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Inward Contaminant Leakage Tests of the S-Tron Corporation Emergency Escape Breathing Device

Phase I: Tests of the Original Design

Phase II: Tests with the Redesigned Neck Seal

Bruce C. Wilcox, Jr.
Harvey M. England, Jr.
Garnet A. McLean

Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, Oklahoma 73125

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16. Abstract

At the request of S-Tron Corporation, to support their contract with the U.S. Navy, performance tests of the Emergency Escape Breathing Device (EEBD) were conducted in the Environmental Physiology Research Section contaminant leakage chamber. Sulfur hexafluoride (SF_6) challenge was used to determine contaminant leakage; oxygen and carbon dioxide levels, as well as temperature readings, were also obtained. Eight successful tests were conducted with the original neck seal design first used by Scott Aviation in their Crewmember Protective Breathing Equipment, four additional tests were conducted with a proprietary new neck seal designed by S-Tron. The EEBD all performed within test limits.

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Inward Contaminant Leakage Tests of the S-Tron Corporation Emergency Escape Breathing Device

Phase I: Tests of the Original Design

INTRODUCTION

Physiology Research Task AM-B-PHY-152 recognizes the lack of commercial testing facilities for protective breathing equipment and authorizes the Aviation Physiology Laboratory to conduct developmental testing of newly designed protective breathing equipment. Pursuant to this authority, and in response to a request from Mr. Ken Warner of S-Tron Corporation, the Environmental Physiology Research Section conducted contaminant leakage tests of the S-Tron Emergency Escape Breathing Device (EEBD), part number (802300-A1), during March 19-21, 1991. The tests were conducted in support of a contract between S-Tron and the U.S. Navy.

The test protocol generally conformed to FAA Technical Standard Order (TSO) C-116 (1), which specifies that human subjects shall be required to wear the protective breathing devices in a gas-filled chamber while performing a variety of activities, while the interior of the protective breathing device is monitored for inward leakage of the test gas. To complete the test successfully, the maximum inward leakage cannot exceed a mean value of 5% of the test chamber atmosphere.

In a slight modification of TSO C-116, no exercise workload was required. Mr. Warner and Ms. Valerie Bagnell, the U.S. Navy representative, were present for the tests.

METHODS

Subjects

The tests of the EEBD employed four male and four female human subjects. Prior to the study, each subject was fully informed about the test procedures and objectives of the research. After this briefing, each subject executed informed consent to proceed with the study. All subjects were in excellent health and generally well-conditioned physically, as verified by a medical history questionnaire, a physical examination, and a pulmonary function evaluation conducted with an SRI Automated Medical Spirometer. Forced Vital Capacity (FVC, in liters), Forced Expiratory Volume in 1 second (FEV1, in liters), and Peak Flow (PF, in liters per minute) were measured for each subject. Subjects' neck circumferences (in cm) ranged from the female 5th percentile to the male 99th percentile (2). Table 1 displays demographic data for all subjects.

Table 1. Subject Demographics

Subj	Sex	Age (yrs)	Ht (in)	Wgt (lbs)	Neck (cm)	FVC (ltr)	FEV1 (ltr)	PF (lpm)
H1026	F	25	62	125	33.0	3.45	2.97	360
L0161	M	39	71	195	41.3	4.94	4.03	548
F2865	M	22	68	127	35.0	5.72	4.52	494
M6279	F	19	55	112	30.0	3.61	3.06	313
J2037	M	26	72	306	46.5	5.56	3.58	341
M4906	F	31	67	124	31.0	4.10	3.65	427
D5968	F	26	64	125	31.9	4.05	3.65	415
H9454	M	28	70	150	37.0	5.37	4.57	398

Test Procedure

On a day soon after the primary history and medical exam were obtained, each subject returned to the laboratory for testing. The subject was given the pulmonary function test and evaluated for any changes in health status, after which electrocardiogram (EKG) electrodes, blood pressure (BP) cuff and arterial oxygen saturation (SaO2) probes were applied. The subject was briefed on the specific test procedures, including the proper procedure for donning and operating the EEBD, and then connected to the data acquisition equipment.

EKG and BP were obtained with a Bosch II medical monitoring system and stored as chart paper recordings, while SaO2 was recorded via a Nellcor 200 pulse oximeter, which was connected to a Hewlett Packard Vectra microcomputer via a Metrabyte DAS-16G analog-to-digital (A/D) data acquisition board. Oxygen, nitrogen, carbon dioxide, and sulfur hexafluoride (SF_6, the test gas) were measured by a Perkin Elmer Medical Gas Analyzer (MGA) Model 1100 (mass spectrometer) also connected to the DAS-16G. Data from the MGA 1100 were routed directly to the A/D board, except for the SF6 signal, which was amplified by a Grass Polygraph direct current (DC) amplifier before A/D conversion. The gas concentrations were measured in both the EEBD and outside the device in the test chamber. Inhalation temperature was also monitored, using an Omega Thin Film Resistance Temperature Detector (RTD) connected to a Metrabyte MB-34 Signal Conditioning Module wired directly to the DAS-16G. Inhalation pressure was monitored, but not recorded, near the mouth to assure that the EEBD was functioning properly.

Raw data from these devices were acquired at a sample rate of 1/sec; switching of the gas sample port occurred every 15 seconds to form four discrete data blocks per minute. Cycling through the sample ports occurred in the following sequence: data from the EEBD lower visor location were recorded during the first 15-second block each minute; the chamber gas concentrations were recorded during the second 15-second block; during the third 15-second block the EEBD upper visor location was sampled; and the chamber gas concentrations were recorded again during the fourth 15-second data block. Thus, in a one-minute sampling period, both EEBD sites were sampled once each with the chamber concentration measurements bracketing these readings.

The safety limits for the interior EEBD atmosphere included a minimum oxygen concentration of 17%, an upper carbon dioxide limit of 8.5%, and a maximum temperature of 47o C. Had these limits been exceeded, testing would have stopped. Subject SaO2 concentrations equal to or below 90% for 30 seconds would also have stopped the test, as would aberrant EKG and/or BP.

After the electrodes and blood pressure cuff were placed on the subject, he/she was seated in the test chamber and attached to the monitoring equipment. The subject was instructed to place the EEBD on his/her head and actuate the canister by pulling the red activation ring. The chamber door was then closed, isolating the test subject from the outside atmosphere. For 2 minutes before data collection began, SF6 was introduced into the test chamber to achieve a stable 1% concentration within the chamber; the EEBD internal oxygen concentration was also increasing during this time. Data collection started at the two-minute mark and continued until 15 minutes had elapsed after the EEBD had been activated. Generally, the subject sat quietly, but was required at 7, 10, and 13 minutes into the 15-minute test period to breathe deeply for 5 seconds, turn his/her head left followed by 2 respirations, turn his/her head right followed by 2 respirations, bend forward at the waist and turn his/her head from side to side 3 times in a steady, smooth fashion, and finally return to the upright position and breathe deeply for 5 seconds.

