Figure C-2. Total Fluorides Sampling Train Assembly

APPENDIX D
TABLE D-1

TOTAL FLUORIDES COLLECTED; FIRING NO. 1

30 METER ARC		60 METER ARC		90 METER ARC	
Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)
		2-1	(<1.0)	3-1	(<1.0)
		2-2	(<1.0)	3-2	(<1.0)
		2-3	2.0	3 3	(<1.0)
		2-4	2.0	3-4	2.5
1-1	(<1.0)	2-5	3.0	3-5	3.2
1-2	4.0	2-6	5.5	3-6	3.0
1-3	6.0	2-7	15.0	3-7	6.0
1-4	29.0	2-8	13.0	3-8	4.0
1-5	51.0	2-9	10.0	3-9	4.8
1-6	12.5	2-10	12.0	3-10	3.0
1-7	3.0	2-11	8.0	3-11	1.7
1-8	1.0	2-12	3.5	3-12	1.1
		2-13	(<1.0)	3-13	1.5
		2-14	(<1.0)	3-14	(<1.0)
		2-15	(<1.0)	3-15	(<1.0)
		2-16	(<1.0)	3-16	(<1.0)
		2-17	(<1.0)		

APPENDIX D
TABLE D-2

TOTAL FLUORIDES COLLECTED; FIRING NO. 2

30 METER ARC		60 METER ARC		90 METER ARC	
Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)
		2-1	(<1.0)	3-1	1.0
		2-2	(<1.0)	3-2	1.0
		2-3	1.0	3-3	1.0
		2-4	1.7	3-4	1.0
1-1	(<1.0)	2-5	2.4	3-5	(<1.0)
1-2	(<1.0)	2-6	13.0	3-6	(<1.0)
1-3	5.7	2-7	24.5	3-7	(<1.0)
1-4	30.0	2-8	12.5	3-8	(<1.0)
1-5	56.0	2-9	2.2	3-9	(<1.0)
1-6	18.5	2-10	(<1.0)	3-10	(<1.0)
1-7	7.5	2-11	(<1.0)	3-11	(<1.0)
1-8	(<1.0)	2-12	(<1.0)	3-12	(<1.0)
		2-13	(<1.0)	3-13	(<1.0)
		2-14	(<1.0)	3-14	(<1.0)
		2-15	(<1.0)	3-15	(<1.0)
		2-16	(<1.0)	3-16	(<1.0)
		2-17	(<1.0)		

APPENDIX D
TABLE D-3

TOTAL FLUORIDES COLLECTED; FIRING NO. 3

30 METER ARC		60 METER ARC		90 METER ARC	
Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)
		2-1	(<1.0)	3-1	(<1.0)
		2-2	(<1.0)	3-2	(<1.0)
		2-3	(<1.0)	3-3	(<1.0)
		2-4	(<1.0)	3-4	(<1.0)
1-1	(<1.0)	2-5	(<1.0)	3-5	(<1.0)
1-2	(<1.0)	2-6	(<1.0)	3-6	(<1.0)
1-3	(<1.0)	2-7	(<1.0)	3-7	(<1.0)
1-4	16.5	2-8	2.6	3-8	(<1.0)
1-5	48.0	2-9	4.2	3-9	(<1.0)
1-6	23.5	2-10	8.0	3-10	2.0
1-7	3.8	2-11	5.8	3-11	3.1
1-8	(<1.0)	2-12	4.5	3-12	1.1
		2-13	2.5	3-13	(<1.0)
		2-14	1.1	3-14	(<1.0)
		2-15	(<1.0)	3-15	(<1.0)
		2-16	(<1.0)	3-16	(<1.0)
		2-17	(<1.0)		

APPENDIX D
TABLE D-4

TOTAL FLUORIDES COLLECTED; FIRING NO. 4

30 METER ARC		60 METER ARC		90 METER ARC	
Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)
		2-1	2.9	3-1	2.5
		2-2	6.3	3-2	1.0
		2-3	4.7	3-3	1.5
		2-4	6.4	3-4	1.0
1-1	4.7	2-5	9.7	3-5	(<1.0)
1-2	8.2	2-6	16.5	3-6	(<1.0)
1-3	22.0	2-7	12.5	3-7	(<1.0)
1-4	44.5	2-8	10.8	3-8	(<1.0)
1-5	54.0	2-9	1.0	3-9	(<1.0)
1-6	14.7	2-10	(<1.0)	3-10	(<1.0)
1-7	6.5	2-11	(<1.0)	3-11	(<1.0)
1-8	(<1.0)	2-12	(<1.0)	3-12	(<1.0)
		2-13	(<1.0)	3-13	(<1.0)
		2-14	(<1.0)	3-14	(<1.0)
		2-15	(<1.0)	3-15	(<1.0)
		2-16	(<1.0)	3-16	(<1.0)
		2-17	(<1.0)		

