DOT/FAA/AM-89-8

Office of Aviation Medicine
Washington, D.C. 20591

Performance Evaluation of the Puritan-Bennett Crew-member Portable Protective Breathing Device as Pre-scribed by Portions of FAA Action Notice A-8150.2

E.A. Higgins
G.A. McLean
P.J. Lyne
G.E. Funkhouser
J.W. Young

Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

May 1989

Final Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department
of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-89/8		

4. Title and Subtitle	5. Report Date
PERFORMANCE EVALUATION OF THE PURITAN-BENNETT CREWMEMBER PORTABLE PROTECTIVE BREATHING DEVICE AS PRESCRIBED BY PORTIONS OF FAA ACTION NOTICE A-8150.2	May 1989
	6. Performing Organization Code
7. Author(s) E.A. Higgins, G.A. McLean, P.J. Lyne, G.E. Funkhouser, and J.W. Young	8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aeromedical Institute P.O. Box 25082 Oklahoma City, Oklahoma 73125	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, S.W. Washington, D.C. 20591	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

Research leading to preparation of this report was performed under tasks AM-B-88-PRS-81.D and AM-B-89-PRS-81.D.

16. Abstract: This study was undertaken, on request, to evaluate the performance of the Puritan-Bennett portable crew protective breathing device for contaminant leaks, O_2, CO_2 levels, inhalation/exhalation pressure, and inhalation temperature. Tests were conducted in the facilities of the FAA Civil Aeromedical Institute (CAMI) in Oklahoma City, OK. (test chamber and altitude chamber). The duration and workload profile are described in FAA Action Notice A-8150.2. The test sequence followed an iterative process in which problems were identified, modifications made to correct deficiencies, and the device retested until problems could be solved. The test sequence was as follows:

First, the neck seal material was not elastic enough and a more suitable material was identified and substituted;

Second, the size of the opening of the neck seal had to be reduced to protect the smaller subjects;

Third, identification of increased CO_2 resulting from the occasional inversion of the exhalation valve was found, and was solved by improving the valve support design;

Fourth, leaks encountered at locations other than neck seals were overcome through improved quality control for more impermeable seams and hardware seals.

Thus, with adequate quality assurance, the final version of the Puritan-Bennett crew-member portable protective breathing device, as tested at CAMI, would meet the requirements of FAA's Action Notice A-8150.2 regarding contaminant leak protection, O_2 concentration, CO_2 concentration, inhalation/exhalation pressures and inhalation temperature.

17. Key Words	18. Distribution Statement
Crew Portable Protective Breathing Equipment, Smoke/Fume Environment.	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	95	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of the following groups and individuals who made significant contributions to the conduct of this study:

Ms. Stacy Terrill, Mr. Gary Sharp, and Mr. Roger Elliott, from the University of Oklahoma Health Sciences Center Physicians Associate Program, for the conduct of the pre-selection physical examinations and the medical monitoring during the conduct of the study.

Mr. Joe Beasley, Ms. Virginia Warren, and Ms. Wilma Fairman of the CAMI Clinical Operations Branch, for their support for physical examinations of the subjects.

Messrs. Chuck Valdez, Dale Nelson, Jim Whitley, and Dave Hehmeyer of the Airman Education Programs Branch for their support in operating the CAMI altitude chamber and providing inside monitoring for the 8,000 ft performance tests.

Messrs. Fenton Winters, David Dyer, and Ellis Young, for photographic documentation.

Table of Contents

Table of Tables

PERFORMANCE EVALUATION OF THE PURITAN-BENNETT CREWMEMBER PORTABLE PROTECTIVE BREATHING DEVICE AS PRESCRIBED BY PORTIONS OF FAA ACTION NOTICE A-8150.2

INTRODUCTION

Mr. Kenton D. Warner, Chemical Products Manager for Puritan-Bennett, sent a letter to Dr. W.E. Collins, Acting Manager of CAMI, June 17, 1988, to request support in the performance testing of their crewmember portable protective breathing device (PBE). Dr. Collins authorized direct coordination with the Survival Research Unit and a performance evaluation was initiated.

TEST PROCEDURES

Tests of the devices for contaminant leaks, O_2, CO_2 levels, inhalation/exhalation pressure, and inhalation temperature were conducted in the CAMI test chamber with the duration and workload profile described in FAA Action Notice A-8150.2. The challenge gas within the test chamber was SF_6, maintained at a concentration of approximately 1% throughout the 15-minute test period. The SF_6 concentration was measured with a Perkin-Elmer (PE), Model 1100, Medical Gas Analyzer (mass spectrometer).

The PBE is designed as a hood with an oral-nasal mask that uses a chemically-generated source of O_2. The device works by using potassium superoxide to convert the wearer's exhaled water vapor and CO_2 to O_2, after an initial burst of O_2 which is generated by a chlorate candle when the PBE is first activated. The amount of O_2 flow, therefore, is not constant, rather is dependent upon the quantity of water vapor and CO_2 supplied in the wearer's exhaled breath.

The chemical generator is mounted externally on the lower posterior portion of the hood, and attached to effluent valves in the oral-nasal mask by soft plastic tubes to form a closed loop. The oral-nasal mask fits snugly over the wearer's mouth and nose, preventing exchange of gases at its exterior edges. Exhaled CO_2 and water vapor exit the oral-nasal mask through the valves and travel to the generator, which then disperses the newly formed O_2 to be inhaled from the hood. Except for the small quantity of air remaining in the dead space in the oral-nasal mask, the wearer is provided at each breath with air essentially free of water vapor and CO_2.

Samples were obtained each minute from the test chamber, from the oral-nasal mask, and from within the PBE outside the oral-nasal mask. Concentration values were resolved electronically to the nearest 1%, and estimated visually to the nearest 0.5% of the challenge atmosphere. The O_2 and CO_2 concentrations were also measured continuously with a second PE Medical Gas Analyzer (MGA). Signals from the MGA were fed directly to a

Analyzer (MGA). Signals from the MGA were fed directly to a Compaq Portable III computer, where data were stored and treated for each test run. Continuous pressure measurements, made with a Stathem pressure transducer, and temperature measurements (in °C), using a copper-constantan thermocouple, were taken within the oral-nasal mask. These responses were also fed to the computer for data storage and handling.

Prior to testing, the tests and objectives were fully described to the subjects, after which they executed an informed consent form. Subjects were then given a physical examination including an exercise stress test at the workload prescribed by the Action Notice.

Performance testing was conducted on a day after the physical exam and workload screening. On the day of the test, subjects received an additional medical screening before viewing a videotape, which described the functioning of the PBE and the proper donning procedure. They then were fitted with plain eye glasses and had an opportunity to practice the donning of a PBE. Subjects were fitted with EKG electrodes and a blood pressure cuff for medical monitoring. After adjusting the bicycle ergometer seat to the correct height, the PBE was donned and activated. The chamber door was closed and the SF_6 introduced. As the SF_6 concentration reached 1% the subject was instructed to begin pedalling the bicycle ergometer. When the subject achieved a rate of 50 rpm, the beginning workload was applied and the 15-min test protocol begun.

Subjects then followed the workload prescribed in the Action Notice, i.e.:

00 to 05 minutes at 0.33 watts/lb body weight
05 to 07 minutes at 0.66 watts/lb body weight
07 to 12 minutes at 0.50 watts/lb body weight
12 to 14 minutes at 0.66 watts/lb body weight
14 to 15 minutes at 0.33 watts/lb body weight

To partially comply with one of the requirements of TSO C-99, subjects moved their heads slowly from side to side (as though scanning instruments) during the seventh minute, moved their heads up and down during the tenth minute, and recited their "ABC's" aloud during the 13th minute of the test.

For subject safety during the test, heart rate (HR) and EKG were monitored continuously and blood pressure periodically.

RESULTS

The first series of tests were begun August 1, 1988. Only eight tests were completed when it became obvious that the devices leaked significantly at the neck seal if subjects had small neck circumferences. The neck seals were constructed of a 0.003" polyurethane film with the neck opening 3.25 " in diameter. At the request of Puritan-Bennett, testing was stopped and was resumed only after modifications could be made to the neck seal. The data from these tests are available, but are not presented in this report.

The second phase of testing began September 14, 1988. Initially, the modified neck seal was made of 0.012" latex with a neck opening of 3.00". This appeared to solve the problems associated with the neck seal leakage, until subjects F-5 and F-6 (Figs. 1 and 2, p. A-3) were tested and the neck seal leakage reappeared. The diameter of the neck seal opening was then reduced to 2 1/2" and these two subjects retested. This eliminated the neck seal leakage problem for these subjects (Figs. 7 and 8, p. A-6).

Even though the challenge gas leakage problem at the neck seal-neck interface appeared to be solved with the implementation of a latex neck seal with an opening of 2 1/2 inches in diameter, there were other leakage problems with five of the test devices. To determine the source of the leaks, those failed devices were first examined visually. For one of the devices, it was obvious that the leaks were from breaks in the seams of the material. For those devices where leak sources could not be determined visually, the devices were placed with the neck seal over a stainless steel cylinder and then filled with one percent SF_6 and the sampling tube of the mass spectrometer passed over the possible sources of leakage until the leak site was located. There were leaks at the seams and hardware (tightening straps) attachment points.

At least two of the devices failed because of excessive CO_2 concentrations within the oral-nasal mask. On visual inspection, it was found that the flapper on one of the exhalation valves was inverted on its support ring (probably caused by the flushing action of the initial surge of O_2 from the chlorate candle), thus preventing the complete clearance of the exhaled breath from the mask. (The graphs of the CO_2 concentrations for these two tests are on page C-3 of Appendix C).

On September 23, Puritan-Bennett requested another break in the testing schedule until these leak problems could be solved by improved quality control procedures.

The third phase of testing was begun on October 11th. All of the tests conducted in the earlier phase, for which there was an adequate protection from the challenge gas, were accepted as representing adequate quality control, and only the failures due to PBE leakage (not from the neck seal) were retested during this final phase. This required the testing of PBE's for 10 males and 5 females, which we felt to be an adequate sample for verifying the needed quality control. These tests were completed on October 19.

The modifications made for added support of the exhalation valve were satisfactory and no new problems with CO_2 were found. Only one test resulted in an unsatisfactory SF_6 leakage and this subject was retested with another PBE.

In addition to the tests run at ground level (Oklahoma City is about 1,300 ft above sea level), three male subjects repeated the test protocol in the CAMI altitude chamber at 8,000 ft simulated altitude for all parameters except the contaminant leak portion of the test. This was done to establish that tests at cabin altitude would not differ significantly from those conducted at ground level.

The test results for these three subjects have been plotted on the same graphs for O_2 concentrations, CO_2 concentrations, inhalation/exhalation pressures, and inhalation temperatures for both altitudes. The graphs for all measured parameters for these three subjects are found in Appendix F.

Table I gives the physical description of the 12 male and 12 female subjects tested while using PBE for which the results of the tests were satifactory. Two of the females were tested with the smallest (2 1/2") diameter neck seal. Based on the anthropometry data cited, the 5th percentile in weight for females is 106 lbs (3) and the 5th percentile female neck circumference is 12.2 " (310 mm) (3). The 95th percentile weight and neck circumference for males are 220 lbs and 16.1" (409 mm), respectively (10).

Results are presented below according to the parameter specifications of the Action Notice.

<u>Contaminant-Leakage:</u>

The results of the contaminant leak tests are presented in graphic form in Appendix A. The SF_6 levels within the PBE were measured once per minute through the profile prescribed by the Action Notice and are presented as a decimal fraction of the challenge atmosphere. The value plotted represents the average of the three values measured: i) within the oral-nasal mask, ii) within the left side of the PBE interior outside the mask, and iii) within the right side of the PBE interior outside the mask.

A successful test required that the average SF_6 level for the 15-min period not exceed 5% of the challenge atmosphere, and that not more than three of the individual measurements could exceed that level, regardless of the 15-min average. The individual graphs of the tests for all 24 subjects are presented in Appendix A. Table II presents the 15-min averages for each subject and the number of points which exceeded the 5% level.

TABLE I
PHYSICAL CHARACTERISTICS OF TEST SUBJECT POPULATION

Subject Number	Age (yrs)	Height (in.)	Weight (lbs.)	Neck Cir (in./mm)	FVC (L)
		Female	Subjects		
F-1	19	67.50	148.00	12.8/325	4.53
F-2	19	63.75	112.00	13.0/330	3.69
F-3	35	69.75	131.50	12.7/323	4.64
F-4	24	59.00	111.25	11.8/300*	3.42
F-5	32	65.50	122.00	12.2/310*	4.10
F-6	25	65.50	113.00	11.4/290*	3.92
F-7	35	69.75	141.50	12.6/320	5.70
F-8	19	67.50	144.00	12.7/323	4.37
F-9	29	68.75	156.00	13.1/333	4.65
F-10	23	60.50	98.50*	11.3/287*	3.44
F-11	20	66.38	135.50	12.2/310*	4.76
F-12	20	63.50	111.50	11.9/302*	3.93

*At or below the fifth percentile.

Subject Number	Age (yrs)	Height (in.)	Weight (lbs.)	Neck Cir (in./mm)	FVC (L)
		Male	Subjects		
M-1	26	71.50	130.00	14.2/361	5.00
M-2	34	68.00	147.25	15.2/386	5.91
M-3	33	70.00	147.00	14.0/356	5.83
M-4	30	75.75	211.50	15.9/404	7.01
M-5	27	71.00	170.00	14.5/368	5.98
M-6	24	72.00	161.25	15.6/396	5.35
M-7	33	69.00	161.00	13.1/333	5.78
M-8	20	71.50	120.50	13.9/353	4.90
M-9	27	71.50	165.00	15.5/394	6.77
M-10	25	68.00	149.25	15.9/404	5.70
M-11	31	73.00	224.00*	16.6/422*	6.20
M-12	23	74.75	183.75	15.5/394	6.46

* At or above the ninety-fifth percentile.

TABLE II
Contaminant Leak Values for Individual Tests

Subject Number	15-min Average	Points Above 5%	Subject Number	15-min Average	Points Above 5%
F-1	.016	0	M-1	.036	0
F-2	.034	0	M-2	.010	0
F-3	.018	0	M-3	.017	0
F-4	.032	0	M-4	.015	0
F-5	.035	0	M-5	.037	0
F-6	.013	0	M-6	.016	0
F-7	.025	0	M-7	.011	0
F-8	.020	0	M-8	.009	0
F-9	.017	0	M-9	.026	0
F-10	.034	2	M-10	.016	0
F-11	.016	0	M-11	.012	0
F-12	.022	0	M-12	.033	0

The population from which the percentiles are derived is an important consideration to the test procedure. Yet, no known data source for the current airline crew population is available. The two graphs that follow demonstrate data for the mean, ± 1, and ± 2 standard deviations for four female populations and four male populations, with the minimum (T MIN) and maximum (T MAX) measurements for each gender from our test population .

As shown, the maximum neck circumference for our test populations (both female and male) exceeded the mean plus two standard deviations for all of the reference populations. The minimum neck circumference for our test populations was larger than the mean minus 2 standard deviations for two of the reference populations for both males and females.

Inhalation Oxygen Concentration:

Although the level of O_2 concentration is not specifically defined in the Action Notice, the O_2 level was measured inside the oral-nasal mask; this concentration always increased throughout the 15-min test period, with no measurements dropping below the normal ambient level of 21%.

Oxygen concentration, across time, has been graphed for all 24 subjects. These graphs are presented in Appendix B.

Inhalation Carbon Dioxide Concentration:

The performance requirement 2.(a) states that the CO_2 concentration level at mouth/nose shall not exceed 4%, although the concentration may increase to 5% for a period not exceeding 2 minutes. None of the values exceeded even the 4% level, so there was no need to determine the average level for the 15-min period.

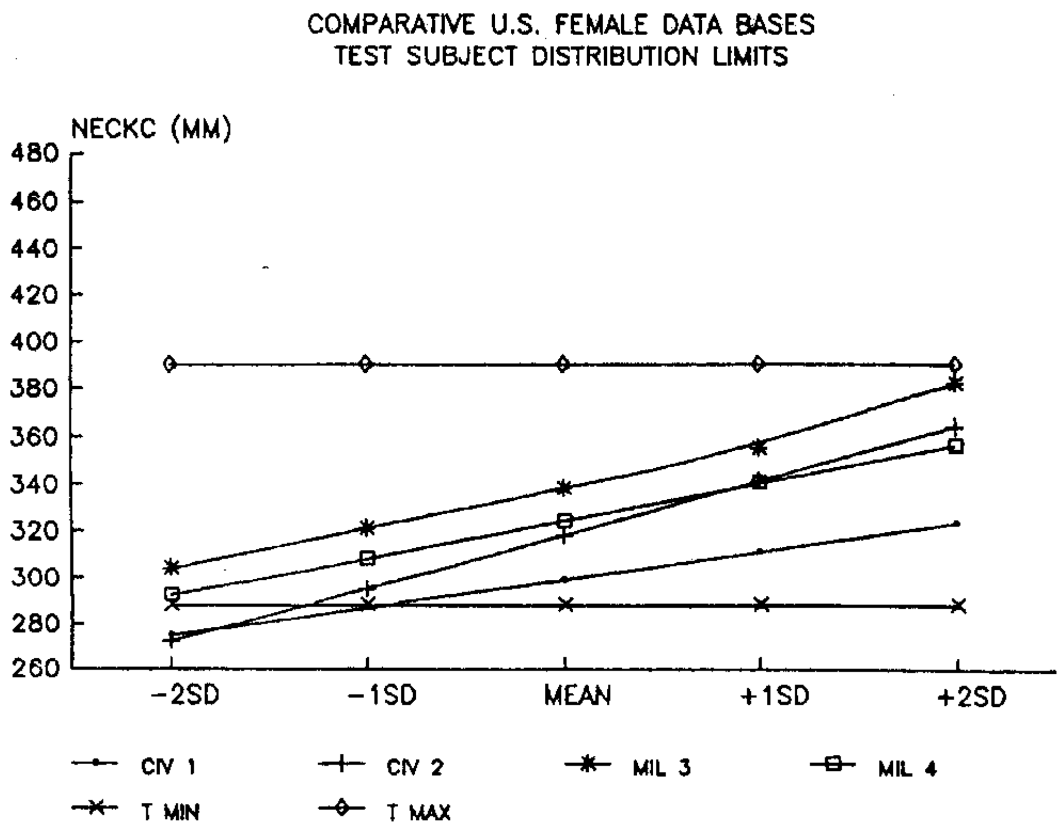
The results of the measured CO_2 levels are presented for all 24 subjects in Appendix C. Both minimum and average values are presented.

Internal PBE Temperature:

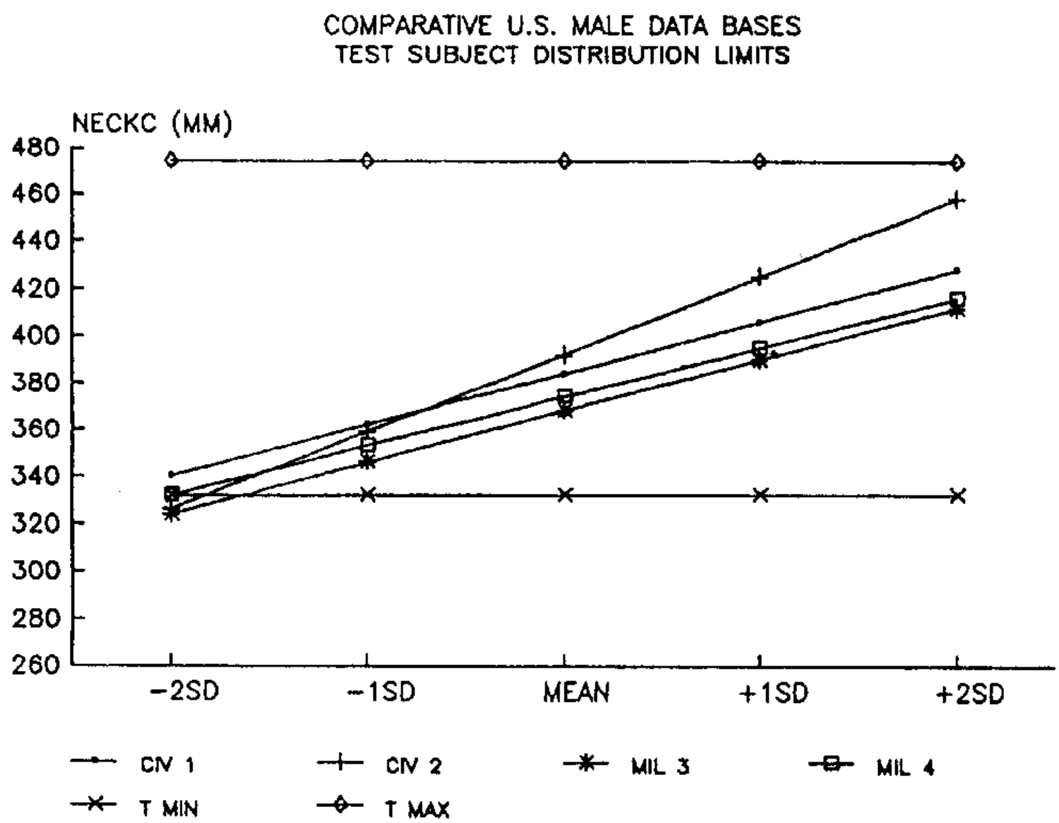
Requirement 5 states: "The internal temperature of the device shall not exceed 40°C, wet bulb, at an ambient temperature of 21°C. With the measurement system used, we were able to measure only dry bulb temperature. However, since the dry bulb never exceeded 40°C, it was not necessary to have the wet bulb. The temperature measurements are presented in graphs for all 24 subjects in Appendix D.

Inhalation/Exhalation Pressures:

Requirement 8 specifies: "The breathing resistance shall not exceed 3 1/2 inches of water from sea level to 8,000 ft



1=CAMI-71 2=CAMI-DB 3=USAF-68 4=USA-77



1=ATC-65 2=CAMI-DB 3=USAF-65 4=USA-66

altitude. The measured pressures are presented in Appendix E. All values were well within the specified limits.

Altitude Comparison Tests:

Although O_2 concentrations were lower at 8,000 ft altitude than at ground level for all three subjects, the concentrations were well above 21% in all instances (pps. F-2 through F-4). Carbon dioxide values were higher at ground level for two subjects and higher at 8,000 ft for one subject, but again all values were well within the acceptable limits (pps. F-5 through F-7). The comparisons of inhalation/exhalation pressures are found on pps. F-8 through F-10, and inhalation temperatures are depicted on pps. F-11 through F-13.

CONCLUSIONS

The iterative process necessary for this series of tests, i.e., assessing performance, identifying problems, correcting the identified problems and retesting, proved to be a good method of assuring that this particular PBE is suitable for its intended use.

To summarize this process: First, the neck seal material was not elastic enough and a more suitable material was identified and substituted. Second, the size of the opening of the neck seal had to be reduced to be protective for the smaller individuals tested; this was accomplished successfully. Then, identification of increased CO_2 resulting from the occasional inversion of the exhalation valve was found, which was solved by improved valve design. Finally, leaks encountered at locations other than neck seals were overcome by more impermeable seams and hardware seals obtained through improved quality control.

Thus, with adequate quality assurance, the final version of the Puritan-Bennett crewmember portable protective breathing device, as tested at CAMI, would meet the requirements of FAA's Action Notice 8150.2 regarding contaminant leak protection, O_2 concentration, inhaled CO_2 concentration, inhalation/exhalation pressures and inhalation temperature.

REFERENCE ANTHROPOMETRY DATA PUBLICATIONS FROM IN NASA 1024**

FEMALE DATA

* 01 DATA SOURCE: #1 FEMALE CIV, FAA-AM-75-2, 1975 (1971)
N = 422 AGE = 19-28

02 DATA SOURCE: #2 FEMALE CIV, USDA MISC PUB NO. 454, 1941
N = 10,042 AGE = --- (CAUCASIAN ONLY)

* 03 DATA SOURCE: #7 FEMALE MIL, USAF AMRL TR 70-5, 1972 (1968)
N = 1905 AGE = 18-57

04 DATA SOURCE: #10 FEMALE MIL, USAF AMRL TR 70-5, 1972 (1968)
N = 131 AGE = 18-57 (NEGROID SUBJECTS)

05 DATA SOURCE: #11 FEMALE CIV, NAT HEALTH EXAM SURVEY 1962
N = 3581 AGE = 18-79

06 DATA SOURCE: #101 FEMALE CIV, HANES, PHS 51-1317, SER. 1, NO. 15
N = 5359 AGE = 18-65

MALE DATA

* 07 DATA SOURCE: #13 MALE CIV, FAA-AM-65-26, 1965
N = 678 AGE = 21-46

08 DATA SOURCE: #18 MALE MIL, USAF WADC TR 52-321, 1954
N = 4000 AGE = 18-45

* 09 DATA SOURCE: #19 MALE MIL, USAF 1965 UNPUB
N = 3859 AGE = ---

* 10 DATA SOURCE: #30 MALE MIL, USANL TR 72-51-CE, 1971 (1966)
N = 6682 AGE = 17-55

11 DATA SOURCE: #31 MALE MIL, USN SURVEY 1966 UNPUB
N = 4095 AGE = 17-31

12 DATA SOURCE: #37 MALE CIV, NAT HEALTH EXAM SURVEY 1962
N = 3091 AGE = 18-70

13 DATA SOURCE: #101 MALE CIV, HANES, PHS 51-1317, SER. 1, NO. 15.
N = 4871 AGE = 18-65

REFERENCE ANTHROPOMETRY DATA PUBLICATIONS NOT IN NASA 1024**

FEMALE DATA

* 14 DATA SOURCE: FEMALE MIL, USANL TR 77/024 & 028, 1977
N = 1330 AGE = 17-55

* 15 DATA SOURCE: FEMALE CIV, FAA CAMI-DB, 1988
N = 373 AGE = 17-68

MALE DATA

* 16 DATA SOURCE: MALE CIV, FAA CAMI-DB, 1988
N = 373 AGE = 17-68

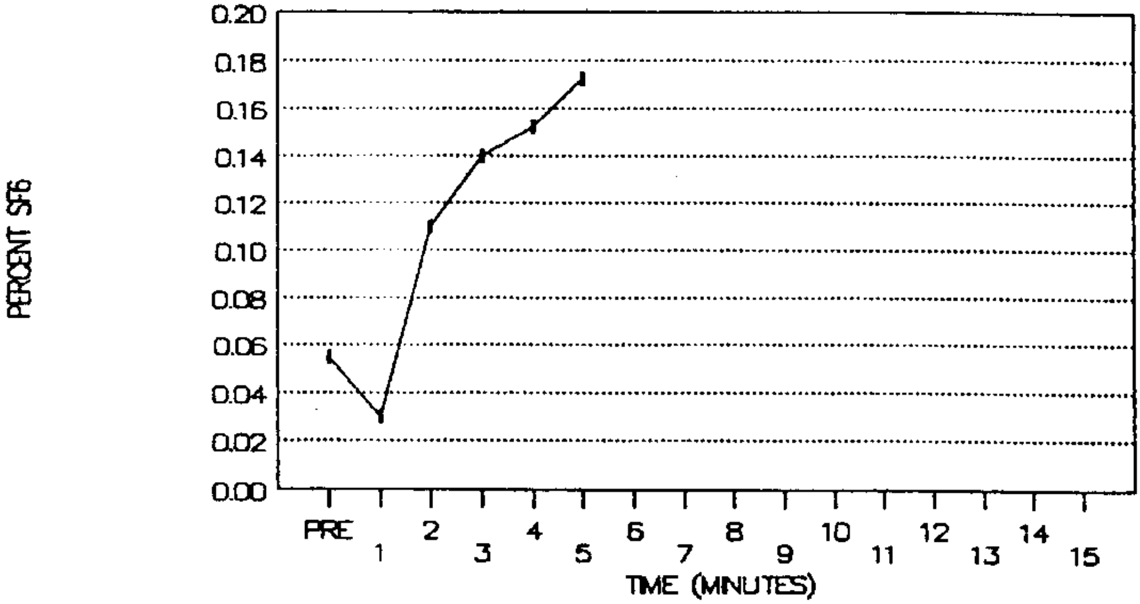
* = Sources used for graphs.

**NASA <u>Reference Publication 1024, Anthropometric Source Book, Edited by Staff of Anthroplogy Research Project</u>, Webb Associates, Yellow Springs, Ohio, NASA Scientific and Technical Information Office, 1978.

APPENDIX A

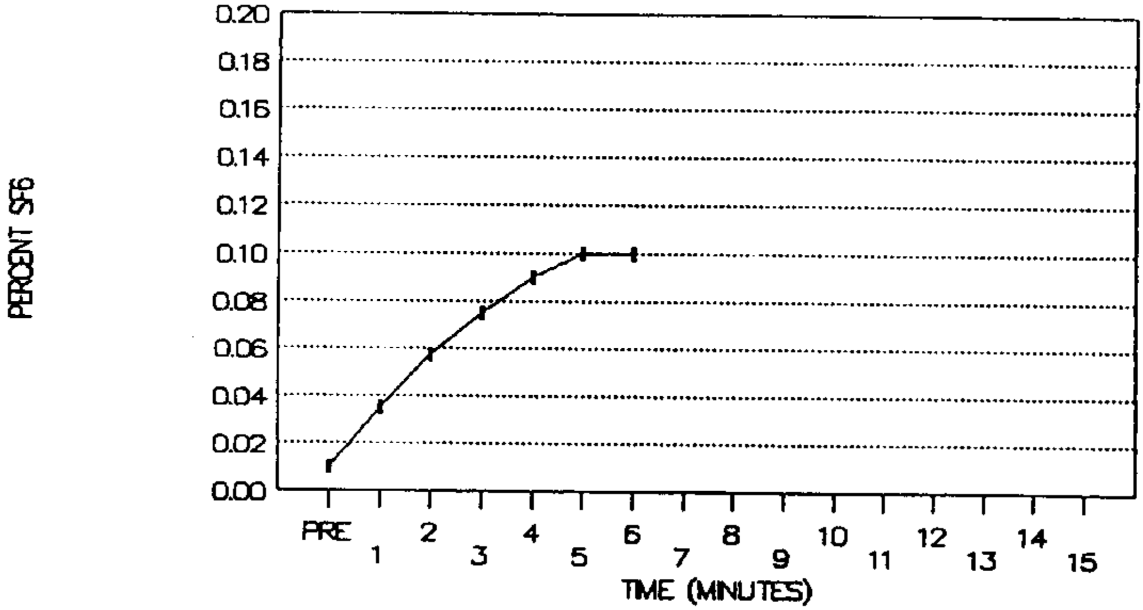
Individual Graphs of Contaminant Leak Tests - Internal PBE Concentrations as Decimal Fraction of Challenge Atmosphere Through Time.