Each of the four data blocks was sampled through a different inlet port on the MGA 1100. These ports had to be selected manually, producing sampling error in the first couple of data points to be acquired in each block. To provide data free from this port- switching error, the first three and last two data points of each data block have been deleted from the analysis. Also, because the SF6 concentration within the chamber could not be stabilized at exactly 1%, an EEBD-to-chamber SF_6 ratio score was obtained by averaging the two EEBD SF_6 mean concentrations per minute and dividing that value by the average of both chamber SF_6 concentration means within the sample minute. This provided the percentage of SF_6 inward leakage relative to the chamber concentration.

RESULTS

No tests had to be aborted because of subject health or safety concerns. Eight EEBD's were successfully tested for the full protocol duration; two other EEBD tests were aborted for technical reasons. The aborted tests resulted from a problem in SF6 delivery to the test chamber which caused the first test to be prematurely halted and a computer malfunction which caused a second test to be aborted. In the successful tests all the oxygen levels within the EEBD's reached average levels of 85% within three minutes, reaching a group average oxygen concentration of greater than 93% for the course of the test run. The carbon dioxide measured for all the tests never reached the cut off point of 8.5% percent, as no values ever exceeded 1.5% carbon dioxide at any time. The mean inward leakages of SF6 ranged from an individual low of 2.29% to a high of 4.38%, averaging 3.46% for the entire group. The temperature also maintained acceptable values, never reaching the cut off point of 47 degrees C for any test, although steady increases in temperature over the course of the testing period were seen for all EEBDs. Graphs of SF6 inward leakage, oxygen level, carbon dioxide level and inhalation temperature are shown for each test in Appendix I; narratives and tabular data for each test are provided below.

Test Data

Test 1. The initial test for subject H1026 was aborted because of difficulty in obtaining the desired SF_6 gas concentration within the chamber. The problem was corrected when a new supply tank of SF6 was installed. The test was repeated, using a new EEBD that performed within limits (Table 2).

Test 2. The initial test for subject L0161 was also aborted because of a computer malfunction during the first test run. The computer problem was corrected, and a new EEBD was used for the second test. The EEBD easily performed within limits during the second test (Table 3).

Table 2. Test 1: Subject H1026

MIN	SF6	CO2	N2	O2	TEMP
3.	1.76	49	14.11	82.82	29.40
4.	2.14	.155	9.34	88.32	29.59
5.	2.25	.043	6.37	91.87	30.33
6.	2.33	.033	4.67	94.33	30.96
7.	2.53	.028	3.77	95.54	31.55
8.	2.92	.056	3.40	96.30	31.84
9.	3.15	.384	3.08	96.29	31.88
10.	2.76	.109	2.84	96.66	32.55
11.	3.01	.183	2.89	96.89	32.71
12.	2.83	.030	2.69	97.08	33.69
13.	2.65	.036	2.61	97.12	34.48
14.	2.71	.182	2.69	96.95	37.19
15.	2.98	.138	2.61	97.30	38.65
mean	2.61	.109	4.69	94.42	32.75

Gas values given in percentages; temp in degrees C

Table 3. Test 2: Subject L0161

MIN	SF6	CO2	N2	O2	TEMP
3.	2.09	.048	13.94	85.57	31.41
4.	2.31	.151	9.20	90.32	31.63
5.	2.93	.045	6.30	93.32	31.29
6.	3.28	.032	4.45	95.03	32.47
7.	4.05	.028	3.50	95.97	31.79
8.	4.69	.053	3.22	96.63	32.50
9.	4.47	.330	2.97	96.34	32.47
10.	4.27	.125	2.80	96.81	33.39
11.	5.05	.199	2.80	96.71	34.90
12.	4.60	.030	2.67	97.04	35.58
13.	4.95	.030	2.64	96.92	37.18
14.	4.88	.212	2.62	97.14	37.39
15.	4.23	.071	2.62	97.05	37.91
mean	3.98	.124	4.59	94.98	33.83

Gas values given in percentages; temp in degrees C

Test 3. The EEBD performed correctly in this test (Table 4).

Test 4. The EEBD performed correctly in this test (Table 5).

Test 5. Although the EEBD appeared to function well during this test, a difficulty related to the subject's head size (99th percentile) was encountered. This difficulty was exhibited by a series of high SF_6 readings taken at the lower visor sample port. This circumstance made it appear initially that the EEBD had developed a large leak; however, the ability of the upper visor sample port to maintain low readings throughout the test mitigated against the initial judgment. Careful examination revealed that the subject's large head size made the lower portion of the visor rest against his face, causing the lower sampling probe to rest against his skin. The probe vacuum produced by the MGA 1100 appeared to pull the subject's skin into the sampling port orifice, causing air from the test chamber outside the EEBD to be drawn into the sample port. Thus, the data from the lower visor sample port were invalid. Because of this sampling defect, only data from the upper visor sampling probe were used to determine EEBD inward leakage. Appendix 2 provides a schematic representation. Note from Table 5 that the highest mean of 4.38% for SF_6 inward leakage was recorded during this test, although this value was still within the limits required to produce a successful test (Table 6).

Test 6. This test produced an increase in SF_6 inward leakage similar to Test 5, although the subject was a small female. It initially appeared that the EEBD had begun to leak around the neck seal, since the increase in EEBD SF_6 level was noted at the 10 and 13 minute marks when her required movements began. The EEBD oxygen levels also fell, and the nitrogen levels increased, during this period. However, it was noted that during the movements the subject placed her hand upon the visor to

Table 4. Test 3: Subject F2865

MIN	SF6	CO2	N2	O2	TEMP
3.	1.69	.624	18.90	79.98	31.07
4.	1.69	.512	11.65	87.52	31.52
5.	1.78	.462	7.54	91.70	32.02
6.	1.86	.488	5.22	94.04	32.46
7.	1.89	.445	3.65	95.64	33.14
8.	2.18	.720	3.03	95.99	33.53
9.	2.17	.492	2.56	96.69	33.90
10.	2.17	.485	2.48	97.08	34.51
11.	3.19	.614	2.82	96.33	35.25
12.	3.35	.484	2.96	96.31	35.90
13.	2.79	.481	2.33	96.95	36.65
14.	3.32	.695	2.53	96.45	37.71
15.	2.96	.784	2.97	95.99	38.82
mean	2.38	.560	5.27	93.89	34.34

Gas values given in percentages; temp in degrees C

Table 5. Test 4: Subject M6279

MIN	SF6	CO2	N2	O2	TEMP
3.	2.07	.391	22.60	76.54	30.45
4.	2.65	.301	15.30	84.01	30.52
5.	2.70	.314	10.77	88.57	31.20
6.	2.93	.287	7.81	91.62	32.09
7.	2.95	.290	6.06	93.34	32.69
8.	3.12	.333	5.16	94.19	33.23
9.	3.08	.333	4.60	94.32	33.74
10.	3.22	.340	4.24	95.17	34.24
11.	3.26	.476	3.97	95.30	34.70
12.	3.21	.382	3.97	95.37	35.24
13.	3.18	.303	3.93	95.47	36.07
14.	3.14	.408	3.88	95.45	36.72
15.	3.25	.356	3.80	95.57	38.12
mean	3.12	.360	5.11	94.18	34.82

Gas values given in percentages; temp in degrees C

steady the EEBD, and during the post- test EEBD inspection, it was found that the integrity of the seals around the probes used to measure temperature and pressure had been compromised. The neck seal had performed well, and the mean inward leakage of 3.11% was within limits (see Table 7).