APPENDIX D
TABLE D-5

TOTAL FLUORIDES COLLECTED; FIRING NO. 5

30 METER ARC		60 METER ARC		90 METER ARC	
Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)
		2-1	(<1.0)	3-1	(<1.0)
		2-2	(<1.0)	3-2	(<1.0)
		2-3	(<1.0)	3-3	(<1.0)
		2-4	(<1.0)	3-4	(<1.0)
1-1	1.0)	2-5	(<1.0)	3-5	(<1.0)
1-2	1.0)	2-6	(<1.0)	3-6	(<1.0)
1-3	(<1.0)	2-7	(<1.0)	3-7	(<1.0)
1-4	18.5	2-8	(<1.0)	3-8	(<1.0)
1-5	68.0	2-9	5.2	3-9	(<1.0)
1-6	32.0	2-10	7.5	3-10	(<1.0)
1-7	(<1.0)	2-11	13.0	3-11	(<1.0)
1-8	(<1.0)	2-12	12.5	3-12	1.4
		2-13	6.0	3-13	3.3
		2-14	2.7	3-14	2.5
		2-15	1.0	3-15	1.0
		2-16	(<1.0)	3-16	(<1.0)
		2-17	(<1.0)		

APPENDIX D
TABLE D-6

TOTAL FLUORIDES COLLECTED; FIRING NO. 7

PARALLEL TO FIRING POINT		30 METER ARC		60 METER ARC	
Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)	Station and Sample No.	Total Fluorides Collected (micrograms)
				2-1	(<1.0)
				2-2	(<1.0)
				2-3	(<1.0)
0-1	1.0			2-4	(<1.0)
0-2	2.0	1-1	2.8	2-5	(<1.0)
		1-2	8.7	2-6	(<1.0)
0-3	30.7	1-3	23.0	2-7	(<1.0)
0-4	35.3	1-4	41.2	2-8	(<1.0)
		1-5	45.5	2-9	(<1.0)
0-5	19.0	1-6	34.8	2-10	(<1.0)
0-6	14.7	1-7	15.6	2-11	(<1.0)
0-7	5.0	1-8	9.5	2-12	(<1.0)
				2-13	(<1.0)
				2-14	(<1.0)
				2-15	(<1.0)
				2-16	(<1.0)
				2-17	(<1.0)

APPENDIX E

CALCULATED EXHAUST CLOUD TOTAL FLUORIDE CONCENTRATIONS; FIRINGS 1 THROUGH 5

Method of Calculation Used For All Firing:

$$\text{Calculated Total Fluoride Concentration} = \frac{\text{Total fluorides collected}}{\text{Sampling Rate X Exposure Time}}$$

a. Calculated total fluoride concentration expressed as micrograms per liter (µg/l).

b. Total fluorides collected obtained from appropriate table in Appendix D; expressed as micrograms (µg).

c. Sampling rate used was two liters per minute (2 l/min).

d. Exposure times used were the appropriate averages presented in Appendix A, Table 2. (Average rather than actual exposure times determined for each firing were selected for use because it was felt they were more representative of the real values. Refer to para 5d(2) for further details regarding the accuracy of exposure time determinations.)

e. Sample Calculation:

DATA: Firing No. 4; Station/sample No. 1-4 total fluorides collected (from Appendix D, Table D-4): 44.5 µg, sampling rate: 2 l/min, exposure time (from Appendix A, Table 2): 8 sec, (average) for a distance of 30 meters from the firing point (30 meter arc)

$$\text{Calculated total fluoride concentration} = \frac{44.5\ \mu g}{2\ l/min \times 8/60\ min} = 167\ \mu g/l$$

(This point appears in the top curve of Appendix E, Figure E-4.)

f. Calculated total fluoride calculations.

(1) Refer to Appendix E, Figures E-1 through E-5 for Firings No. 1 through 5.

(2) Refer to Appendix B, Figure 3 for the calculated values of Firing No. 7.