PURITAN CREW PBE INFILTRATION
SUBJECT F-5, 3.0 INCH NECKSEAL



-Figure 1-

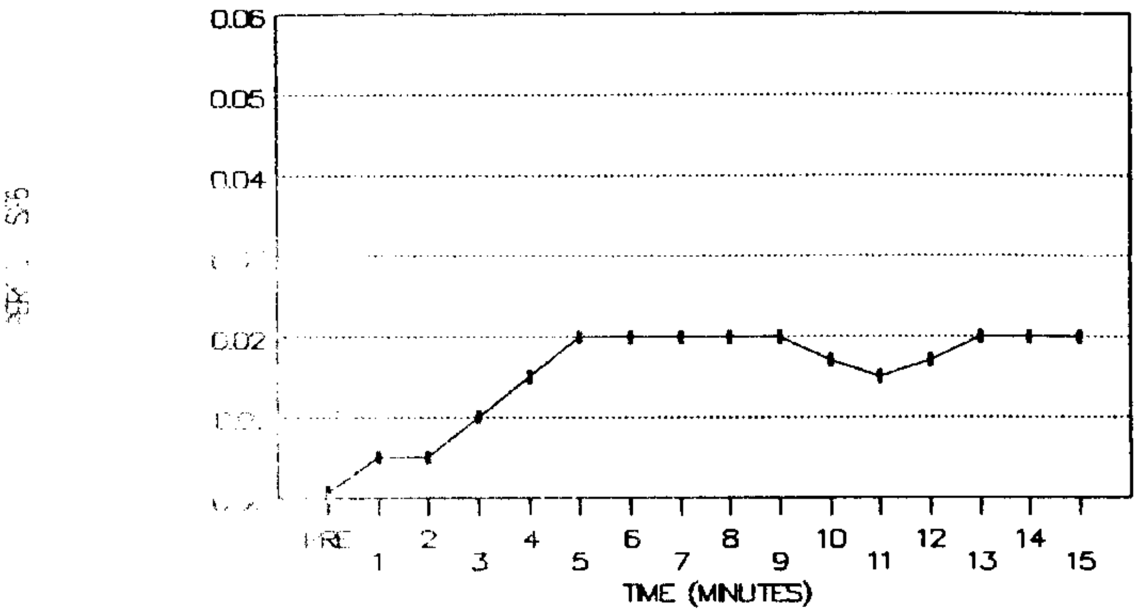
PURITAN CREW PBE INFILTRATION
SUBJECT F-6, 3.0 INCH NECKSEAL



-Figure 2-

PURITAN CREW PBE INFILTRATION

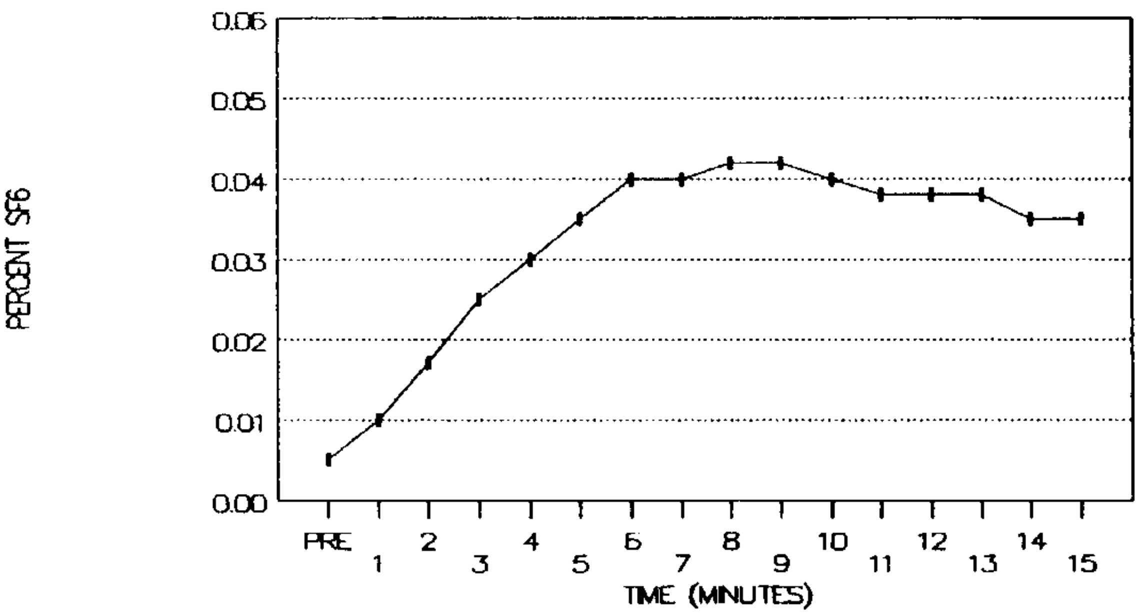
SUBJECT F-1



-Figure 3-

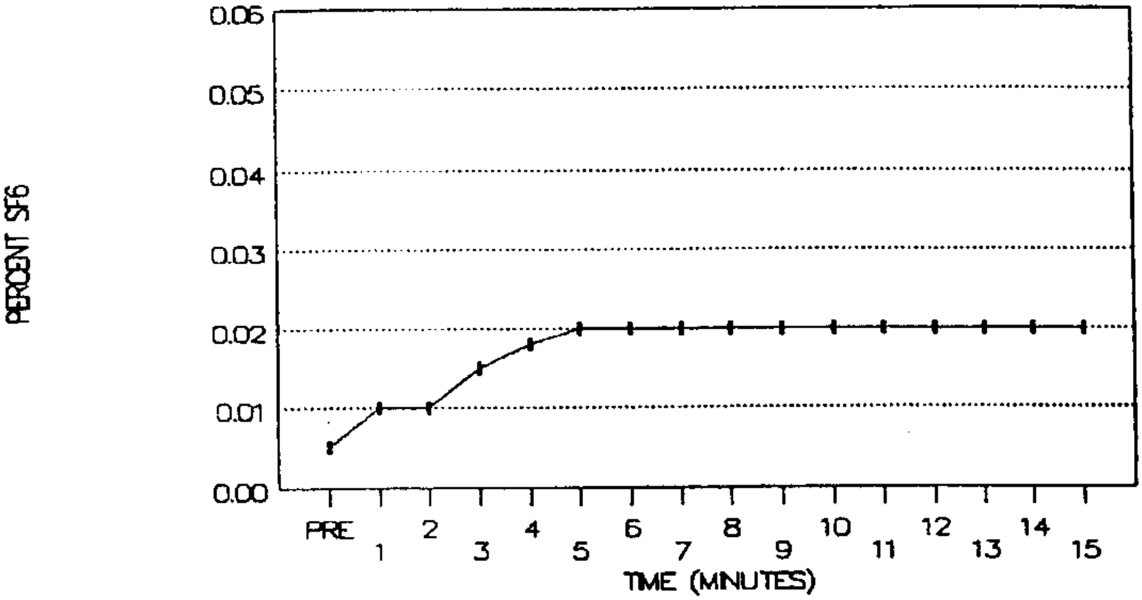
PURITAN CREW PBE INFILTRATION

SUBJECT F-2



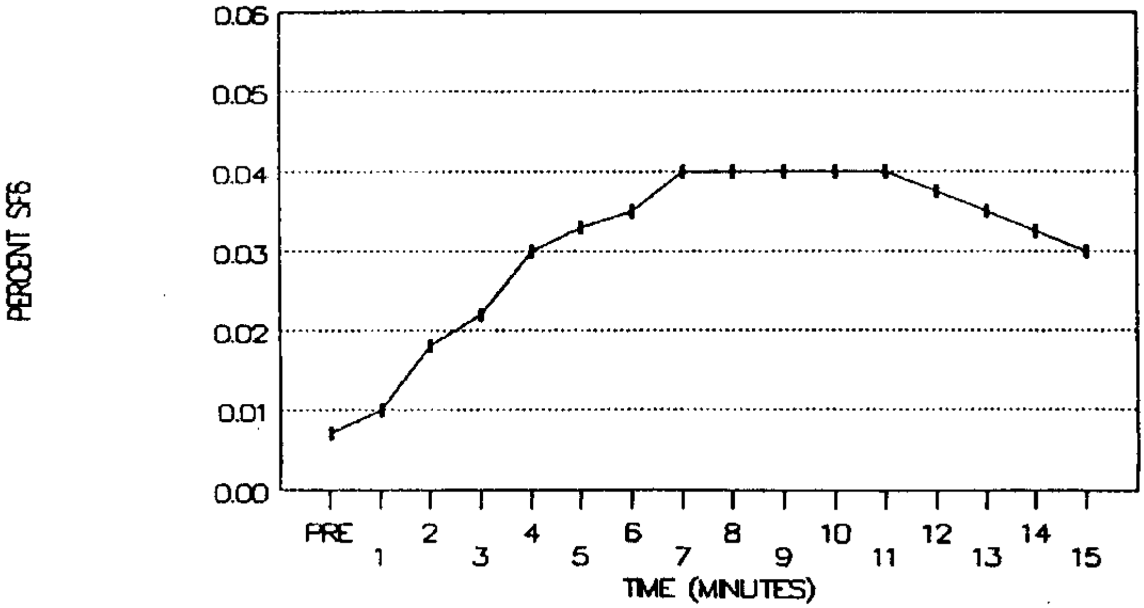
-Figure 4-

PURITAN CREW PBE INFILTRATION
SUBJECT F-3



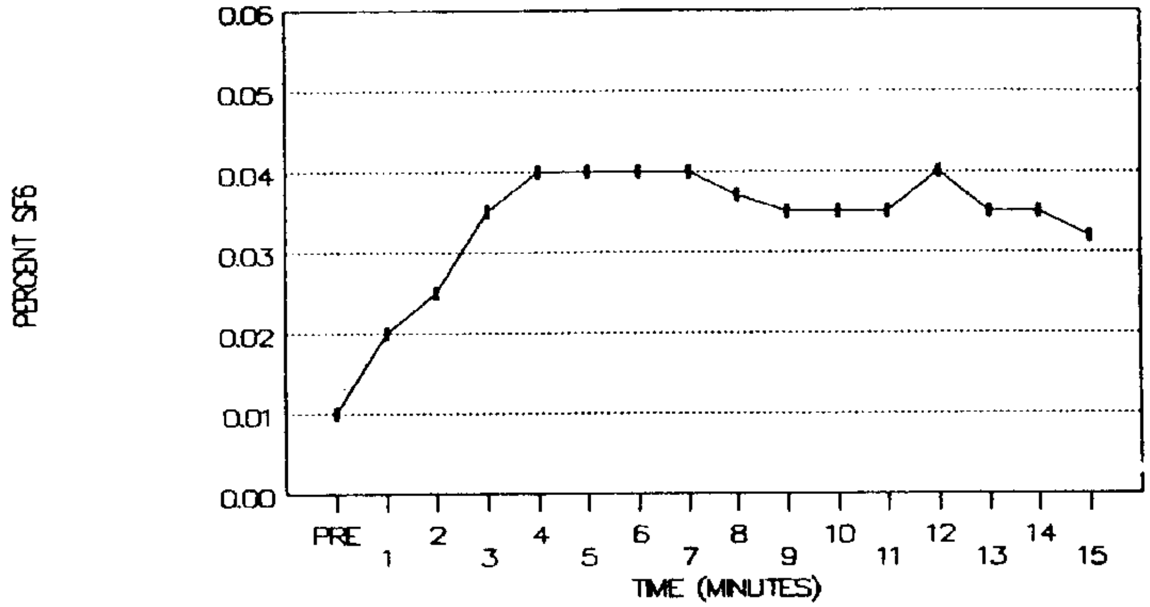
-Figure 5-

PURITAN CREW PBE INFILTRATION
SUBJECT F-4



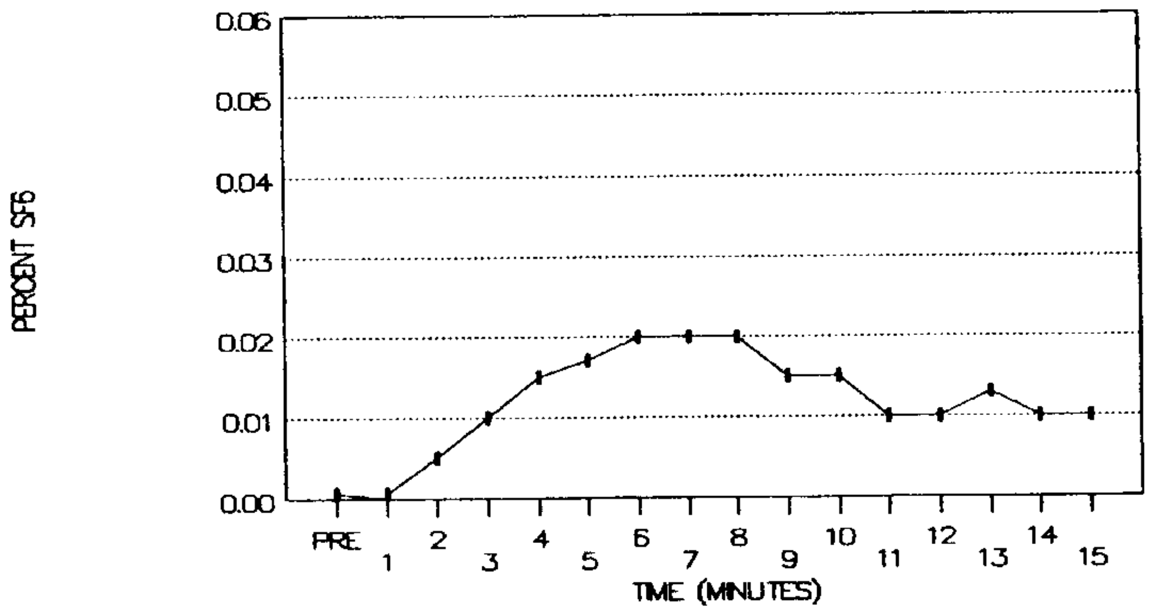
-Figure 6-

PURITAN CREW PBE INFILTRATION
SUBJECT F-5



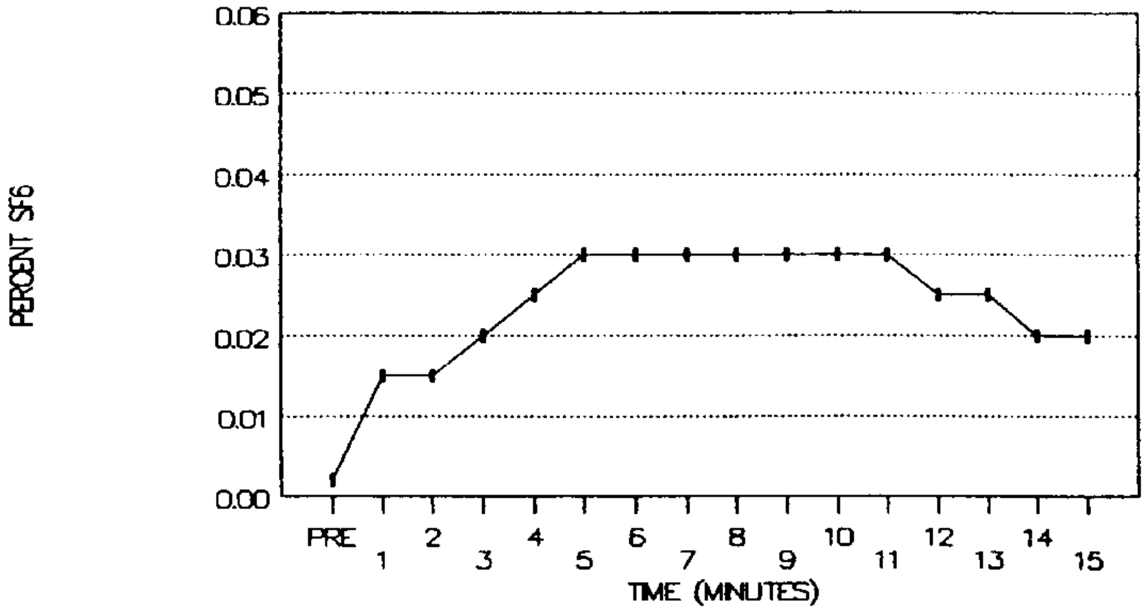
-Figure7-

PURITAN CREW PBE INFILTRATION
SUBJECT F-6



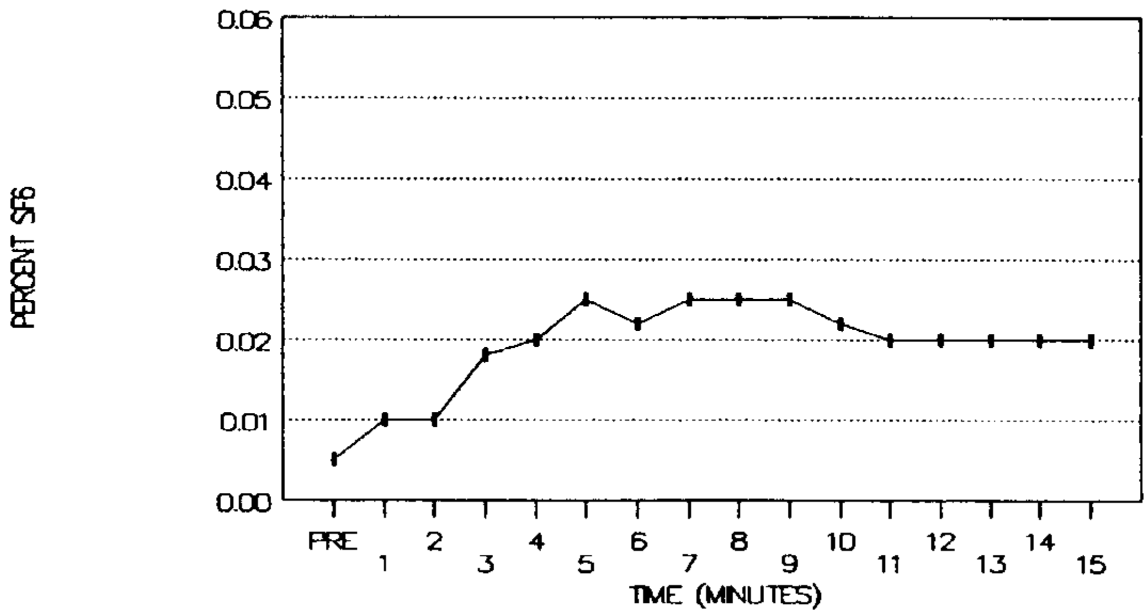
-Figure 8-

PURITAN CREW PBE INFILTRATION
SUBJECT F-7



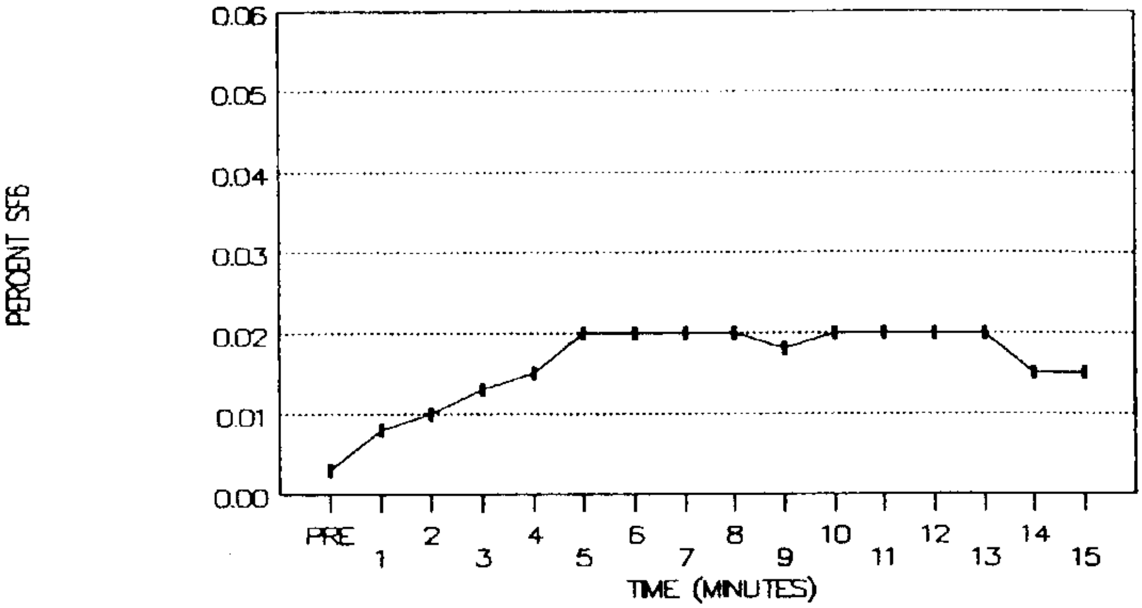
-Figure 9-

PURITAN CREW PBE INFILTRATION
SUBJECT F-8



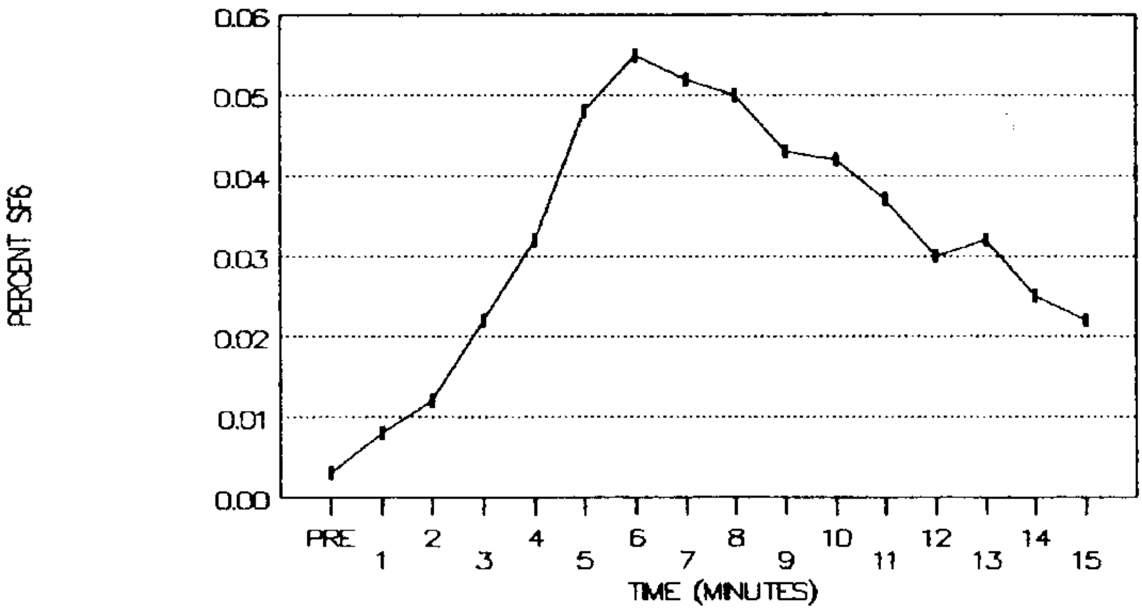
-Figure 10-

PURITAN CREW PBE INFILTRATION
SUBJECT F-9



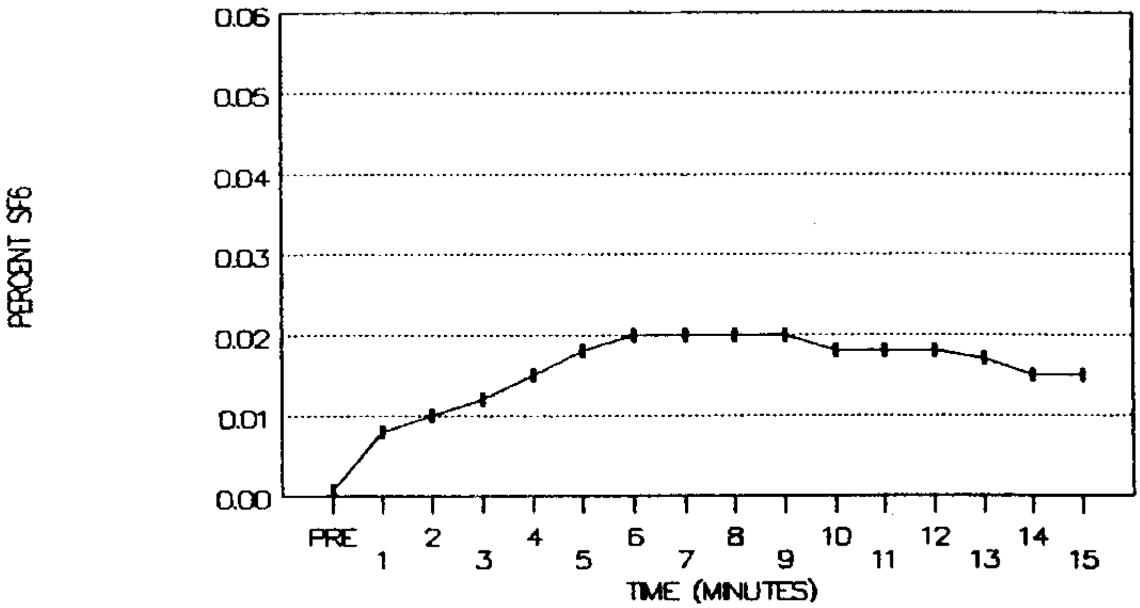
-Figure 11-

PURITAN CREW PBE INFILTRATION
SUBJECT F-10



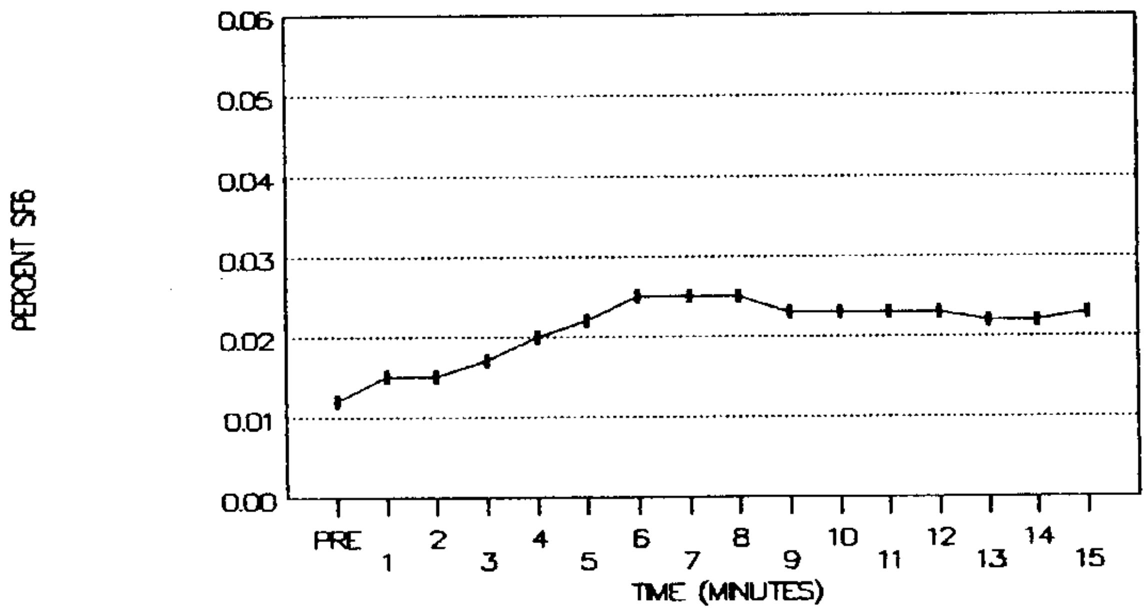
-Figure 12-

PURITAN CREW PBE INFILTRATION
SUBJECT F-11



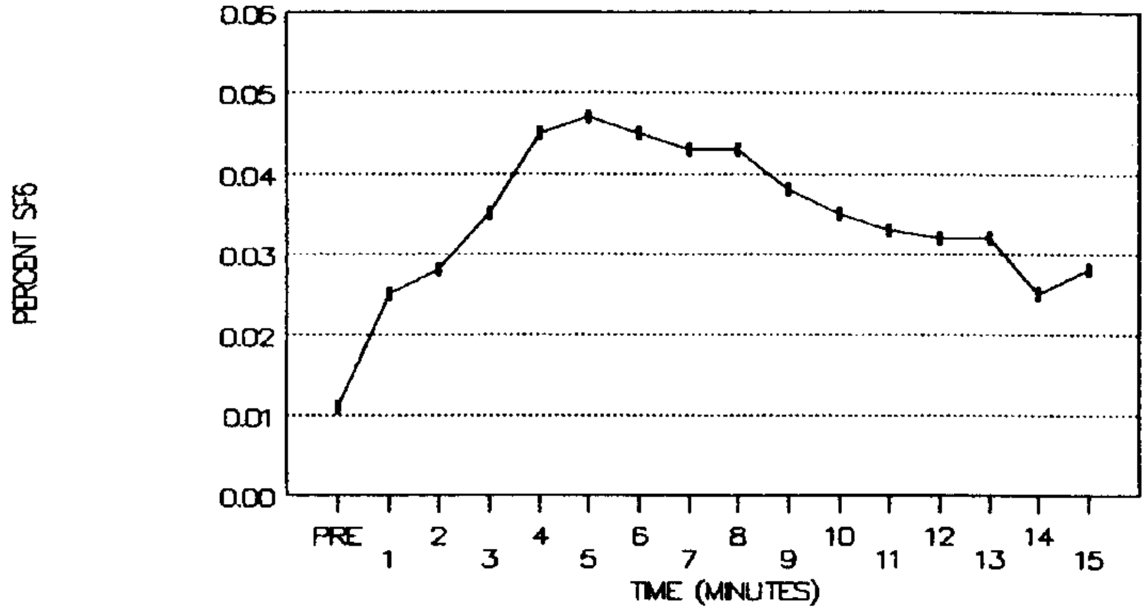
-Figure 13-

PURITAN CREW PBE INFILTRATION
SUBJECT F-12



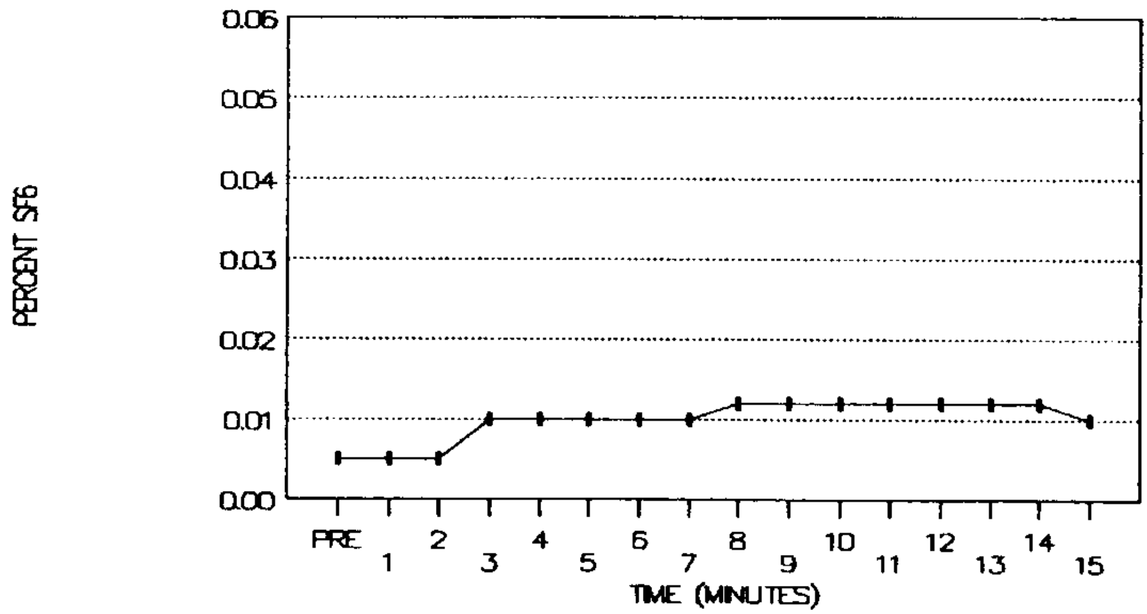
-Figure 14-

PURITAN CREW PBE INFILTRATION
SUBJECT M-1



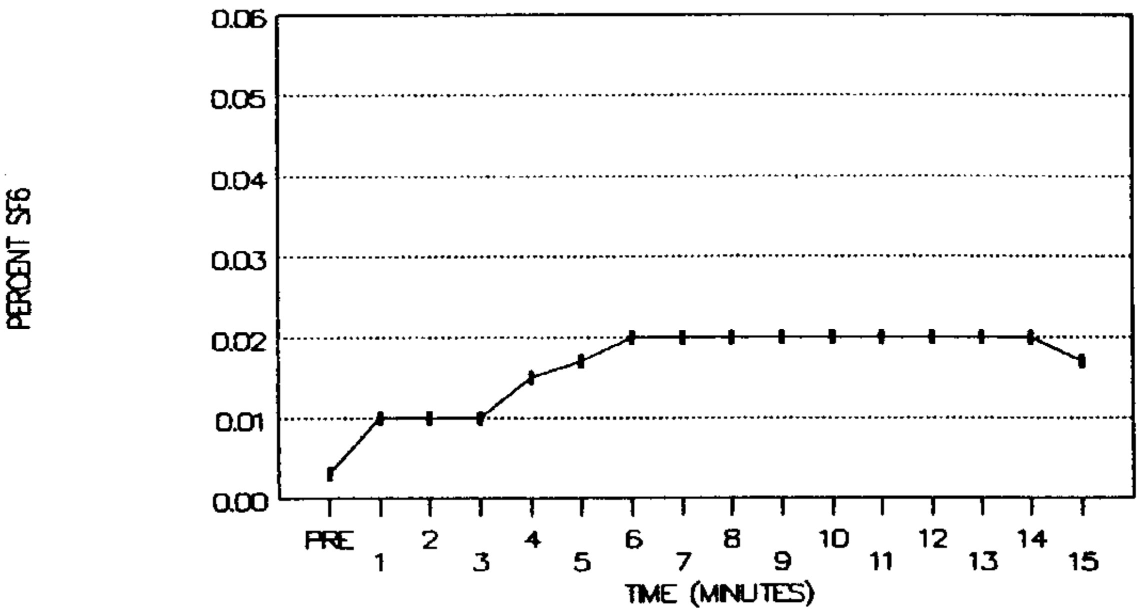
-Figure 15-

PURITAN CREW PBE INFILTRATION
SUBJECT M-2



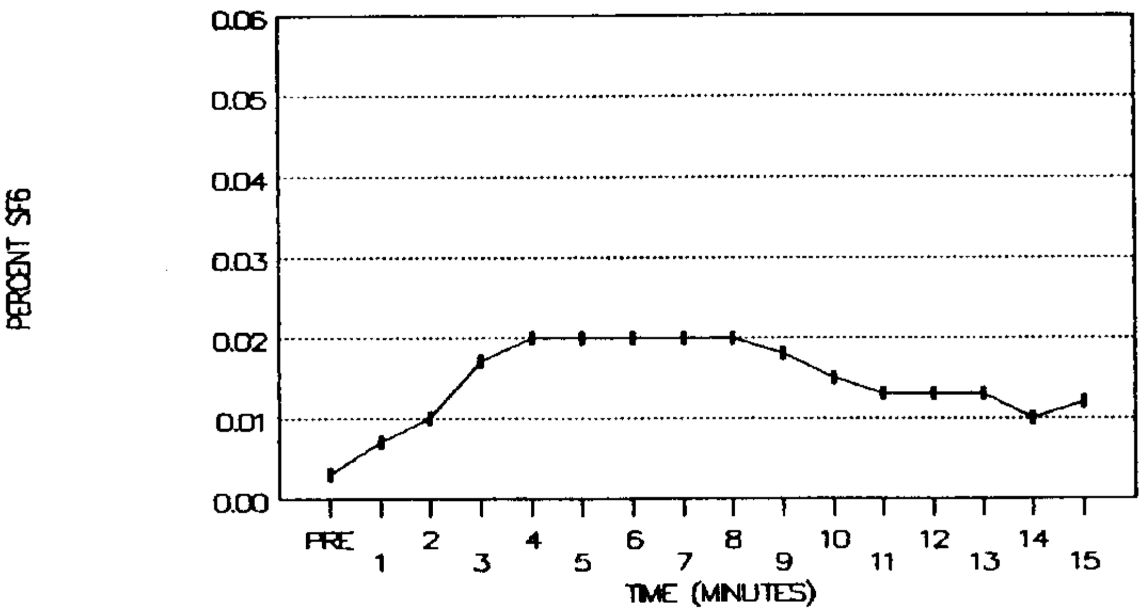
-Figure 16-

PURITAN CREW PBE INFILTRATION
SUBJECT M-3



-Figure 17-

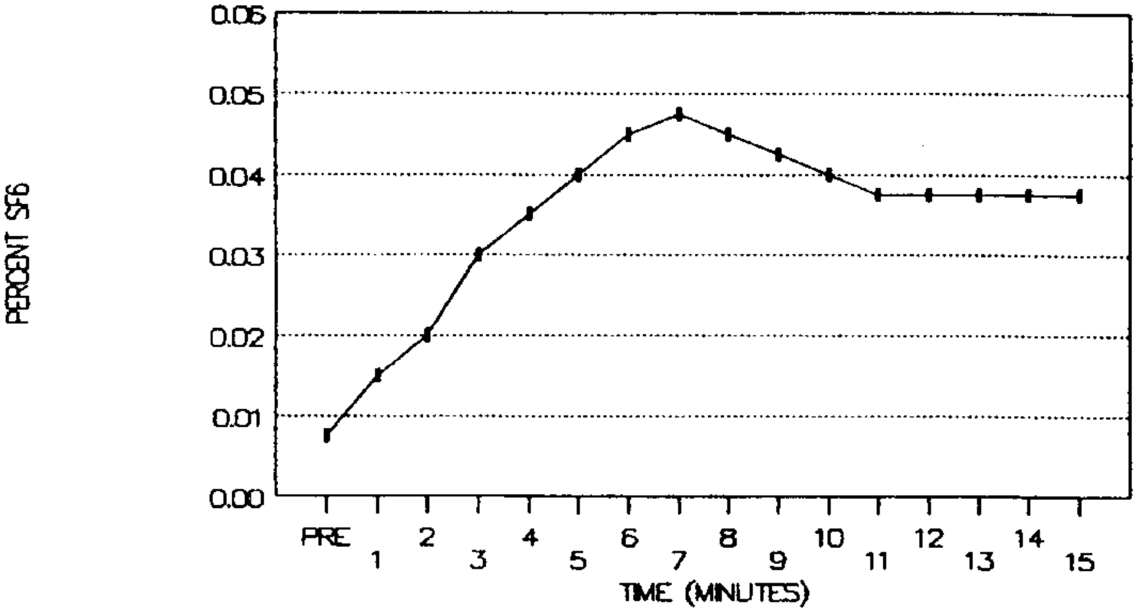
PURITAN CREW PBE INFILTRATION
SUBJECT M-4



-Figure 18-

PURITAN CREW PBE INFILTRATION

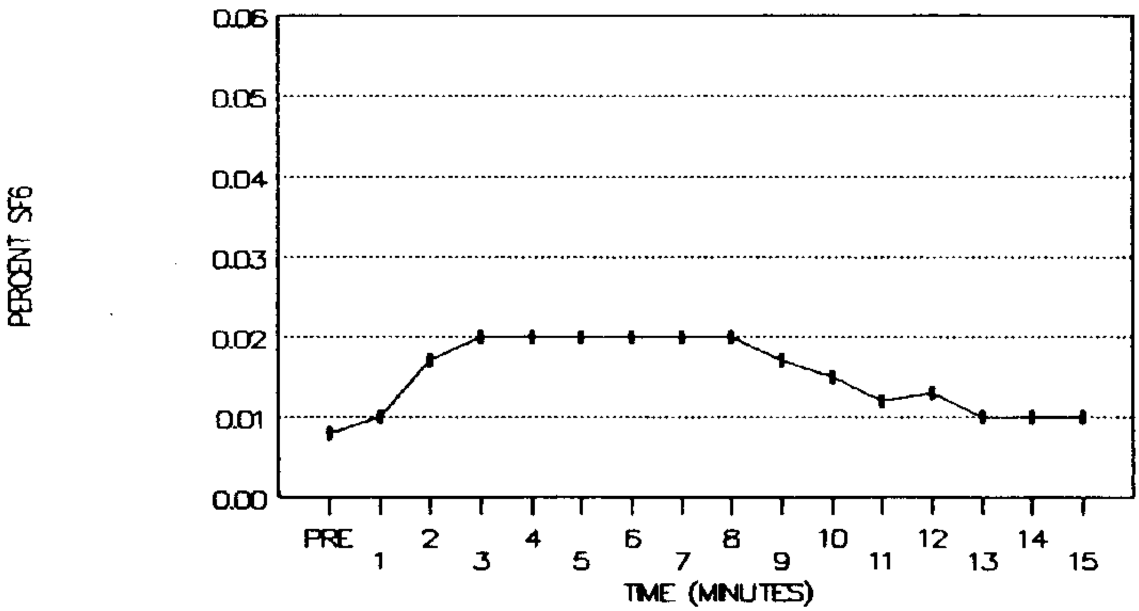
SUBJECT M-5



-Figure 19-

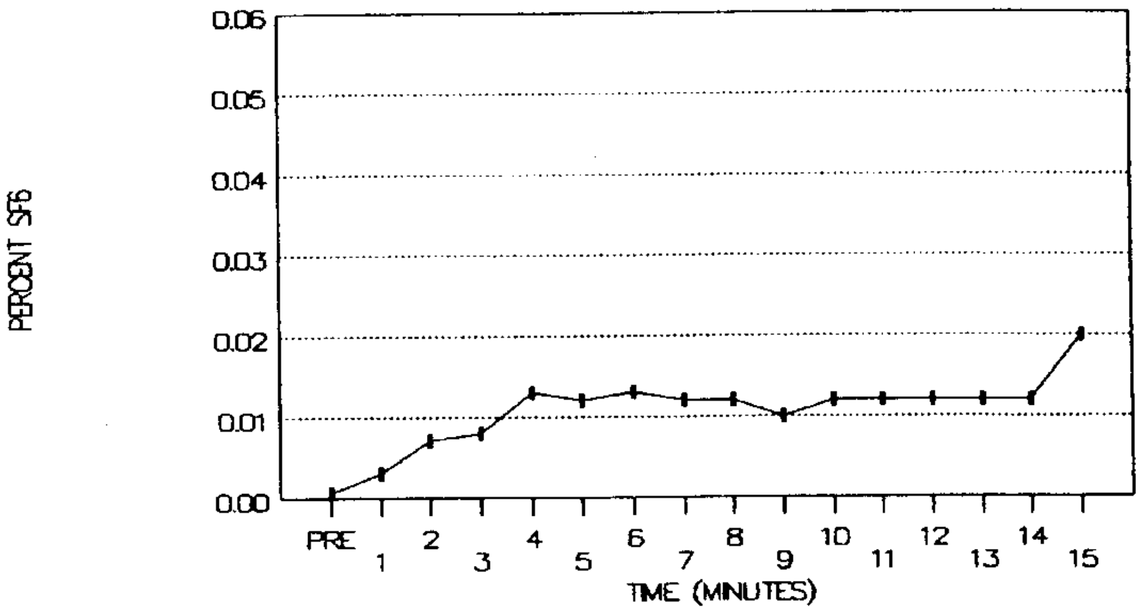
PURITAN CREW PBE INFILTRATION

SUBJECT M-6



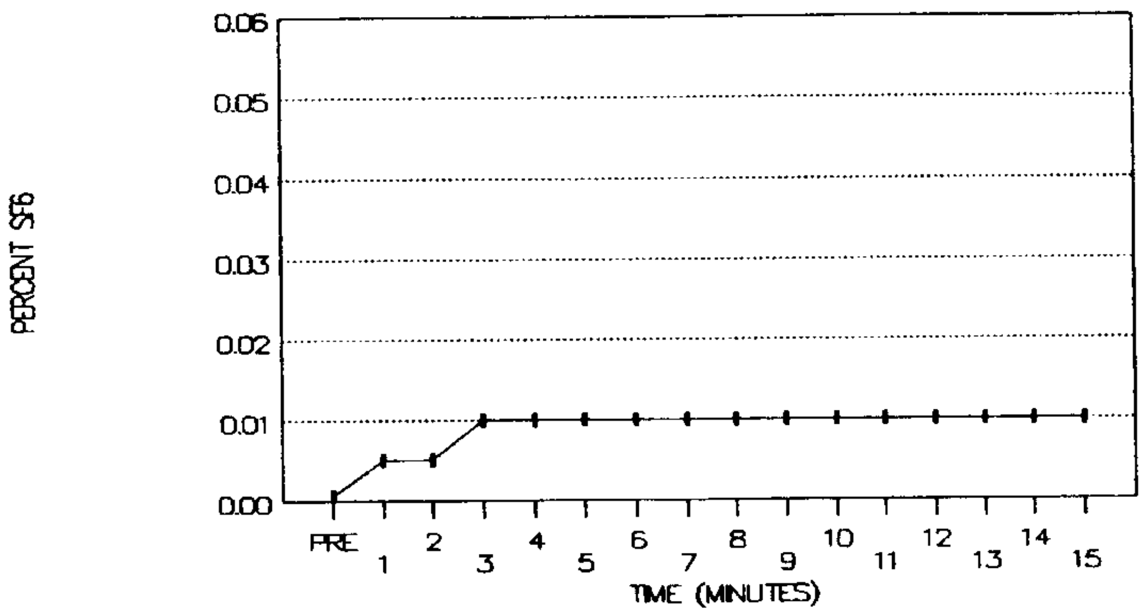
-Figure 20-

PURITAN CREW PBE INFILTRATION
SUBJECT M-7



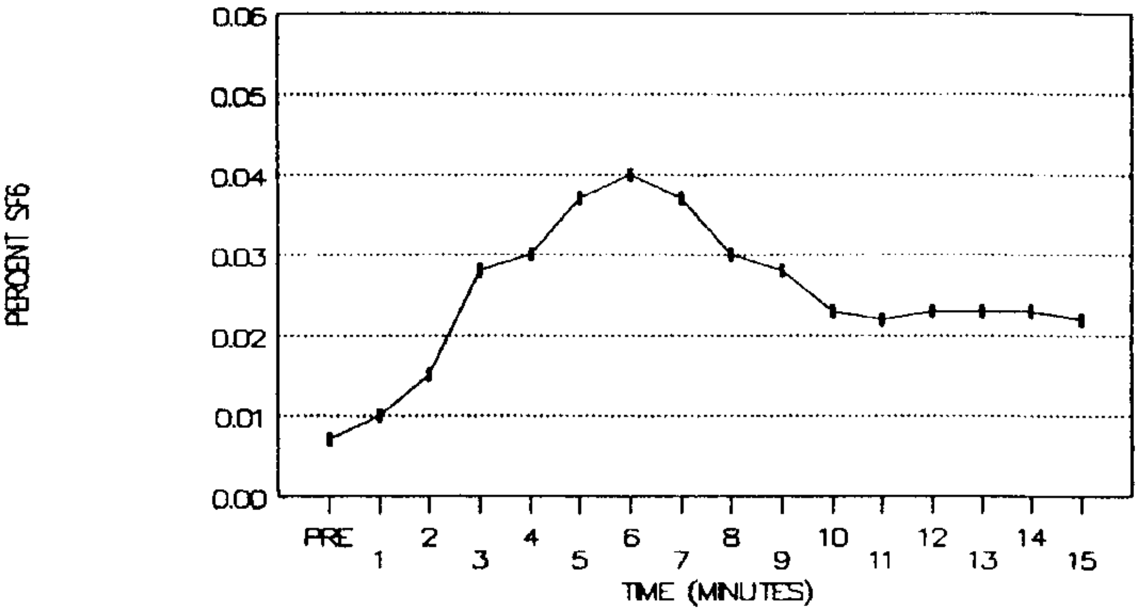
-Figure 21-

PURITAN CREW PBE INFILTRATION
SUBJECT M-8



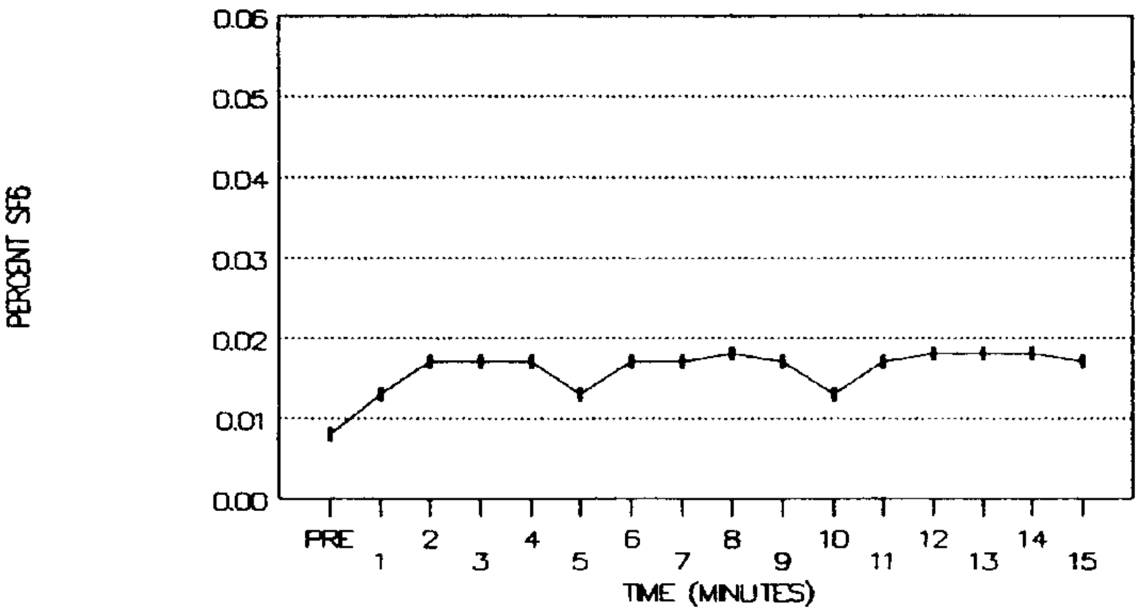
-Figure 22-

PURITAN CREW PBE INFILTRATION
SUBJECT M-9



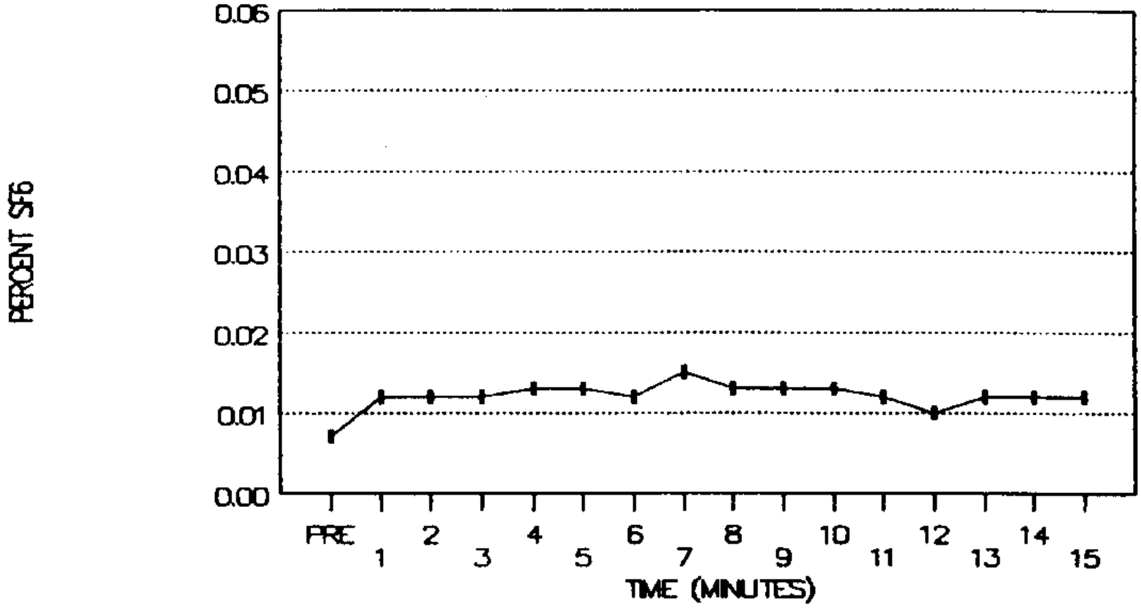
-Figure 23-

PURITAN CREW PBE INFILTRATION
SUBJECT M-10



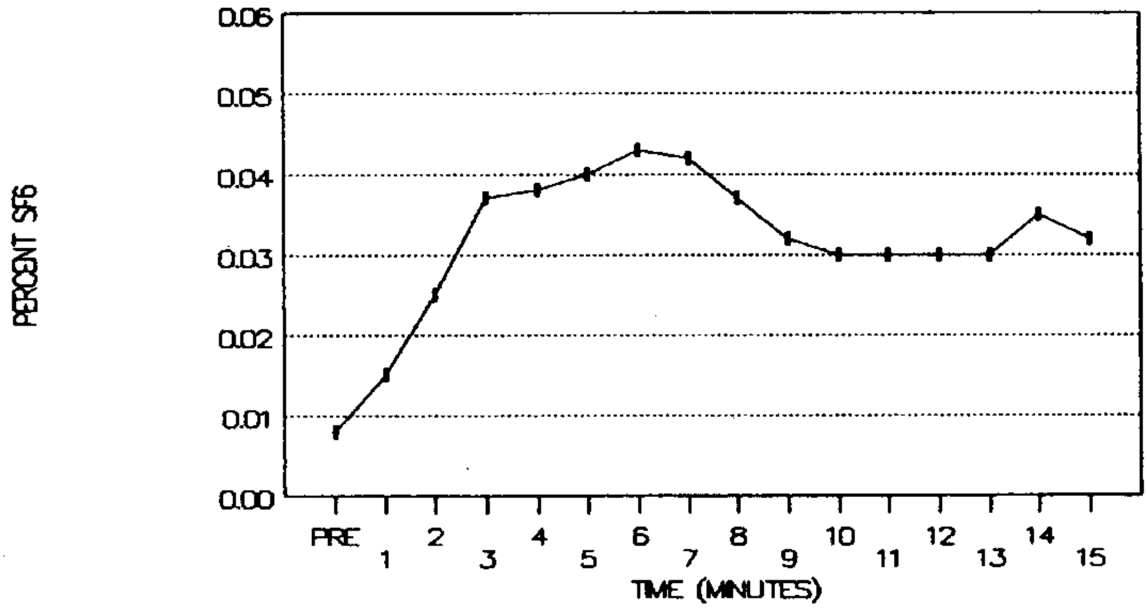
-Figure 24-

PURITAN CREW PBE INFILTRATION
SUBJECT M-11



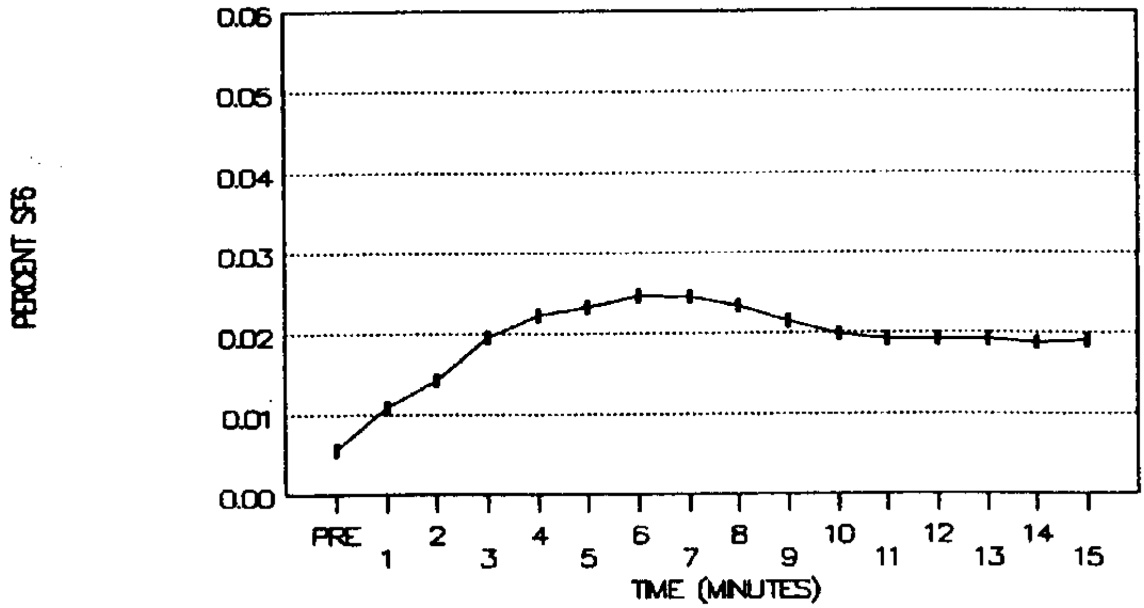
-Figure 25-

PURITAN CREW PBE INFILTRATION
SUBJECT M-12



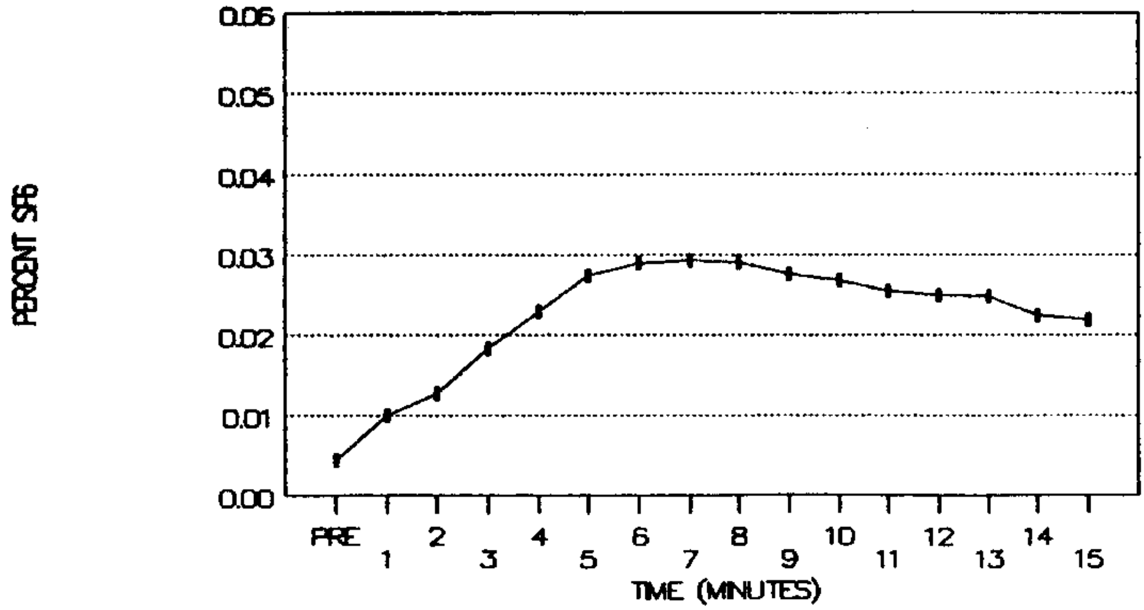
-Figure 26-

PURITAN CREW PBE INFILTRATION
AVERAGE – ALL MALE SUBJECTS



-Figure 27-

PURITAN CREW PBE INFILTRATION
AVERAGE – ALL FEMALE SUBJECTS

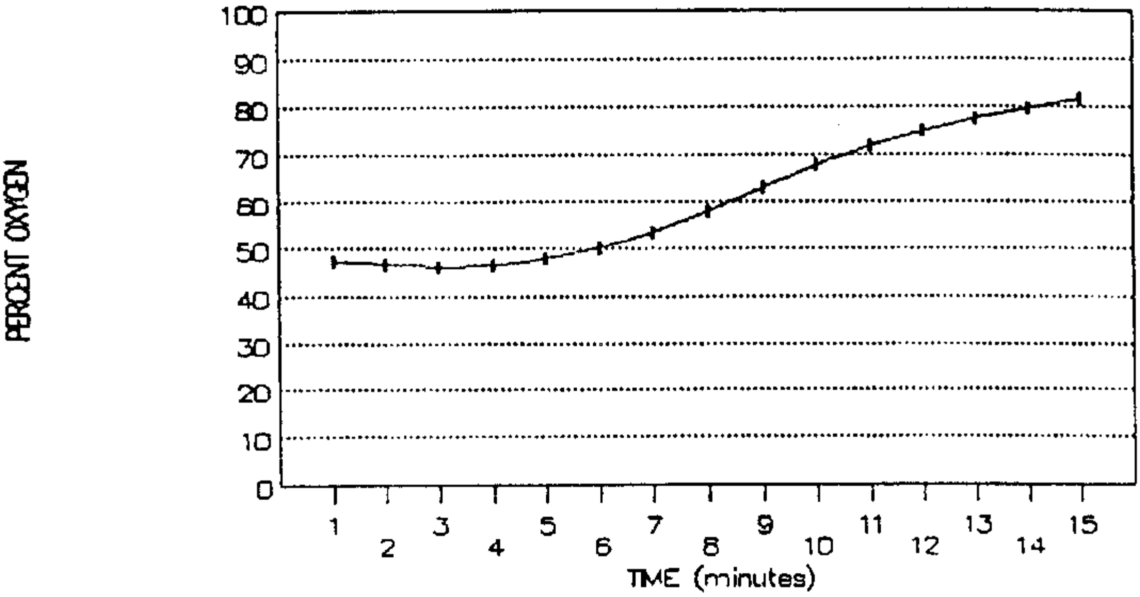


-Figure 28-

APPENDIX B

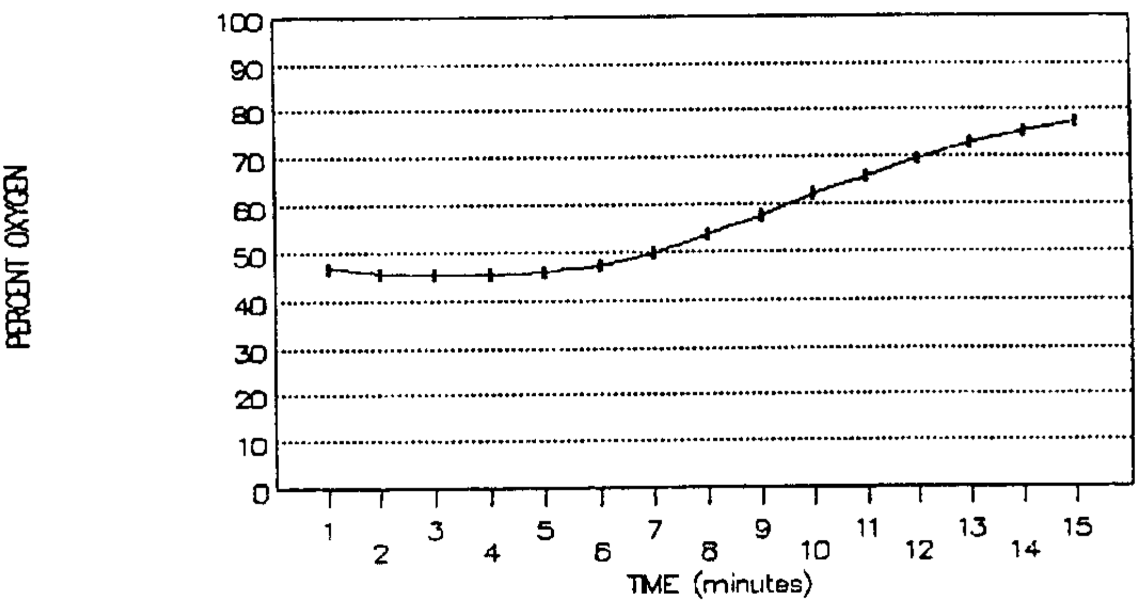
Individual Graphs of Internal PBE Oxygen Concentration in Percent Through Time