Test 7. A problem with equipment calibration was encountered during this test. A drift in the base line setting of the DC amplifier produced a shift in the recorded SF_6 level, requiring that the data be read directly from the MGA 1100 nixie tube display by the test operator and recorded manually. All other data were unaffected by this problem. Because the SF_6 levels were well within the specified limits, the manually-obtained data were adequate to assess the EEBD inward leakage. This problem was eliminated from subsequent tests by recalibration of the amplifier (Table 8).

Test 8. The EEBD performed within limits, except for a brief alteration in gas concentrations in the next to last minute of the test, that returned to previous levels quickly. No apparent explanation was readily available, except that later review of the data isolated this problem to the lower sample port. The oxygen level recorded was extremely low, whereas the nitrogen and SF_6 levels were higher than expected. Again, it is likely that one of the subject's sampling tubes may have been compromised. The changes produced by this event were too small to affect the success of the test (Table 9).

Table 6. Test 5: Subject J2037

MIN	SF6	CO2	N2	O2	TEMP
3.	2.48	.924	17.80	80.90	34.95
4.	2.50	.781	11.62	87.30	35.53
5.	3.40	.740	8.62	90.19	35.98
6.	2.90	.682	7.03	91.84	36.36
7.	3.29	.591	6.10	92.85	36.63
8.	4.22	.694	6.44	92.29	36.87
9.	3.53	.731	5.52	93.13	37.12
10.	4.22	.694	5.70	93.08	37.17
11.	4.53	.774	5.76	92.70	37.35
12.	5.57	.828	6.66	91.63	37.81
13.	6.04	.604	6.68	92.16	38.33
14.	6.97	.709	7.90	90.57	38.70
15.	7.25	.779	7.46	90.99	39.43
mean	4.38	.733	7.94	90.74	37.13

Gas values given in percentages; temp in degrees C

Table 7. Test 6: Subject M4906

MIN	SF6	CO2	N2	O2	TEMP
3.	.222	.467	21.88	77.24	31.82
4.	.270	.272	13.85	85.53	32.45
5.	.288	.432	9.30	89.99	33.01
6.	.455	.219	6.34	93.17	33.63
7.	.349	.216	4.44	95.16	34.18
8.	2.49	.390	4.67	94.55	34.88
9.	3.95	.414	5.02	94.23	35.61
10.	2.41	.333	4.24	95.50	36.28
11.	7.28	.459	7.96	89.50	36.90
12.	4.92	.305	6.30	94.29	37.62
13.	3.16	.284	4.41	95.55	38.20
14.	8.65	.534	5.14	91.80	39.35
15.	5.96	.194	7.13	93.91	39.90
mean	3.10	.347	7.74	91.57	35.67

Gas values given in percentages; temp in degrees C

DISCUSSION

The S-TRON EEBD generally performed as expected. In most of the tests all the parameters were well within the specified limits; mechanical problems in sampling probes were responsible where recorded values ranged outside these limits. The 93% group mean oxygen concentrations were more than adequate to meet physiological requirements, and the 0.41% carbon dioxide group mean concentrations never approached levels that would merit concern. Similarly, the 3.46% group mean inward leakage of SF_6 indicated a protection factor generally above that required. Inhalation temperatures were rather high, but still within the 47° C limit required. These data indicate that the S-Tron EEBD should provide the emergency escape breathing protection desired.

PHASE II: TESTS WITH THE REDESIGNED NECK SEAL

INTRODUCTION

In response to another request from Mr. Ken Warner of S-Tron Corporation, the Environmental Physiology Research Section conducted a second series of contaminant leakage tests of the S-Tron Emergency Escape Breathing Device (EEBD), part number (802300-A1), on April 29, 1991. This device was essentially identical to the S-Tron EEBD tested in March 1991, with the exception of a change in neck seal materials. The original S-Tron EEBD neck seal design had conformed to that of the original Scott Aviation crewmember protective breathing device to which it had been engineered; that design consisted of a neoprene foam neck seal bonded to the

Table 8. Test 7: Subject D5968

MIN	SF6	CO2	N2	O2	TEMP
3.	2.48	.457	21.99	77.14	32.35
4.	3.14	.420	15.28	83.93	33.04
5.	3.16	.381	10.58	88.77	33.67
6.	3.55	.419	7.96	91.33	34.32
7.	4.07	.337	6.49	92.91	34.88
8.	4.26	.481	6.81	93.62	35.34
9.	4.78	.407	5.20	94.06	35.86
10.	4.60	.507	4.02	94.28	36.49
11.	4.59	.580	4.92	94.23	36.90
12.	4.12	.626	4.75	94.33	37.21
13.	4.17	.536	4.59	94.51	37.99
14.	4.47	.896	4.98	94.14	38.97
15.	4.42	.615	4.96	94.10	39.60
mean	3.98	.512	7.88	91.08	35.89

Gas values given in percentages; temp in degrees C

Table 9. Test 8: Subject H9454

MIN	SF6	CO2	N2	O2	TEMP
3.	2.10	.871	28.00	70.64	32.61
4.	3.20	.641	20.00	78.94	33.21
5.	3.53	.545	14.10	85.00	33.68
6.	3.73	.387	10.52	88.63	34.61
7.	3.95	.590	8.41	89.90	35.26
8.	4.08	.560	7.15	91.31	36.00
9.	3.88	.510	6.09	92.57	36.58
10.	4.06	.550	5.68	93.44	37.12
11.	4.21	.513	5.55	93.62	37.69
12.	4.27	.564	5.47	93.68	38.37
13.	4.75	.569	5.71	93.51	39.03
14.	4.96	.554	9.47	88.93	39.39
15.	4.68	.550	5.61	93.60	40.16
mean	3.95	.569	10.13	88.75	36.43

Gas values given in percentages; temp in degrees C

outer EEBD material with glue. The new S-Tron neck seal design tested in this study consisted of a proprietary latex material bonded to the outer EEBD material via a heat-sealing process. The tests were conducted in further support of a contract between S-Tron and the U.S. Navy. The test protocol was identical to that used in the Phase I tests. Mr. Warner was again present for the tests.