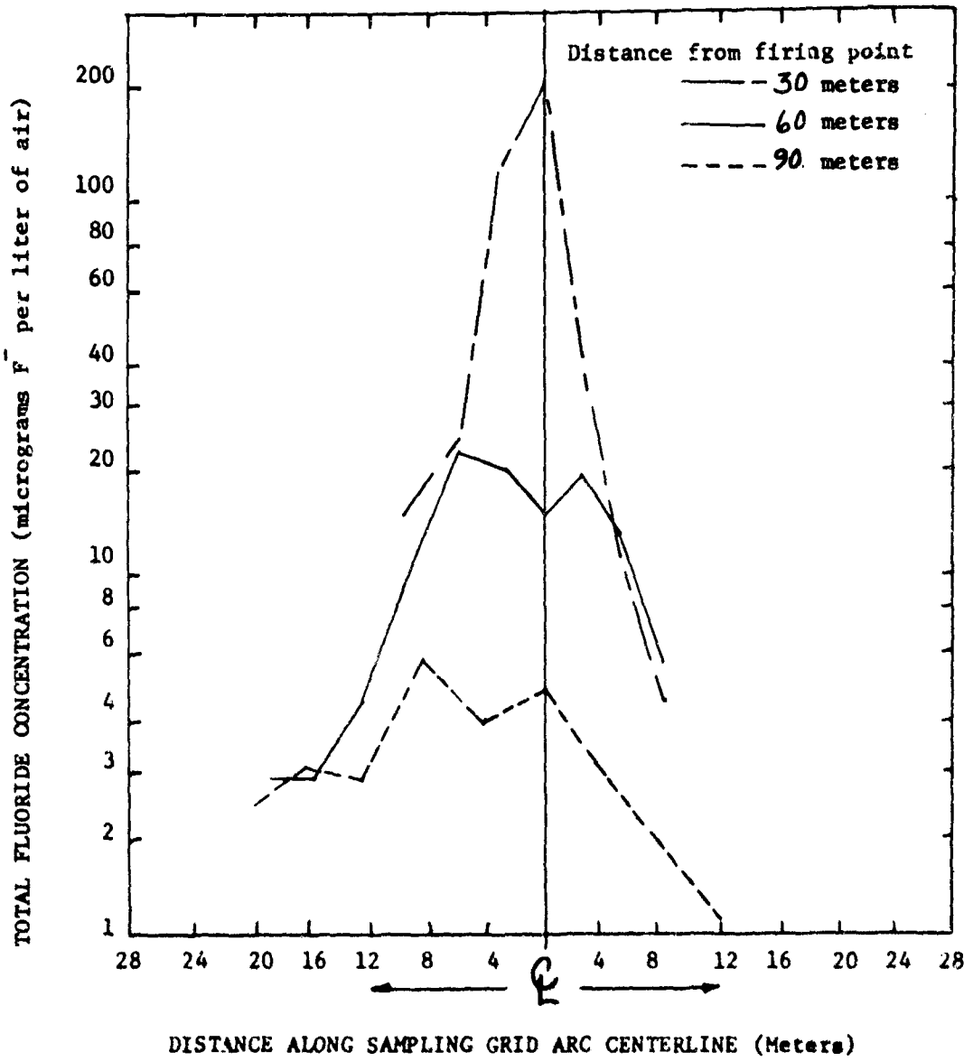


FIGURE E-1. TOTAL FLUORIDE CONCENTRATIONS; FIRING NO. 1

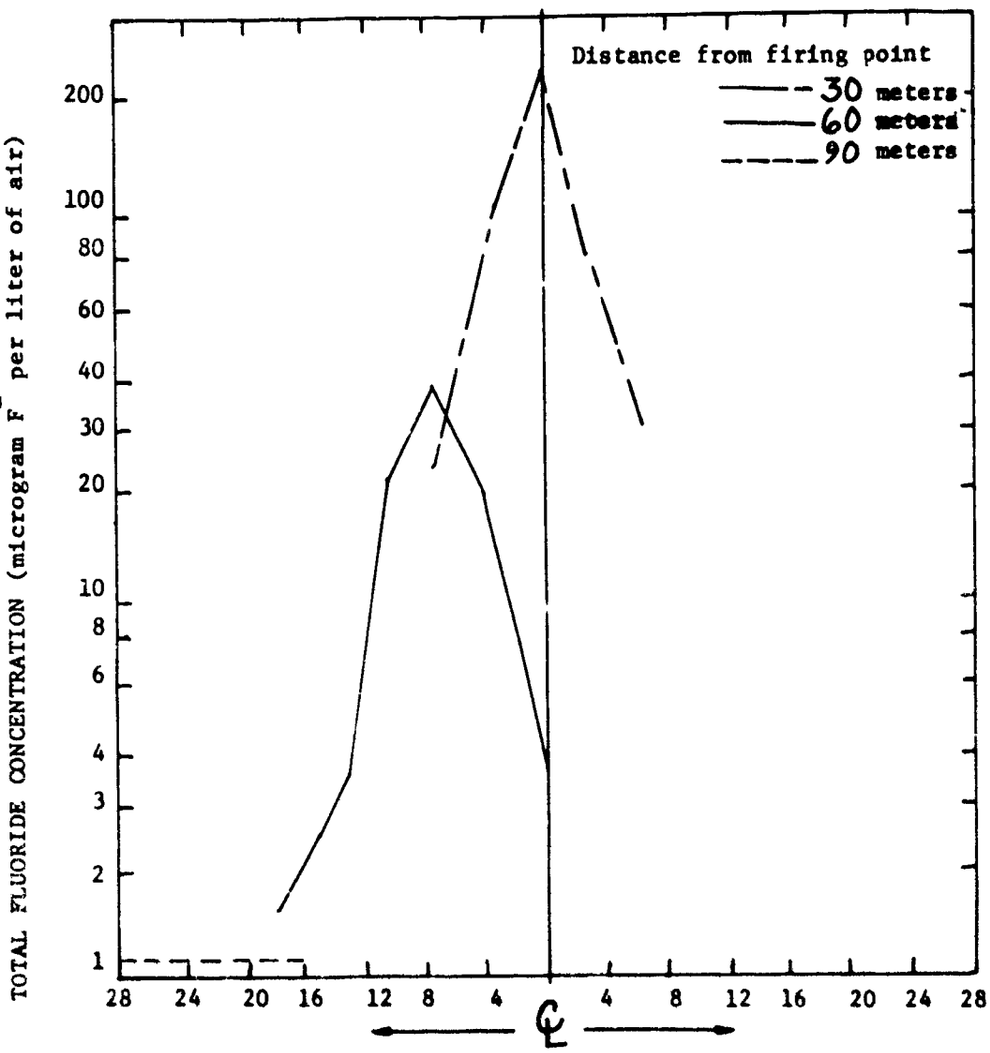


FIGURE E-2. TOTAL FLUORIDE CONCENTRATIONS; FIRING NO. 2

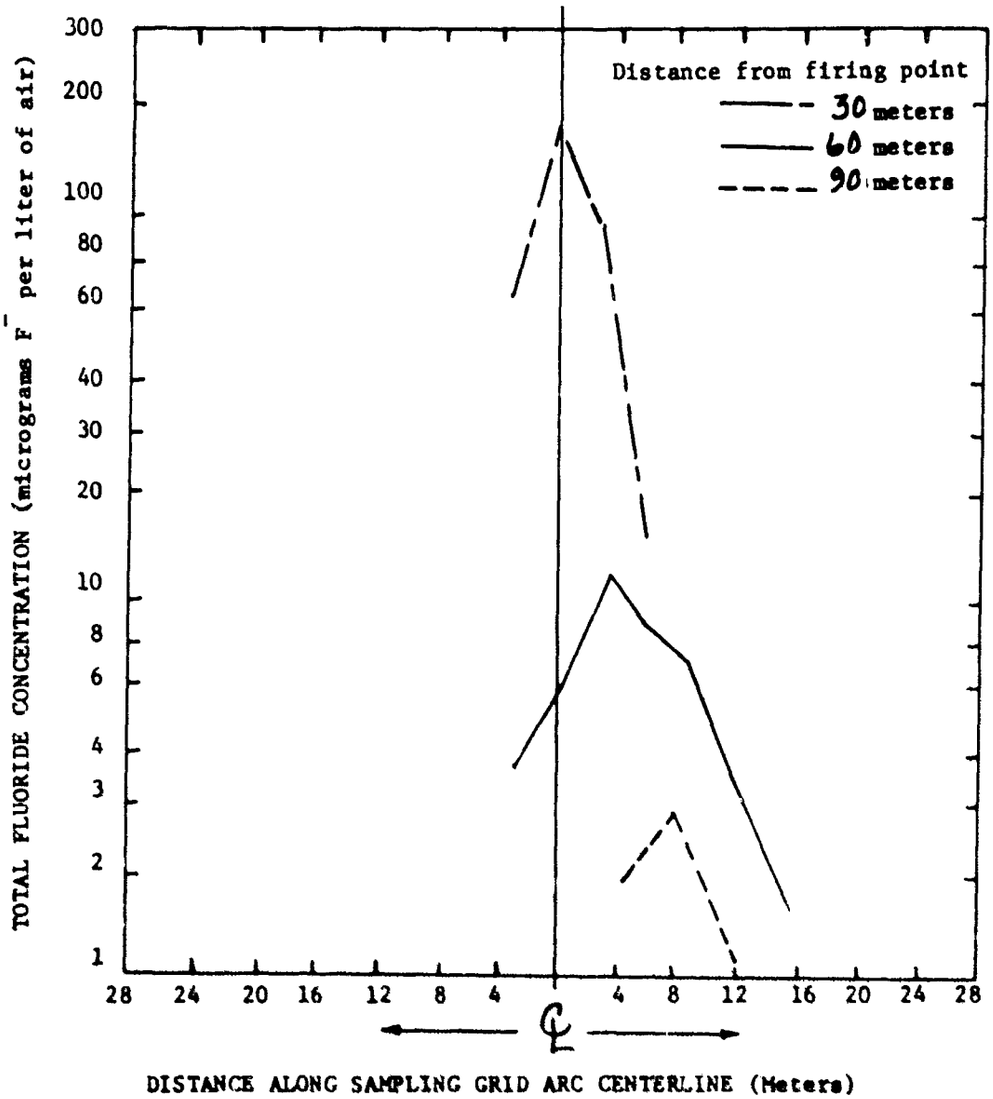


FIGURE E-3. TOTAL FLUORIDE CONCENTRATIONS; FIRING NO. 3

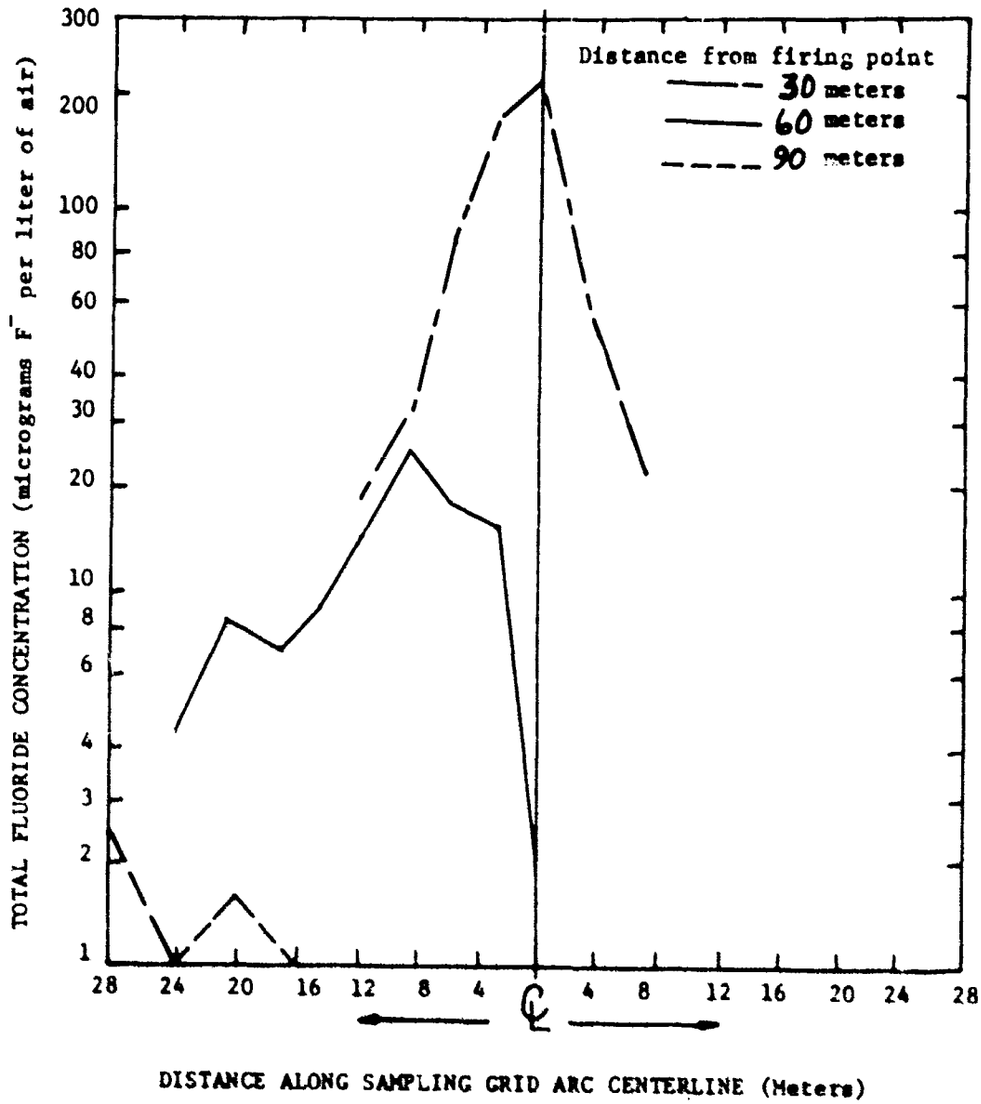


FIGURE E-4. TOTAL FLUORIDE CONCENTRATIONS; FIRING NO. 4

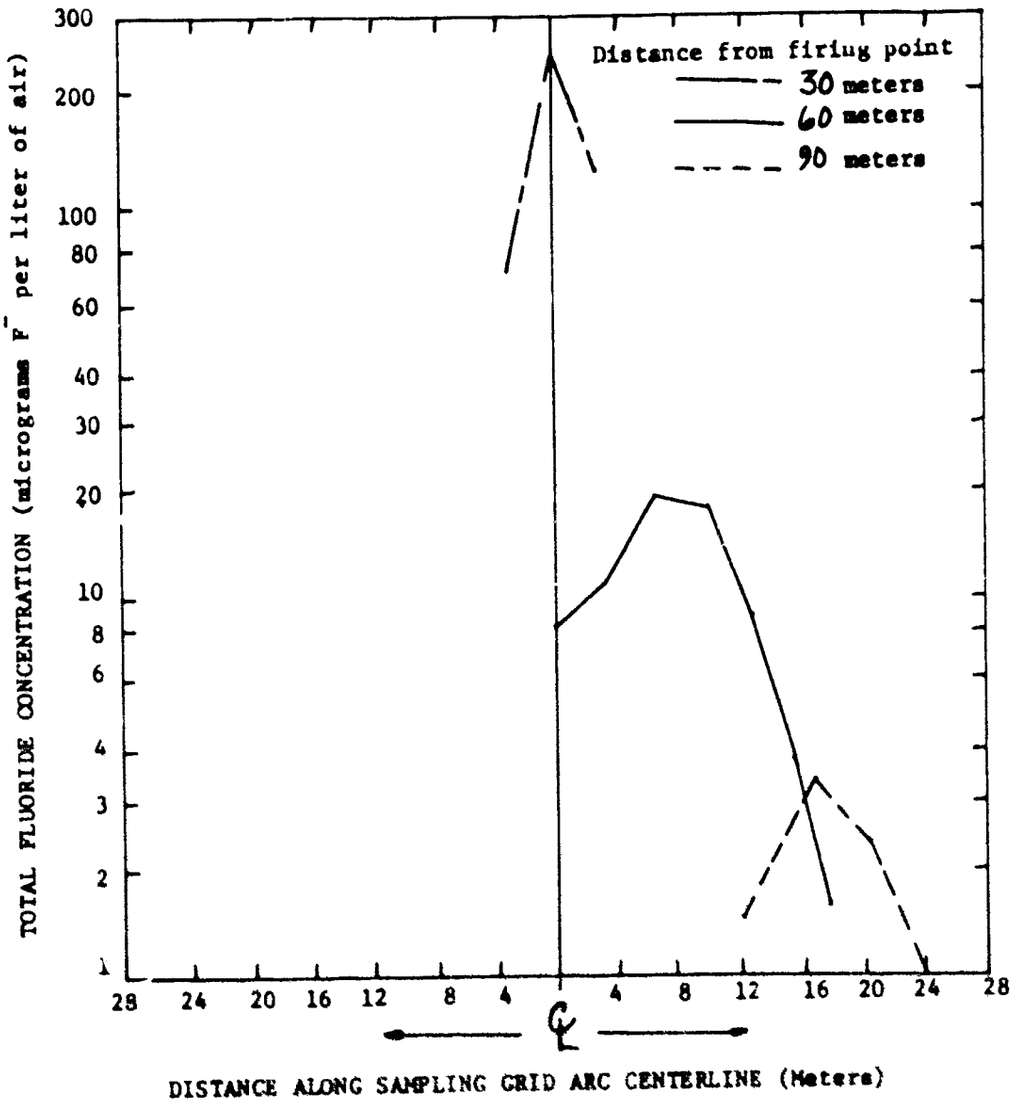


FIGURE E-5. TOTAL FLUORIDE CONCENTRATIONS; FIRING NO. 5

APPENDIX I
TABLE F-1

METEOROLOGICAL CONDITIONS DURING FIRINGS

FIRING NO.	DATE	TIME (CST)	WIND DIRECTION[1,2] (degrees, direction)	WIND SPEED[2] (miles per hour)	TEMP.[3] (°F)	RELATIVE[3] HUMIDITY (percent)	CLOUD[3] COVER (tenths)	BAROMETRIC[3] PRESSURE (in. Hg)	ATMOSPHERIC[4] STABILITY