INSPIRATORY OXYGEN VALUES
F-1, CAMI TESTS - GROUND LEVEL



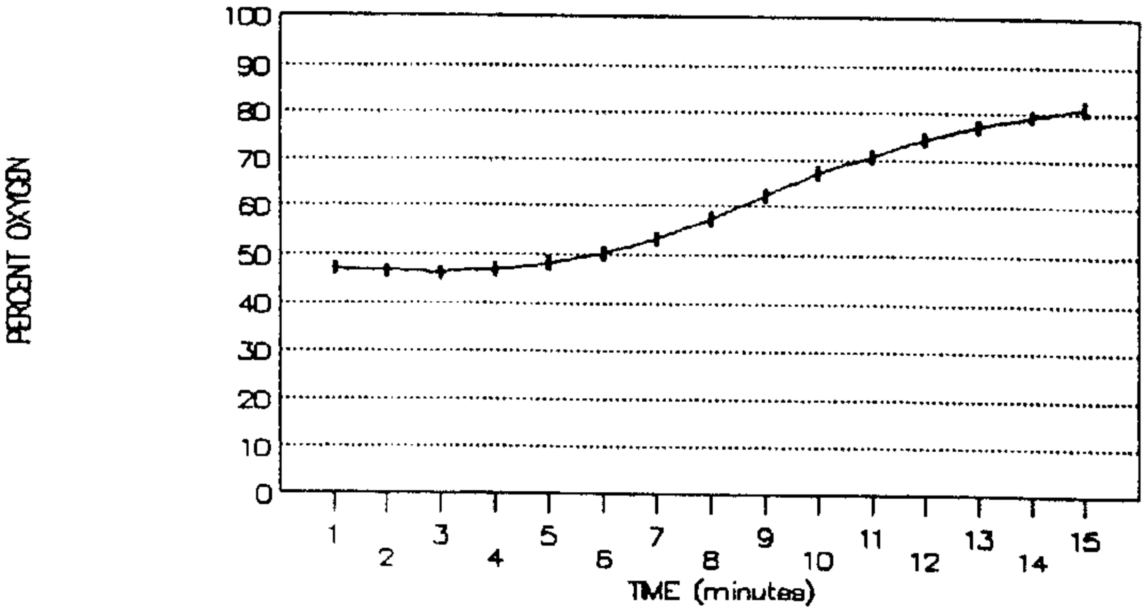
-Figure 29-

INSPIRATORY OXYGEN VALUES
F-2, CAMI TESTS - GROUND LEVEL



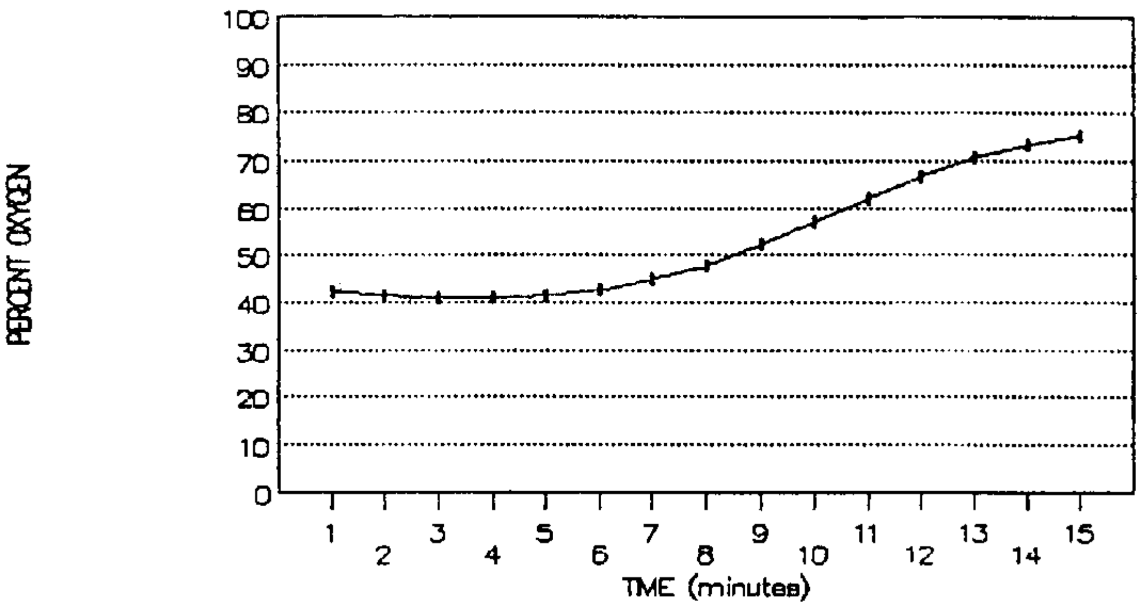
-Figure 30-

INSPIRATORY OXYGEN VALUES
F-3, CAMI TESTS - GROUND LEVEL



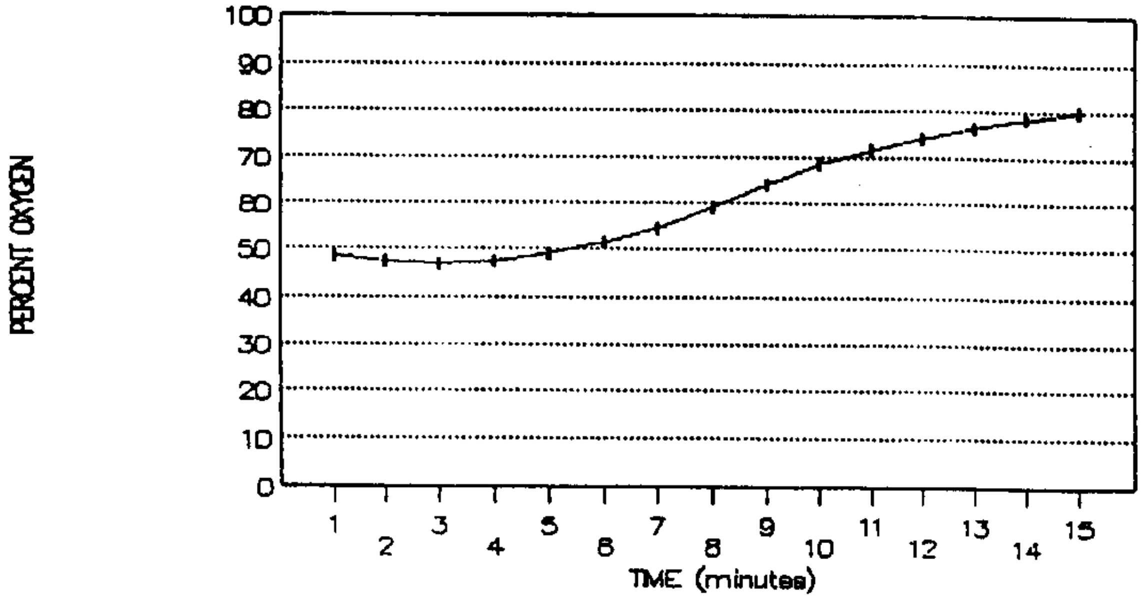
-Figure 31-

INSPIRATORY OXYGEN VALUES
F-4, CAMI TESTS - GROUND LEVEL



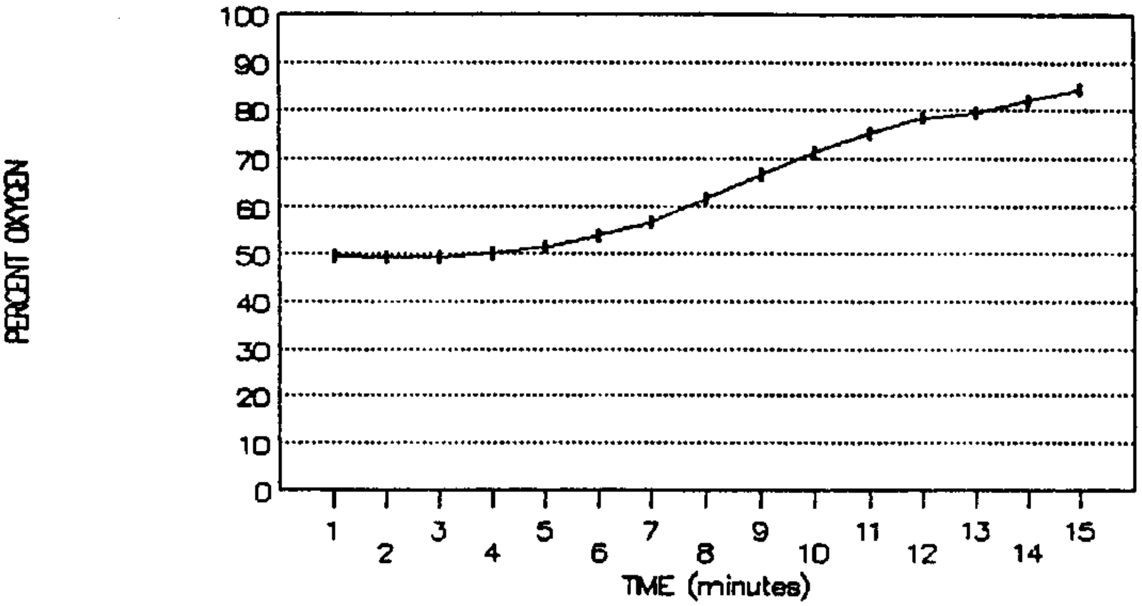
-Figure 32-

INSPIRATORY OXYGEN VALUES
F-5, CAMI TESTS - GROUND LEVEL



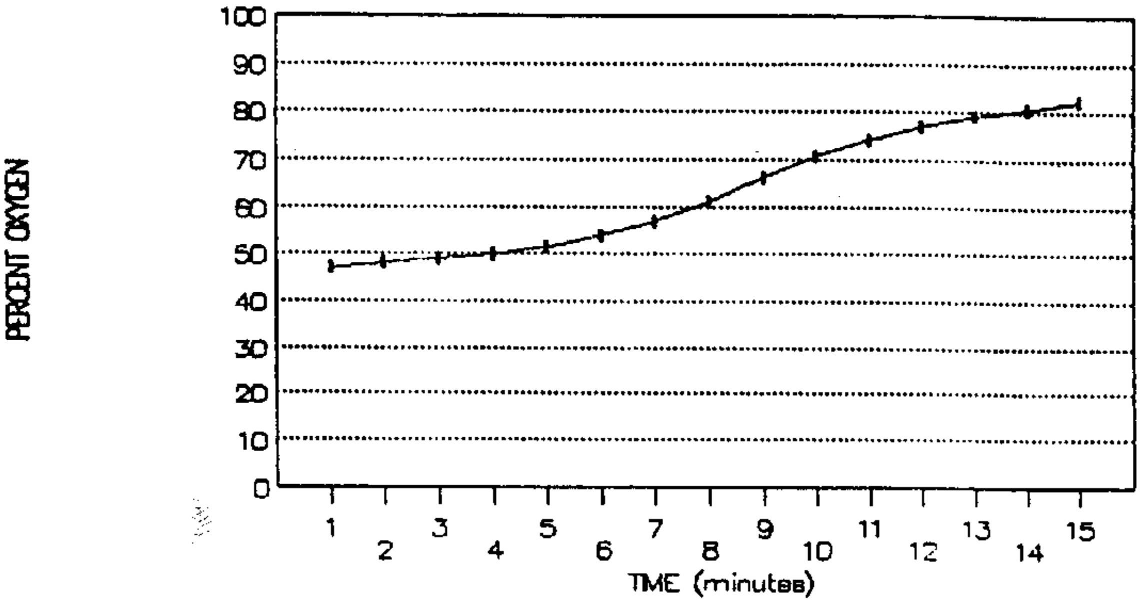
-Figure 33-

INSPIRATORY OXYGEN VALUES
F-6, CAMI TESTS - GROUND LEVEL



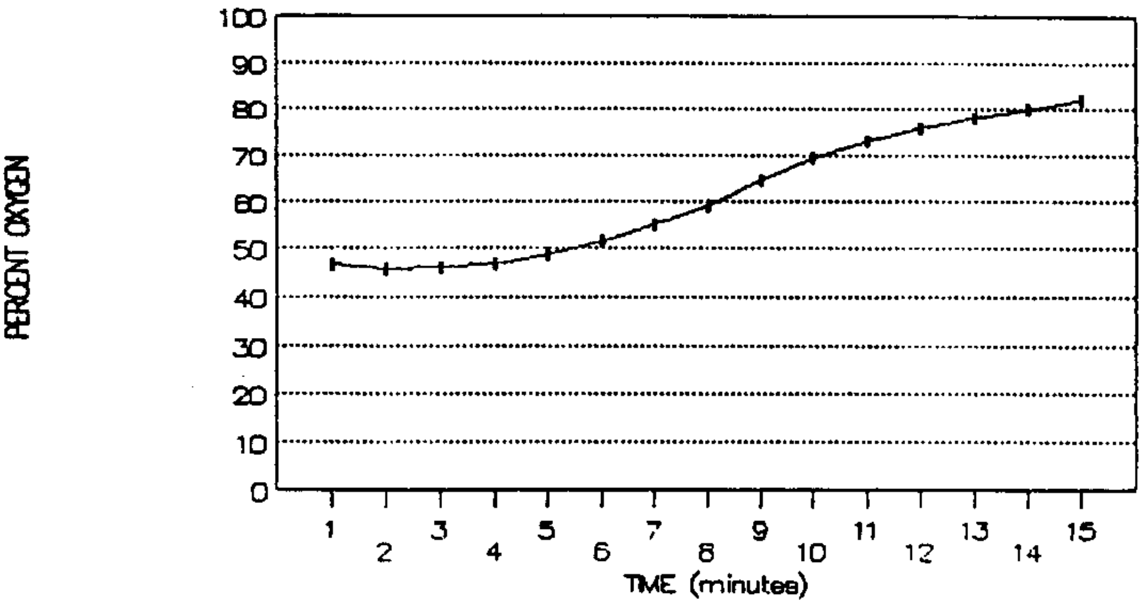
-Figure 34-

INSPIRATORY OXYGEN VALUES
F-7, CAMI TESTS - GROUND LEVEL



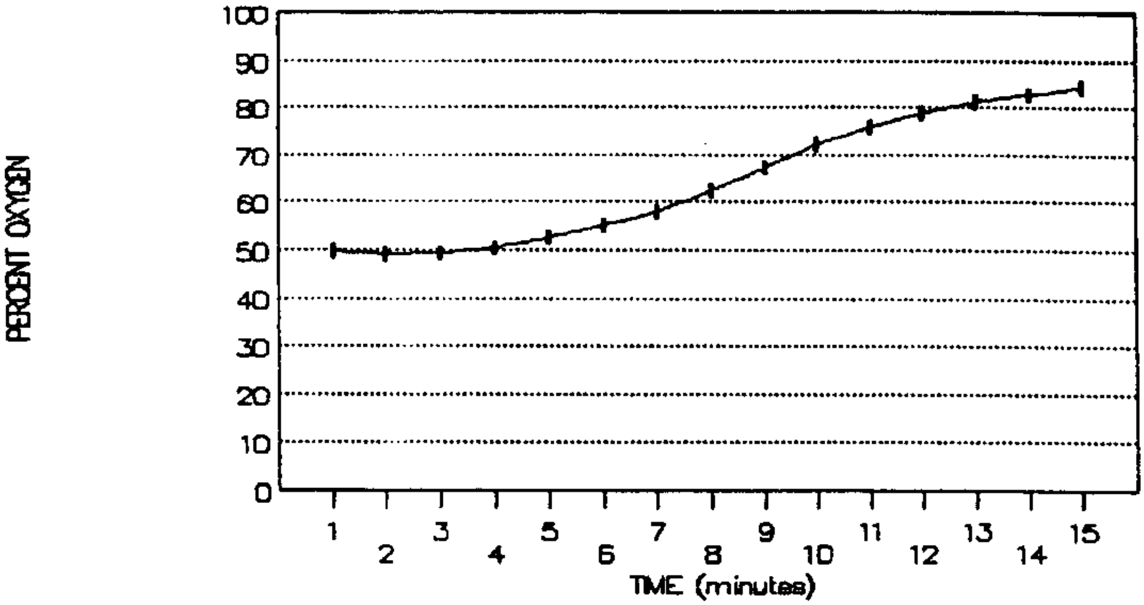
-Figure 35-

INSPIRATORY OXYGEN VALUES
F-8, CAMI TESTS - GROUND LEVEL



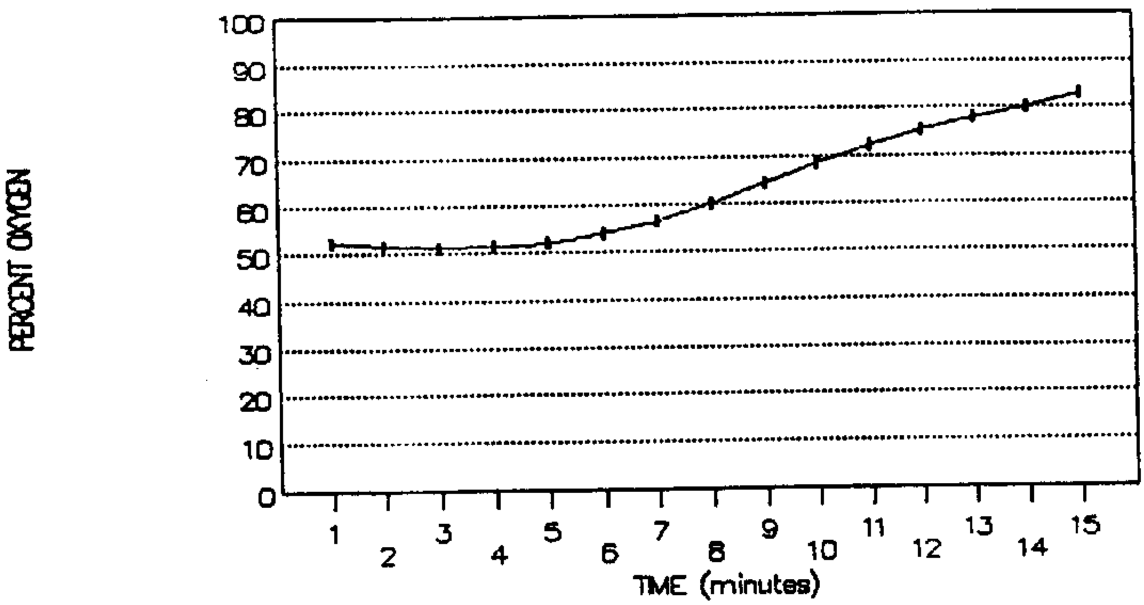
-Figure 36-

INSPIRATORY OXYGEN VALUES
F-9, CAMI TESTS - GROUND LEVEL



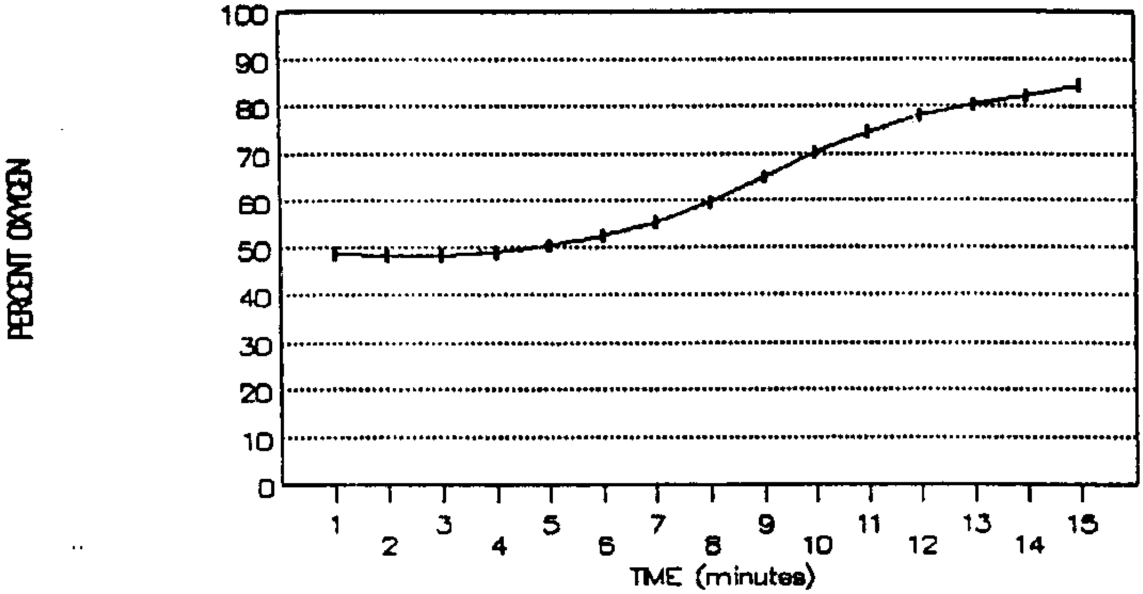
-Figure 37-

INSPIRATORY OXYGEN VALUES
F-10, CAMI TESTS - GROUND LEVEL



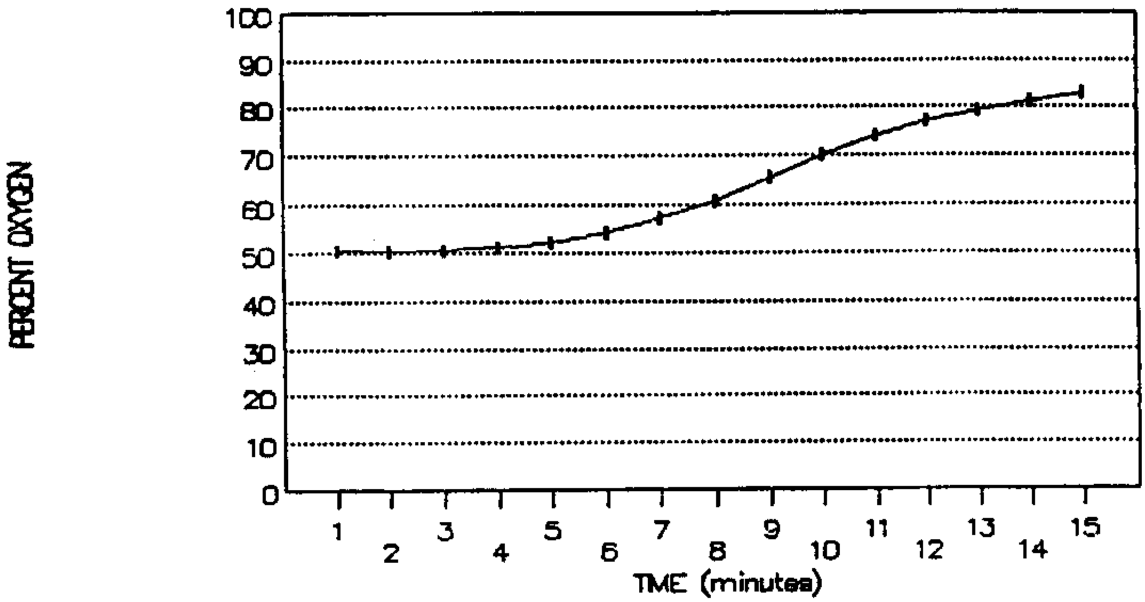
-Figure 38-

INSPIRATORY OXYGEN VALUES
F-11, CAMI TESTS - GROUND LEVEL



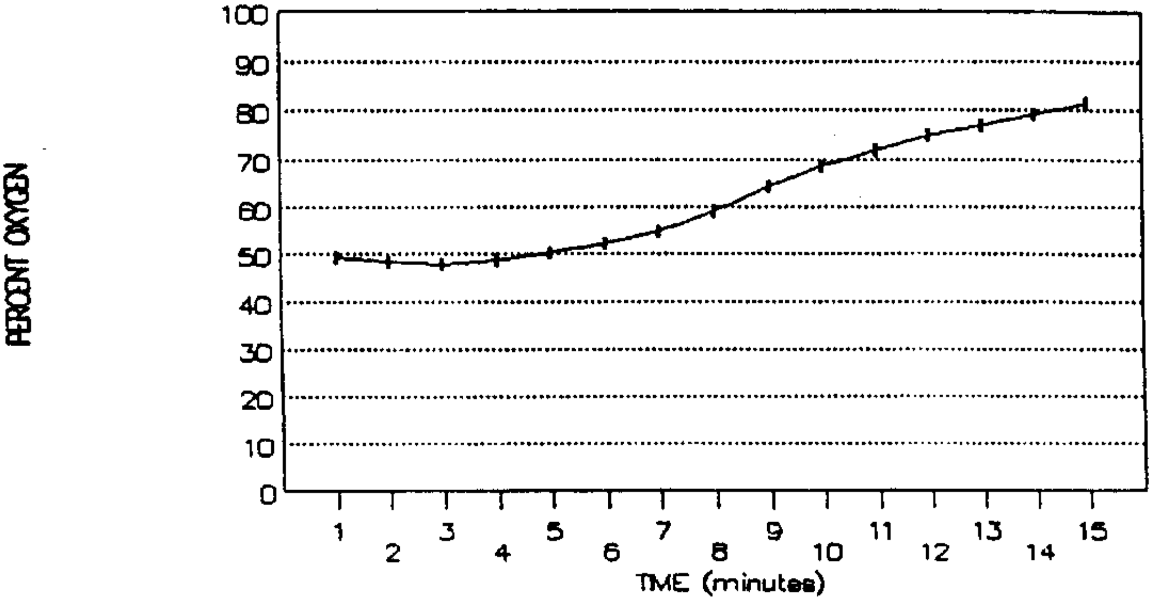
-Figure 39-

INSPIRATORY OXYGEN VALUES
F-12, CAMI TESTS - GROUND LEVEL



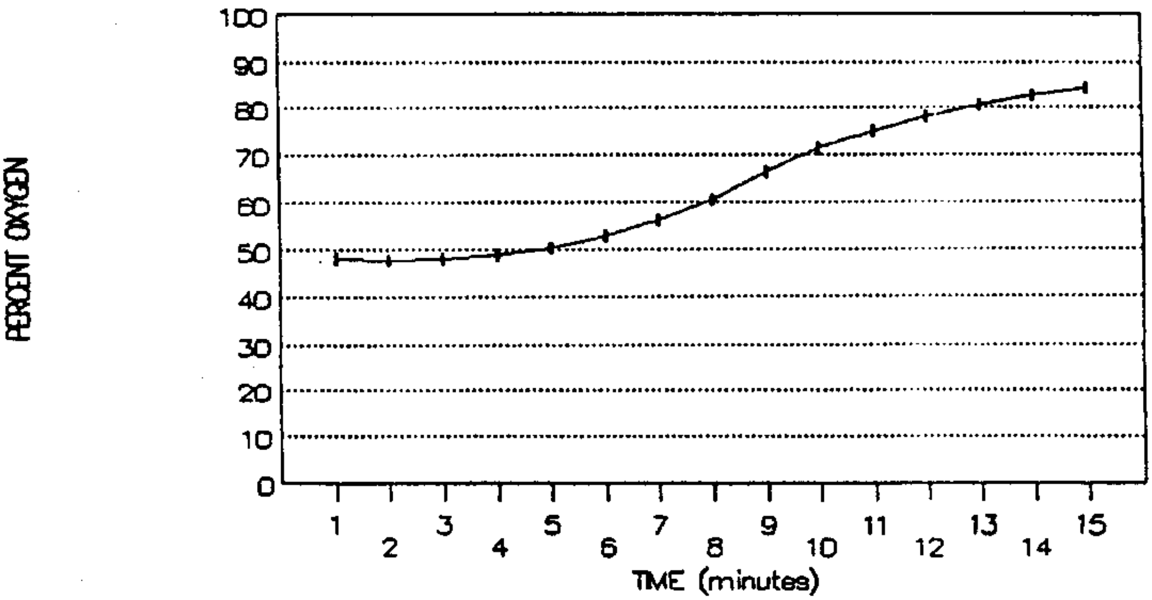
-Figure 40-

INSPIRATORY OXYGEN VALUES
M-1, CAMI TESTS – GROUND LEVEL



-Figure 41-

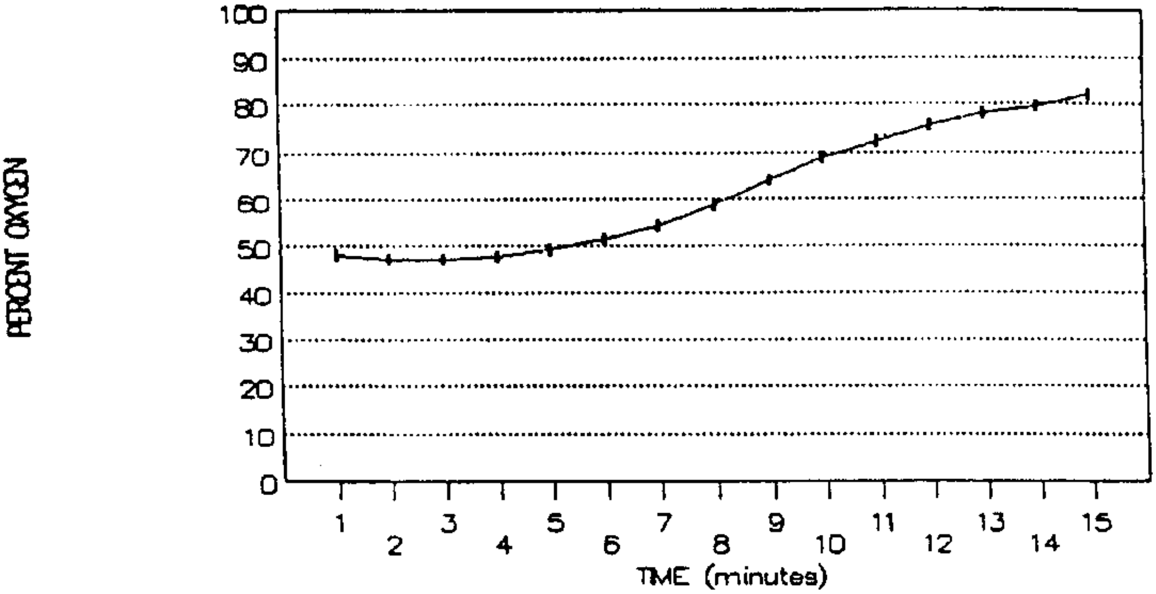
INSPIRATORY OXYGEN VALUES
M-2, CAMI TESTS – GROUND LEVEL



-Figure 42-

INSPIRATORY OXYGEN VALUES

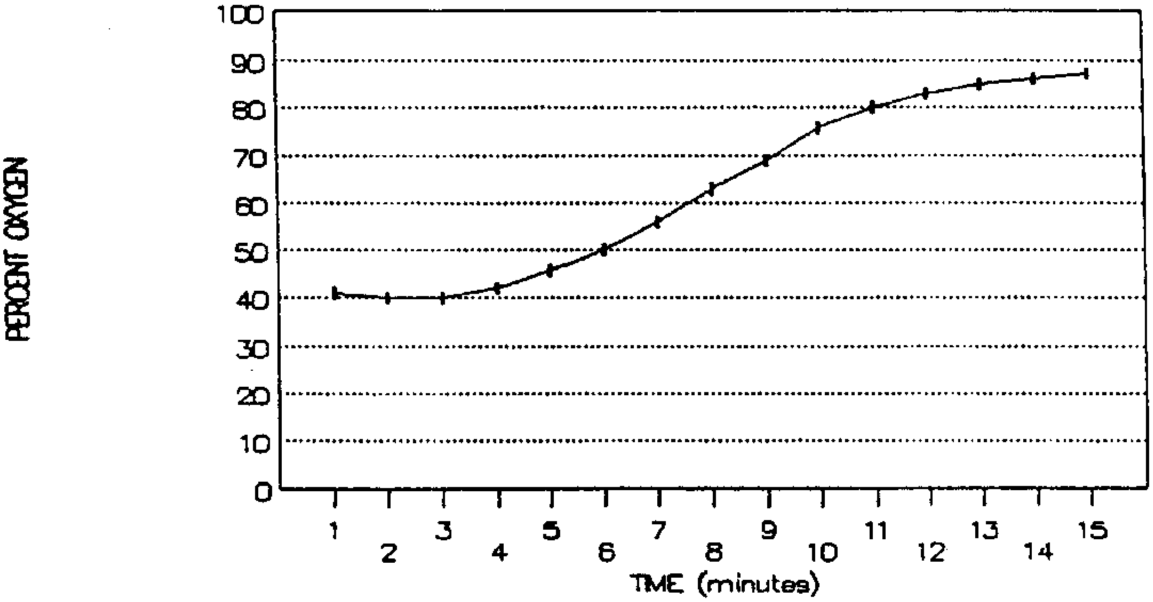
M-3, CAMI TESTS - GROUND LEVEL



-Figure 43-

INSPIRATORY OXYGEN VALUES

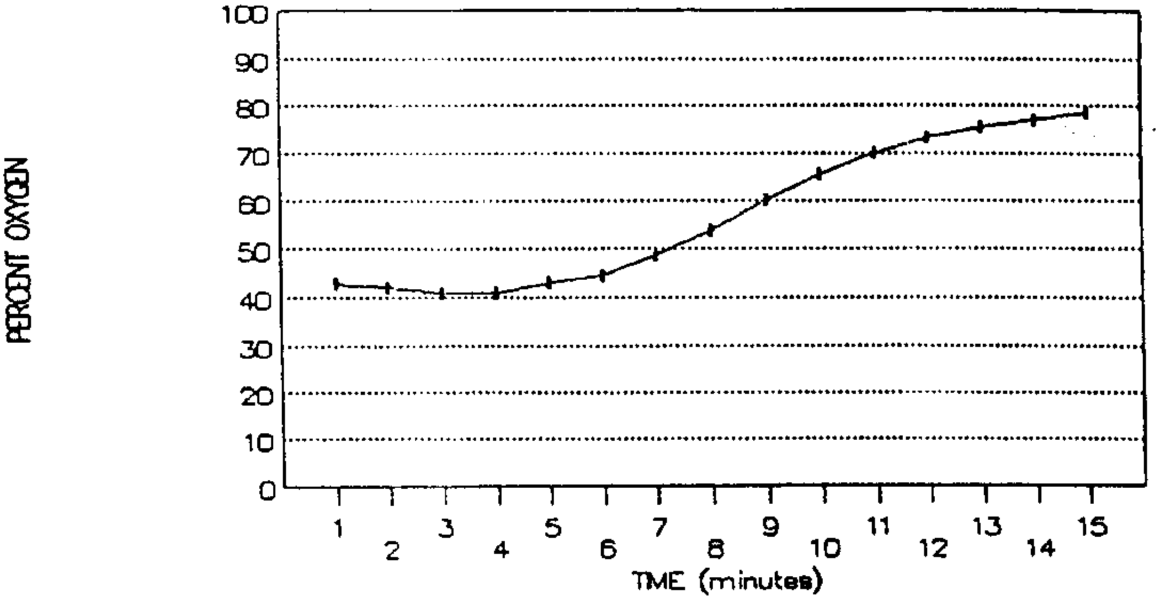
M-4, CAMI TESTS - GROUND LEVEL



-Figure 44-

INSPIRATORY OXYGEN VALUES

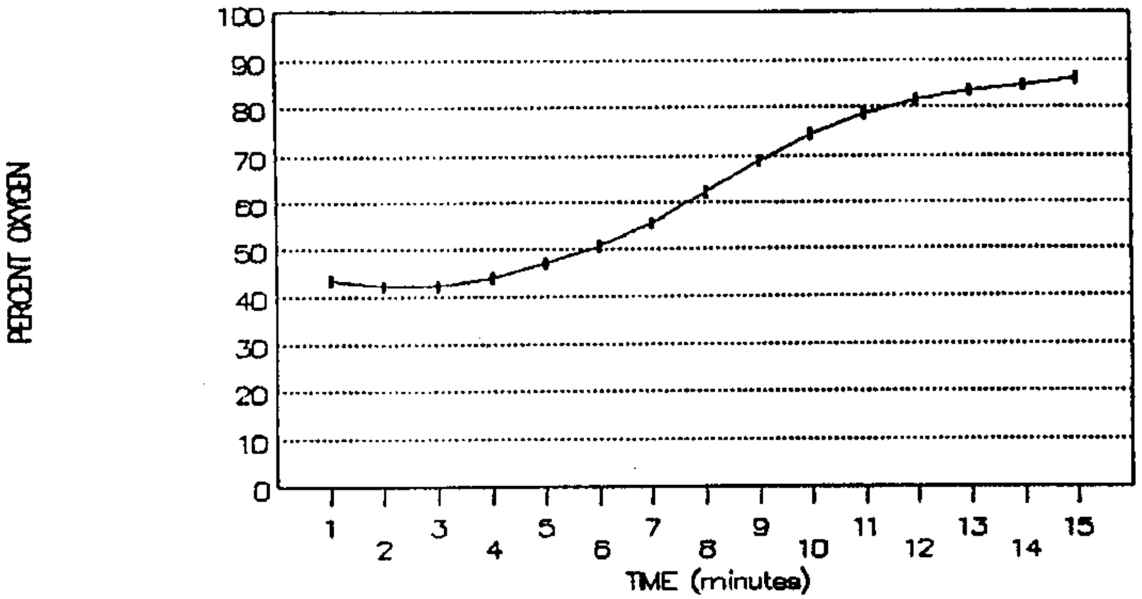
M-5, CAMI TESTS - GROUND LEVEL



-Figure 45-

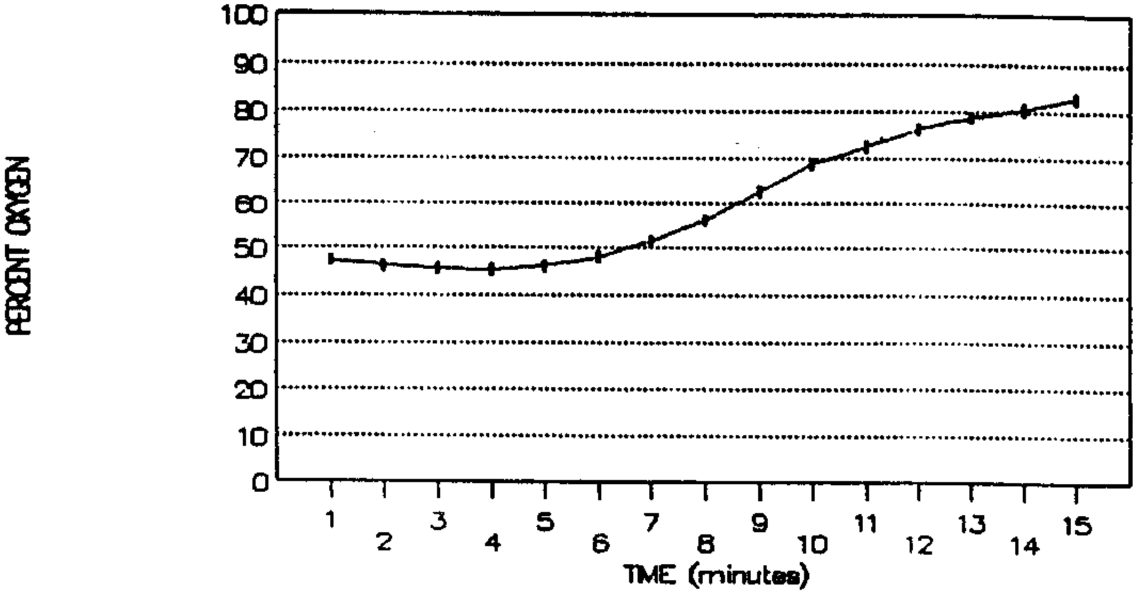
INSPIRATORY OXYGEN VALUES

M-6, CAMI TESTS - GROUND LEVEL



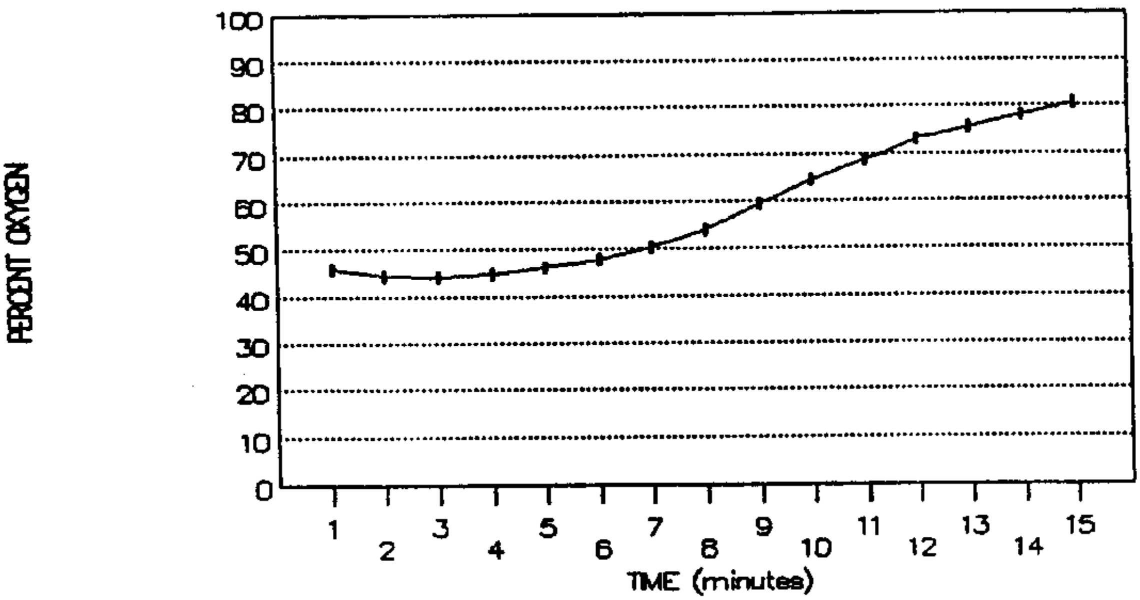
-Figure 46-

INSPIRATORY OXYGEN VALUES
M-7, CAMI TESTS - GROUND LEVEL



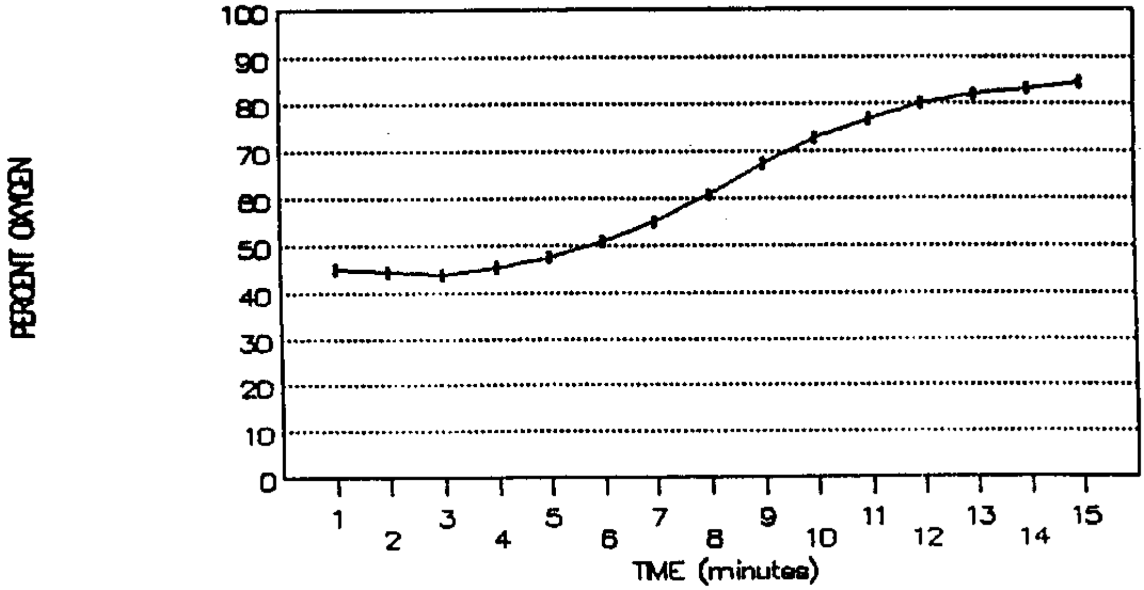
-Figure 47-

INSPIRATORY OXYGEN VALUES
M-8, CAMI TESTS - GROUND LEVEL



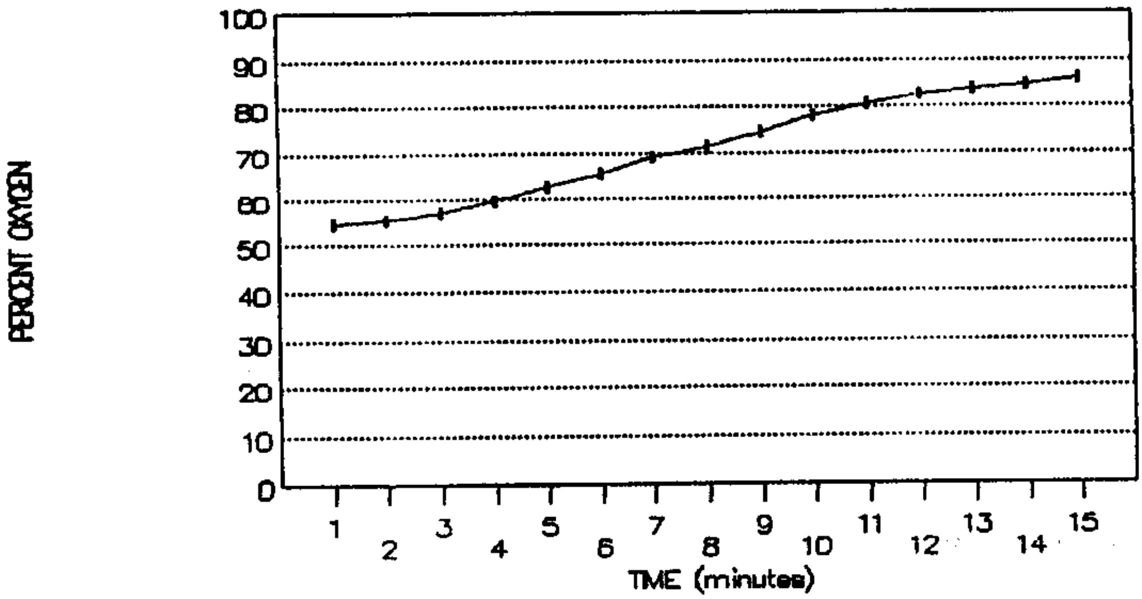
-Figure 48-

INSPIRATORY OXYGEN VALUES
M-9, CAMI TESTS - GROUND LEVEL



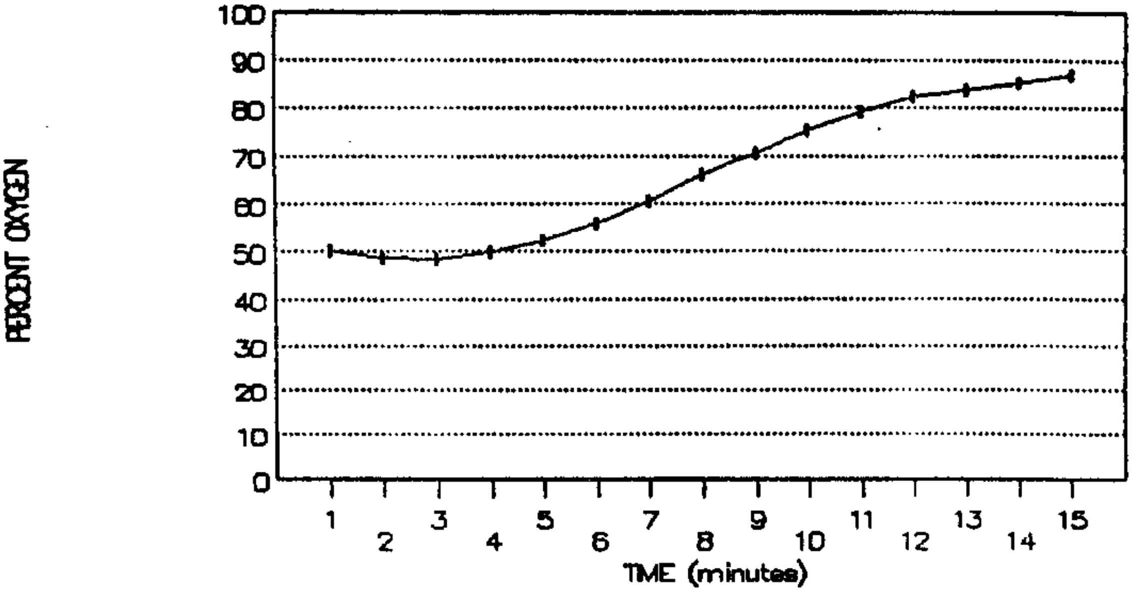
-Figure 49-

INSPIRATORY OXYGEN VALUES
M-10, CAMI TESTS - GROUND LEVEL



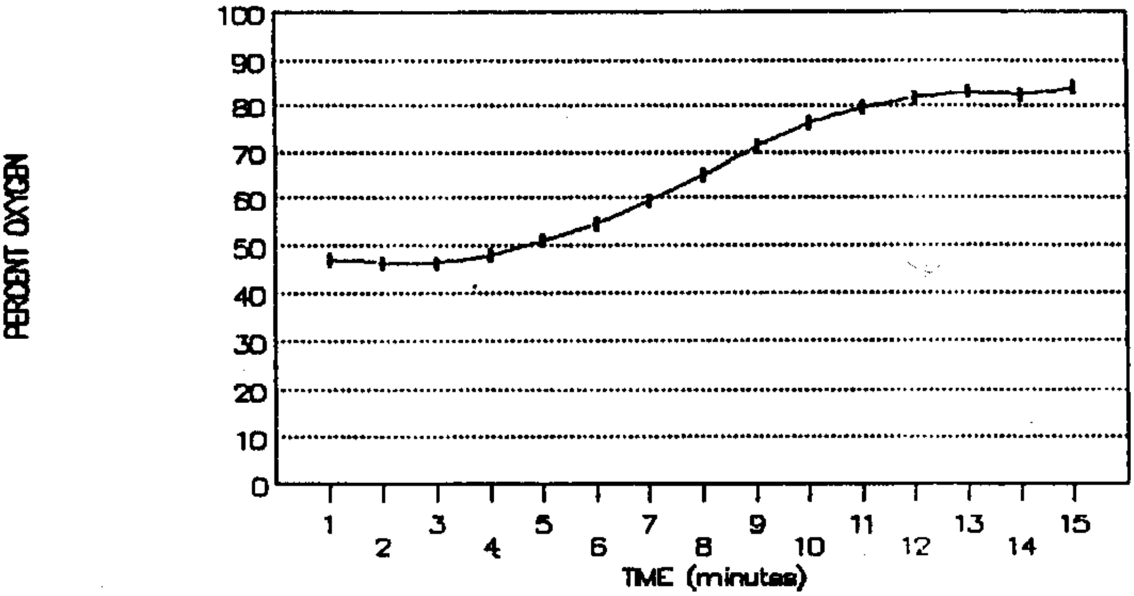
-Figure 50-

INSPIRATORY OXYGEN VALUES
M-11, CAMI TESTS - GROUND LEVEL



-Figure 51-

INSPIRATORY OXYGEN VALUES
M-12, CAMI TESTS - GROUND LEVEL



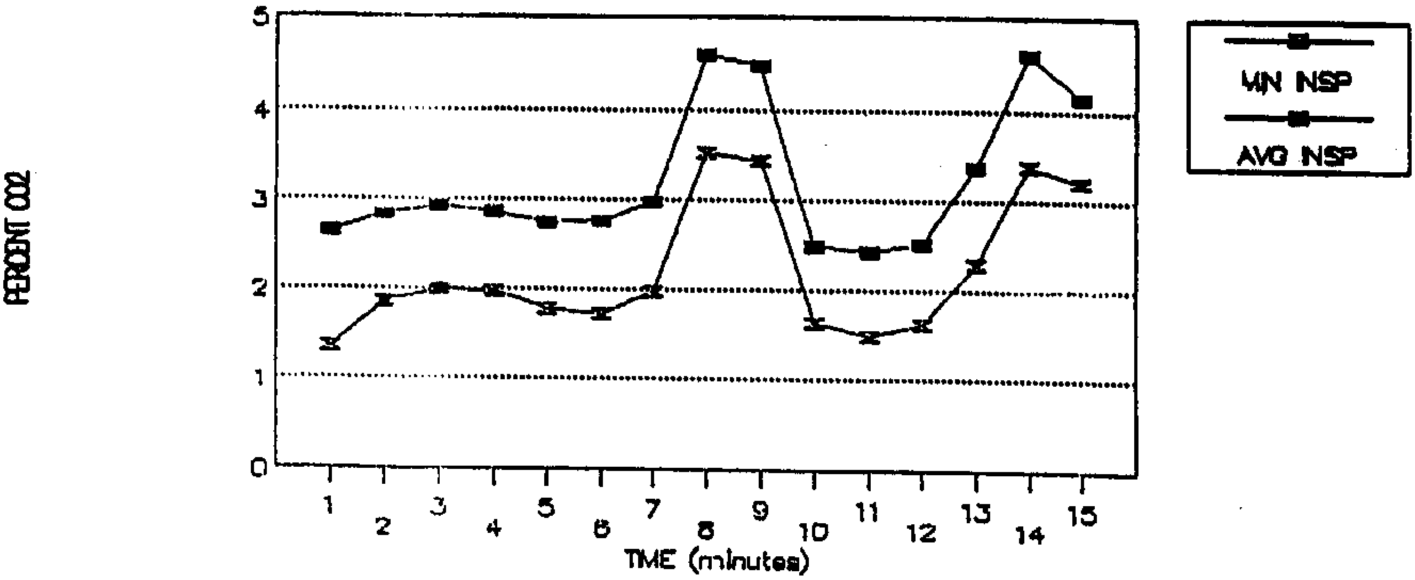
-Figure 52

APPENDIX C

Individual Graphs of Inhalation Carbon Dioxide Concentration in Percent Through Time

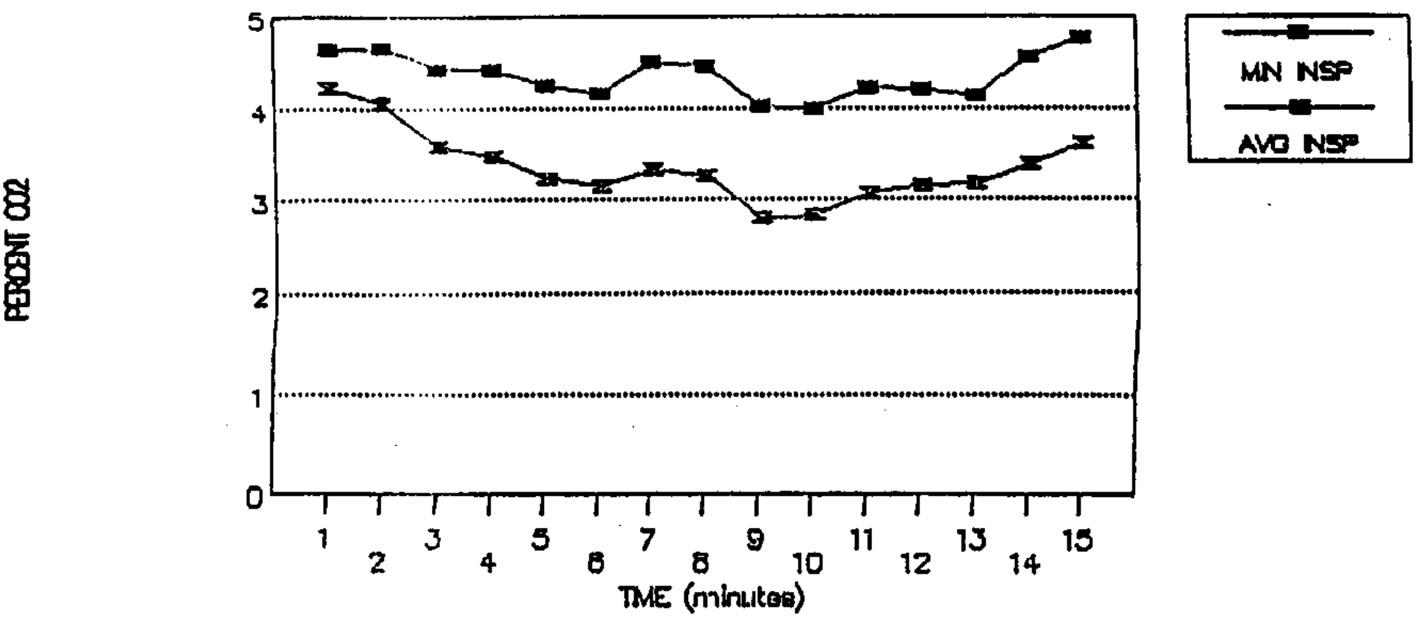
APPENDIX C - continued

INSPIRATORY CO2 VALUES
MALE 4/15/88, HIGH CO2 LEVEL



-Figure 53-

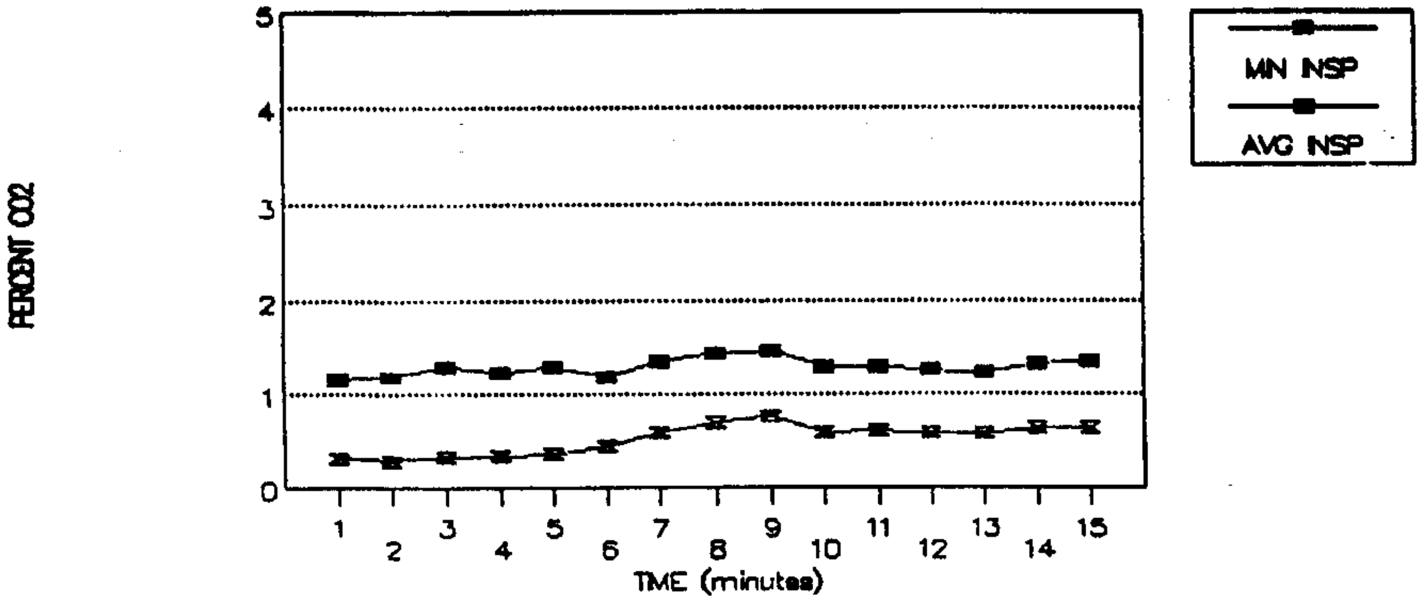
INSPIRATORY CO2 VALUES
FEMALE 9/23/88, HIGH CO2 LEVEL