METHODS

Subjects

The tests of the EEBD employed two male and two female human subjects; one subject of each gender had previously participated in the Phase I tests. Prior to the study, each subject was fully informed about the test procedures and objectives of the research. After this briefing, each subject executed informed consent to proceed with the study.

The subjects were in excellent health and generally well-conditioned physically, as verified by a medical history questionnaire, a physical examination, and a pulmonary function evaluation conducted with an SRI Automated Medical Spirometer. Forced Vital Capacity (FVC, in liters), Forced Expiratory Volume in 1 second (FEV1, in liters), and Peak Flow (PF, in liters per minute) were measured for each subject. Subjects' neck circumferences (in cm) ranged from the female 10th percentile to the male 98th percentile (2). Table 10 displays demographic data for all subjects.

Test Procedure

The tests were conducted in the Environmental Physiology Research Section contaminant leakage chamber, using test procedues, apparatus and safety limits identical to those in Phase I to produce a strict replication of the Phase I tests (see Phase I methods).

Table 10. Subject Demographics

Subj	Sex	Age (yrs)	Ht (in)	Wgt (lbs)	Neck (cm)	FVC (ltr)	FEV1 (ltr)	PF (lpm)
M6128	F	36	59	125	29.8	3.60	3.23	330
W8860	M	34	74	210	42.4	3.60	5.26	610
L0161	M	39	71	195	41.3	4.94	4.03	548
M6279	F	19	55	112	30.0	3.61	3.06	313
D5968	F	26	64	125	31.9	4.05	3.65	415
H9454	M	28	70	150	37.0	5.37	4.57	398

RESULTS

No tests had to be aborted due to subject health or safety. Four EEBD's were successfully tested. In two EEBD the oxygen levels increased more slowly than the other two, although all the EEBD had internal oxygen concentrations greater than 70% at the start of data collection. These values increased to greater than 90% after reaching asymptote. The carbon dioxide measured for all the tests never exceeded 1.0%.

The mean inward leakage of SF_6 ranged from an individual low of 2.08% to a high of 3.13%, averaging 2.42% for the entire group. The temperature also maintained acceptable values, never reaching greater than 40 degrees C for any test, although steady increases in temperature were observed for all EEBD's.

Narratives and tabular data describing each test are provided below; graphs of SF6 inward leakage, oxygen level, carbon dioxide level and inhalation temperature are shown for each test in Appendix A.

Test Data

Test 1. The EEBD performed very well in this test. No problems were encountered, and all test parameters were easily within limits (Table 11).

Table 11. Test 1: Subject M6128

MIN	SF6	CO2	N2	O2	TEMP
3.	1.63	.277	21.92	77.47	28.40
4.	2.35	.280	12.51	86.91	29.07
5.	2.63	.256	8.50	91.00	29.76
6.	2.86	.228	6.52	93.02	30.37
7.	3.64	.220	5.34	94.28	31.05
8.	3.30	.312	5.18	94.31	31.76
9.	3.22	.222	4.78	94.78	32.49
10.	3.30	.259	4.80	94.73	33.23
11.	3.55	.287	4.96	94.72	34.03
12.	3.53	.251	4.78	94.56	34.71
13.	4.04	.204	4.88	94.69	35.51
14.	3.83	.666	5.35	93.76	36.17
15.	3.23	.219	5.19	94.39	36.89
mean	3.16	.283	7.28	92.35	32.57

Gas values given in percentages; temp in degrees C

Table 12. Test 2: Subject W8860

MIN	SF6	CO2	N2	O2	TEMP
3.	1.07	.205	18.86	80.57	29.76
4.	1.52	.170	11.73	87.81	30.45
5.	[illegible]	.209	7.82	91.73	31.29
6.	1.85	.216	5.89	93.67	32.64
7.	1.95	.197	4.08	95.52	33.19
8.	2.71	.333	4.04	95.43	34.43
9.	2.06	.264	3.25	96.28	35.93
10.	2.09	.409	3.12	96.25	36.87
11.	2.42	.387	3.02	96.39	37.85
12.	2.17	.262	3.06	96.43	38.42
13.	2.34	.627	3.11	96.05	39.24
14.	2.56	.442	3.18	96.21	39.92
15.	2.53	.380	3.22	96.20	39.98
mean	2.07	.314	5.72	93.73	35.65

Gas values given in percentages; temp in degrees C

Test 2. The EEBD performed very well in this test. No problems were encountered, and all test parameters were easily within limits (Table 12).

Test 3. The EEBD performed within limits for this test. However, the SF_6 inward leakage did exceed the 5% level at the 10 and 13 minute marks, when the subject was turning his head and breathing deeply. Because this change in gas concentration had appeared at the upper visor location, and since the oxygen concentration had also dipped slightly, it appeared likely that the sampling probe had come in contact with the subject's skin, causing gases from the chamber to be drawn in around the sample tube.

Careful examination of the subject's forehead immediately after the test run revealed a red spot which looked as if it had been produced by the vacuum suction from the MGA 1100, suggesting that our interpretation was correct. Appendix II provides a schematic representation (Table 13).

Test 4. The EEBD performed very well in this test. No problems were encountered, and all test parameters were easily within limits (Table 14).

Table 13. Test 3: Subject L0161

MIN	SF6	CO2	N2	O2	TEMP
3.	1.09	.459	23.33	75.82	29.01
4.	1.44	.478	15.49	83.68	29.93
5.	1.74	.469	10.52	91.60	30.85
6.	1.79	.507	7.65	93.63	31.62
7.	1.92	.561	5.59	90.24	32.55
8.	2.11	.460	9.95	95.37	33.56
9.	1.92	.622	3.79	96.04	34.36
10.	1.83	.454	3.29	94.90	35.28
11.	5.36	.308	4.40	96.42	36.27
12.	1.97	.467	2.93	96.58	37.16
13.	1.89	.470	2.75	95.37	37.72
14.	5.30	.454	3.89	94.73	38.32
15.	2.04	.453	2.82	96.56	39.20
mean	2.33	.474	7.41	92.38	34.29

Gas values given in percentages; temp in degrees C

Table 14. Test 4: Subject M6279

MIN	SF6	CO2	N2	O2	TEMP
3.	1.40	.484	21.25	77.87	28.37
4.	1.85	.343	14.04	85.30	28.74
5.	2.06	.337	9.16	90.22	29.28
6.	2.08	.332	6.67	92.79	29.84
7.	2.15	.286	5.02	94.48	30.51
8.	2.22	.509	4.21	95.08	31.05
9.	2.20	.417	3.84	95.53	31.45
10.	2.29	.410	3.56	95.80	32.03
11.	2.13	.576	3.39	95.81	32.78
12.	2.22	.479	3.44	95.87	33.28
13.	2.32	.413	3.35	95.97	33.90
14.	2.42	.573	3.34	95.90	34.51
15.	2.45	.341	3.35	96.11	35.04
mean	2.13	.423	6.50	92.82	31.59

Gas values given in percentages; temp in degrees C

DISCUSSION

The S-TRON EEBD (part # 802399-A1) with redesigned neck seal generally performed as expected. In all of the tests the parameters were well within the specified limits; the mechanical problems associated with the sampling probes in the March 1991 tests of the EEBD with the original neck seal had been overcome, except in one instance. The group mean oxygen concentrations above 90% were more than adequate to meet physiological requirements, and the very low carbon dioxide group mean concentrations of 0.37% were remarkable. Also similar to the first series of original EEBD tests, the 2.42% group mean inward leakage of SF_6 indicated a protection factor well above that required to meet specifications. Inhalation temperatures continued to be rather high, but again were still within the 47° C limit required.