1	3 JUN 69	1600	360(N)	4	79	22	3	29.31	Very unstable
2	5 JUN 69	0915	360(N)	2 1/2	77	43	5	29.36	Very unstable
3	16 JUN 69	0830	090 (SE)	7	65	70	10	29.31	Neutral
4	16 JUN 69	1020	350 (N)	5	68	72	10	29.32	Neutral
5	17 JUN 69	0845	090 (SE)	2 1/2	72	63	2	29.31	Very unstable
6	25 JUN 69	0930	240 (SSW)	4 1/2	83	74	2	29.31	Slightly unstable
7	25 JUN 69	1210	360 (N)	7	91	58	5	29.30	Slightly unstable

1. A wind direction of 090 degrees would have blown along the sampling grid centerline.
2. Determined at the firing site.
3. Obtained from Huntsville Municipal Airport.
4. Determined by resolution of continuous wind direction data obtained at firing site.

APPENDIX F
TABLE F-2

MICROMETEOROLOGICAL CONDITIONS DURING FIRING

FIRING NO.	ARC (distance from motor; meters)	WIND SPEED (mph)	WIND DIRECTION (degrees; direction)
1	30	6	360 (N)
	60	4	360 (N)
	90	3	010 (N)
2	30	2	360 (N)
	60	2 1/2	350 (N)
	90	3	340 (N)
3	30	7	50 (NE)
	60	8	55 (NE)
	90	5 1/2	40 (NE)
4	30	5	350 (N)
	60	6	340 (NNW)
	90	4	350 (N)
5	30	2 1/2	50 (NE)
	60	2 1/2	90 (E)
	90	3 1/2	60 (ENE)
6	30	5	200 (SSW)
	60*	4	200 (SSW)
7	30	8	180 (S)
	60*	6	190 (S)

*Firing Nos. 6 and 7 were made when the wind was blowing against the exhaust thrust. In each case, the exhaust cloud did not reach the 60 meter arc.

APPENDIX G

REFERENCES

1. TM 11-2446, Department of the Army Technical Manual, "Wind Measuring Set AN/GMQ-12", Department of the Army, May 1957.

2. Mandl, R. H., L. H. Weinstein, J. S. Jacobson, D. C. McCune and A. E. Hitchcock; "Simplified Semi-Automated Analysis of Fluoride", presented at the Technicon Symposium, New York, N. Y., 8 September 1965.

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A field study was conducted at Redstone Arsenal, Huntsville, Alabama to measure the concentration of and determine areas of exposure to total fluorides in the exhaust cloud of statically fired six pound motors utilizing a developmental Rohm and Haas NF propellant. Results of the study gave strong indications that only areas exposed to the visible exhaust would be contaminated by fluorides. The study results also indicated that all fluorides in the exhaust were predominantly in the gaseous state. Areas of greatest exhaust cloud total fluoride concentration were found to be at the approximate location where the cloud was initially formed. In the firing tests conducted, exposure to the cloud at any point within its path was determined to be less than one minute in all cases observed. It was estimated that areas at distances greater than 150 meters from the firing point of the six-pound motors would not be significantly exposed to fluorides from the exhaust.

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