-Figure 54-

INSPIRATORY CO2 VALUES

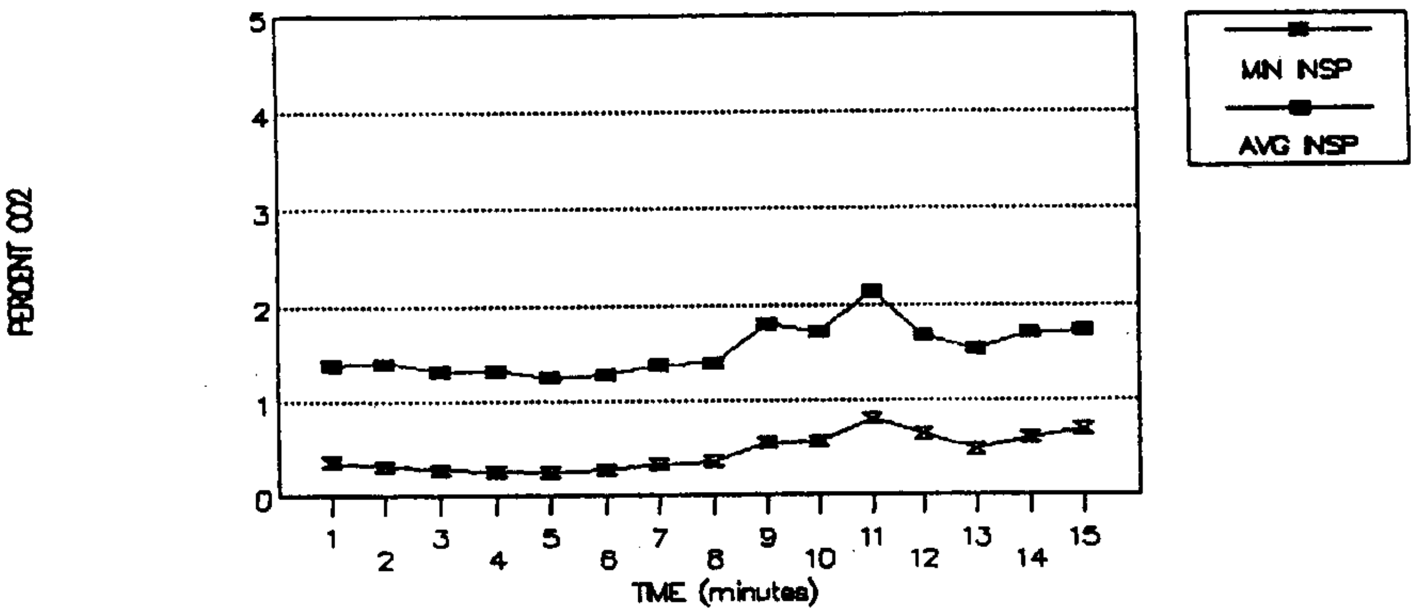
F-1, CAMI TESTS - GROUND LEVEL



-Figure 55-

INSPIRATORY CO2 VALUES

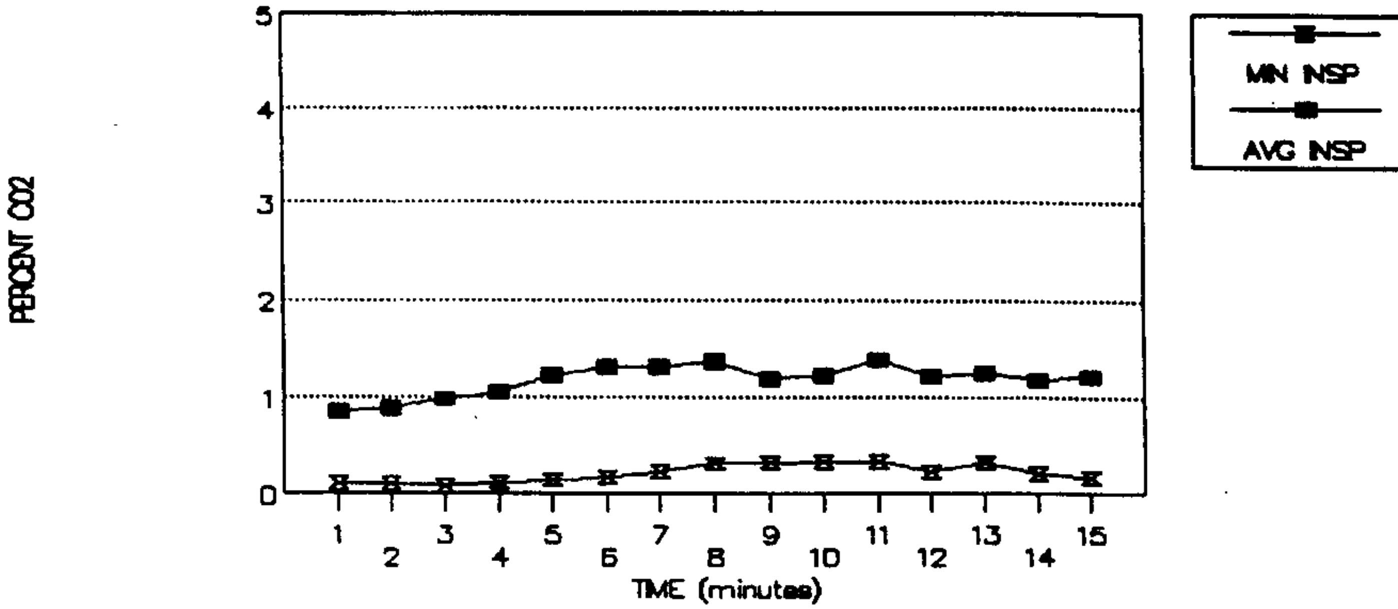
F-2, CAMI TESTS - GROUND LEVEL



-Figure 56-

INSPIRATORY CO2 VALUES

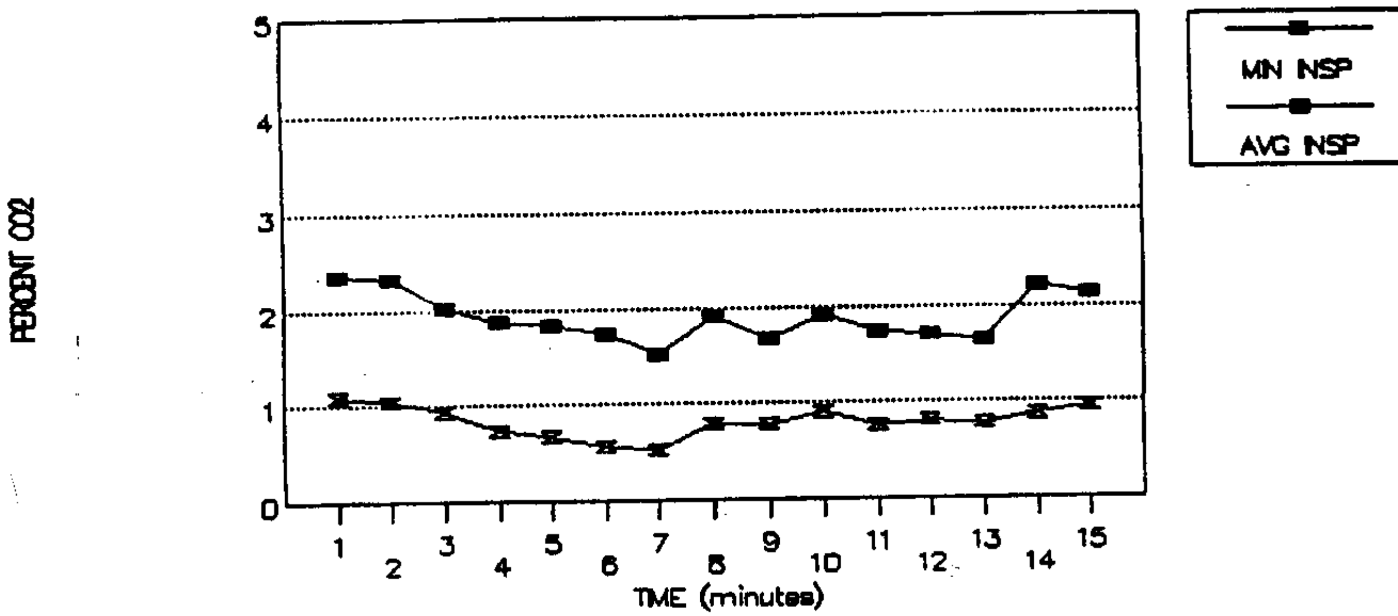
F-3, CAMI TESTS - GROUND LEVEL



-Figure 57-

INSPIRATORY CO2 VALUES

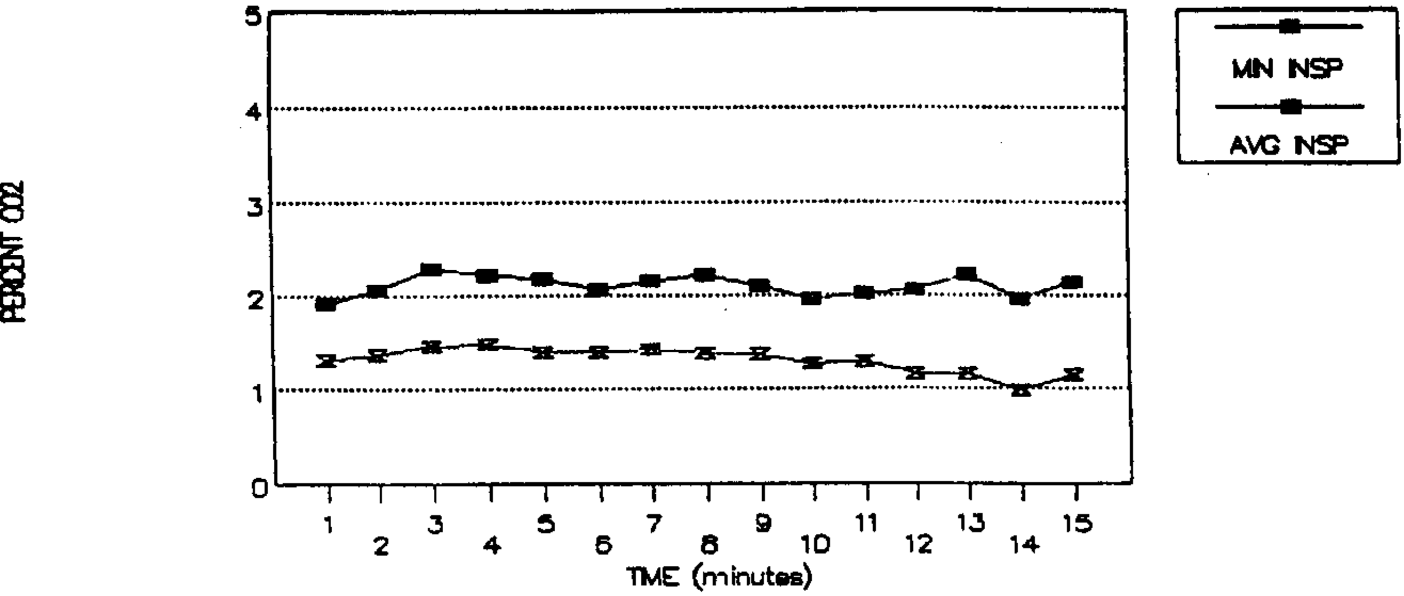
F-4, CAMI TESTS - GROUND LEVEL



-Figure 58-

INSPIRATORY CO2 VALUES

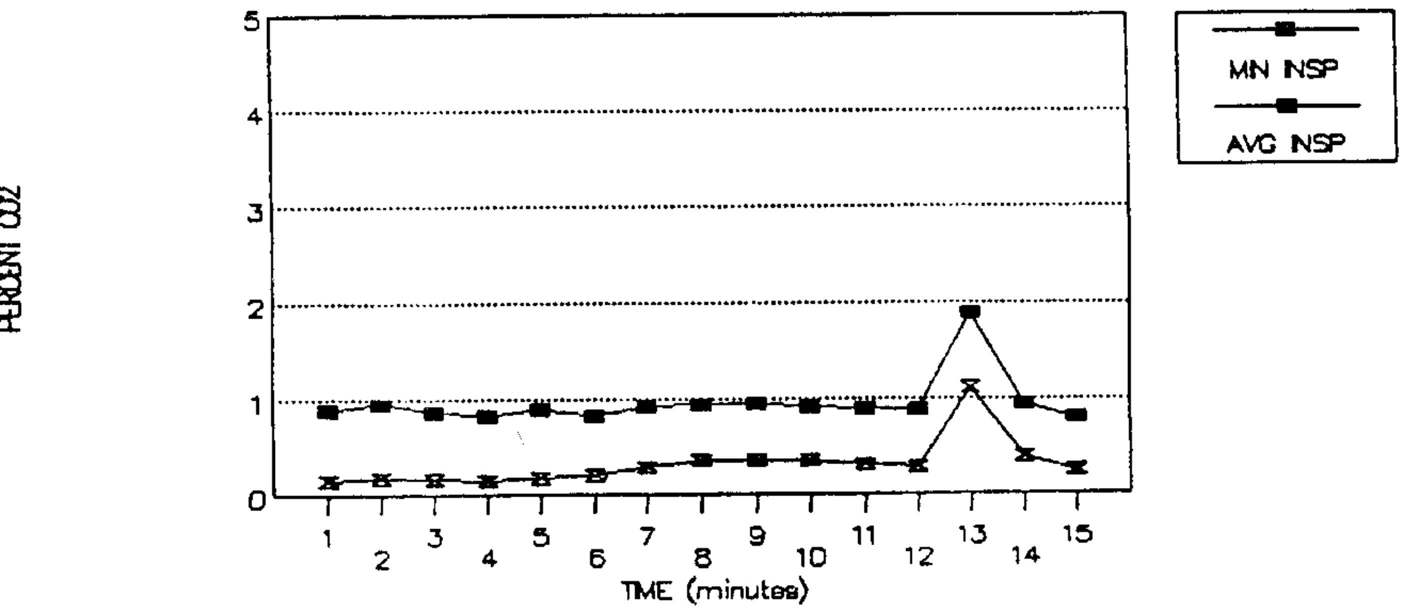
F-5, CAMI TESTS - GROUND LEVEL



-Figure 59-

INSPIRATORY CO2 VALUES

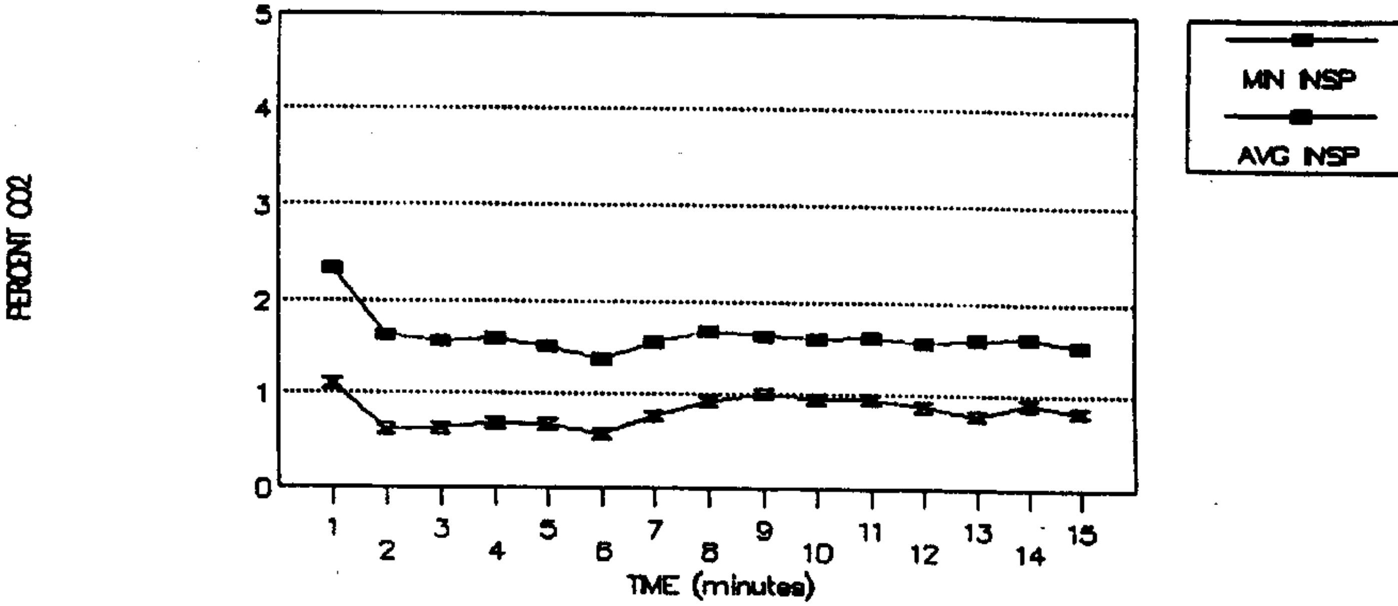
F-6, CAMI TESTS - GROUND LEVEL



-Figure 60-

INSPIRATORY CO2 VALUES

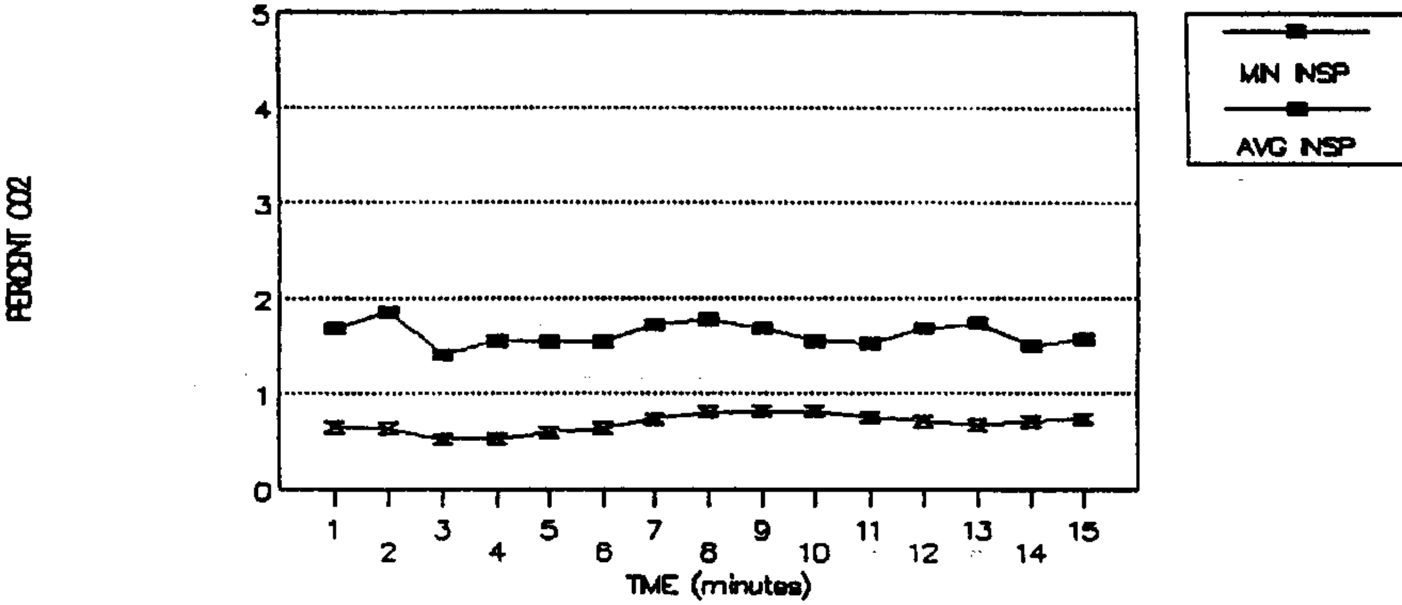
F-7, CAMI TESTS - GROUND LEVEL



-Figure 61-

INSPIRATORY CO2 VALUES

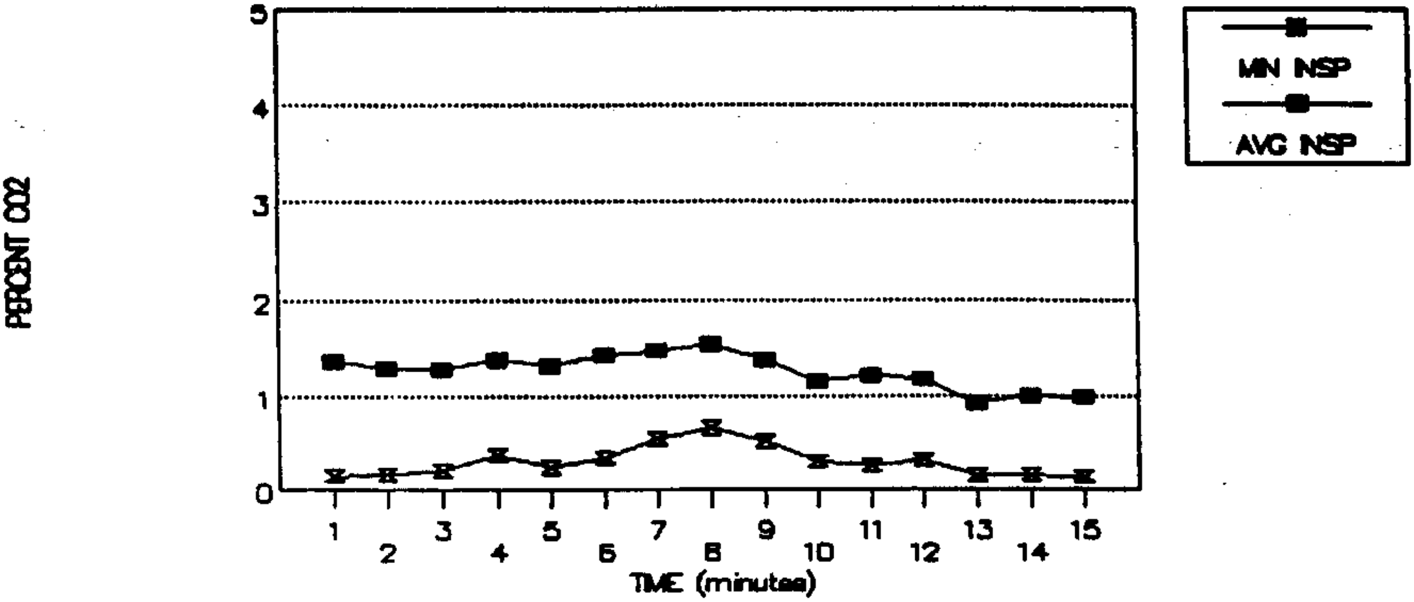
F-8, CAMI TESTS - GROUND LEVEL



-Figure 62-

INSPIRATORY CO2 VALUES

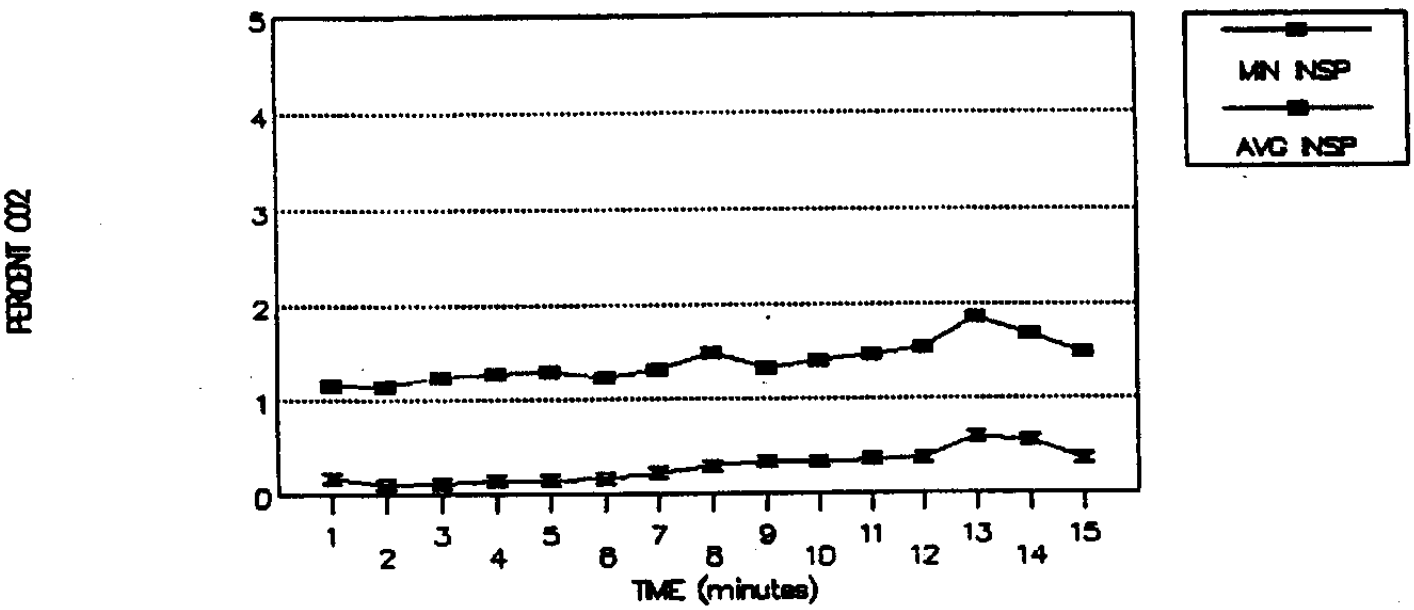
F-9, CAMI TESTS – GROUND LEVEL



-Figure 63-

INSPIRATORY CO2 VALUES

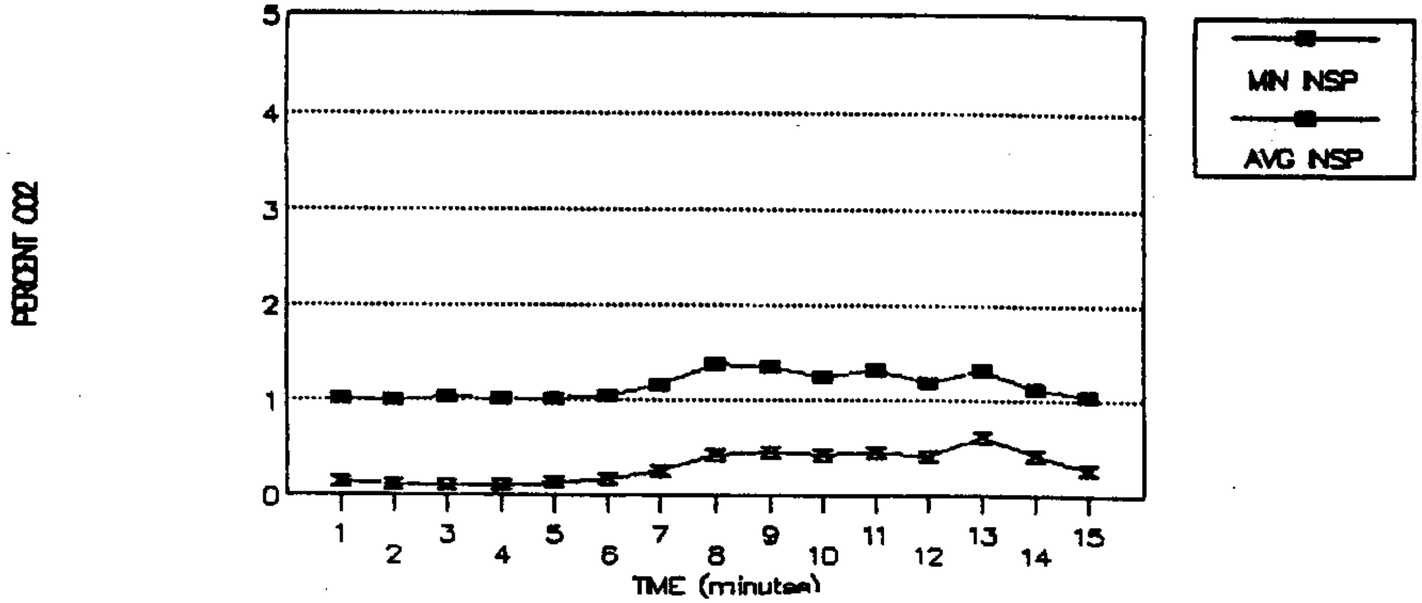
F-10, CAMI TESTS – GROUND LEVEL



-Figure 64-

INSPIRATORY CO2 VALUES

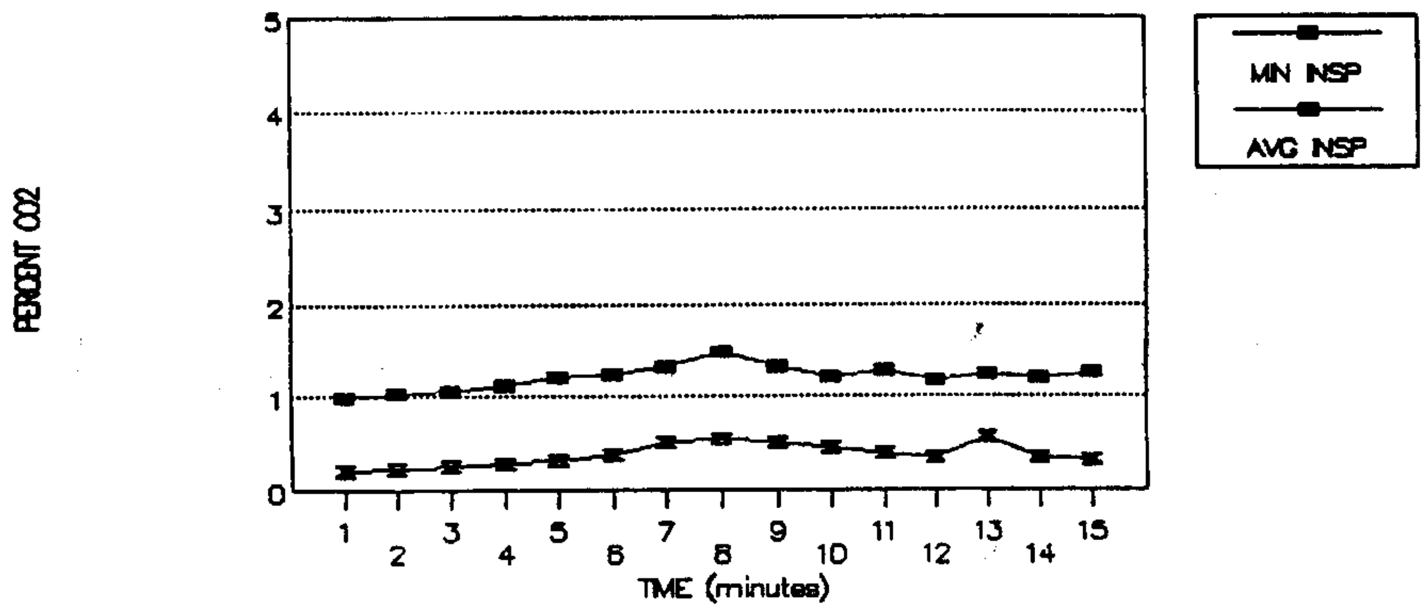
F-11, CAMI TESTS - GROUND LEVEL



-Figure 65-

INSPIRATORY CO2 VALUES

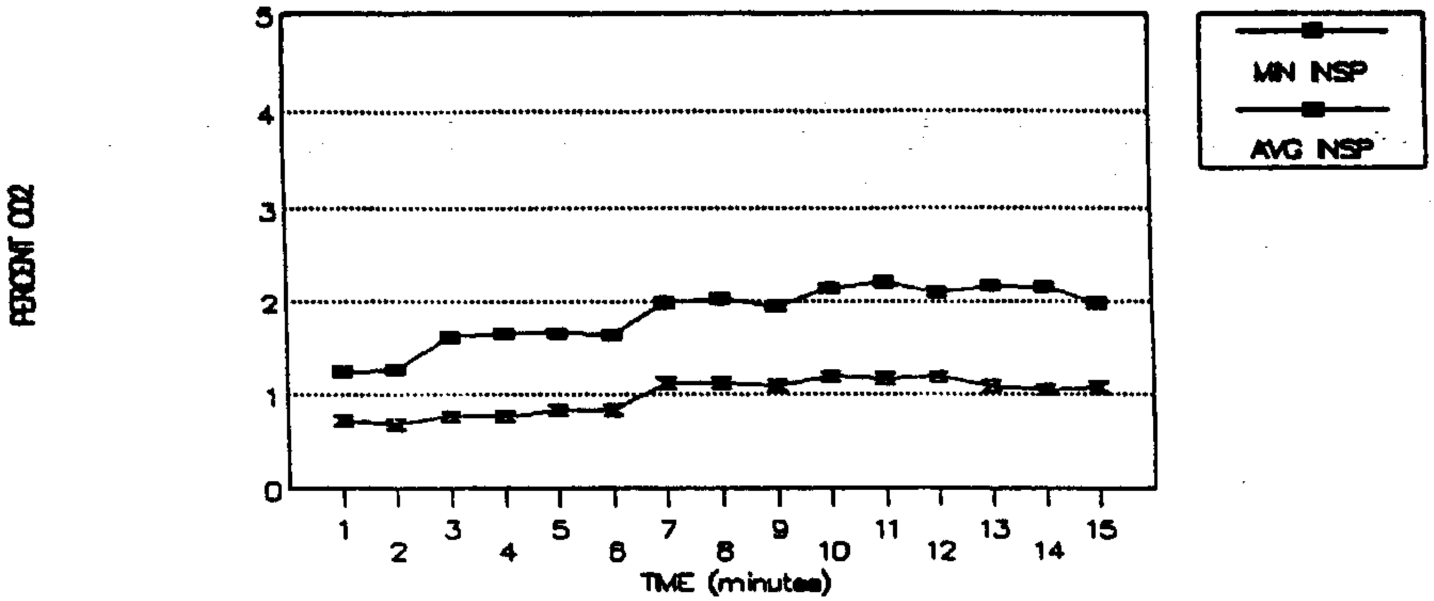
F-12, CAMI TESTS - GROUND LEVEL



-Figure 66-

INSPIRATORY CO2 VALUES

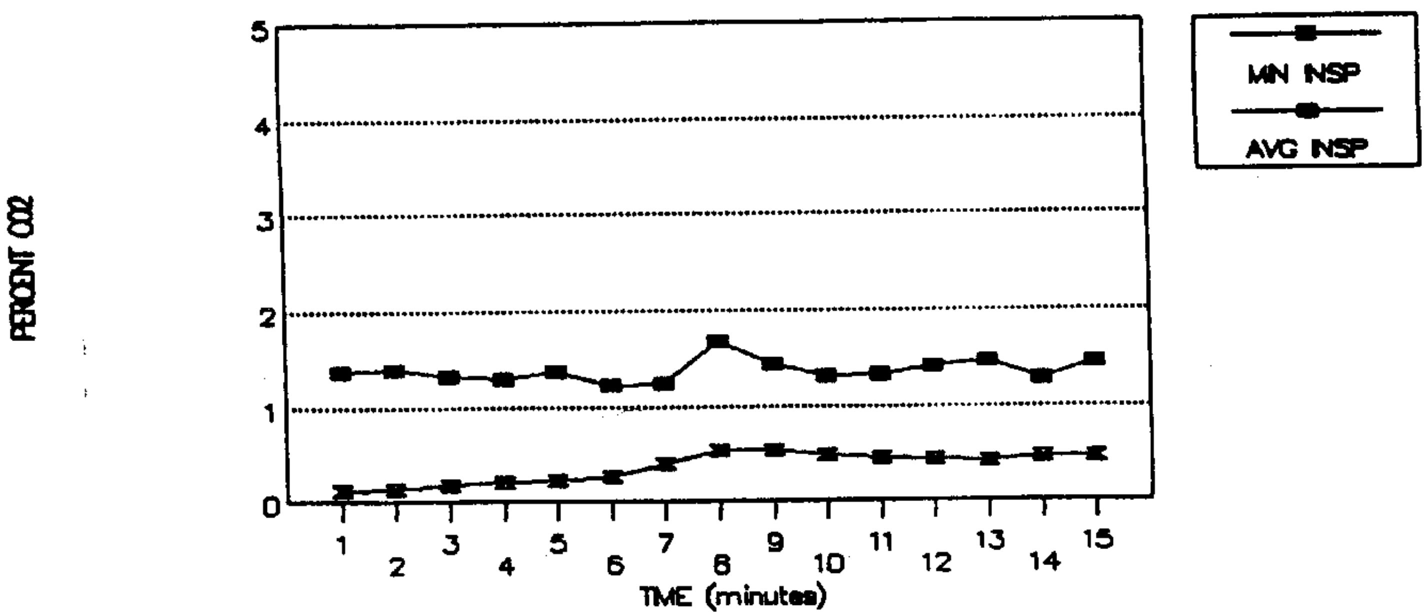
M-1, CAMI TESTS - GROUND LEVEL



-Figure 67-

INSPIRATORY CO2 VALUES

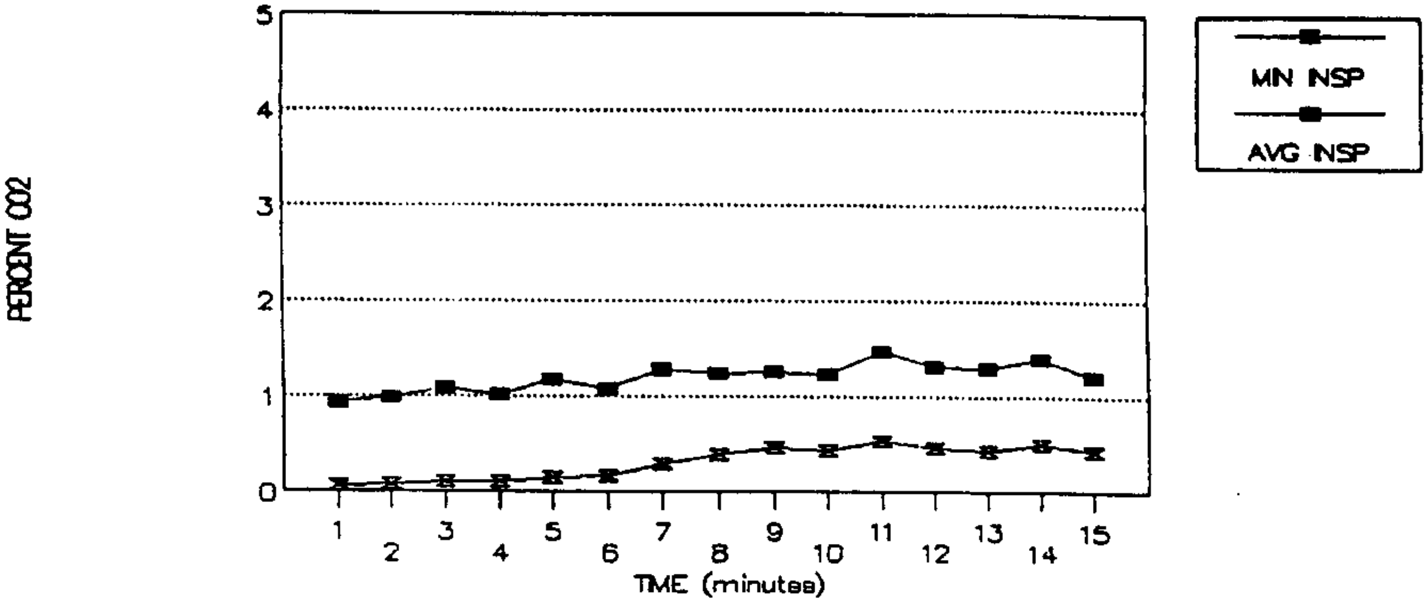
M-2, CAMI TESTS - GROUND LEVEL



-Figure 68-

INSPIRATORY CO2 VALUES

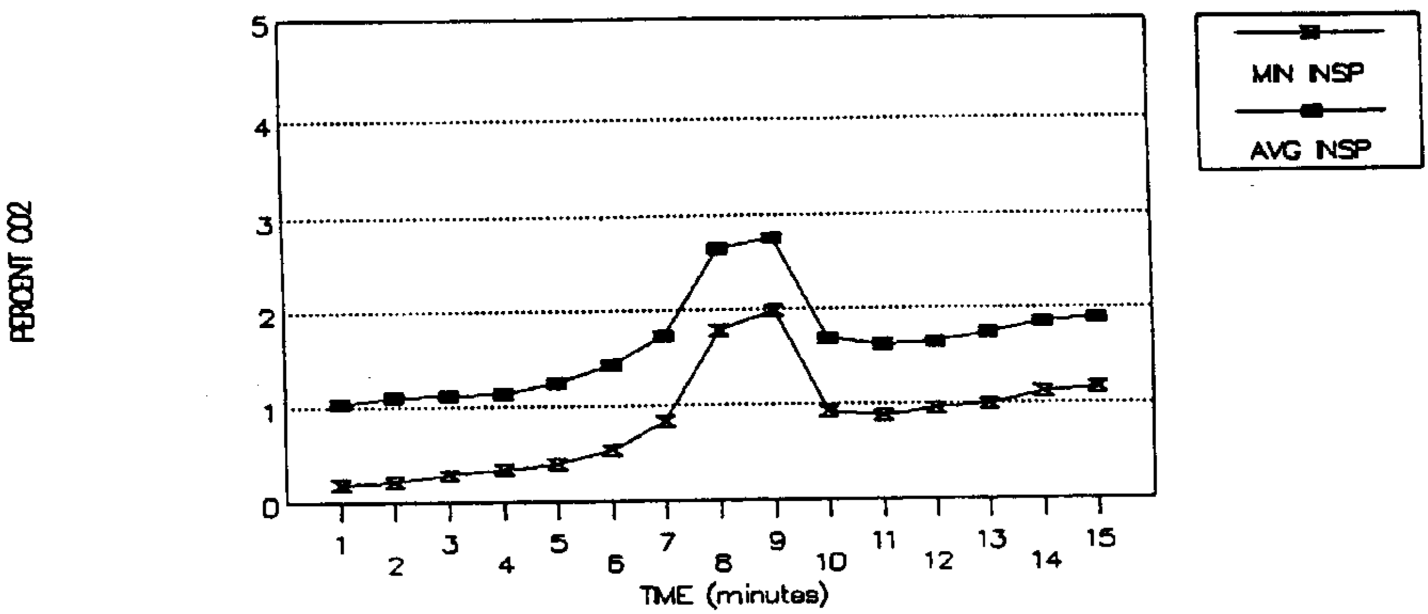
M-3, CAMI TESTS - GROUND LEVEL



-Figure 69-

INSPIRATORY CO2 VALUES

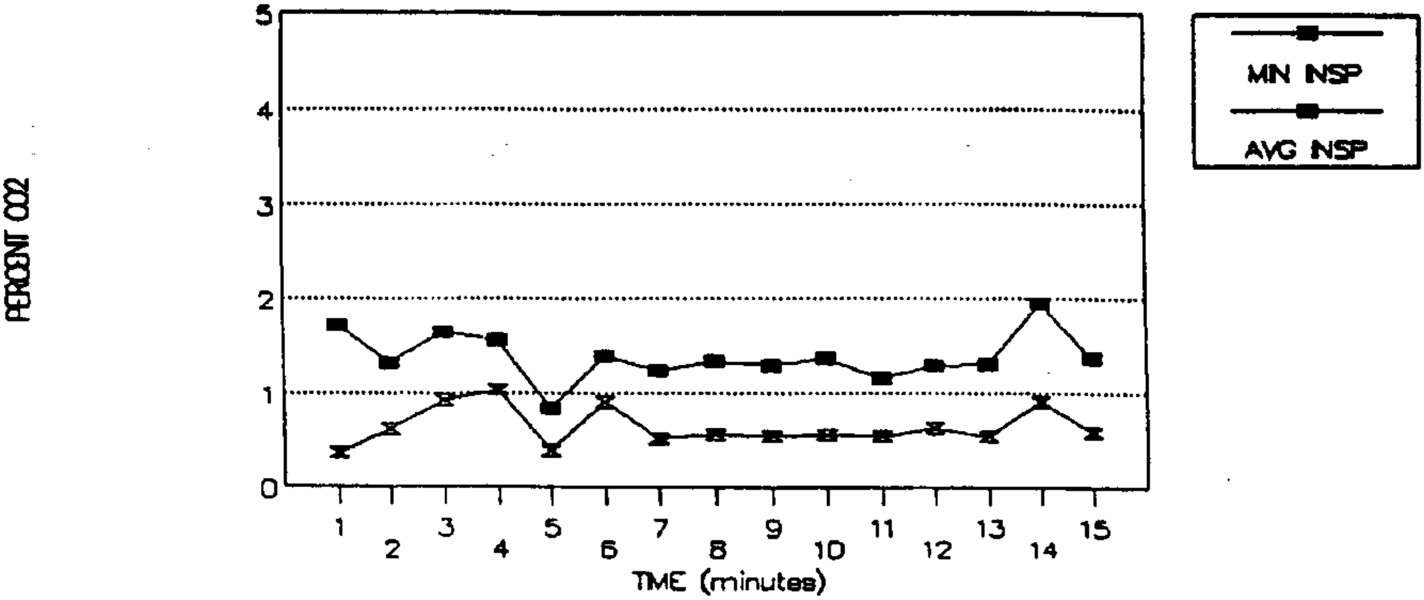
M-4, CAMI TESTS - GROUND LEVEL



-Figure 70-