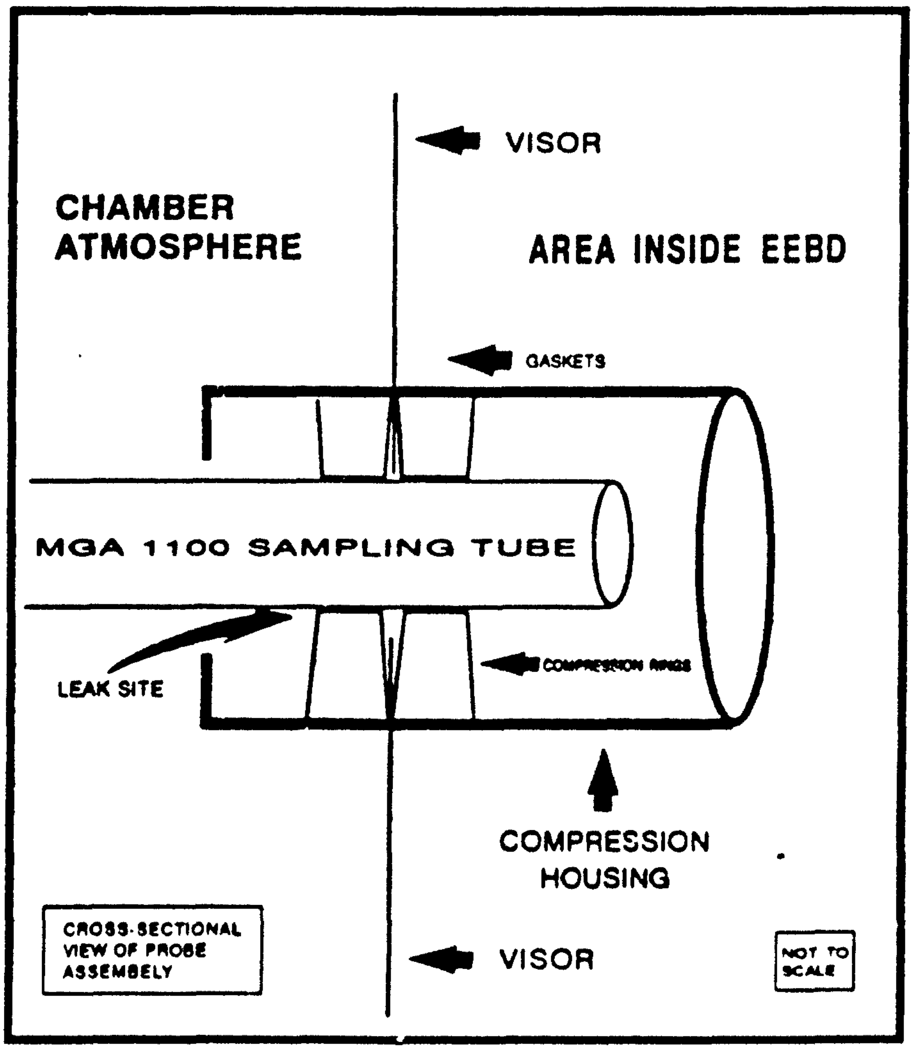
The variance in gas concentration data associated with the redesigned neck seal also appeared to be reduced from that found with the original EEBD, indicating that the EEBD with the new neckseal seal out-performed the original EEBD in terms of inward leakage protection. This enhancement in inward leakage performance should provide an overall increase in breathing protection.

REFERENCES

1. Federal Aviation Administration Technical Standard Order C-116, Crewmember Protective Breathing Equipment, March 1, 1990.

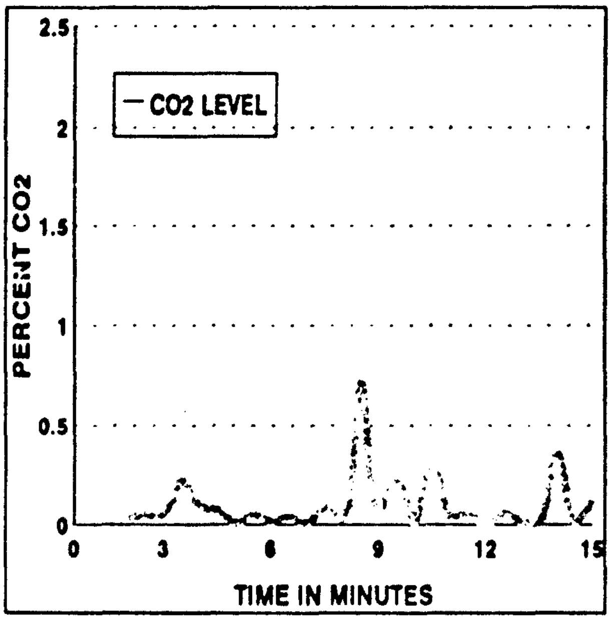
2. Gordon CC, Bradtmiller B, Churchill T, Clauser CE, McConville JT, Tebbetts I, Walker W: 1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics, US Army Natick RD&E Center, Natick, MA.

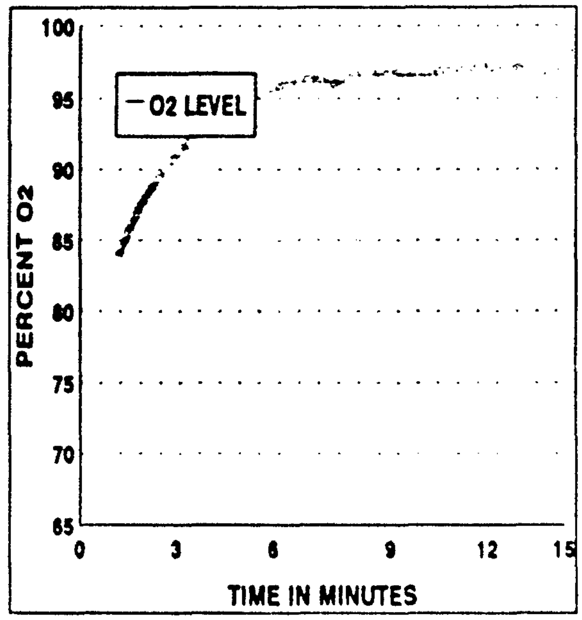
APPENDIX A.

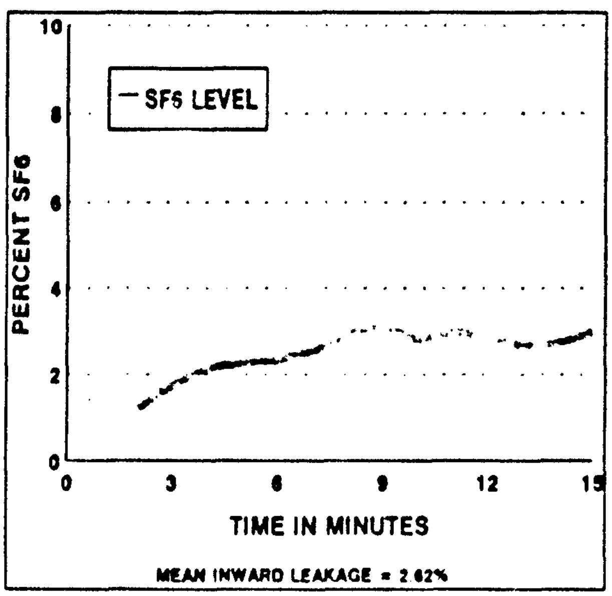

VISOR
CHAMBER ATMOSPHERE
AREA INSIDE EEBD
GASKETS
MGA 1100 SAMPLING TUBE
COMPRESSION RINGS
LEAK SITE
COMPRESSION HOUSING
CROSS-SECTIONAL VIEW OF PROBE ASSEMBELY
VISOR
NOT TO SCALE

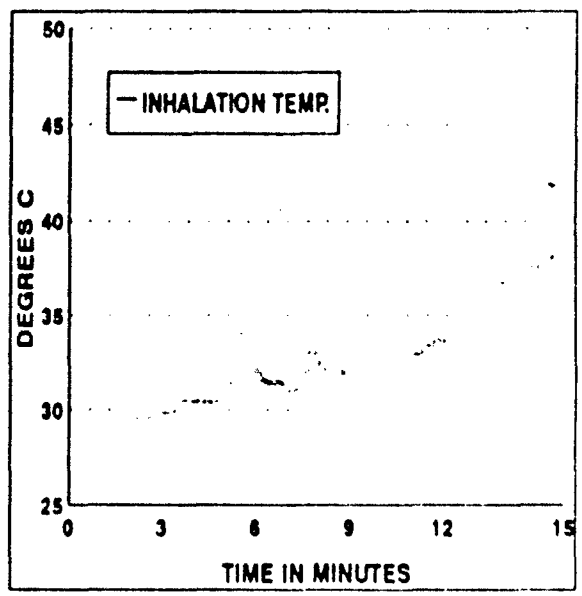
APPENDIX B. PHASE I. EEBD TEST PARAMETERS