INSPIRATORY CO2 VALUES

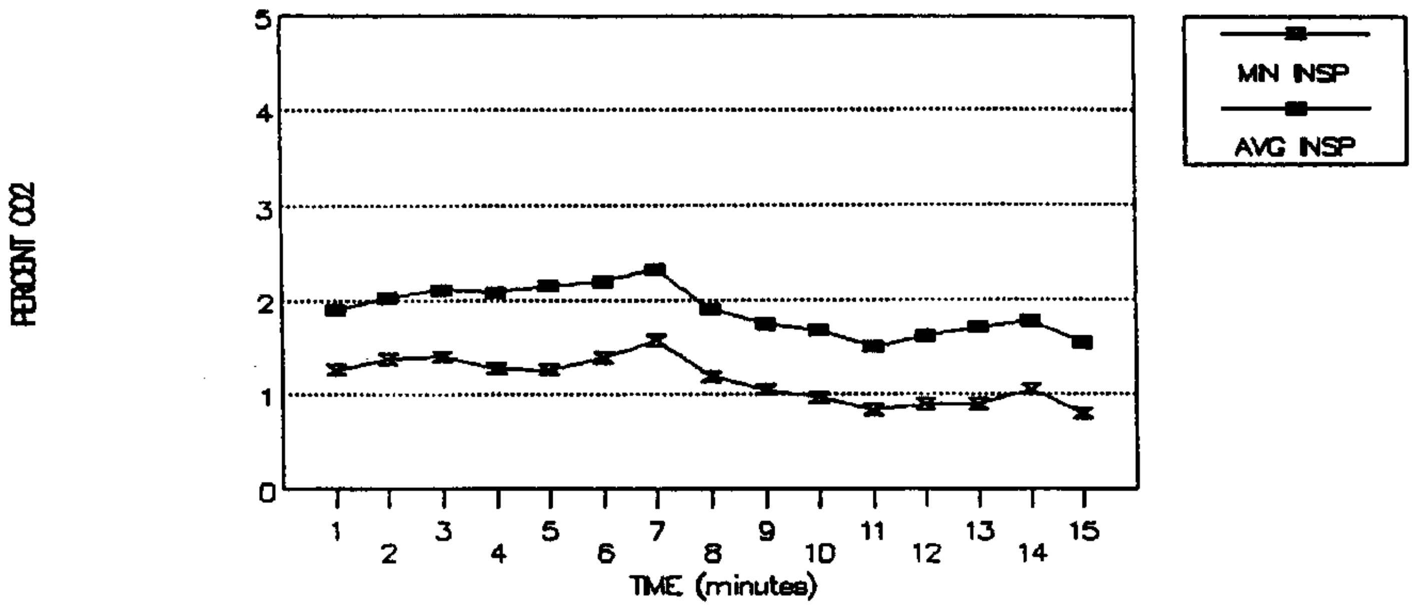
M-5, CAMI TESTS - GROUND LEVEL



-Figure 71-

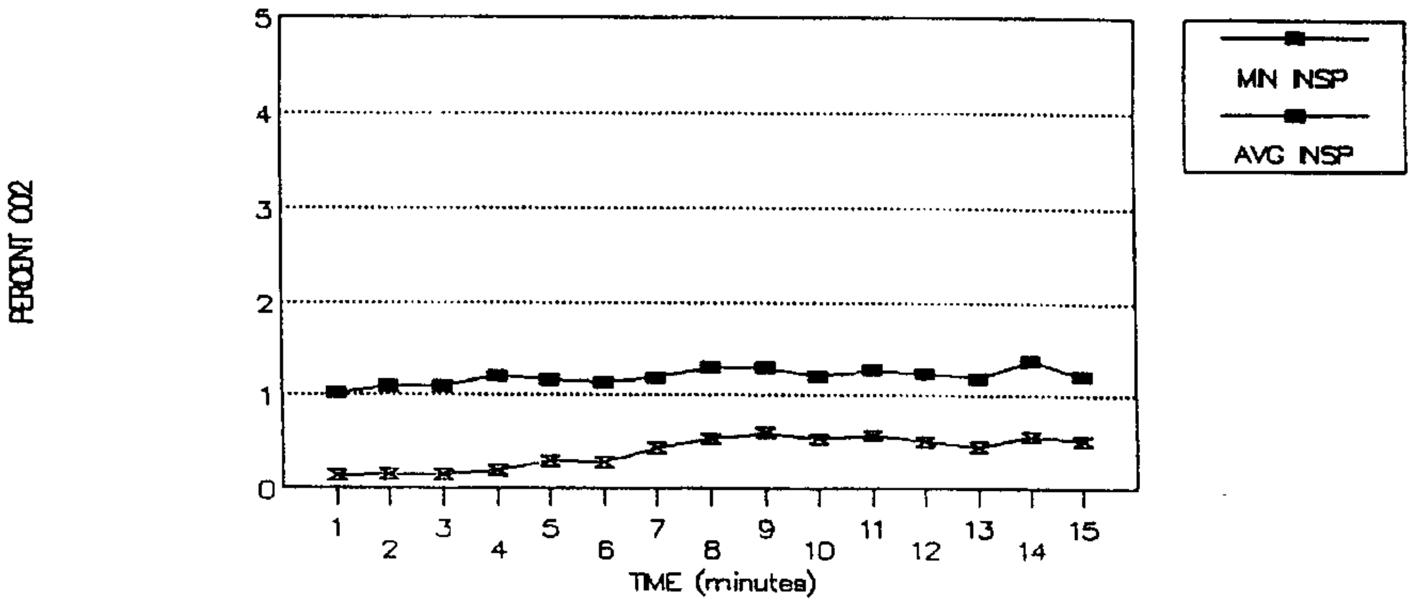
INSPIRATORY CO2 VALUES

M-6, CAMI TESTS - GROUND LEVEL



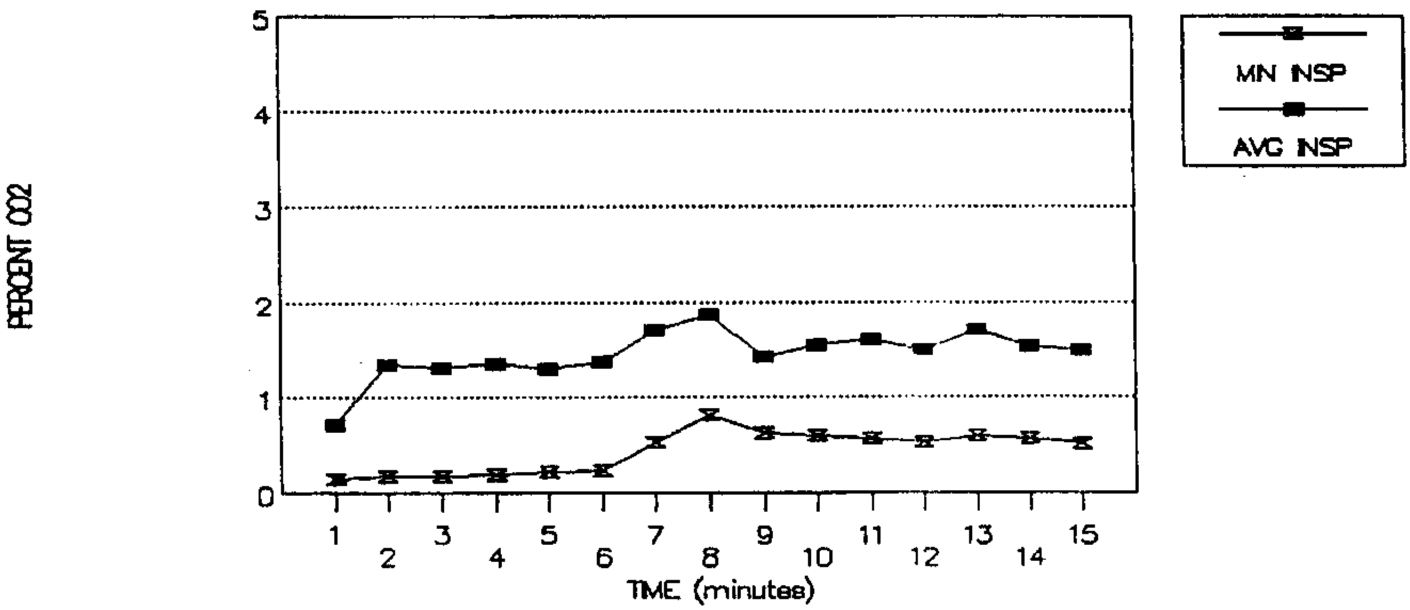
-Figure 72-

INSPIRATORY CO2 VALUES
M-7, CAMI TESTS - GROUND LEVEL



-Figure 73-

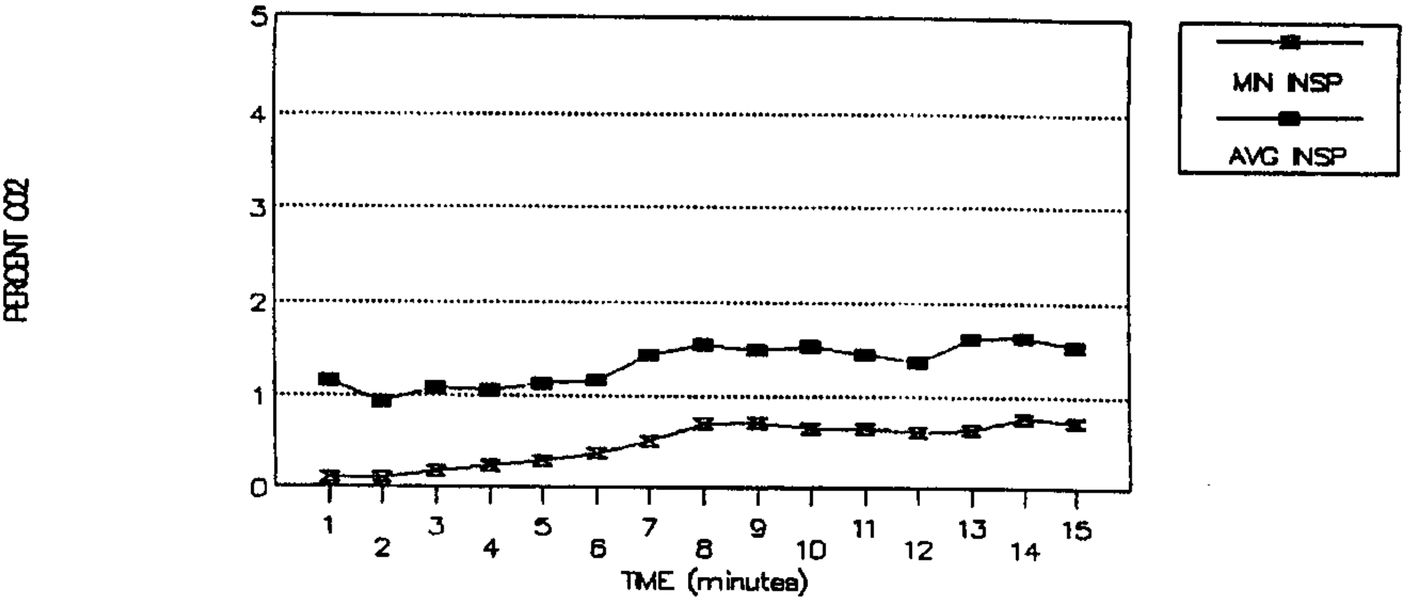
INSPIRATORY CO2 VALUES
M-8, CAMI TESTS - GROUND LEVEL



-Figure 74-

INSPIRATORY CO2 VALUES

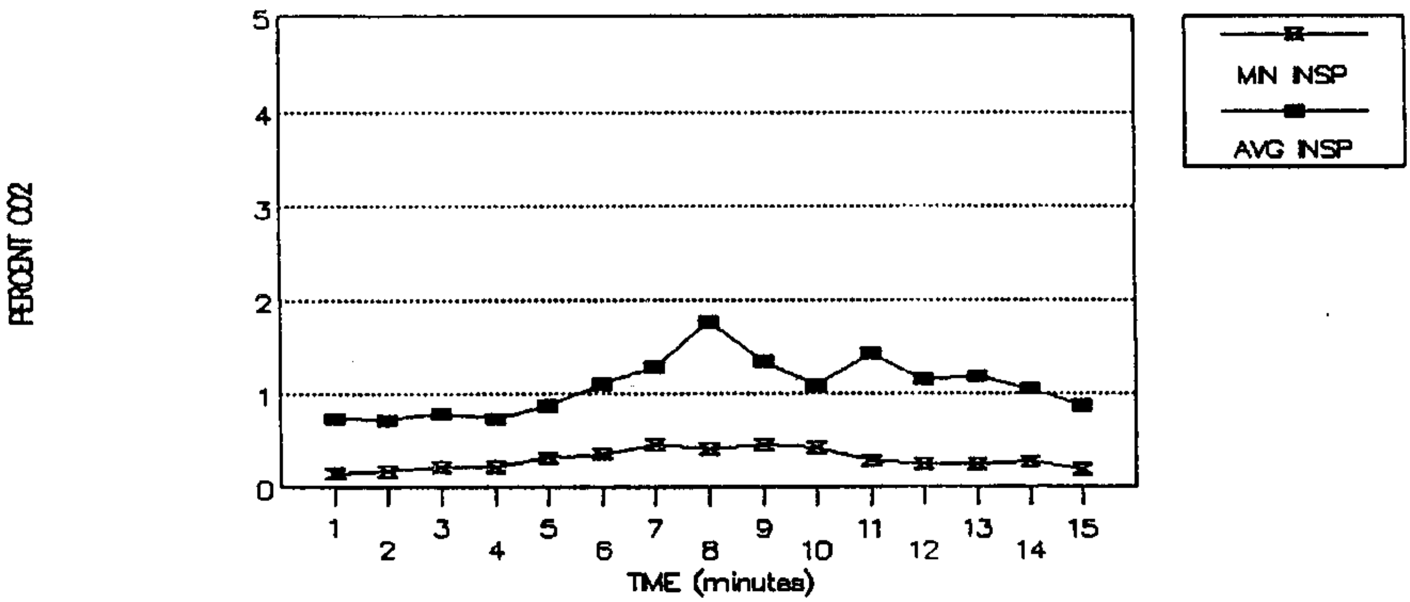
M-9, CAMI TESTS - GROUND LEVEL



-Figure 75-

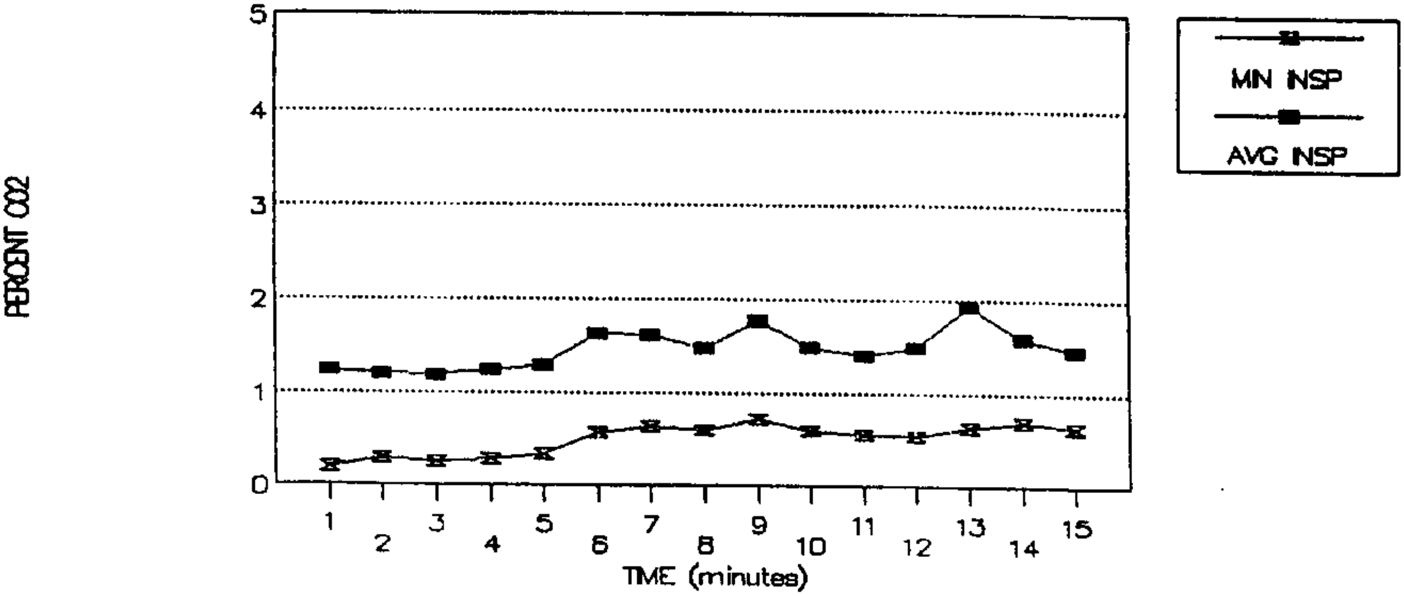
INSPIRATORY CO2 VALUES

M-10, CAMI TESTS - GROUND LEVEL



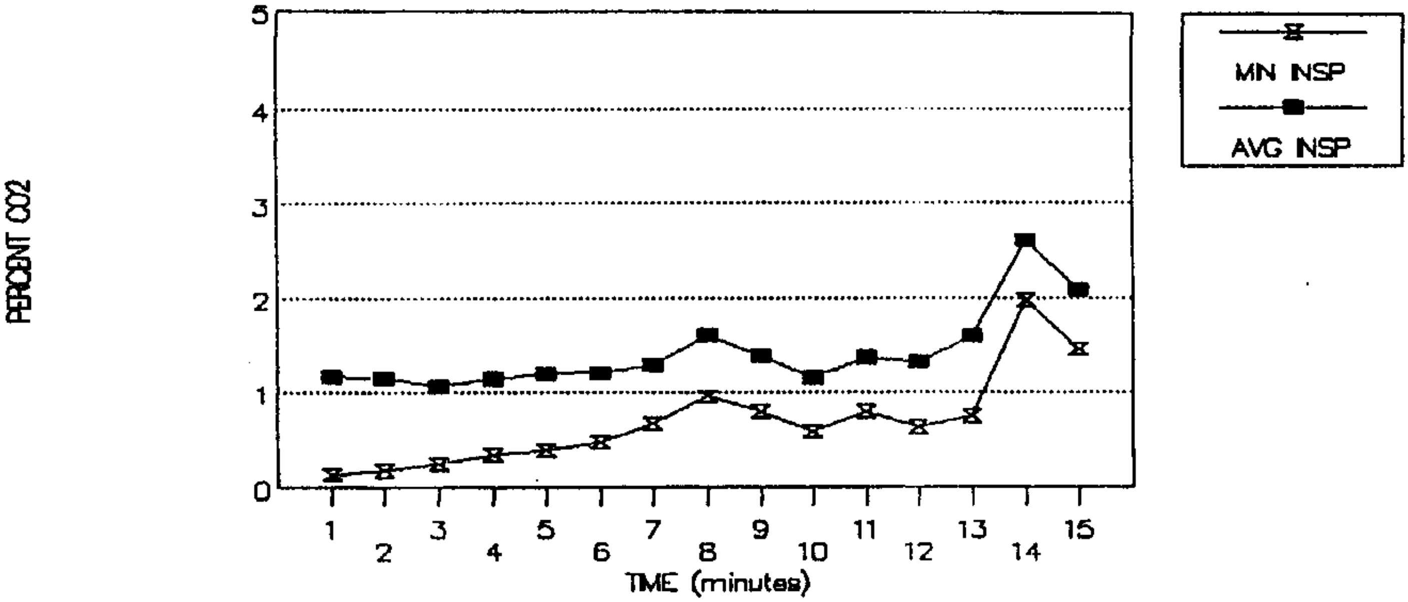
-Figure 76-

INSPIRATORY CO2 VALUES
M-11, CAMI TESTS - GROUND LEVEL



-Figure 77-

INSPIRATORY CO2 VALUES
M-12, CAMI TESTS - GROUND LEVEL



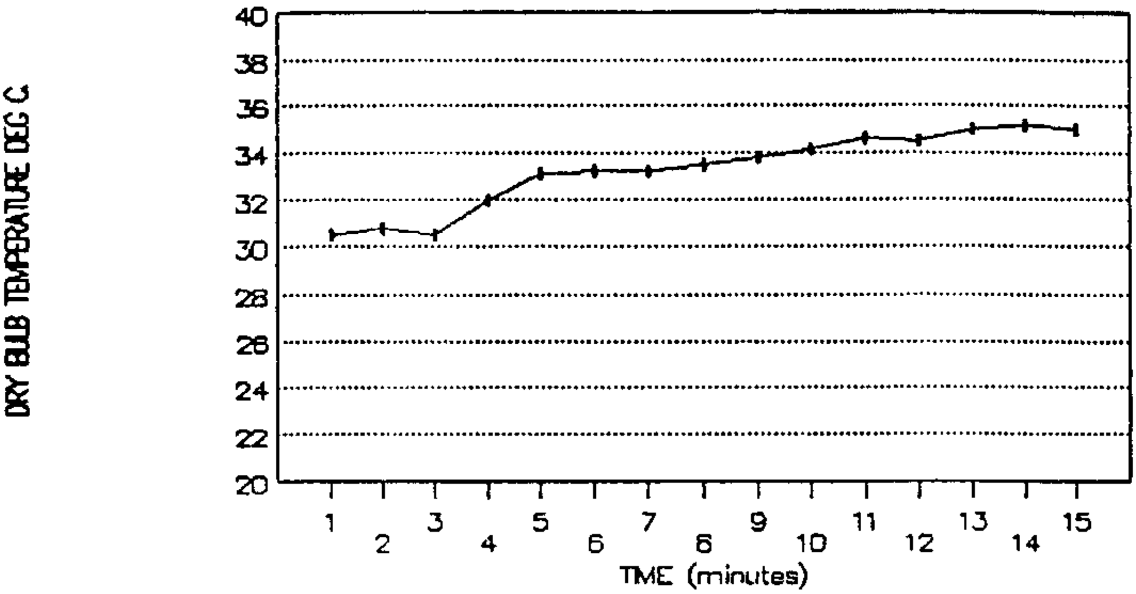
-Figure 78-

APPENDIX D

Individual Graphs of Internal PBE Dry Bulb Temperature in °C Through Time

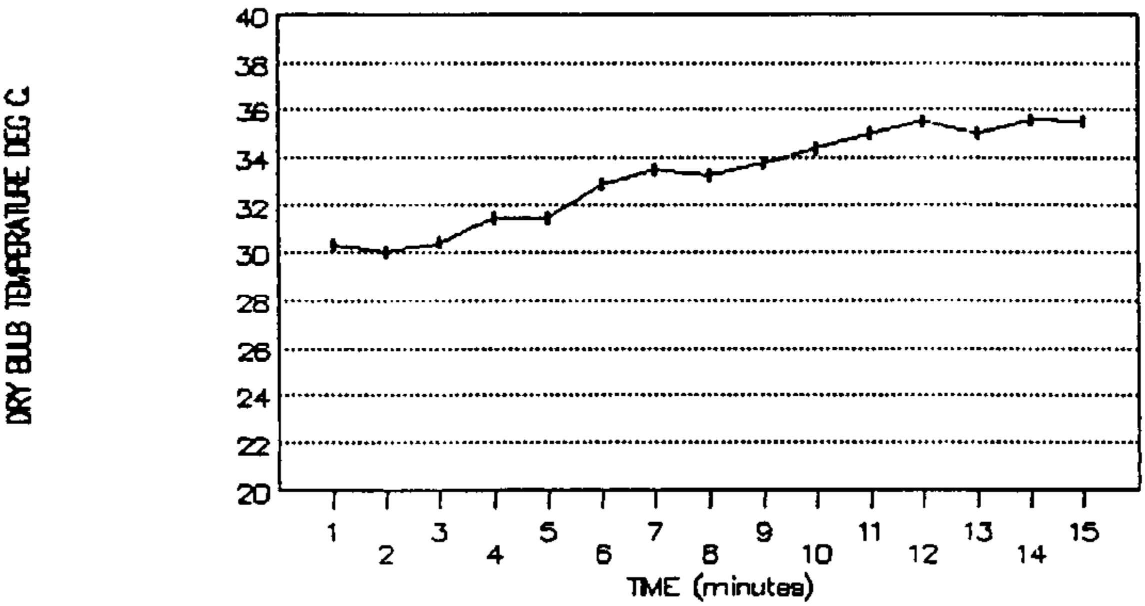
APPENDIX D

MASK INTERNAL TEMPERATURE
F-1, CAMI TEST - GROUND LEVEL



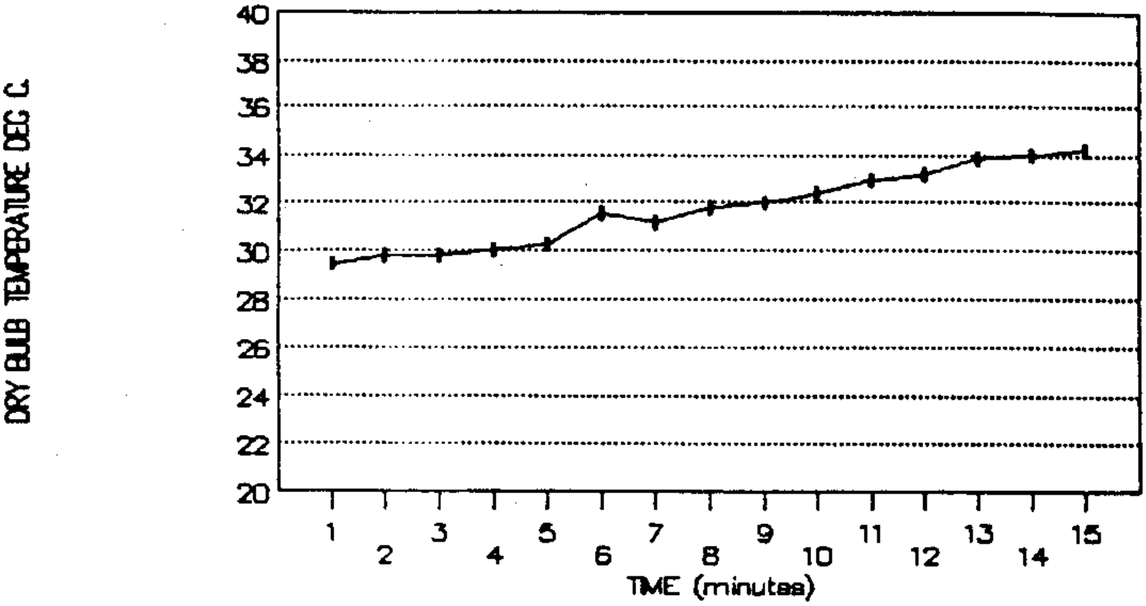
-Figure 79-

MASK INTERNAL TEMPERATURE
F-2, CAMI TEST - GROUND LEVEL



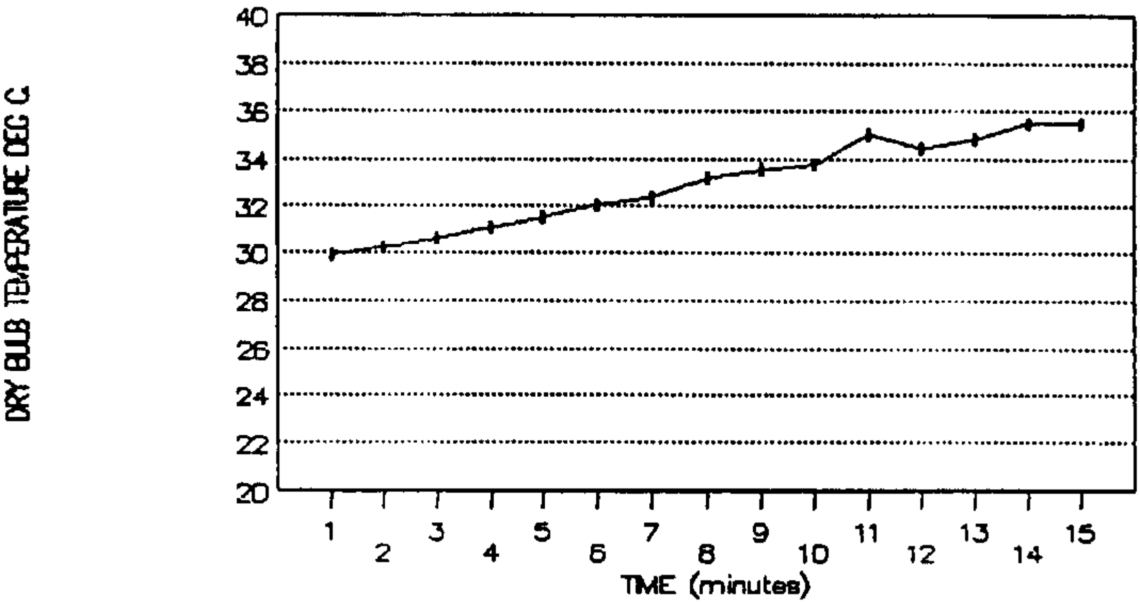
-Figure 80-

MASK INTERNAL TEMPERATURE
F-3, CAMI TEST - GROUND LEVEL



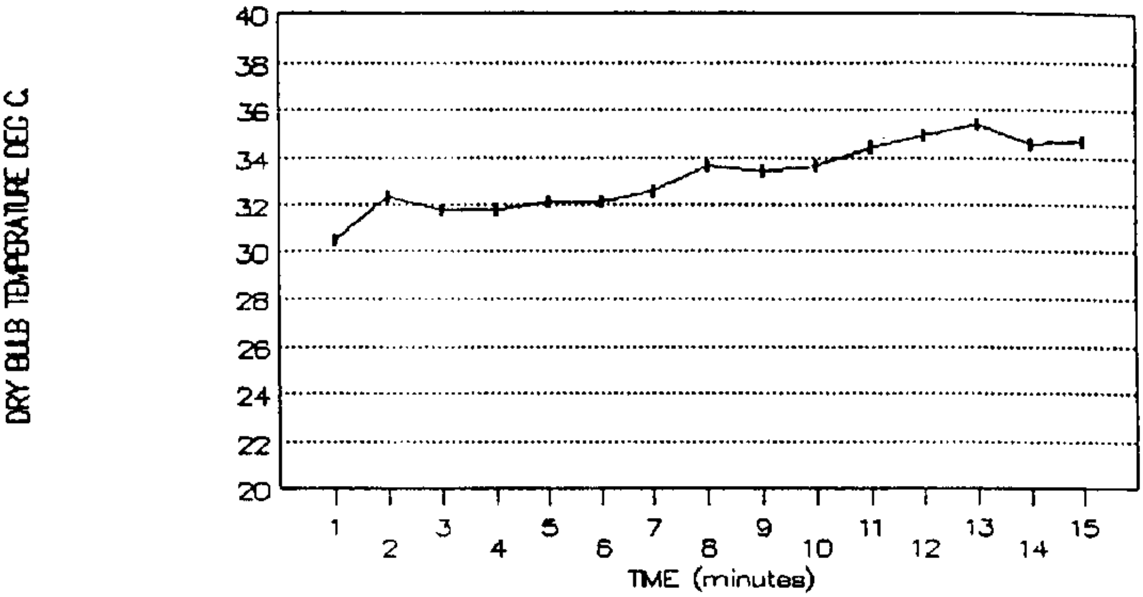
-Figure 81-

MASK INTERNAL TEMPERATURE
F-4, CAMI TEST - GROUND LEVEL



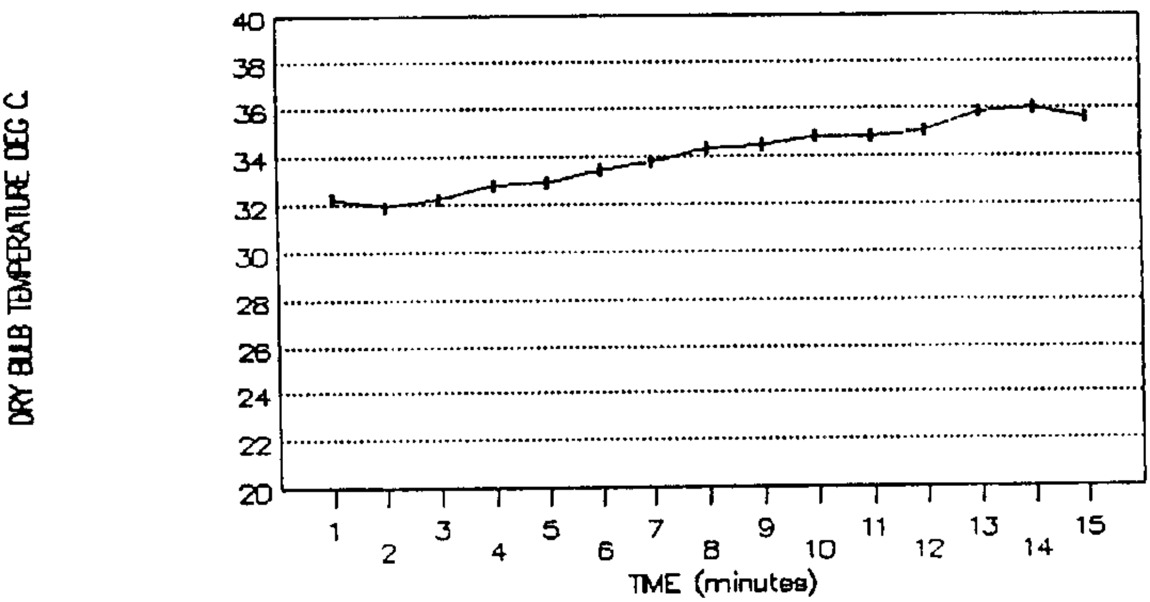
-Figure 82-

MASK INTERNAL TEMPERATURE
F—5, CAMI TEST — GROUND LEVEL



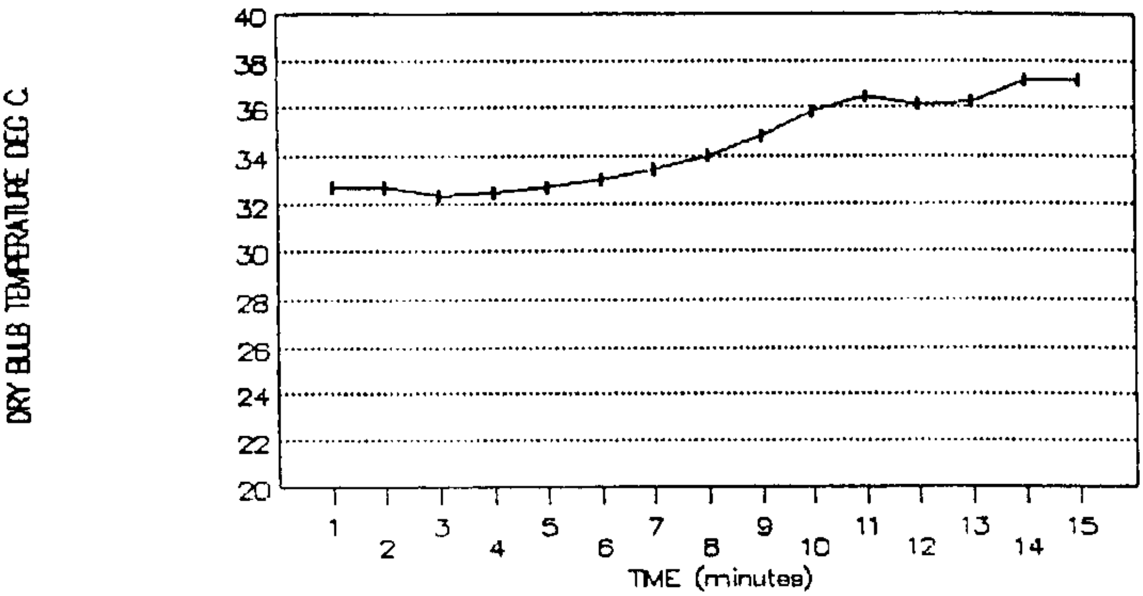
-Figure 83-

MASK INTERNAL TEMPERATURE
F—6, CAMI TEST — GROUND LEVEL



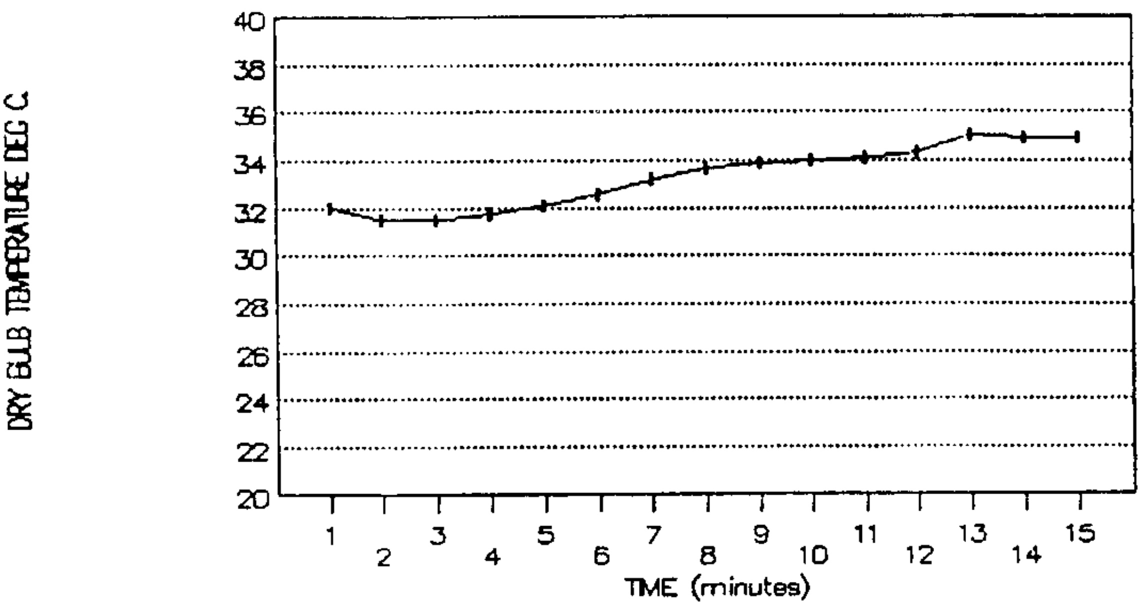
-Figure 84-

MASK INTERNAL TEMPERATURE
F-7, CAMI TEST - GROUND LEVEL



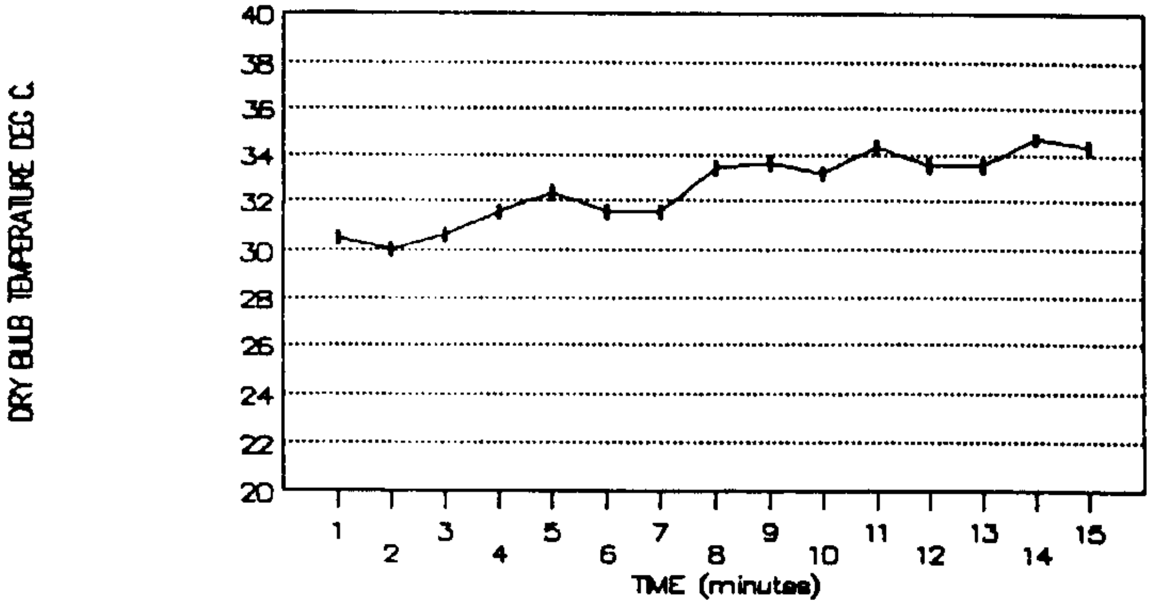