EEBD Tests: H1026

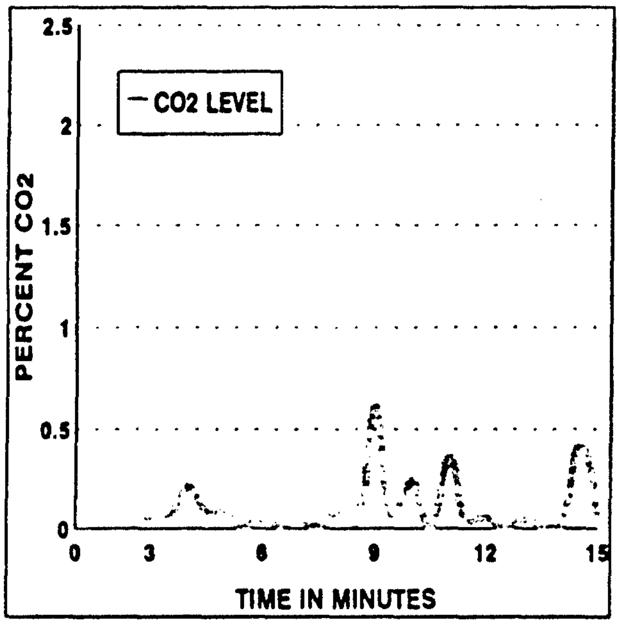


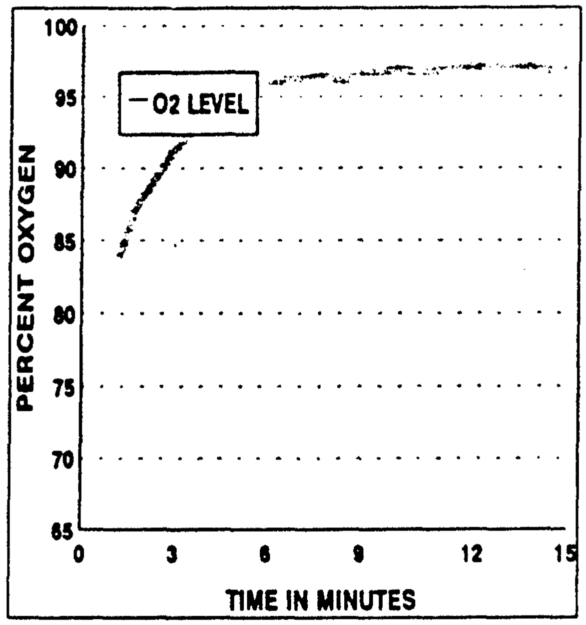


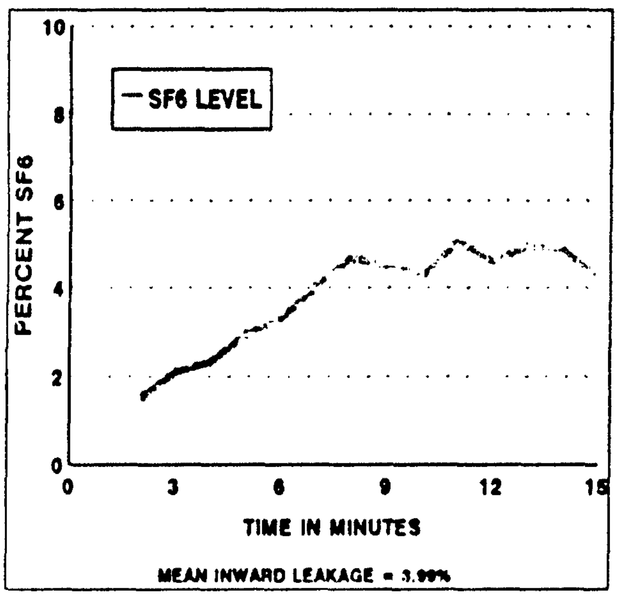


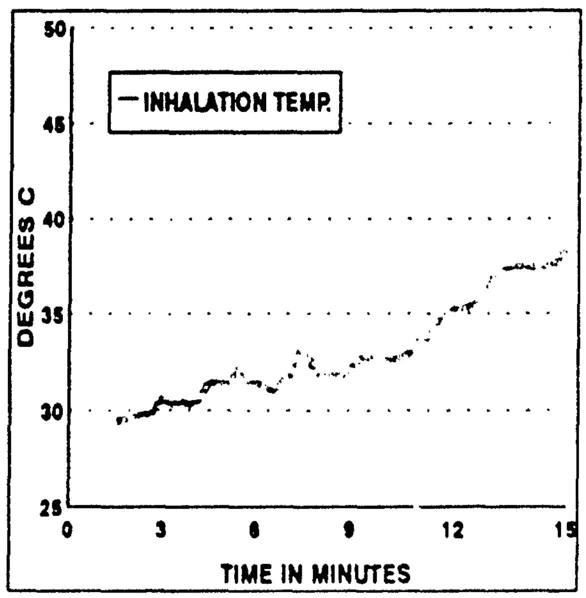


EEBD Tests: L0161

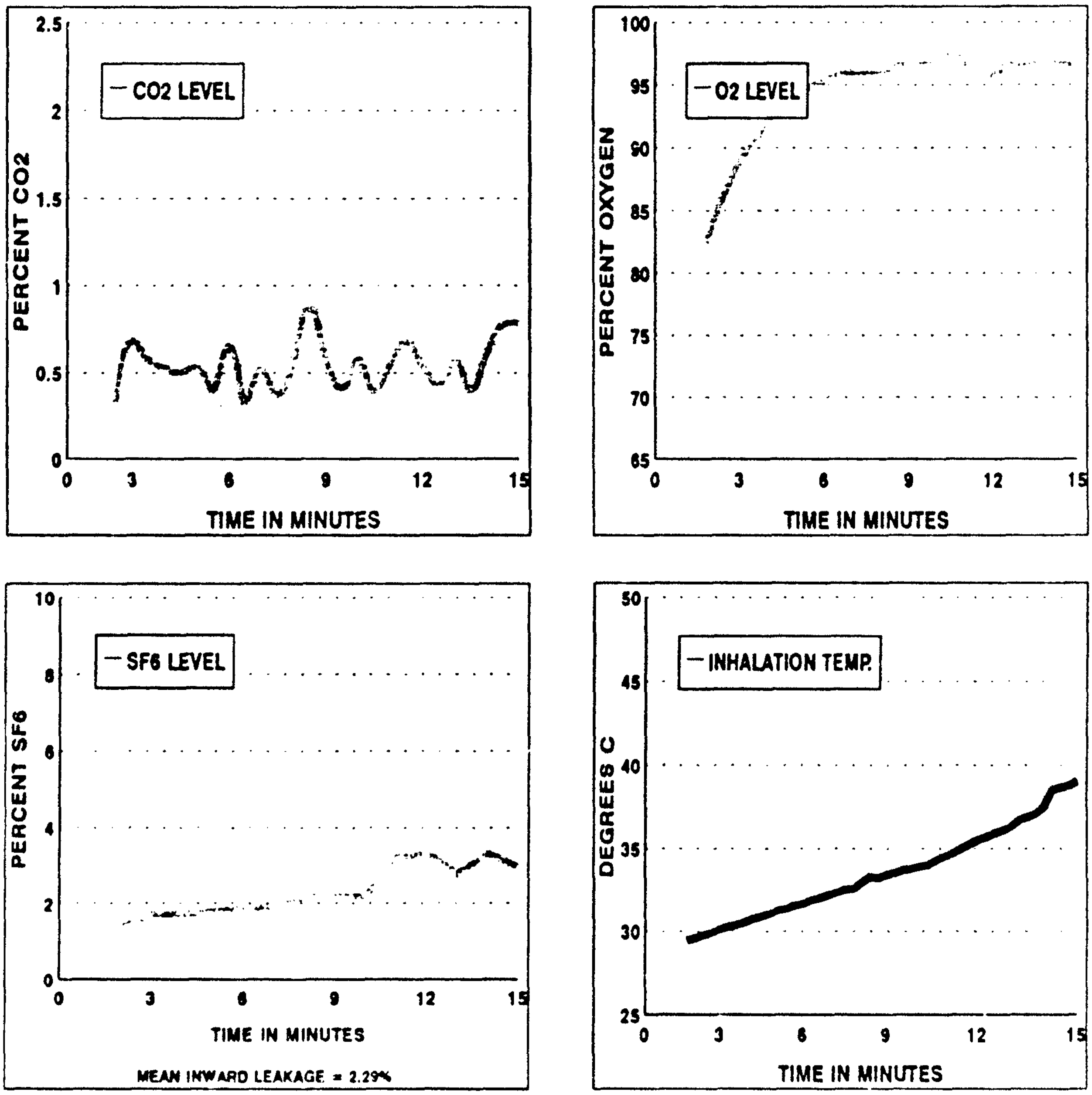




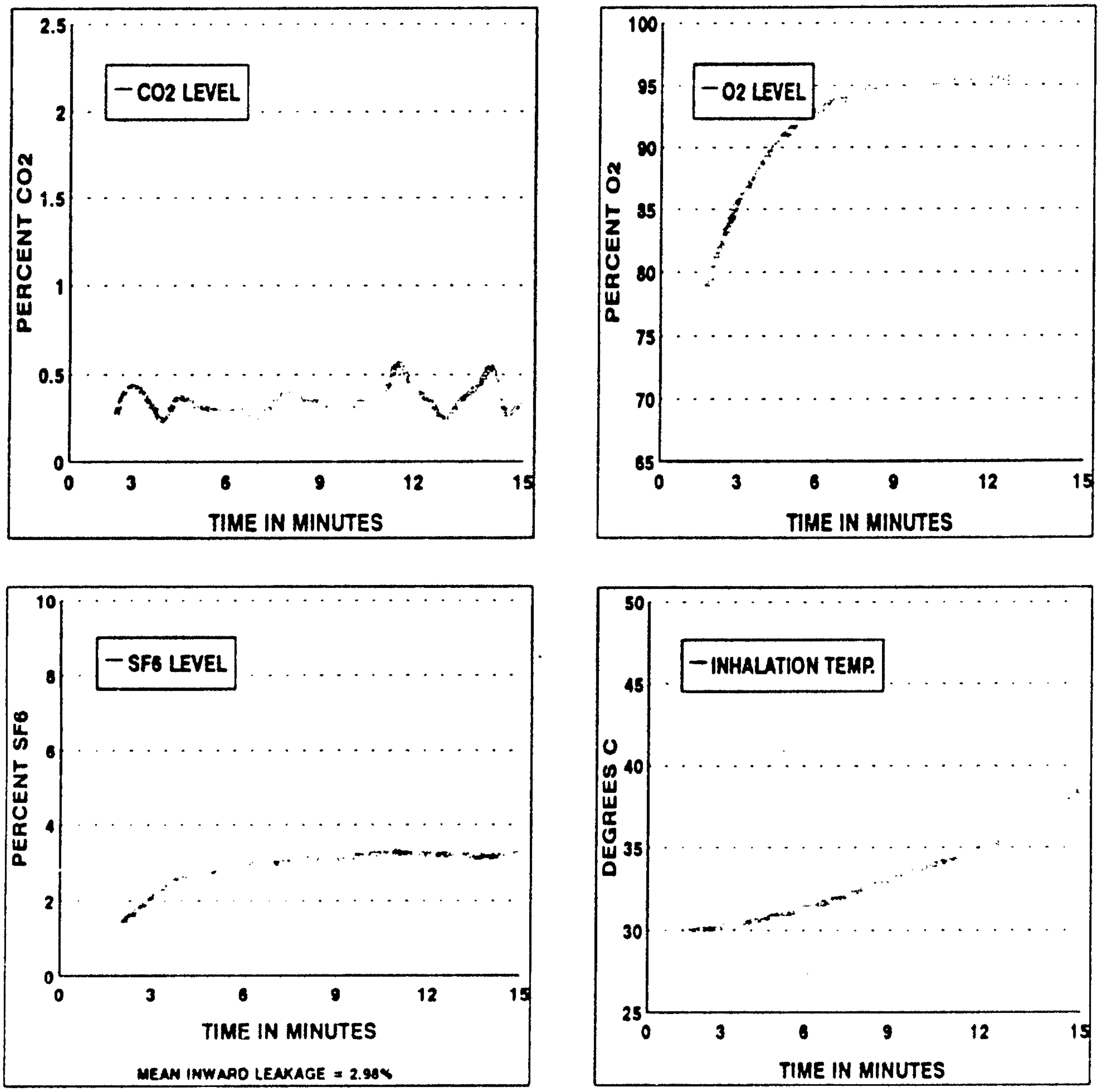