-Figure 85-

MASK INTERNAL TEMPERATURE
F-8, CAMI TEST - GROUND LEVEL



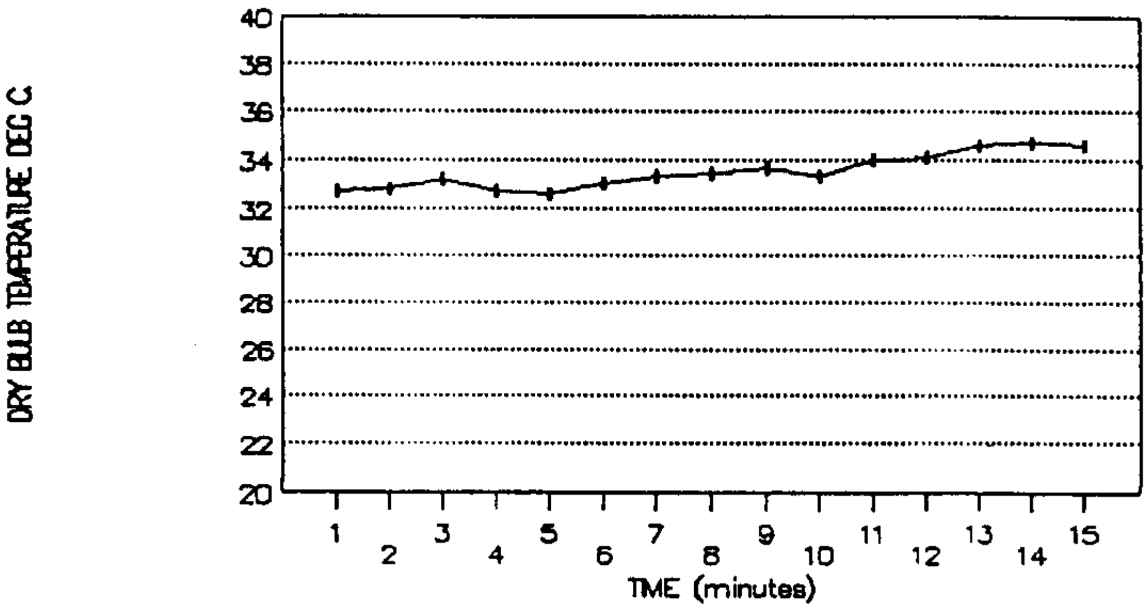
-Figure 86-

MASK INTERNAL TEMPERATURE
F-9, CAMI TEST - GROUND LEVEL



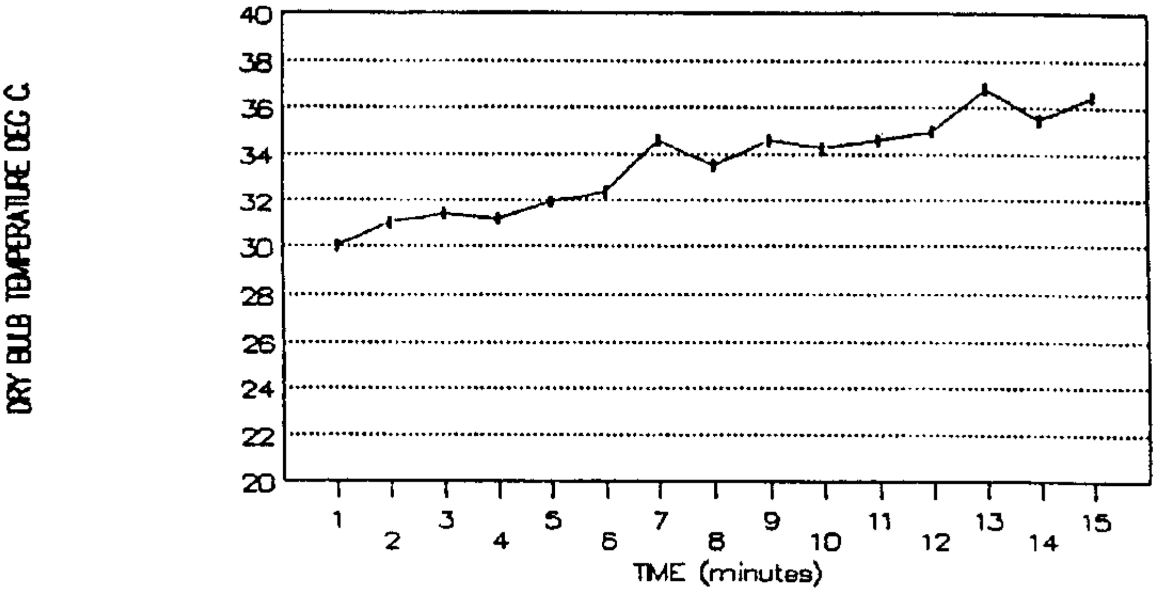
-Figure 87-

MASK INTERNAL TEMPERATURE
F-10, CAMI TEST - GROUND LEVEL



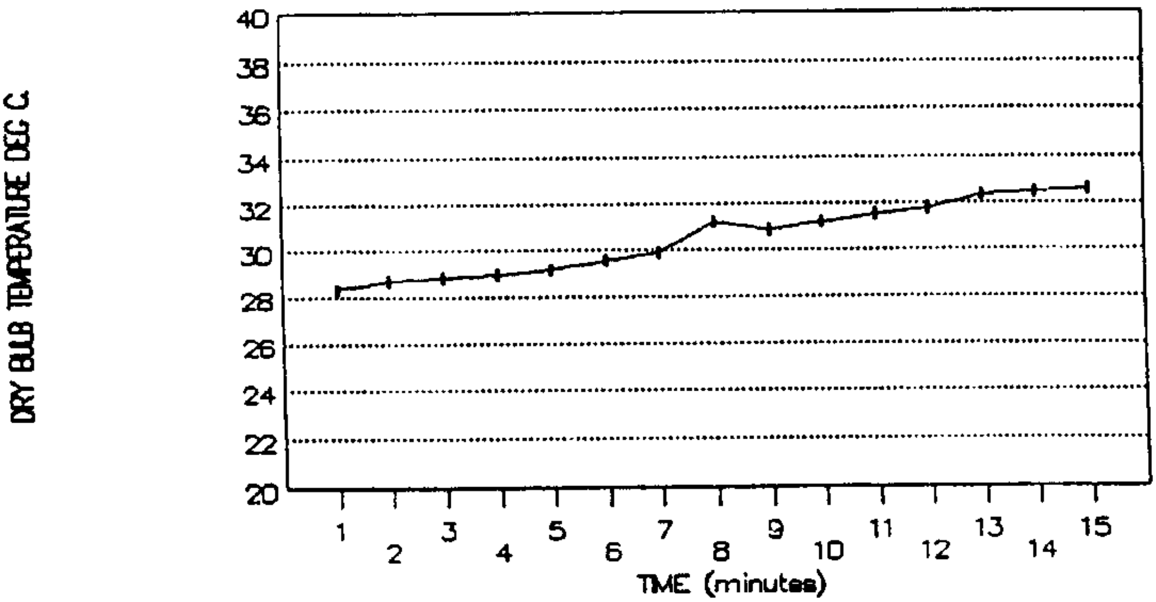
-Figure 88-

MASK INTERNAL TEMPERATURE
M-1, CAMI TESTS – GROUND LEVEL



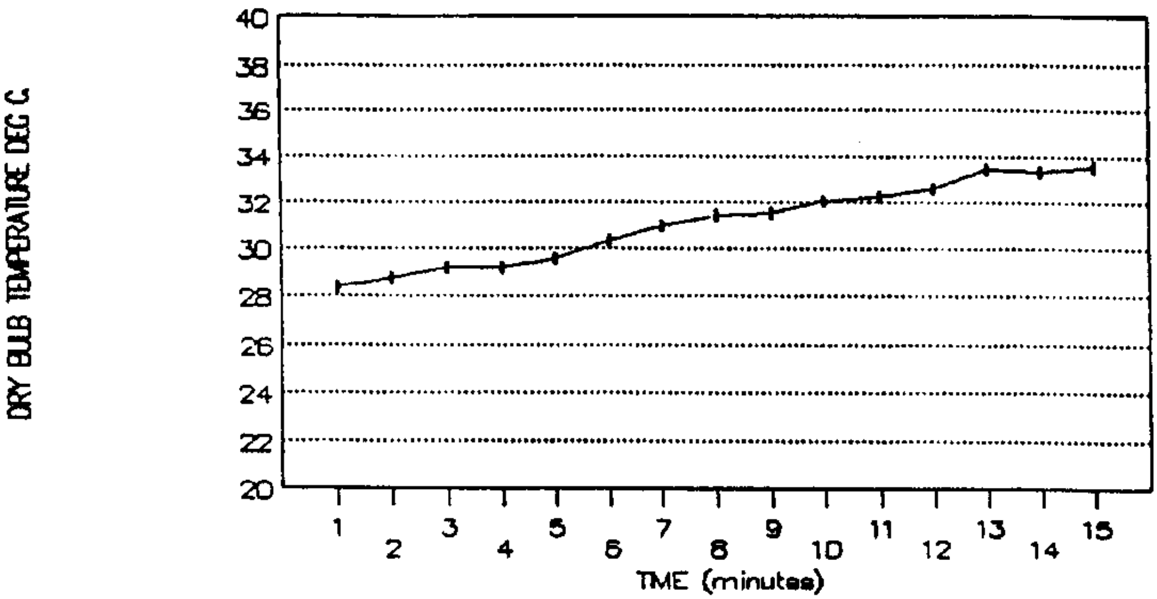
-Figure 91-

MASK INTERNAL TEMPERATURE
M-2, CAMI TESTS – GROUND LEVEL



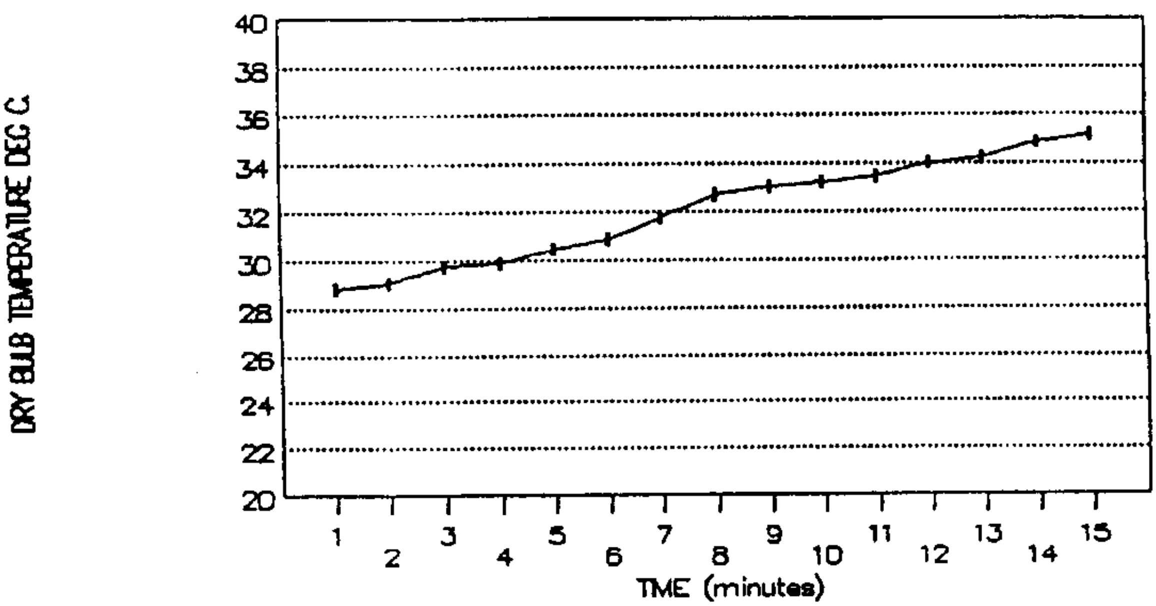
-Figure 92-

MASK INTERNAL TEMPERATURE
M-3, CAMI TESTS - GROUND LEVEL



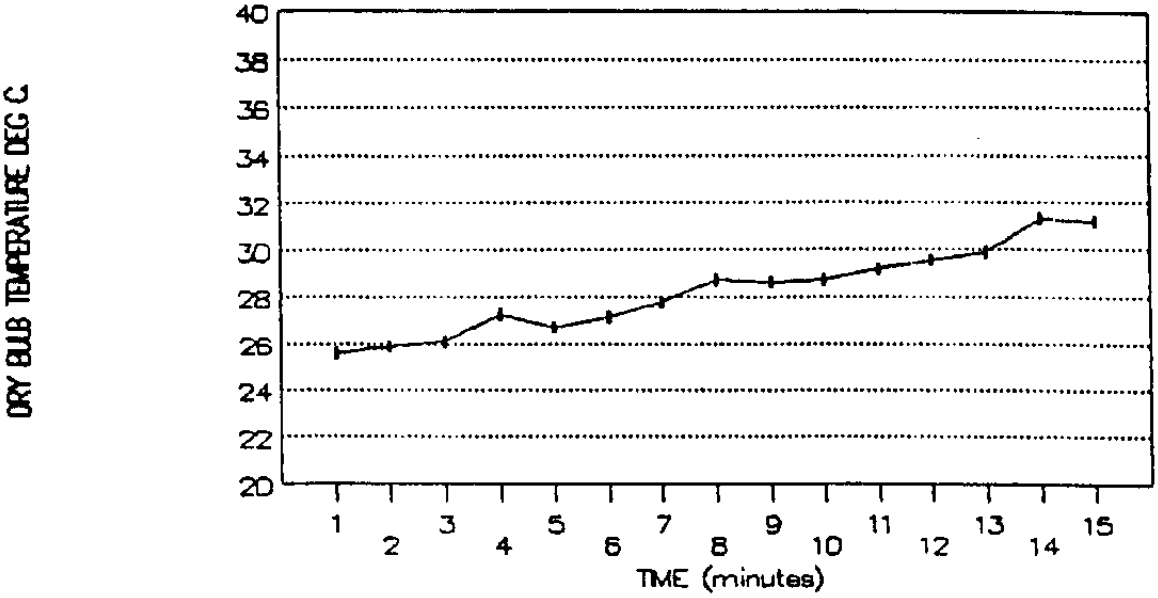
-Figure 93-

MASK INTERNAL TEMPERATURE
M-4, CAMI TESTS - GROUND LEVEL



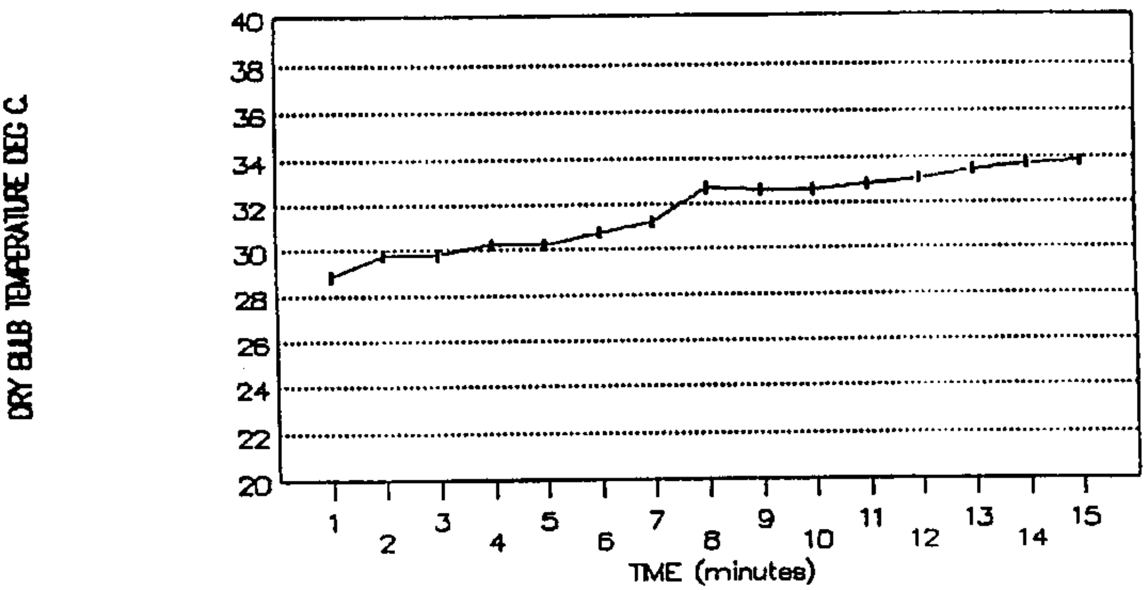
-Figure 94-

MASK INTERNAL TEMPERATURE
M–5, CAMI TESTS – GROUND LEVEL



-Figure 95-

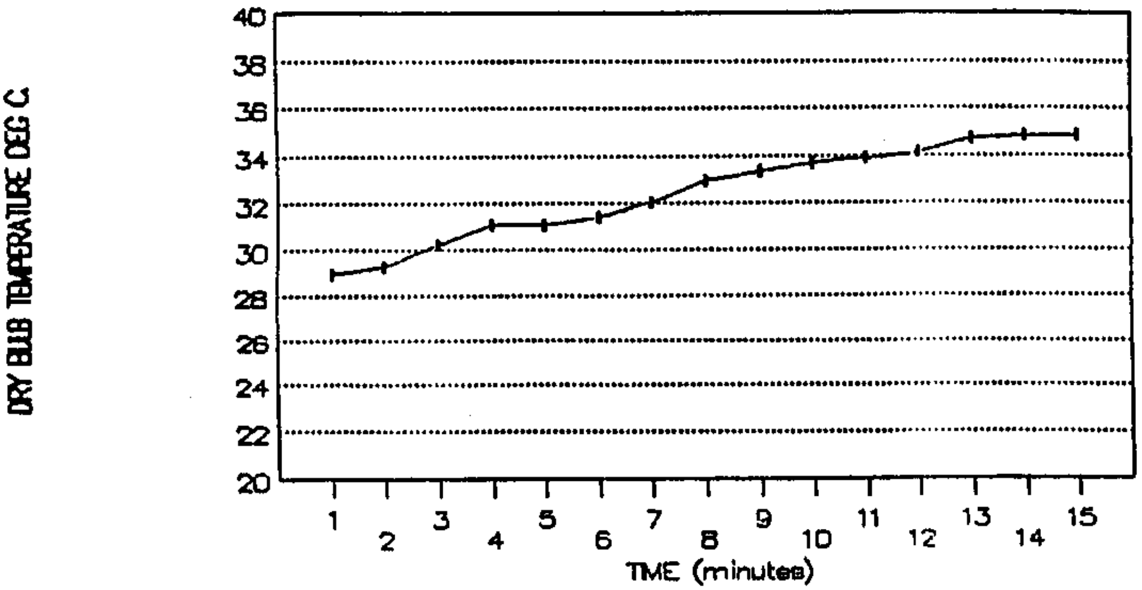
MASK INTERNAL TEMPERATURE
M–6, CAMI TESTS – GROUND LEVEL



-Figure 96-

MASK INTERNAL TEMPERATURE

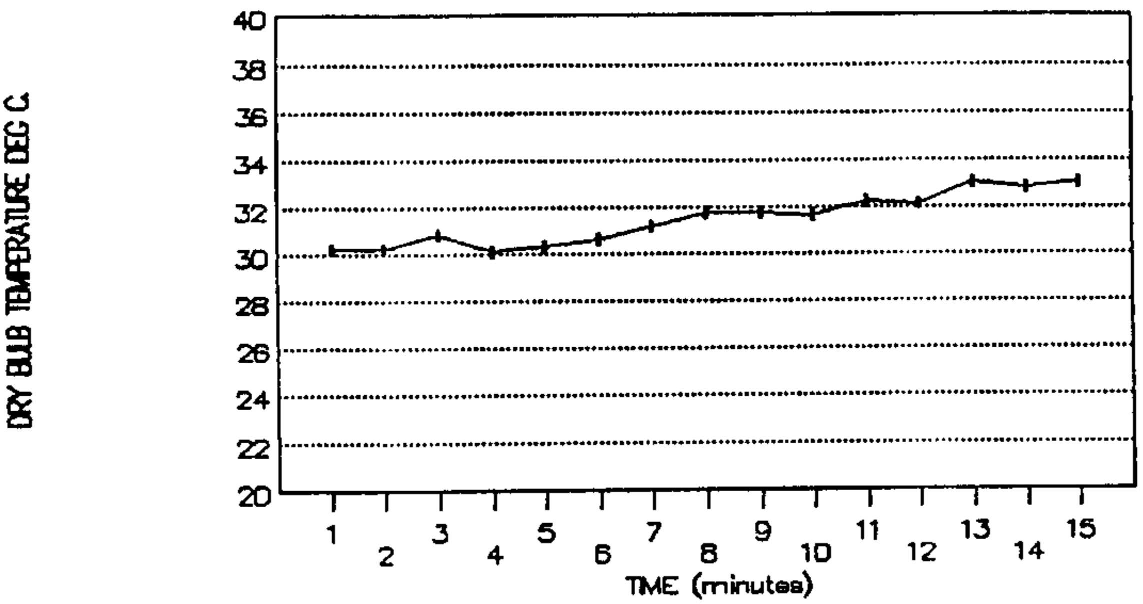
M-7, CAMI TESTS - GROUND LEVEL



-Figure 97-

MASK INTERNAL TEMPERATURE

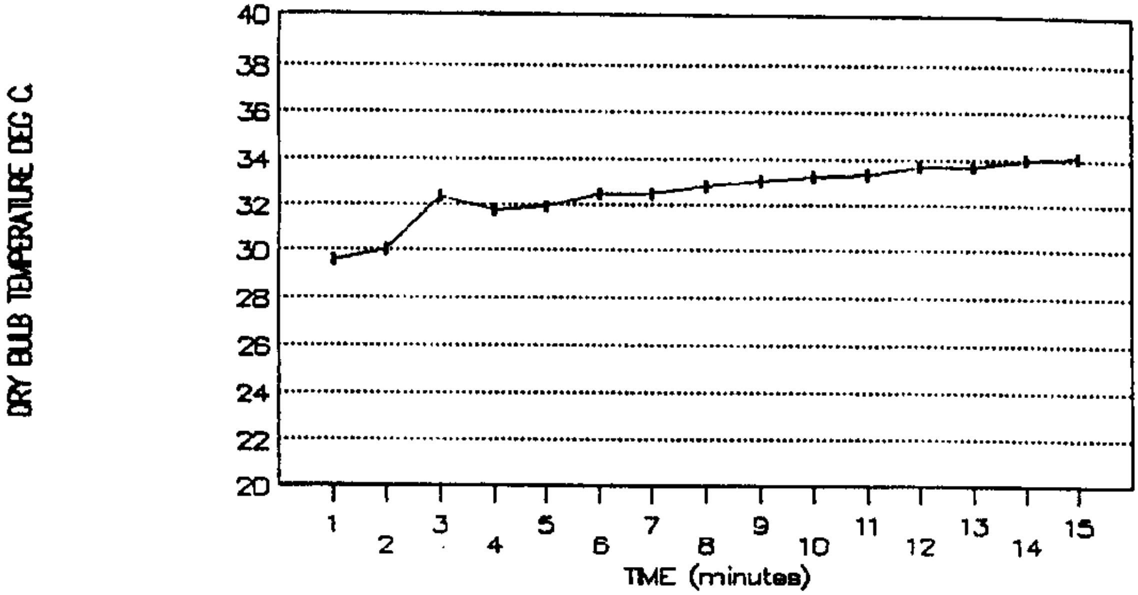
M-8, CAMI TESTS - GROUND LEVEL



-Figure 98-

MASK INTERNAL TEMPERATURE

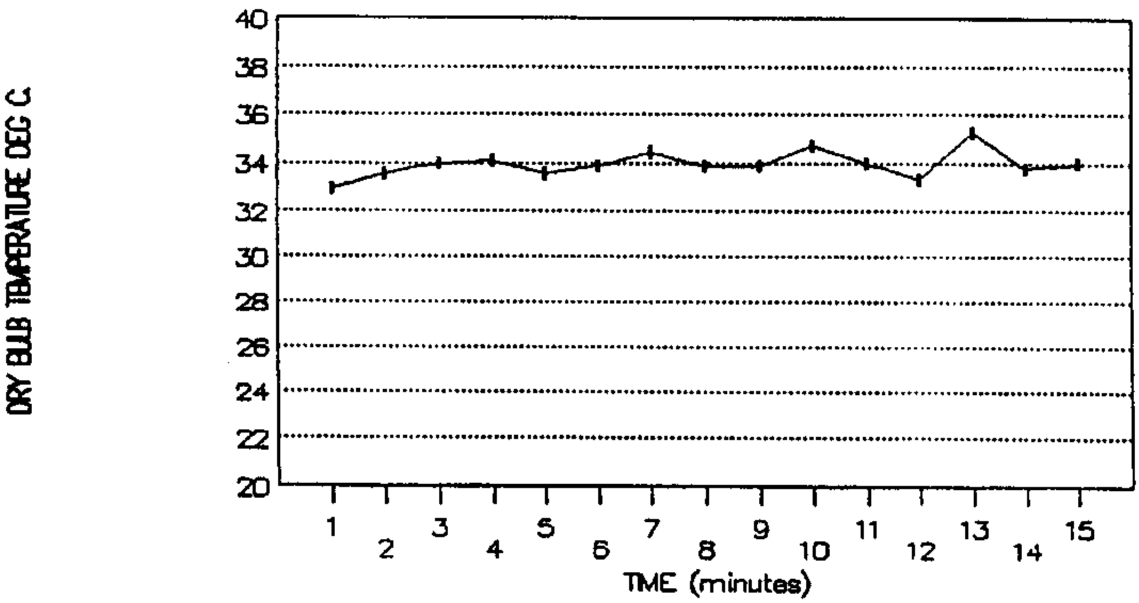
M-9, CAMI TESTS - GROUND LEVEL



-Figure 99-

MASK INTERNAL TEMPERATURE

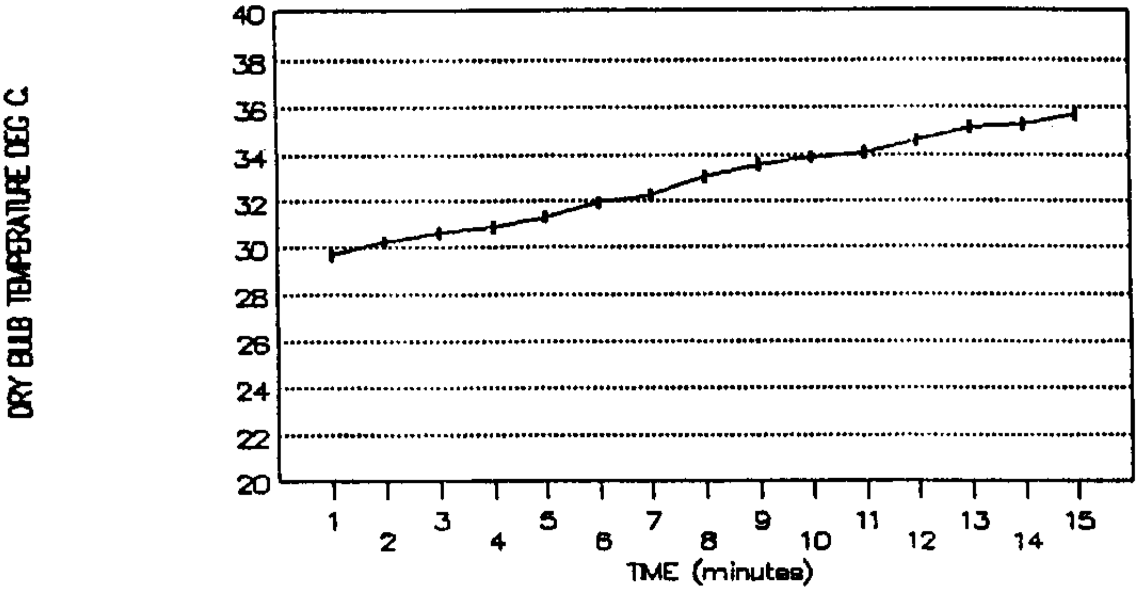
M-10, CAMI TESTS - GROUND LEVEL



-Figure 100-

MASK INTERNAL TEMPERATURE

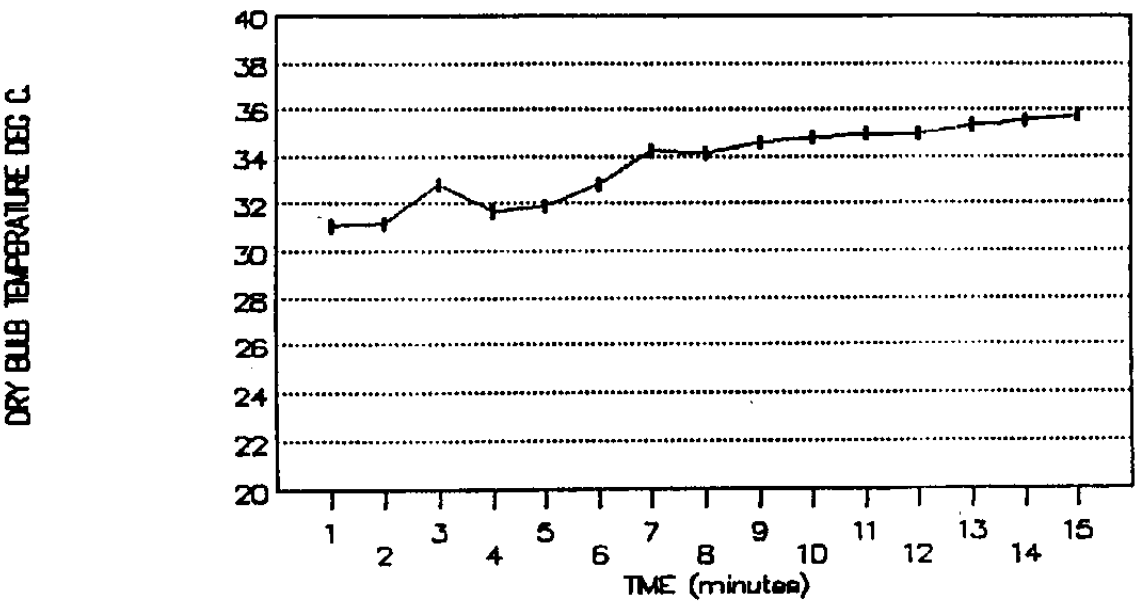
M–11, CAMI TESTS – GROUND LEVEL



-Figure 101-

MASK INTERNAL TEMPERATURE

M–12, CAMI TESTS – GROUND LEVEL



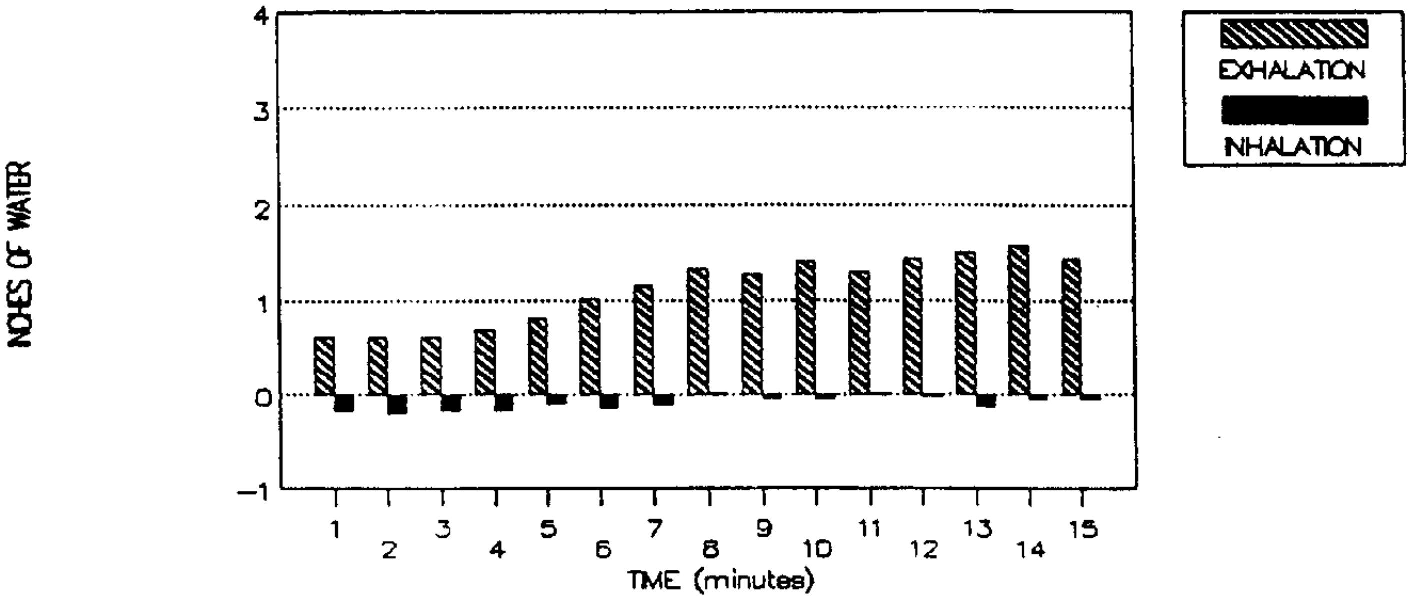
-Figure 102-

APPENDIX E

Individual Graphs of Inhalation/Exhalation Pressures in Inches of Water Through Time

BREATHING RESISTANCE

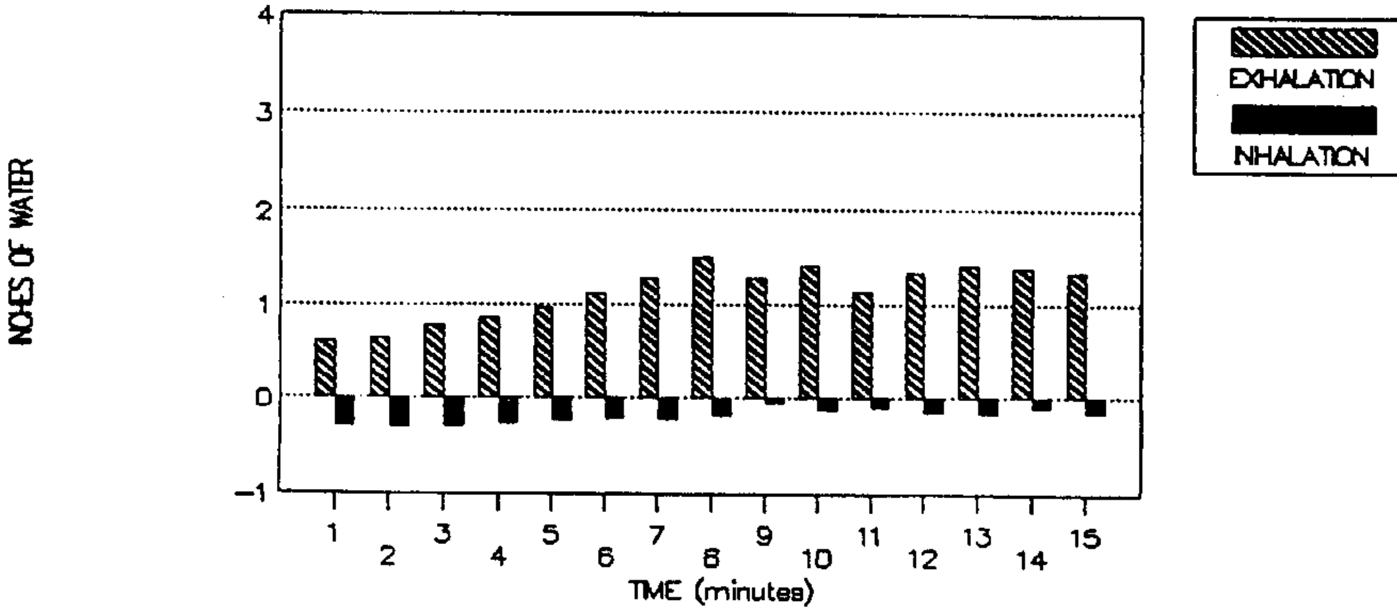
F-1, CAMI TESTS - GROUND LEVEL



-Figure 103-

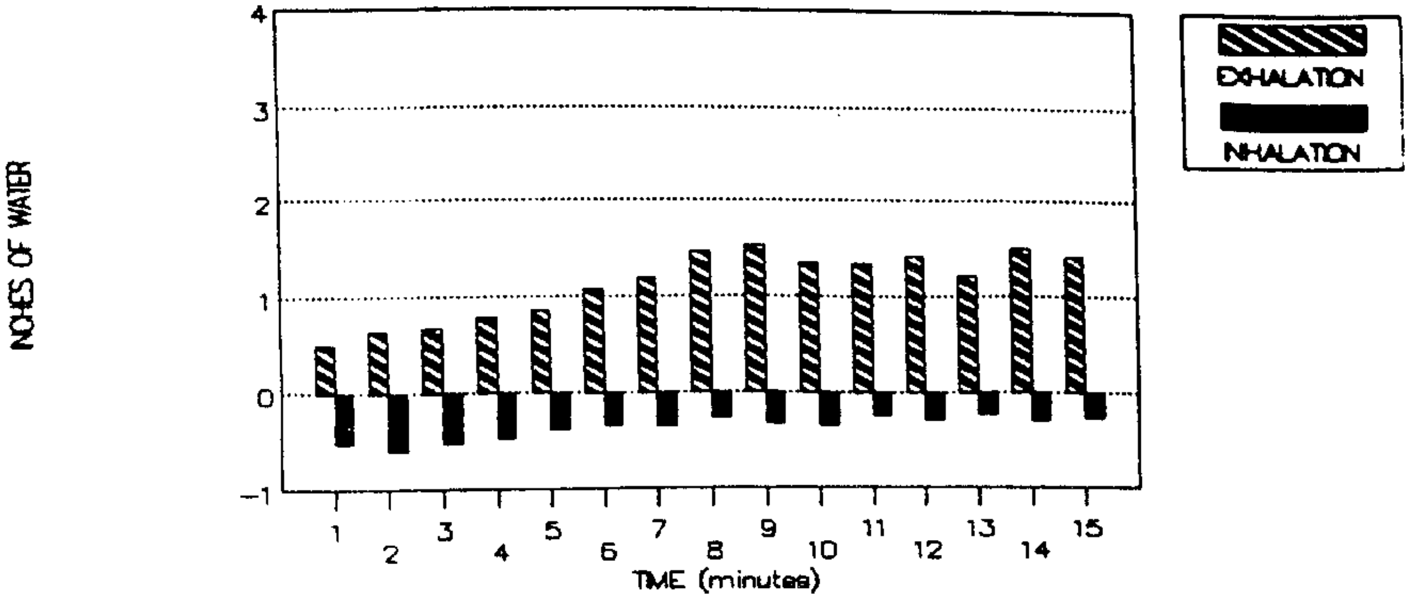
BREATHING RESISTANCE

F-2, CAMI TESTS - GROUND LEVEL



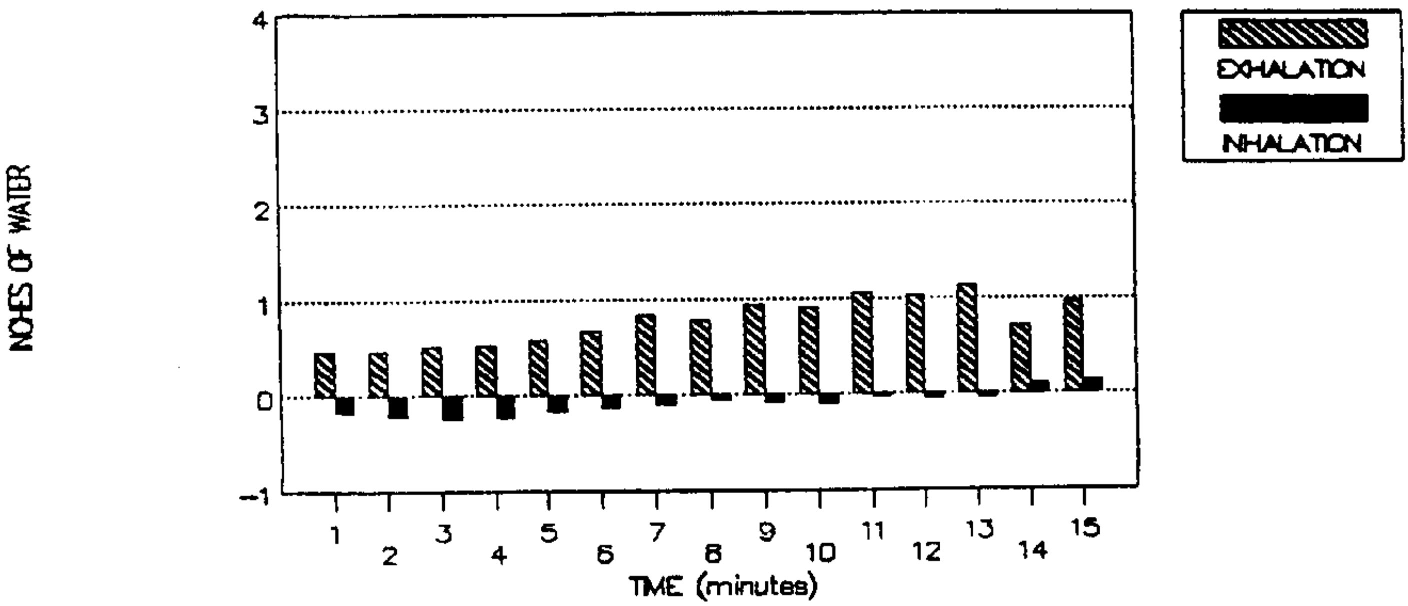
-Figure 104-

BREATHING RESISTANCE
F-3, CAMI TESTS - GROUND LEVEL



-Figure 105-

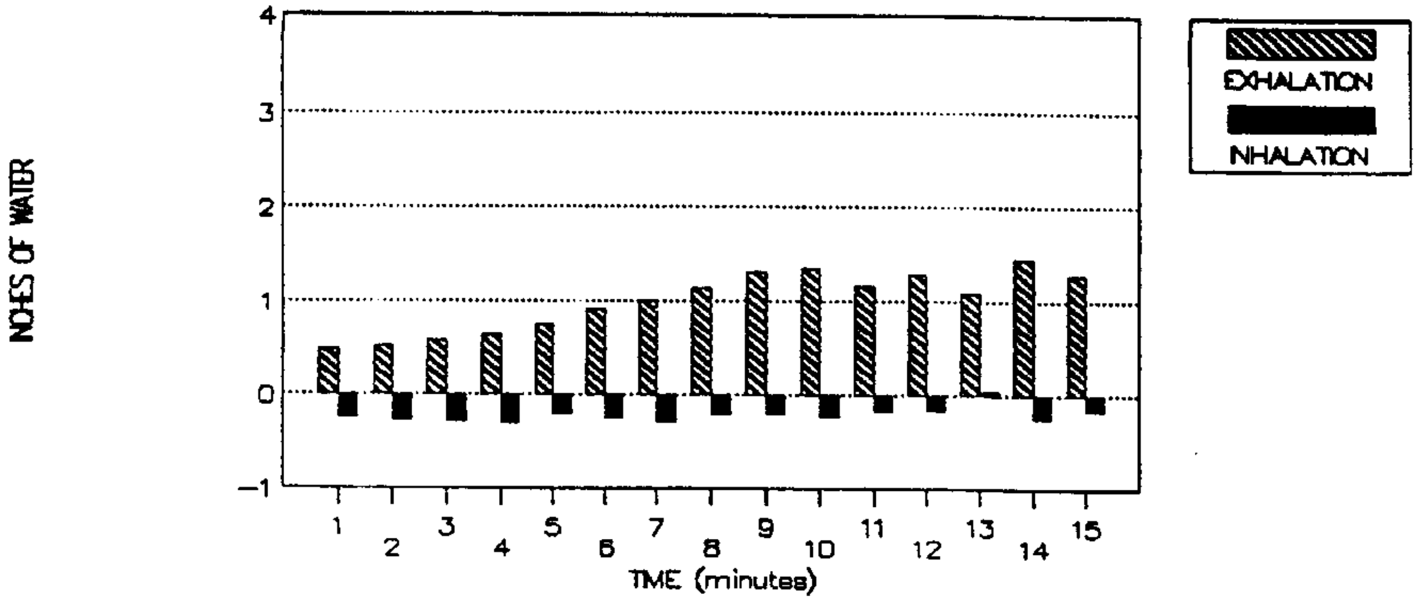
BREATHING RESISTANCE
F-4, CAMI TESTS - GROUND LEVEL



-Figure 106-

BREATHING RESISTANCE

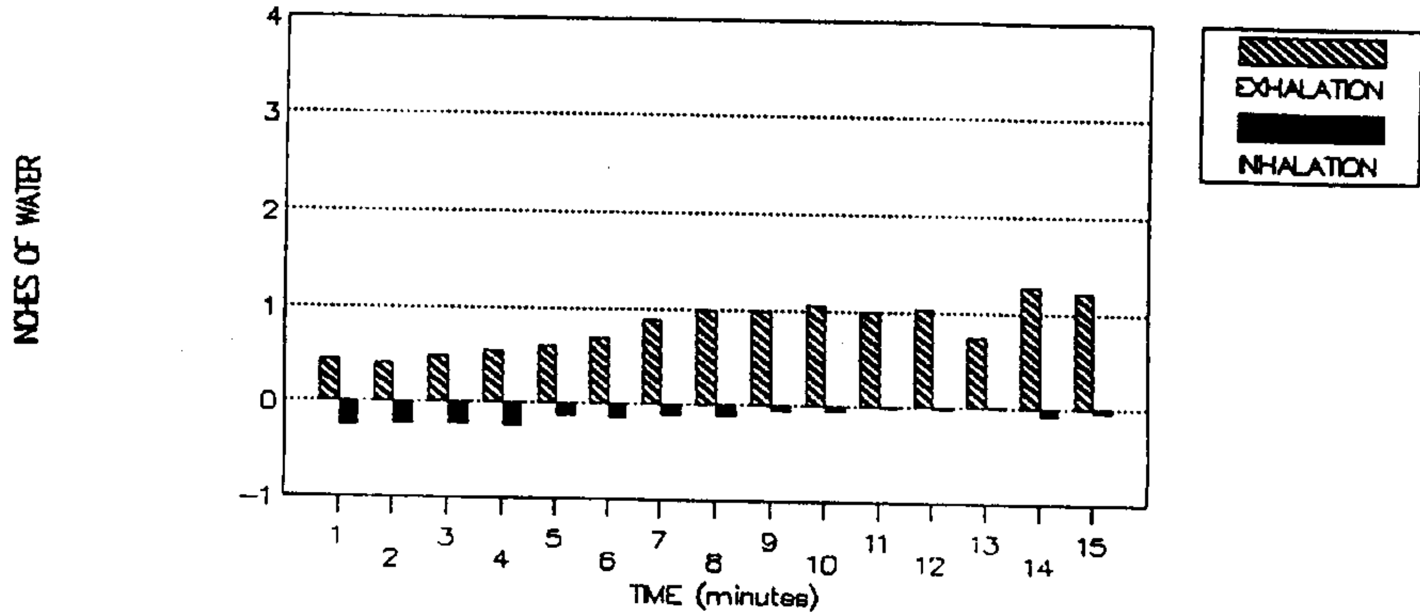
F–5, CAMI TESTS – GROUND LEVEL



-Figure 107-

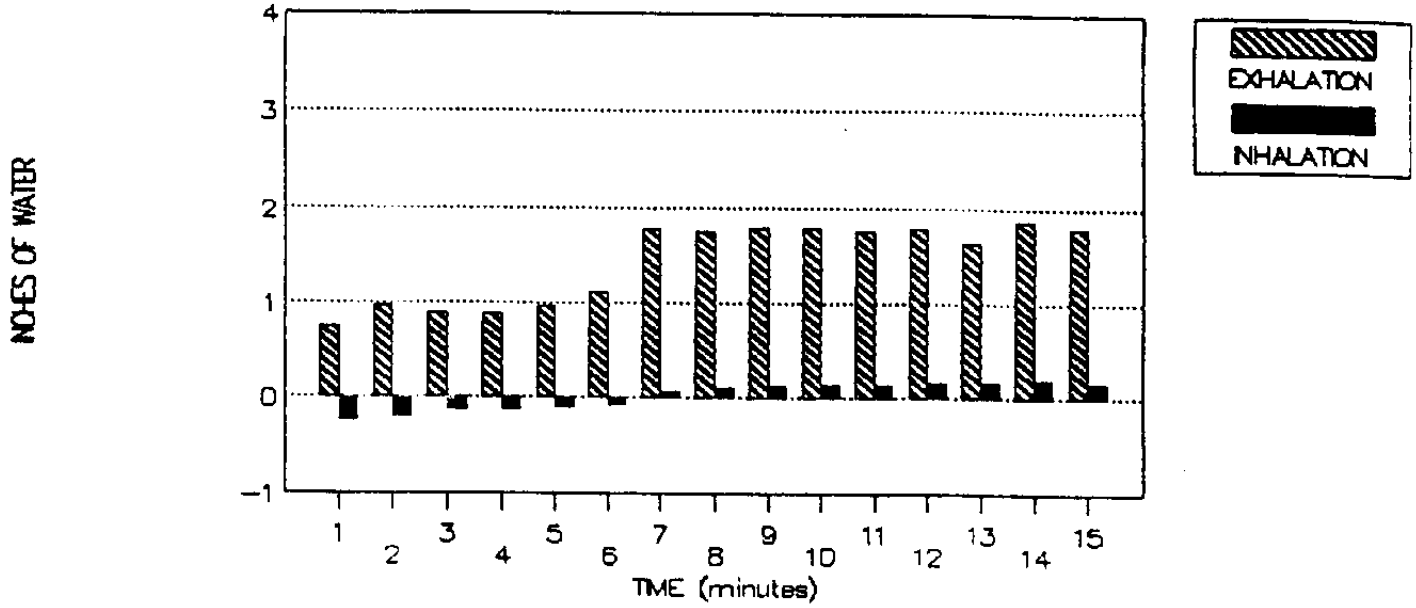
BREATHING RESISTANCE

F–6, CAMI TESTS – GROUND LEVEL



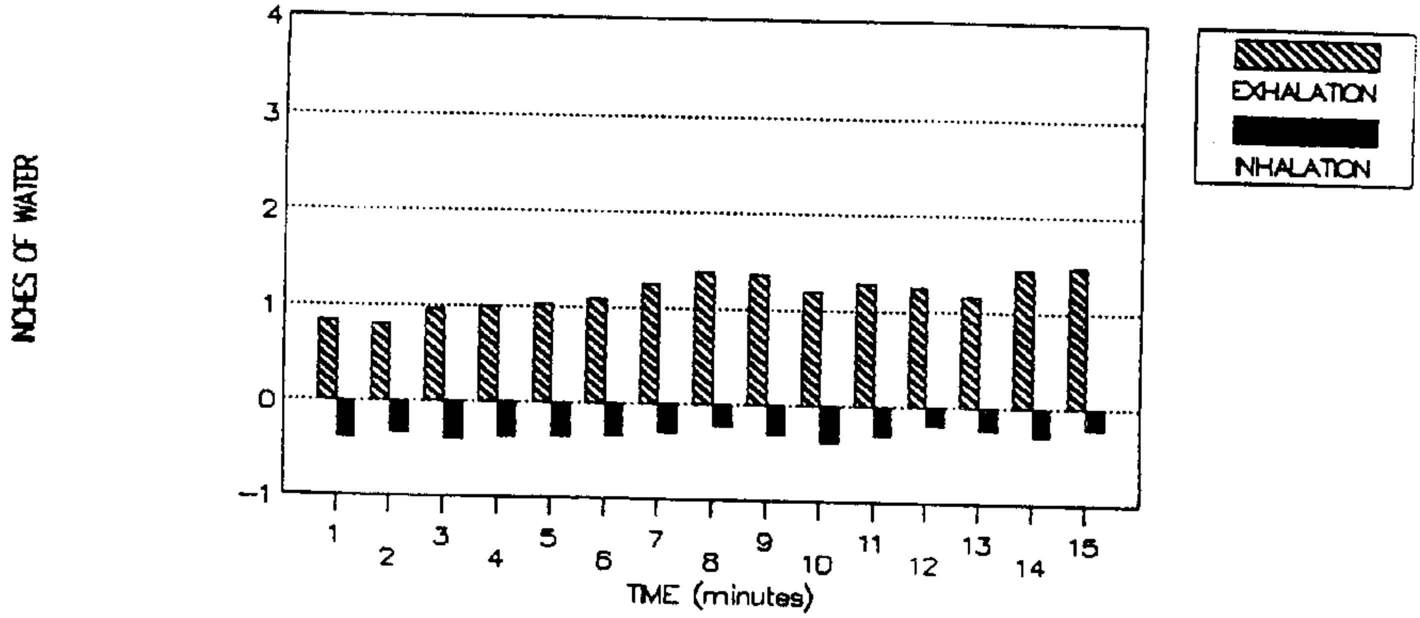
-Figure 108-

BREATHING RESISTANCE
F-7, CAMI TESTS – GROUND LEVEL



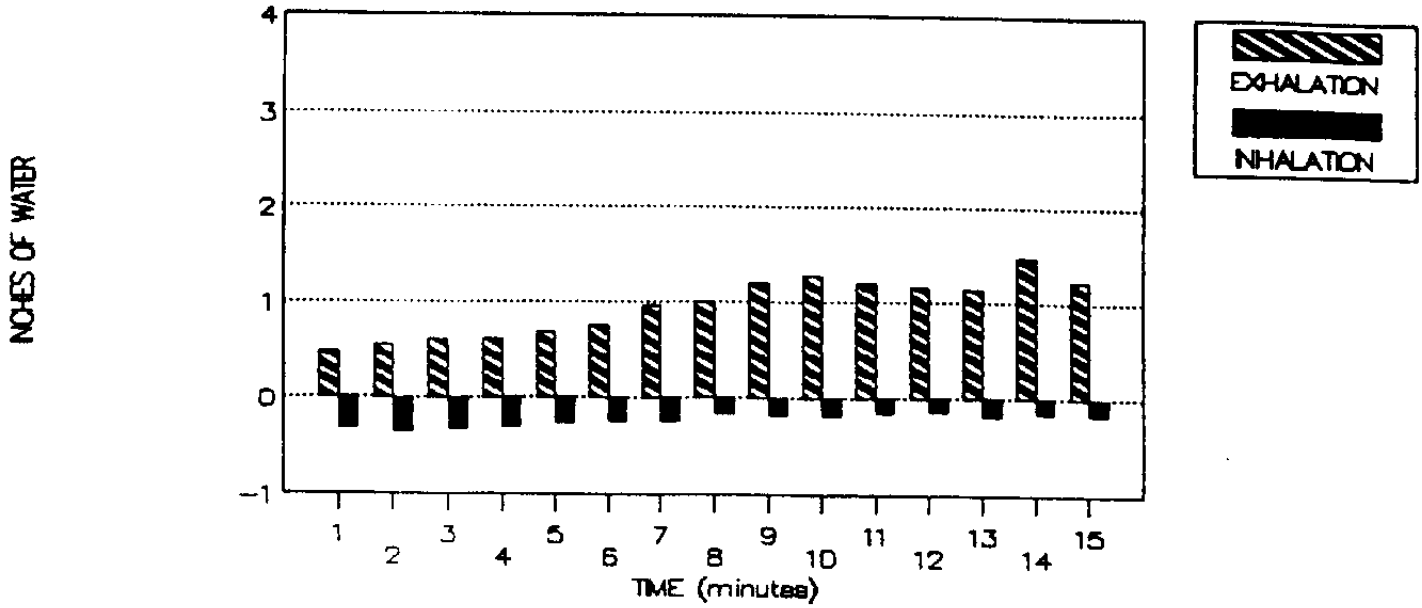
-Figure 109-

BREATHING RESISTANCE
F-8, CAMI TESTS – GROUND LEVEL



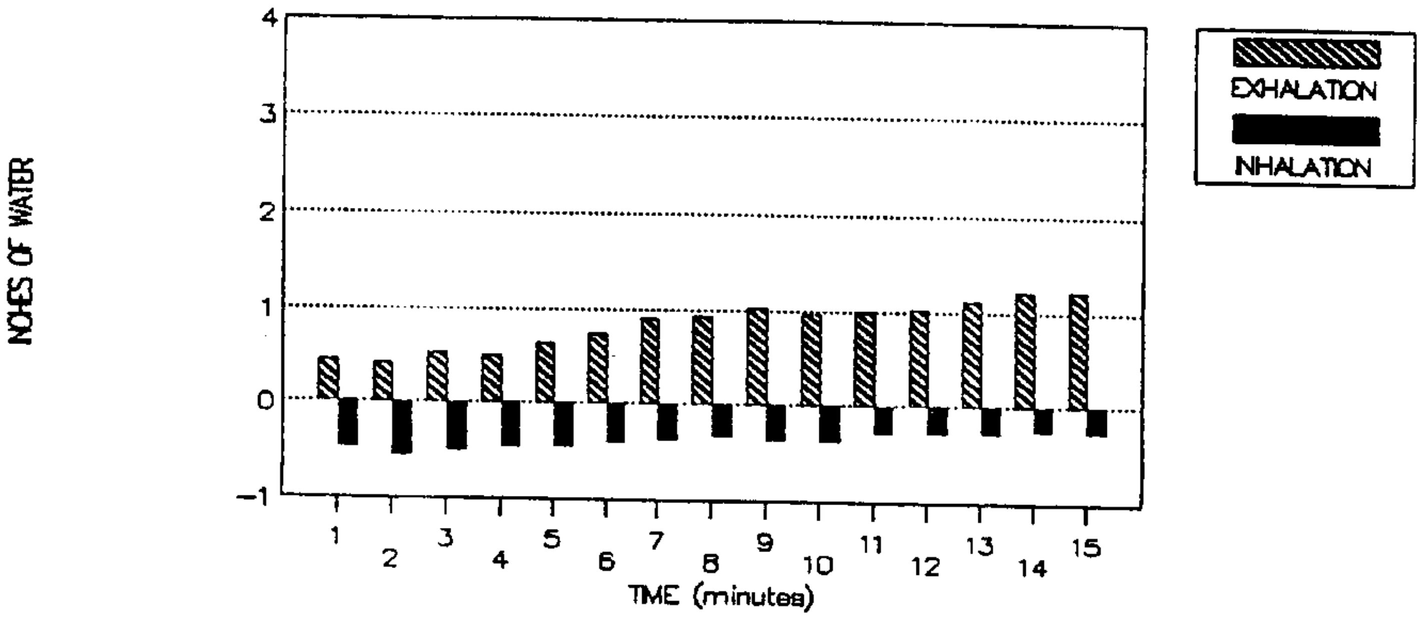
-Figure 110-

BREATHING RESISTANCE
F–9, CAMI TESTS – GROUND LEVEL



-Figure 111-

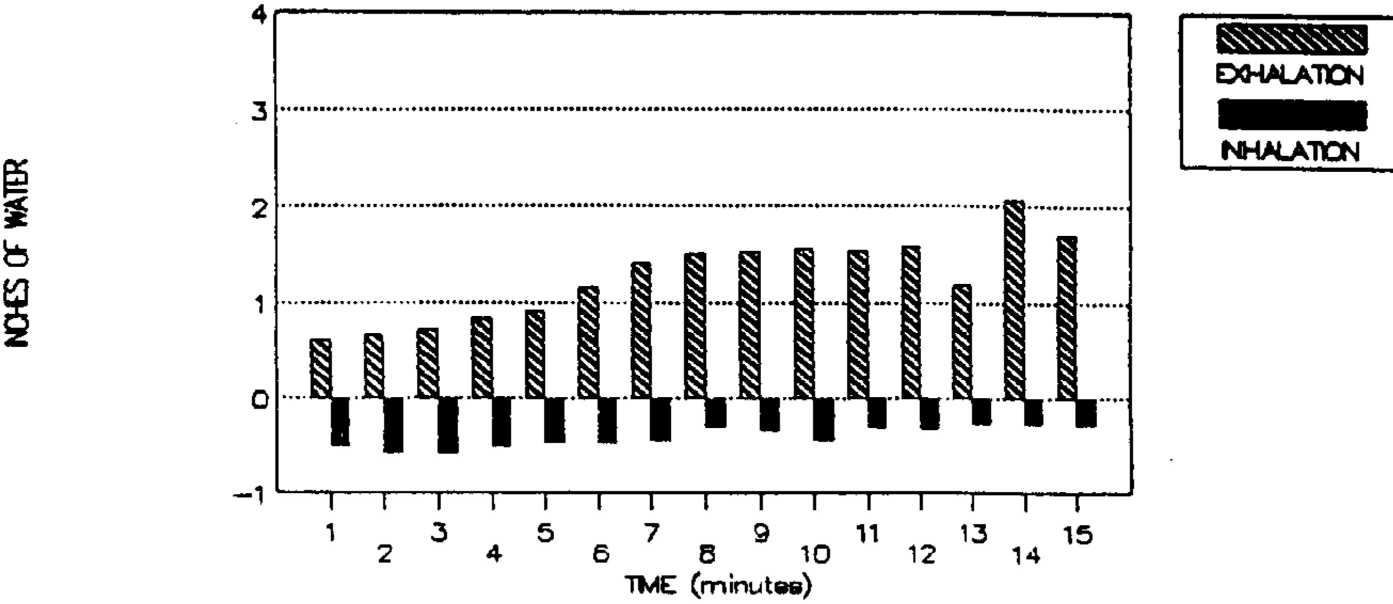
BREATHING RESISTANCE
F–10, CAMI TESTS – GROUND LEVEL



-Figure 112-

BREATHING RESISTANCE

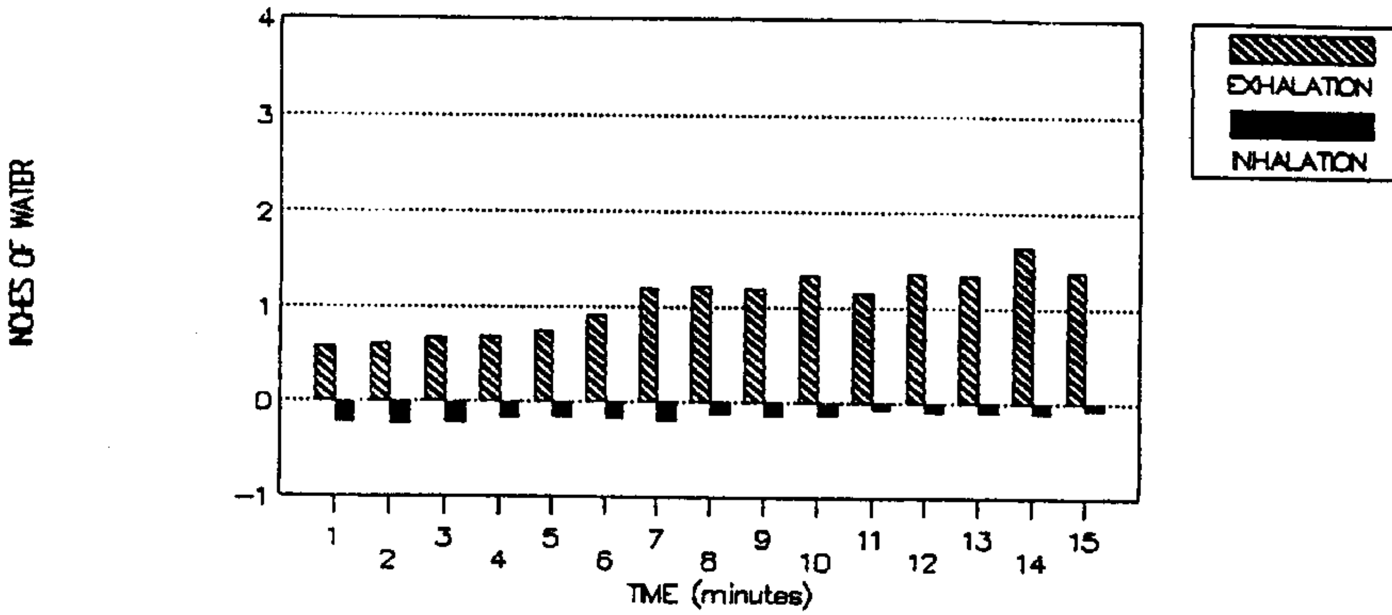
F–11, CAMI TESTS – GROUND LEVEL



-Figure 113-

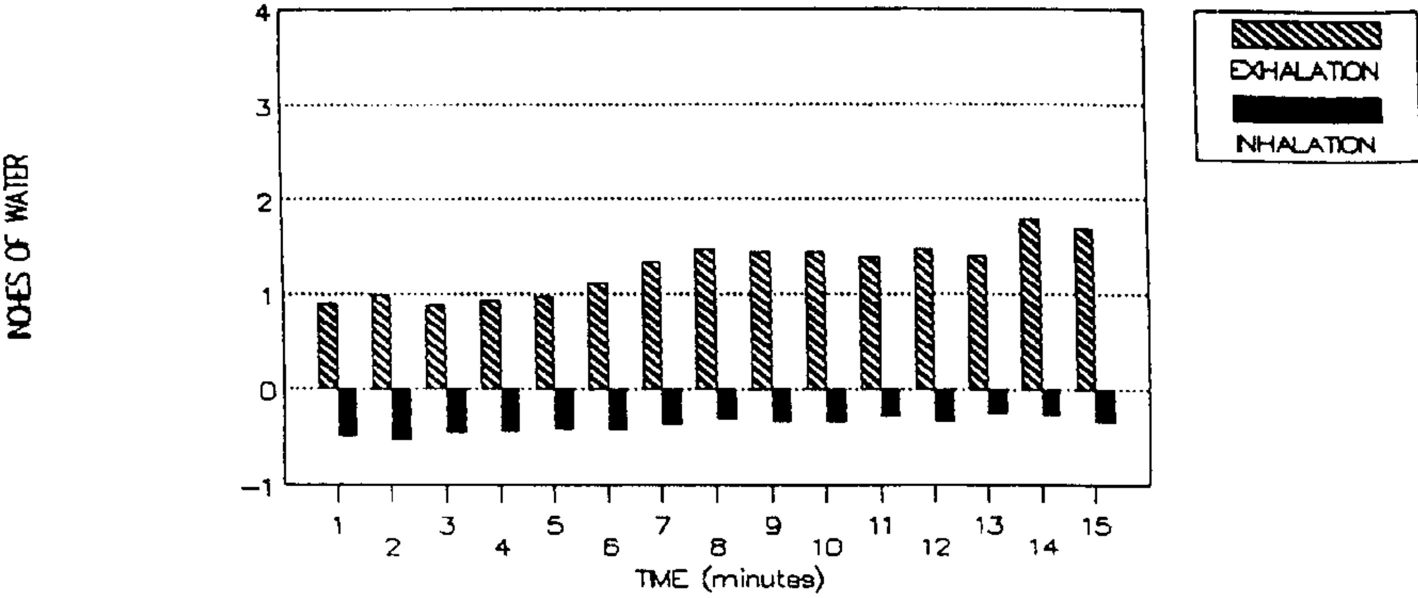
BREATHING RESISTANCE

F–12, CAMI TESTS – GROUND LEVEL



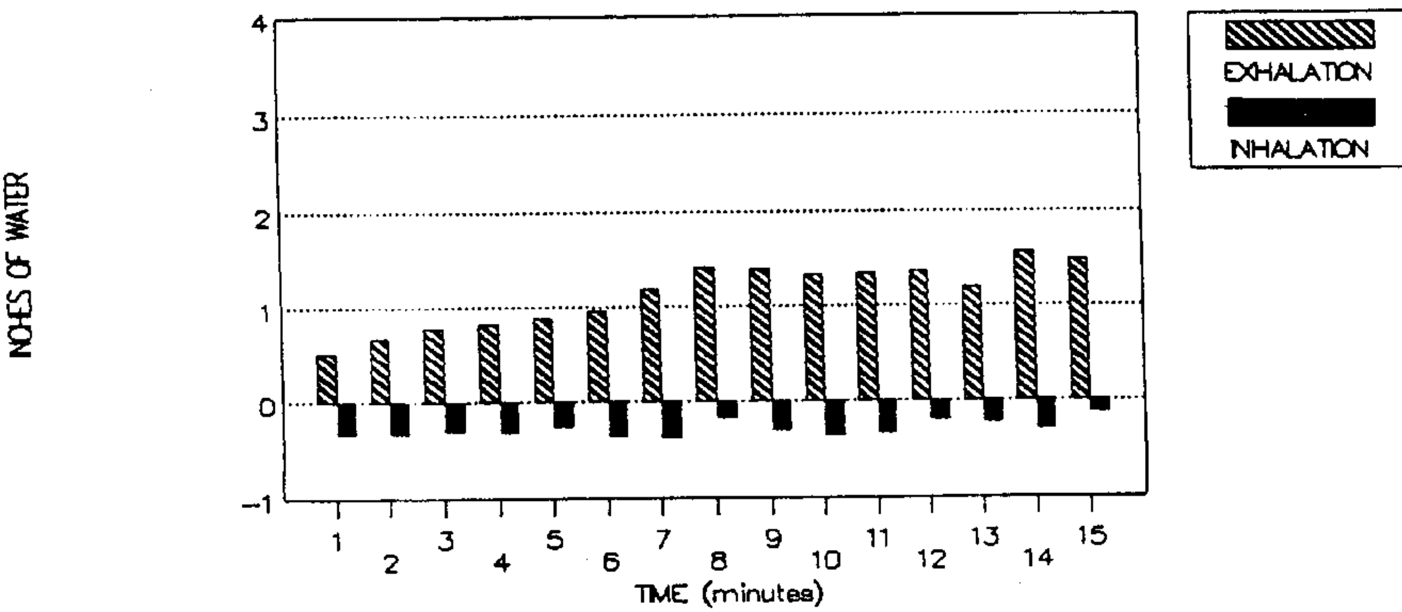
-Figure 114-

BREATHING RESISTANCE
M-1, CAMI TESTS - GROUND LEVEL



-Figure 115-

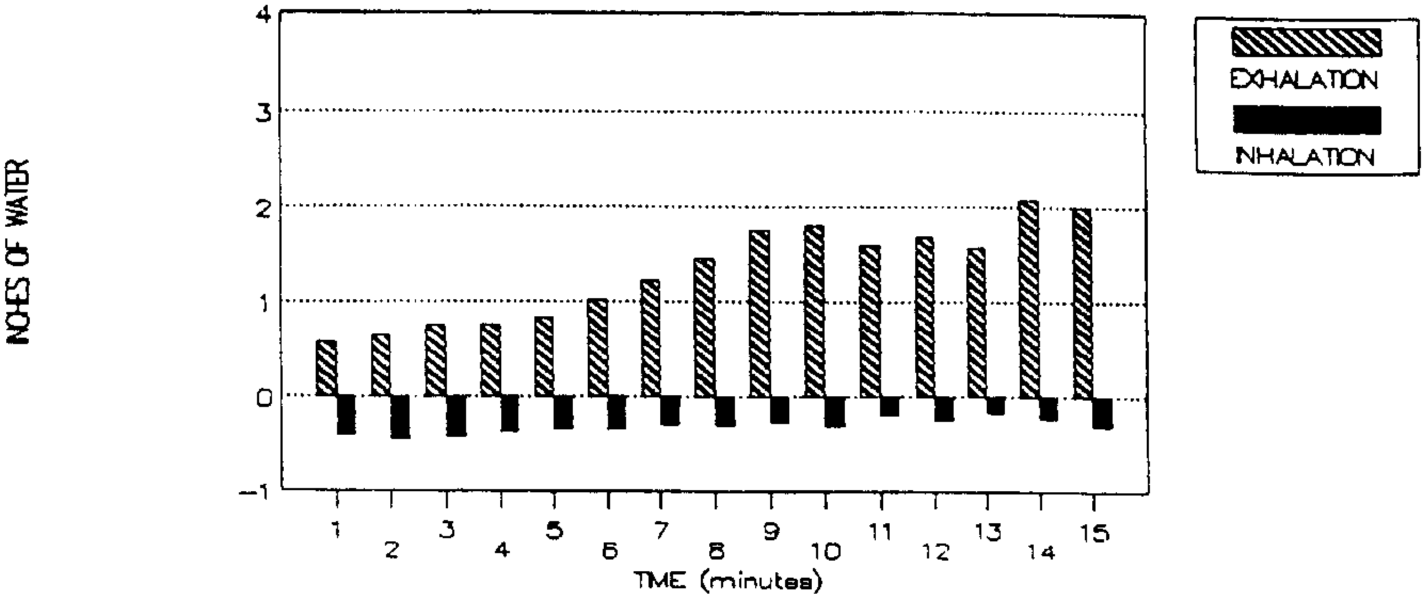
BREATHING RESISTANCE
M-2, CAMI TESTS - GROUND LEVEL



-Figure 116-

BREATHING RESISTANCE

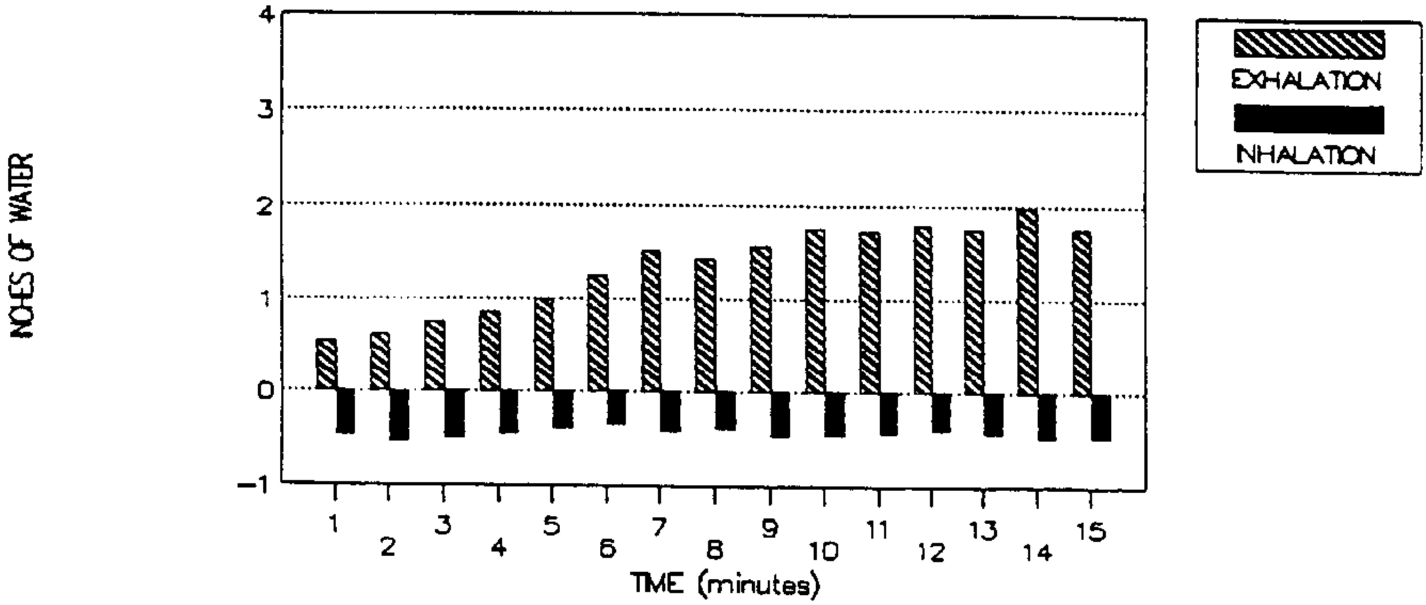
M–3, CAMI TESTS – GROUND LEVEL



-Figure 117-

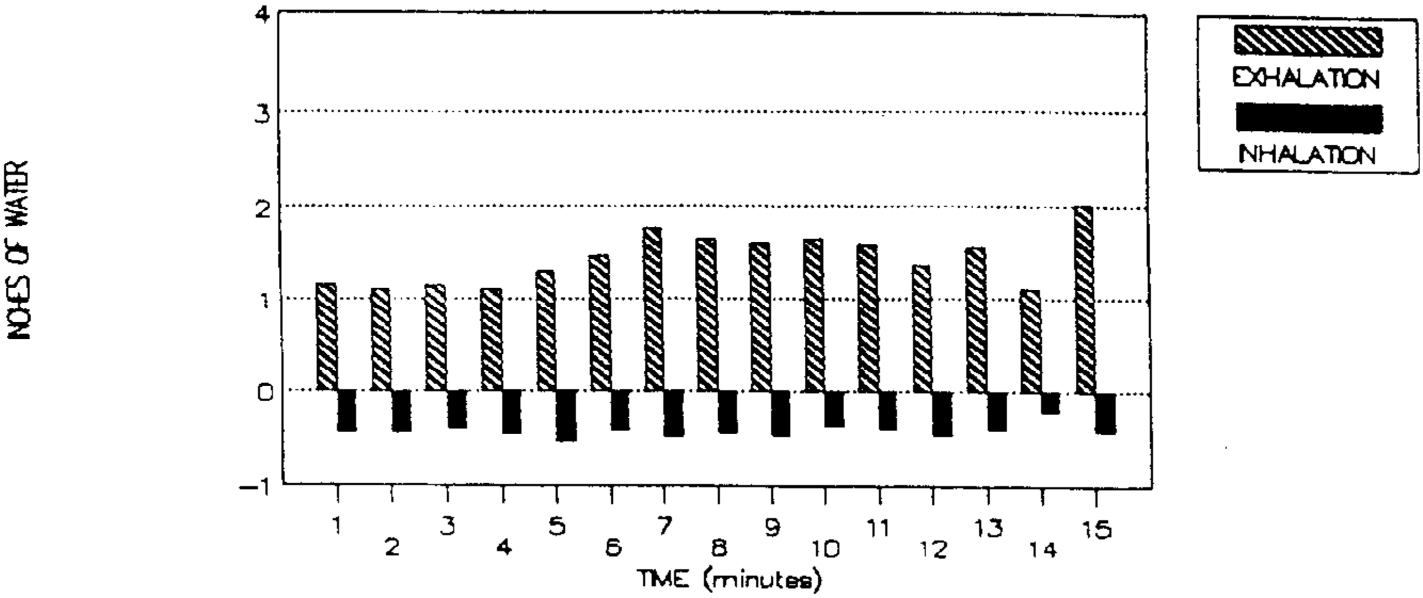
BREATHING RESISTANCE

M–4, CAMI TESTS – GROUND LEVEL



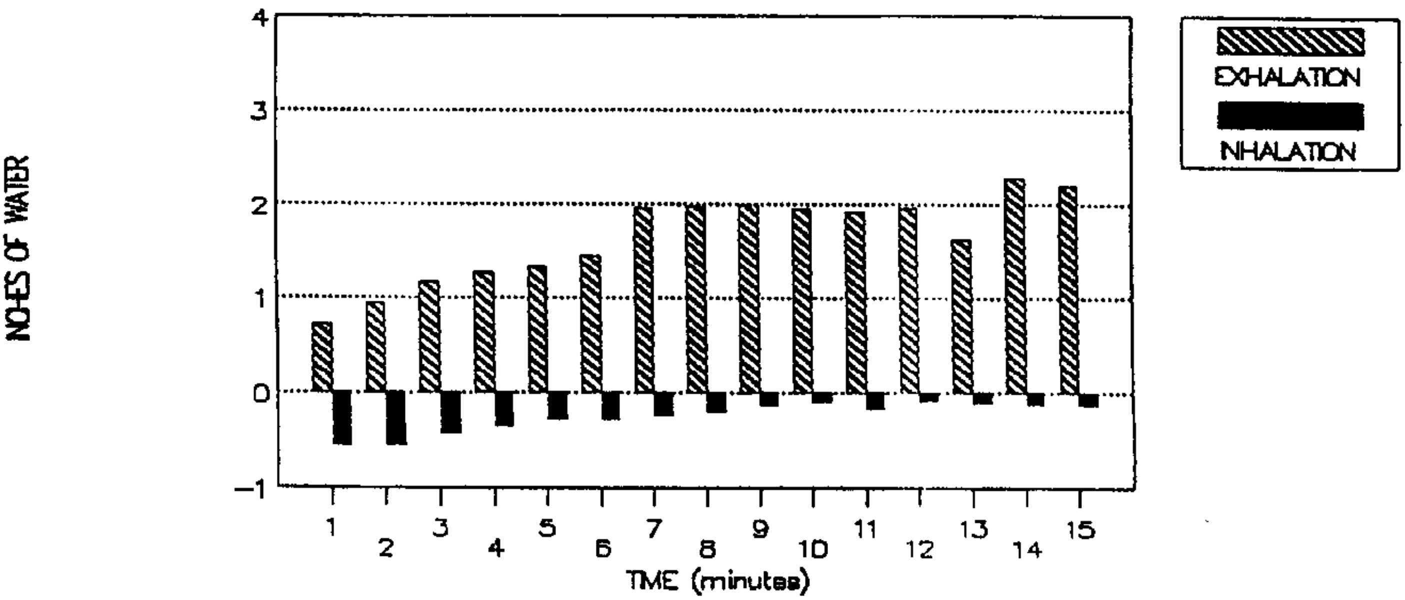
-Figure 118-

BREATHING RESISTANCE
M–5, CAMI TESTS – GROUND LEVEL



-Figure 119-

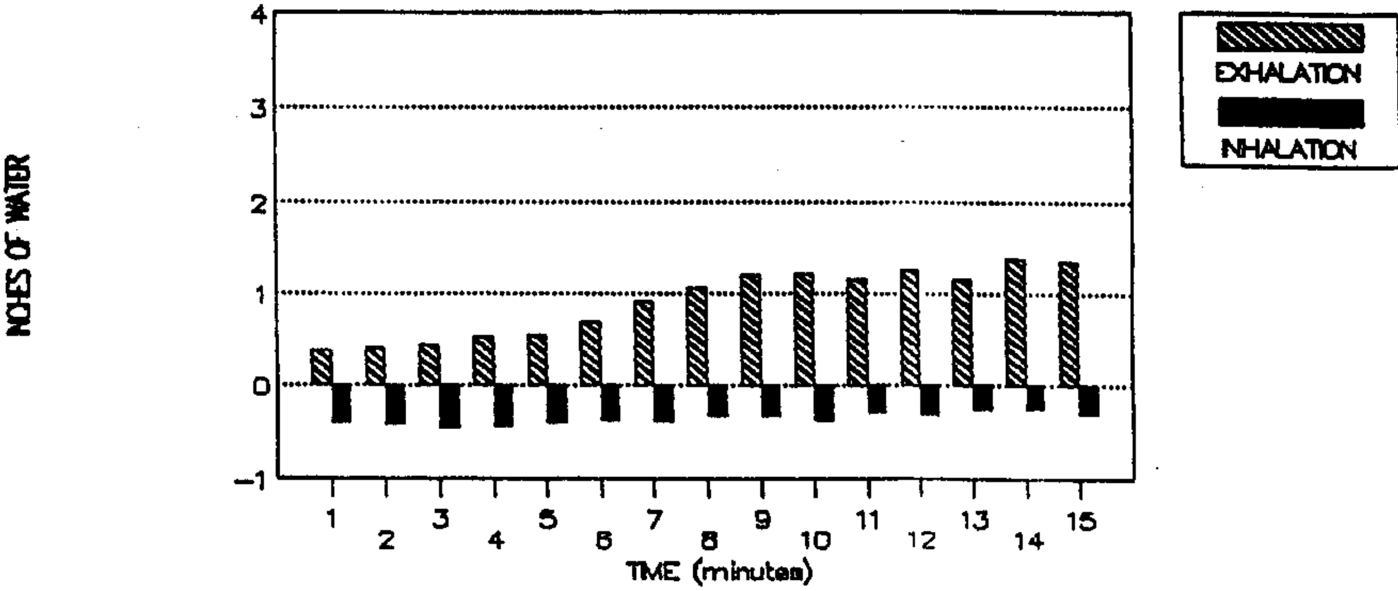
BREATHING RESISTANCE
M–6, CAMI TESTS – GROUND LEVEL



-Figure 120-

BREATHING RESISTANCE

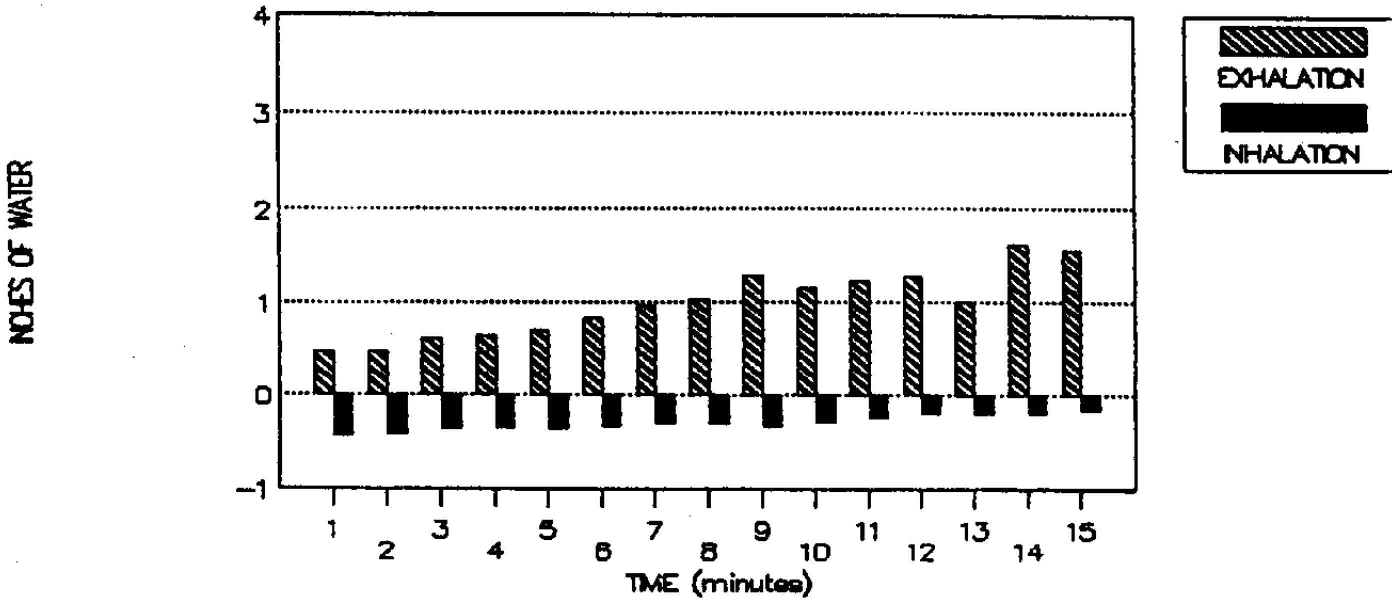
M-7, CAMI TESTS - GROUND LEVEL



-Figure 121-

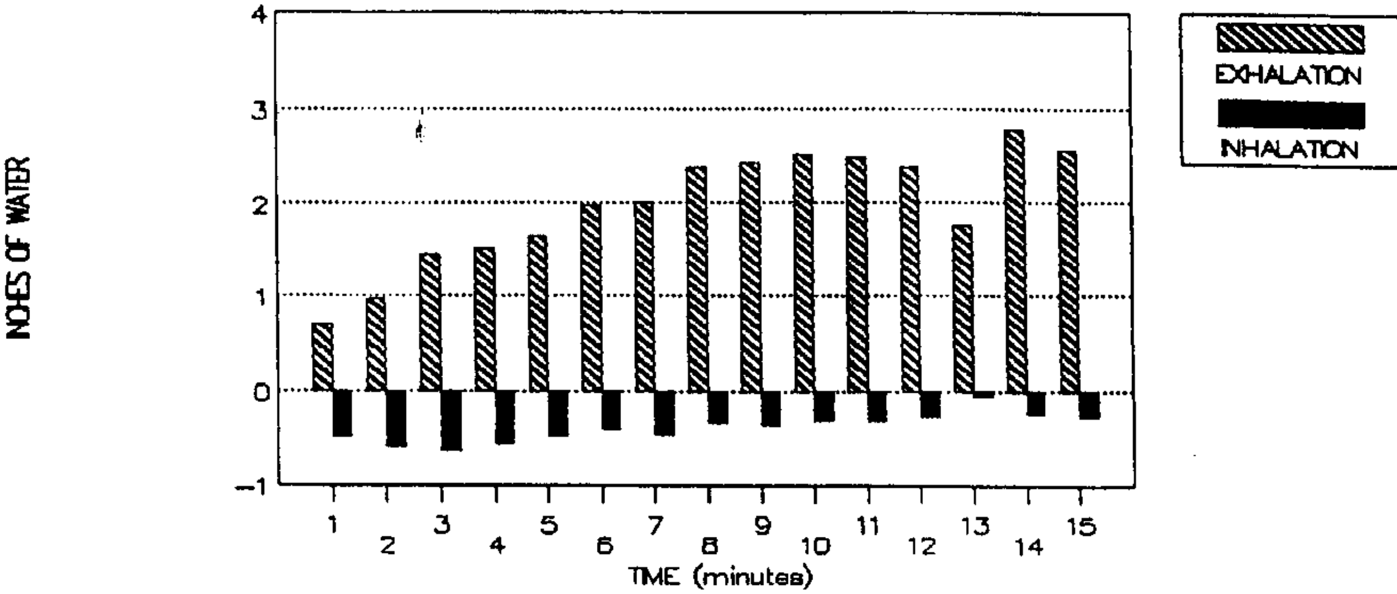
BREATHING RESISTANCE

M-8, CAMI TESTS - GROUND LEVEL



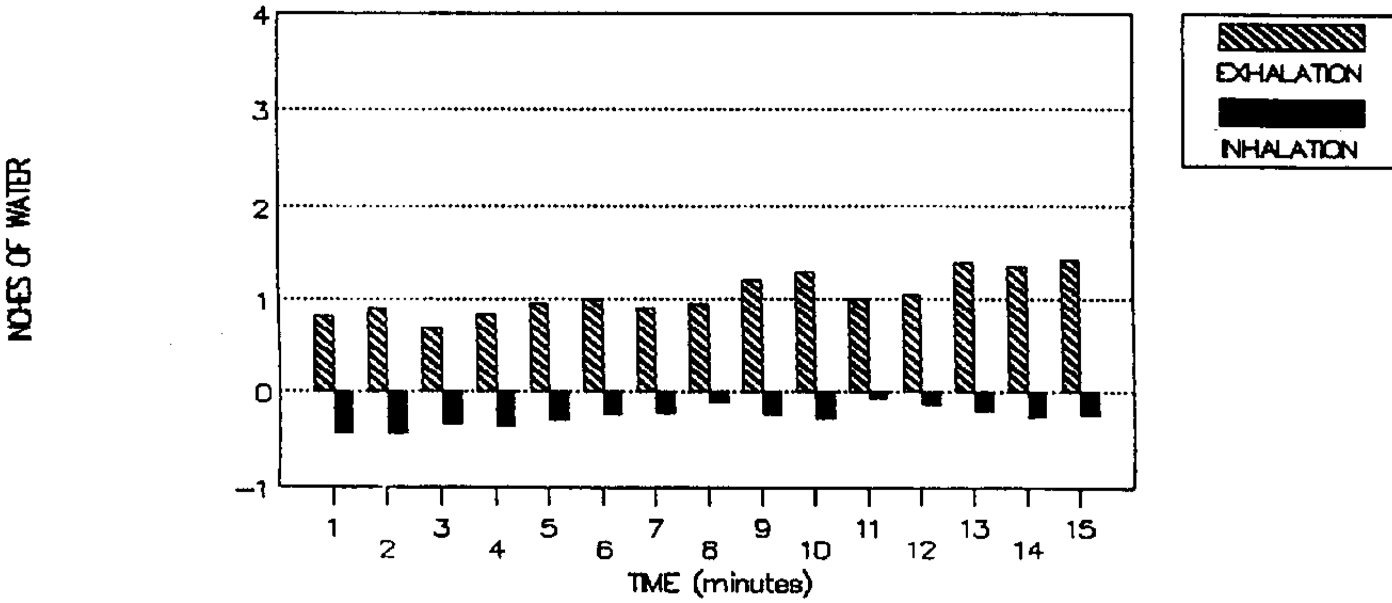
-Figure 122-

BREATHING RESISTANCE
M-9, CAMI TESTS - GROUND LEVEL



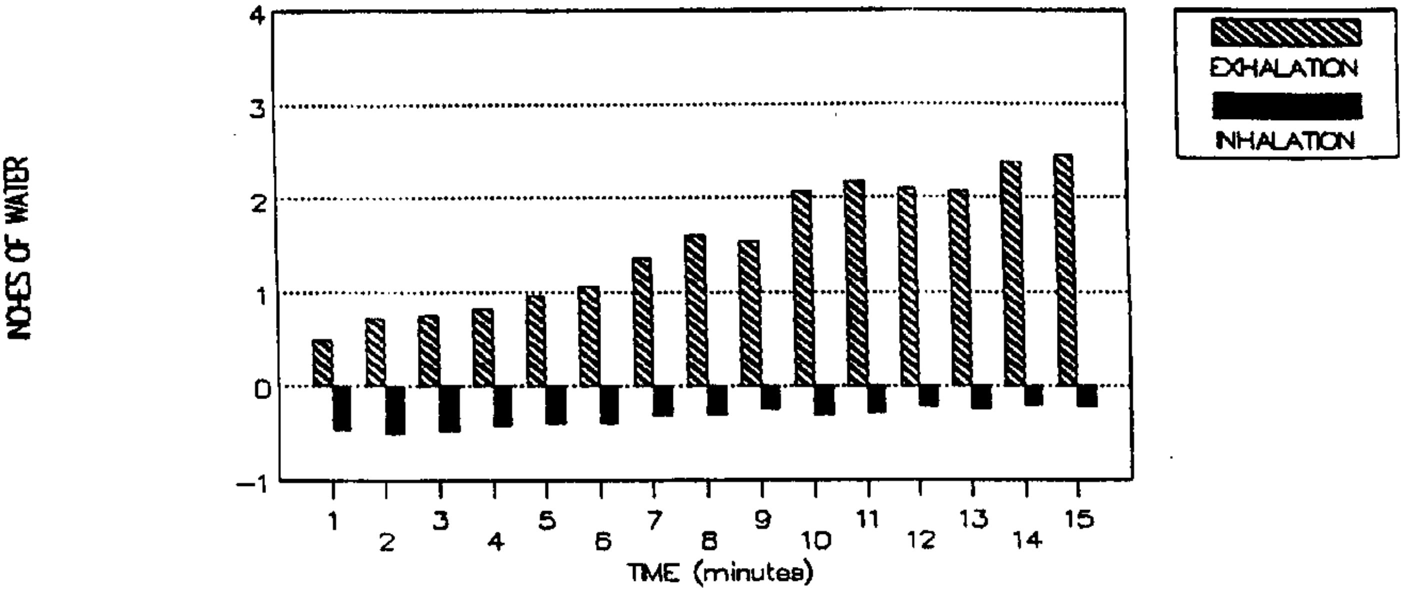
-Figure 123-

BREATHING RESISTANCE
M-10, CAMI TESTS - GROUND LEVEL



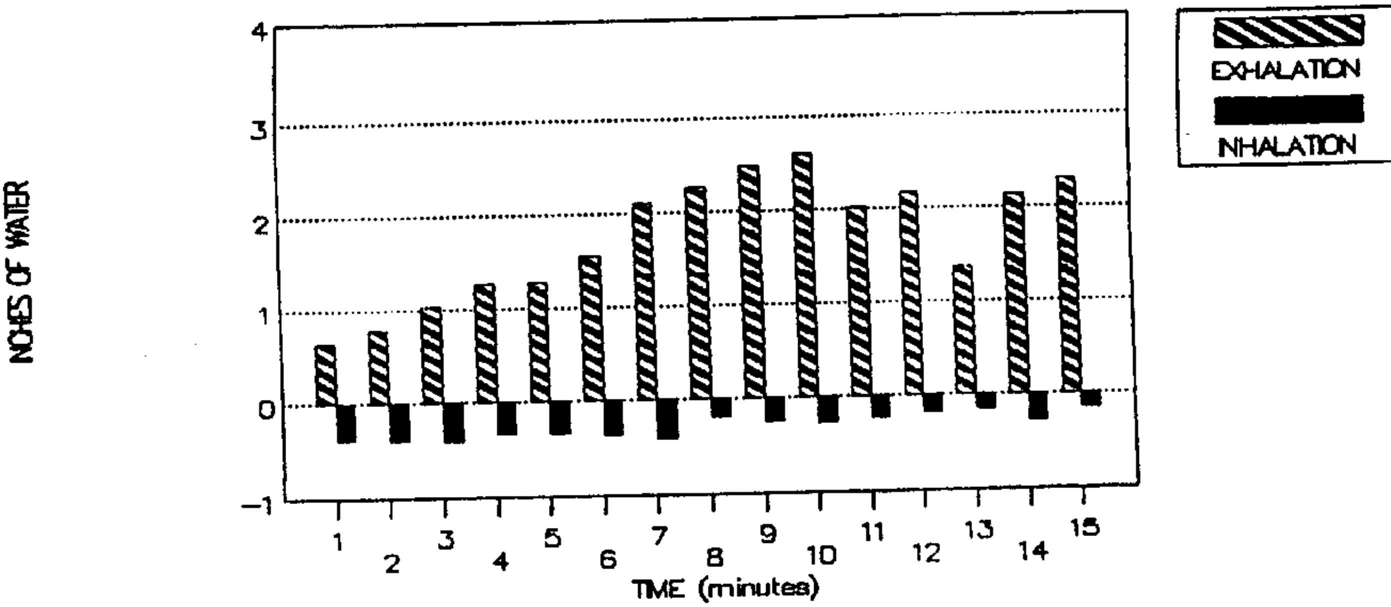
-Figure 124-

BREATHING RESISTANCE
M-11, CAMI TESTS - GROUND LEVEL



-Figure 125-

BREATHING RESISTANCE
M-12, CAMI TESTS - GROUND LEVEL

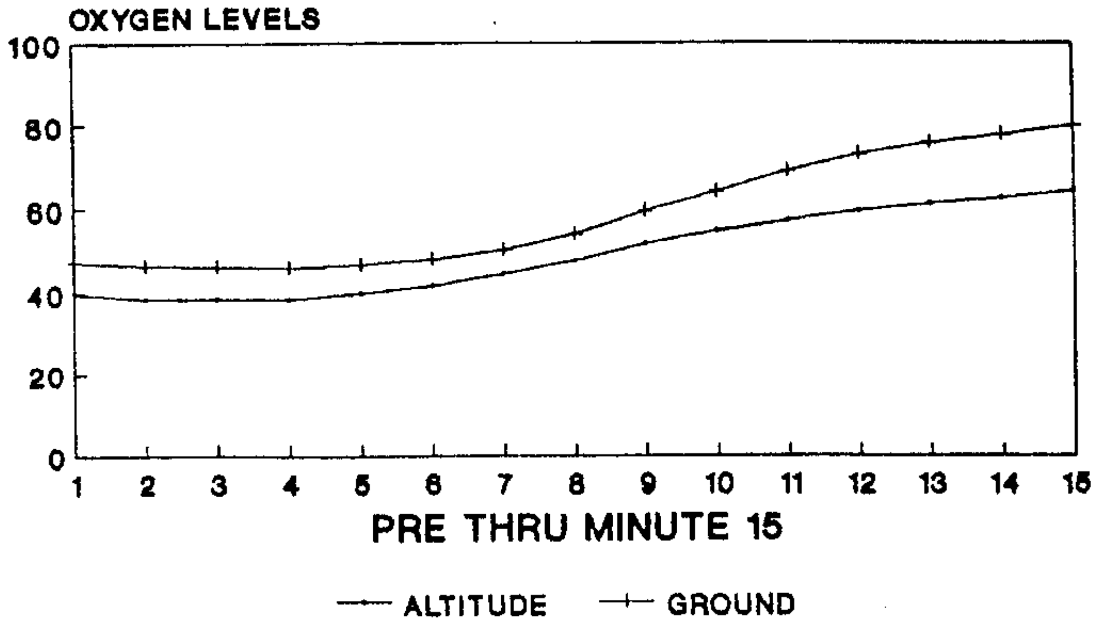


-Figure 126-

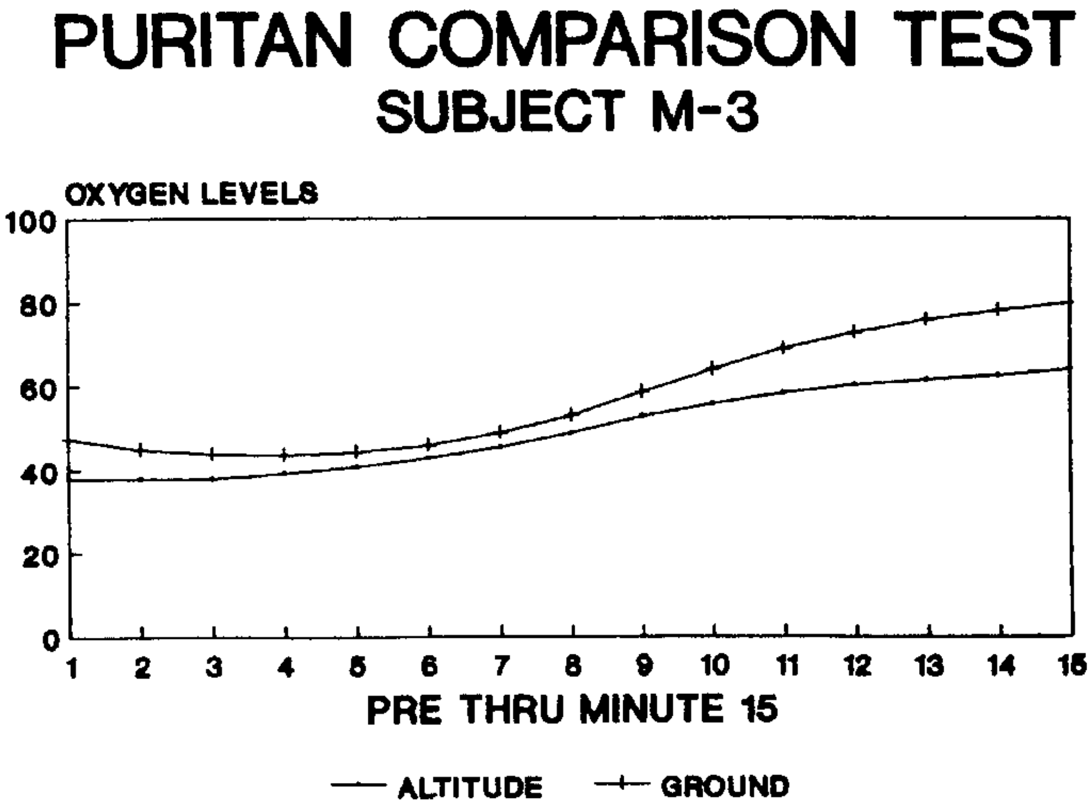
APPENDIX F

Graphs of Oxygen Concentration, Carbon Dioxide Concentration, Inhalation/Exhalation Pressures, and Internal PBE Dry Bulb Temperature for Three Subjects Comparing Ground Level Data to Data at 8,000 ft Simulated Altitude

PURITAN COMPARISON TEST
SUBJECT M-2

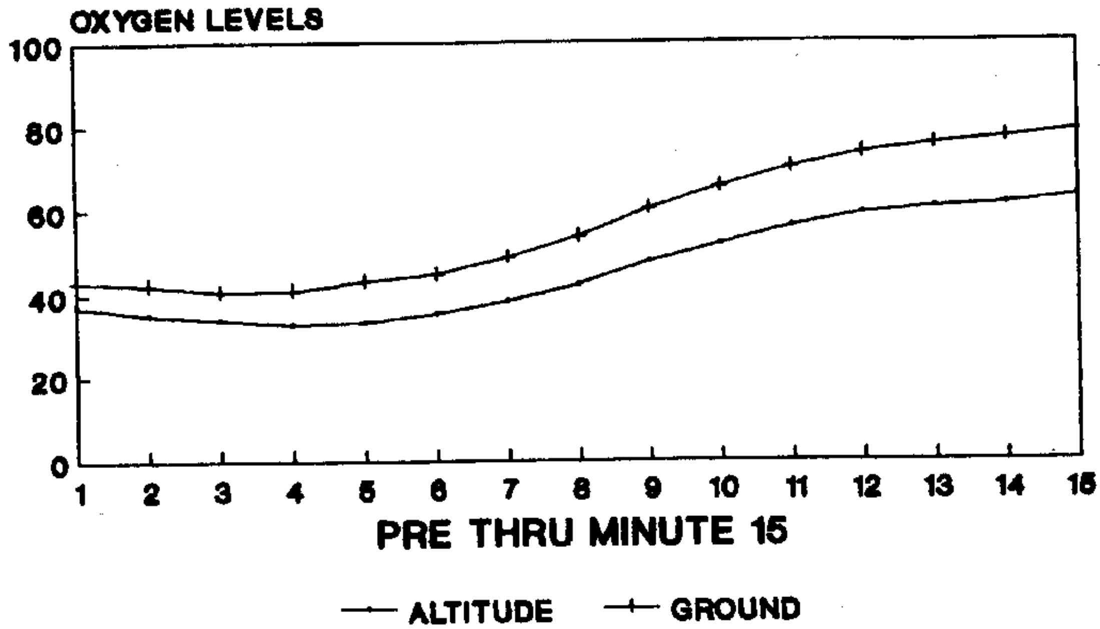


-Figure 127-


PURITAN COMPARISON TEST
SUBJECT M-3
OXYGEN LEVELS
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
PRE THRU MINUTE 15
ALTITUDE
GROUND

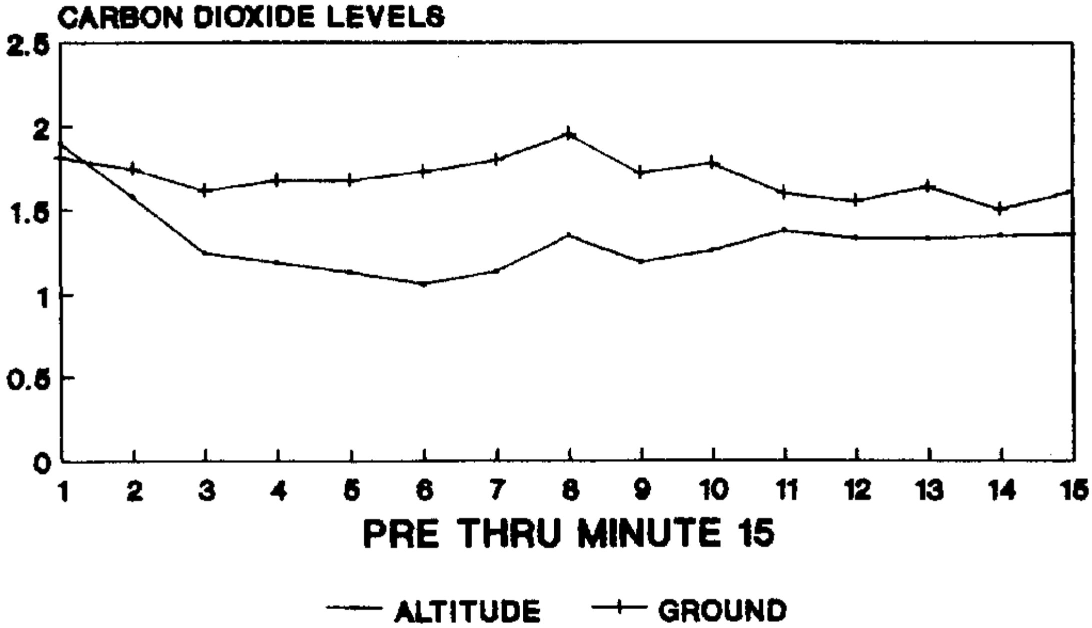
-Figure 128-

PURITAN COMPARISON TEST
SUBJECT M-5



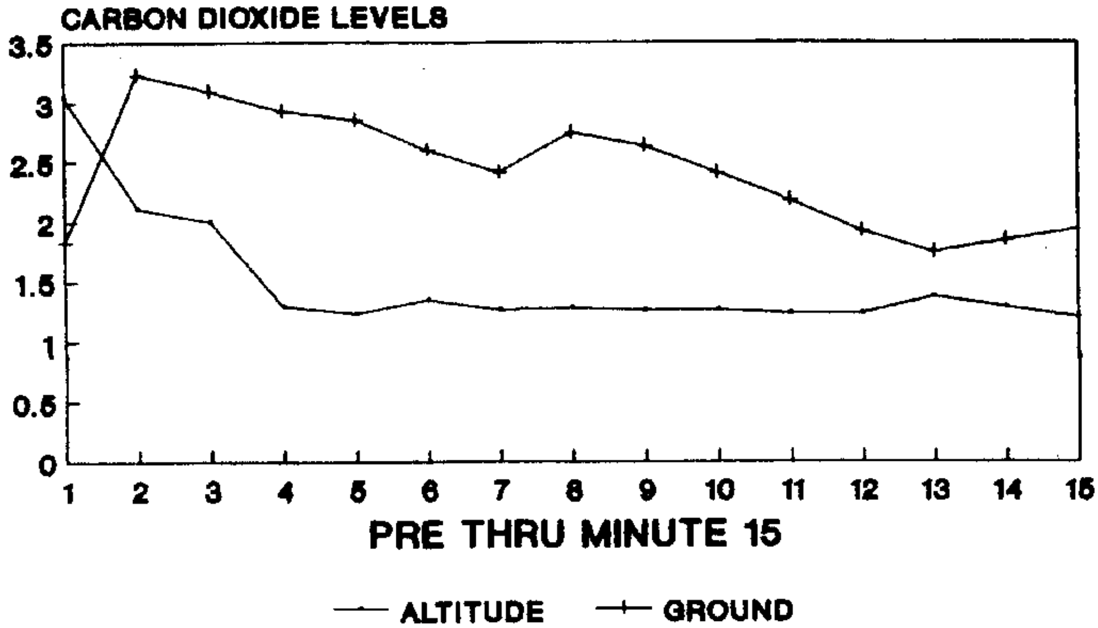
-Figure 129-

PURITAN COMPARISON TEST
SUBJECT M-2

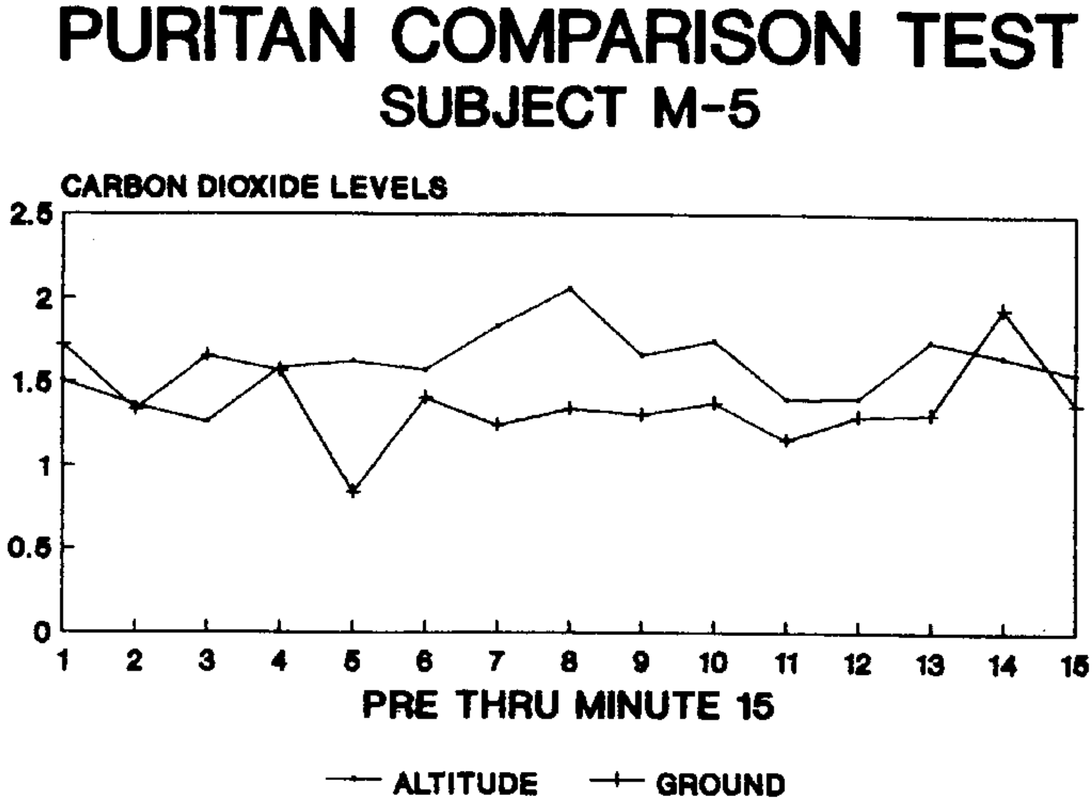


-Figure 130-

PURITAN COMPARISON TEST
SUBJECT M-3

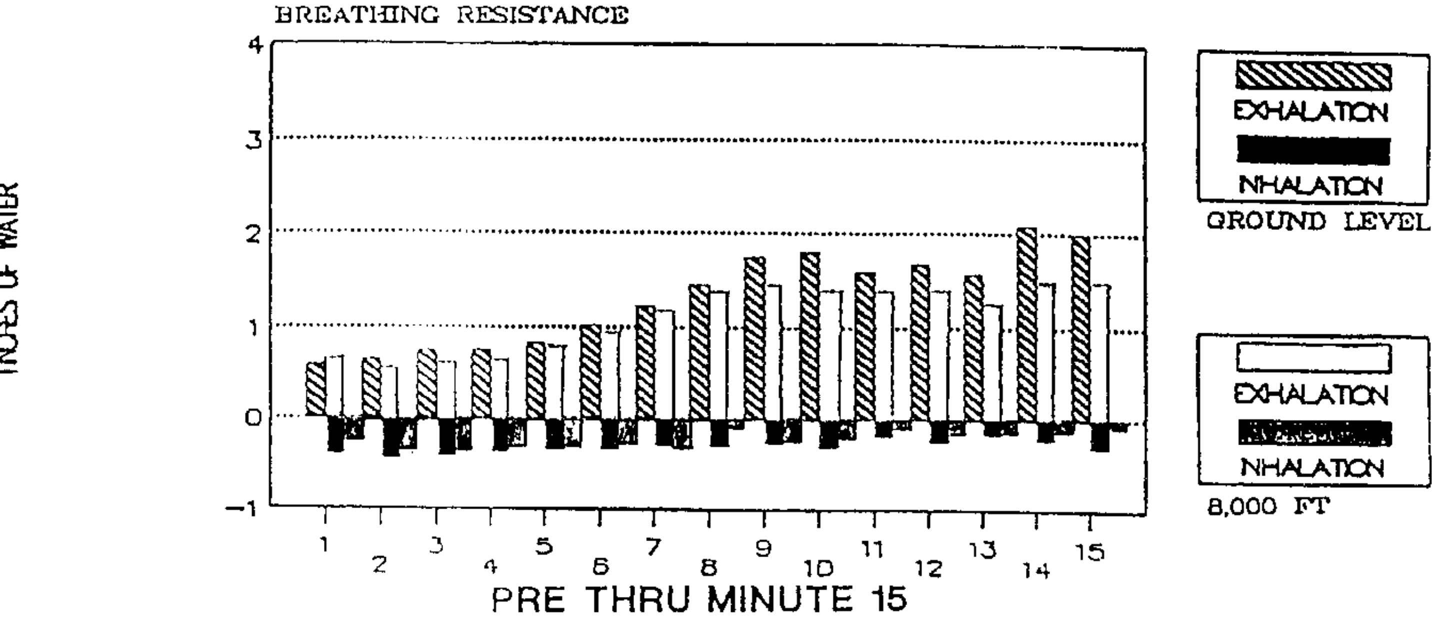


-Figure 131-


PURITAN COMPARISON TEST
SUBJECT M-5
CARBON DIOXIDE LEVELS
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
PRE THRU MINUTE 15
ALTITUDE
GROUND

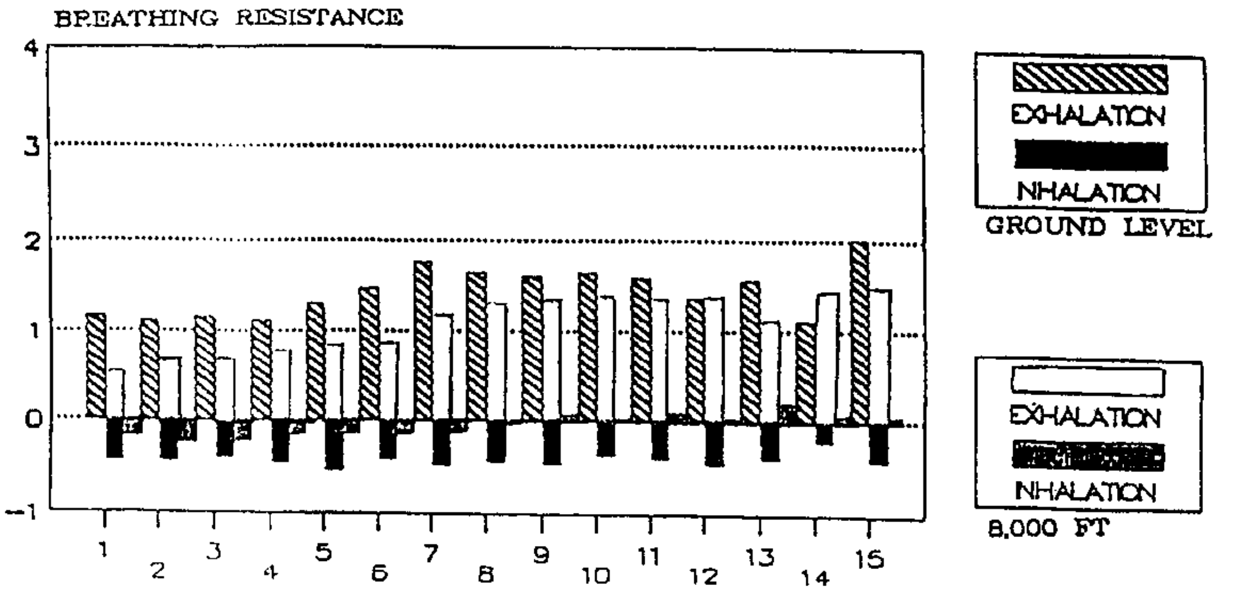
-Figure 132-

PURITAN COMPARISON TEST
SUBJECT M-3



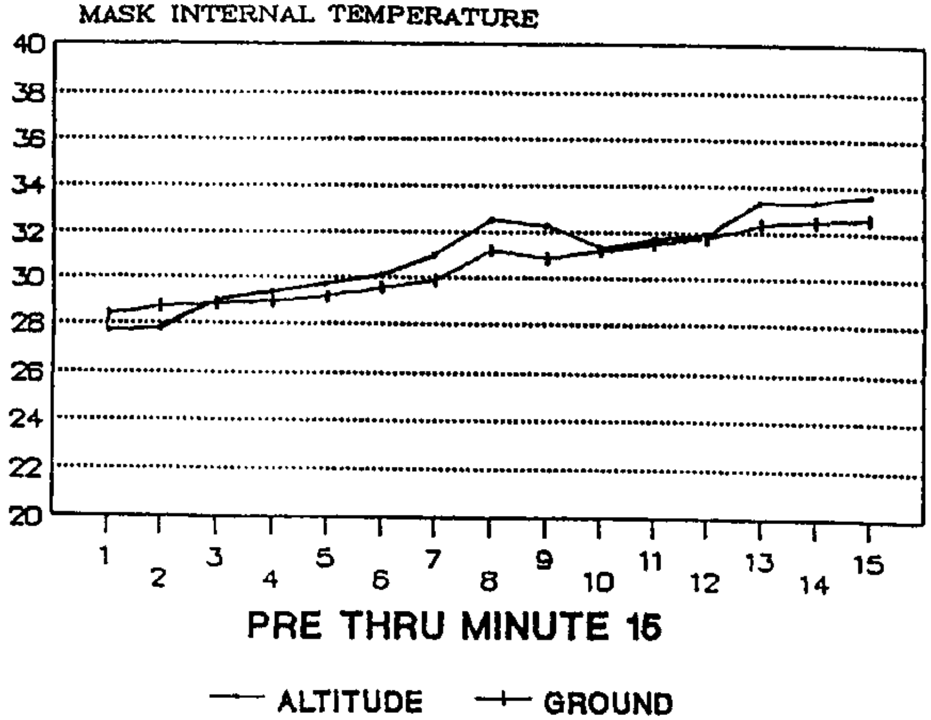
-Figure 134-

PURITAN COMPARISON TEST
SUBJECT M-5



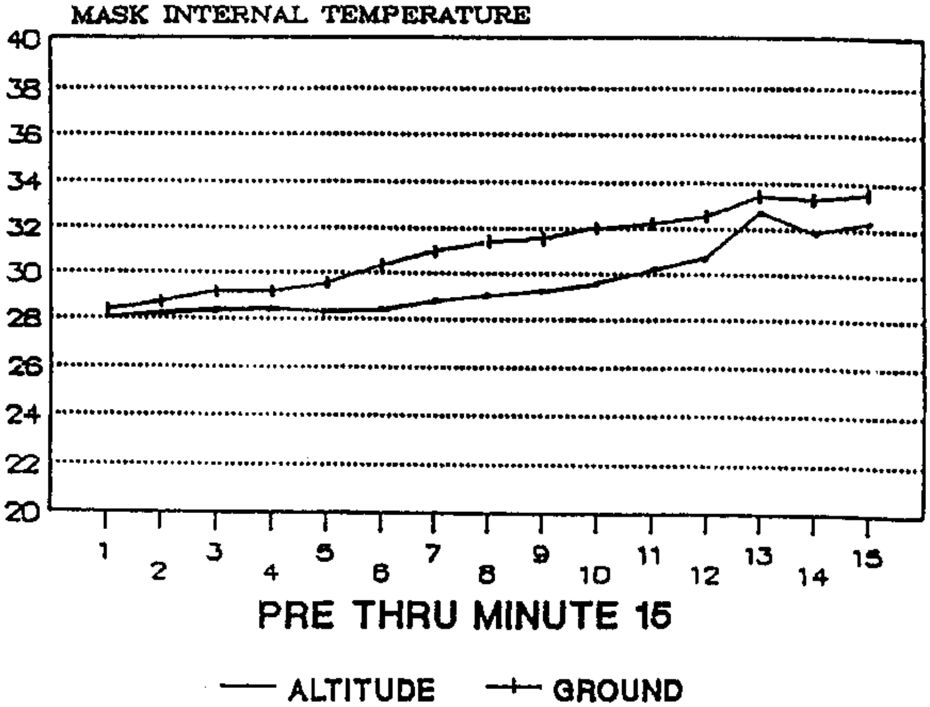
-Figure 135-

PURITAN COMPARISON TEST
SUBJECT M-2



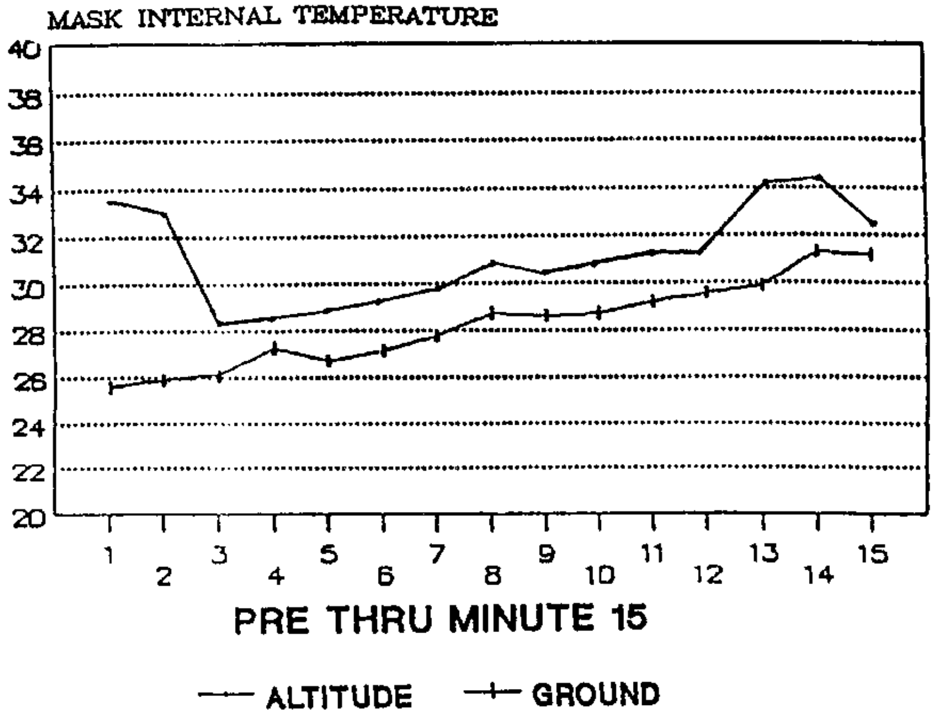
-Figure 136-

PURITAN COMPARISON TEST
SUBJECT M-3



-Figure 137-

PURITAN COMPARISON TEST
SUBJECT M-5



-Figure 138-