EEBD Tests: F2865



EEBD Tests: M6279



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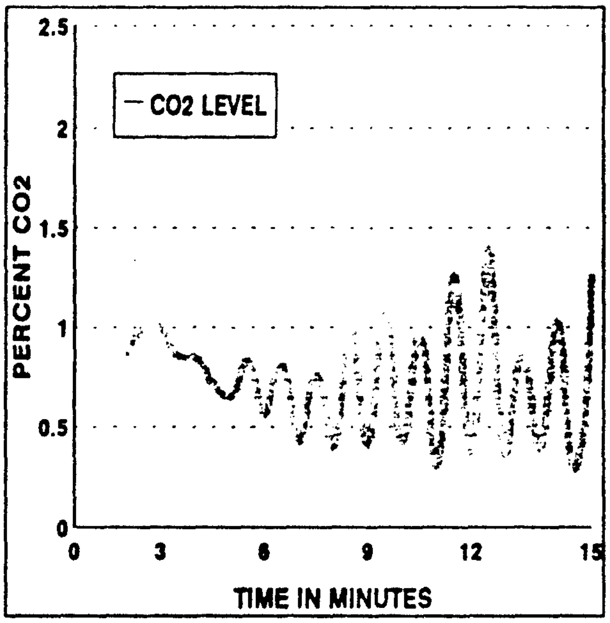
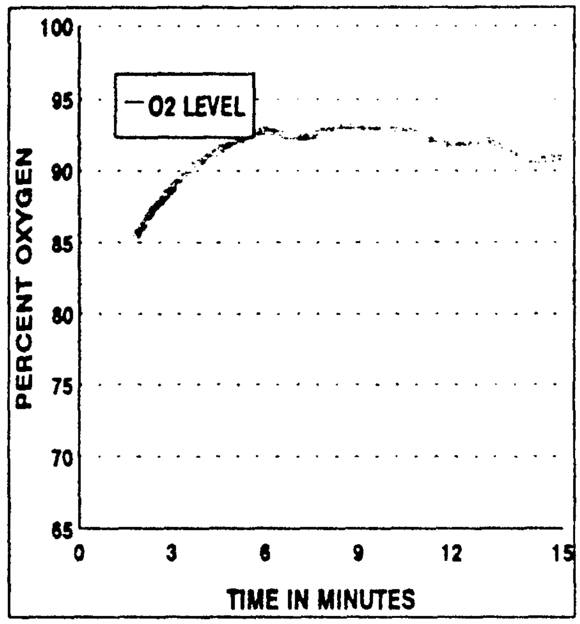
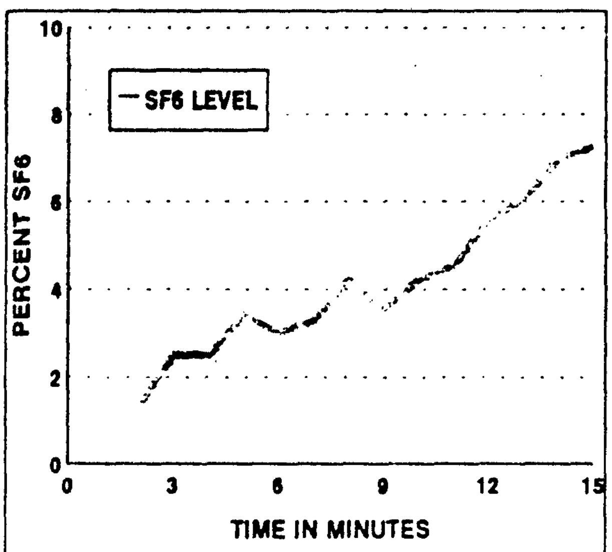
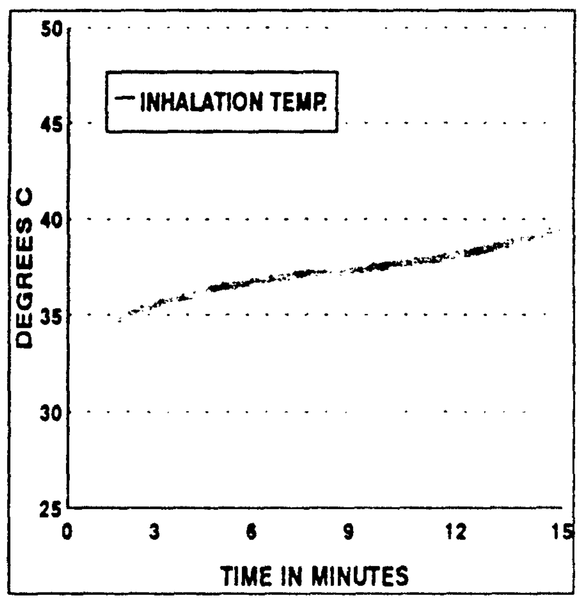


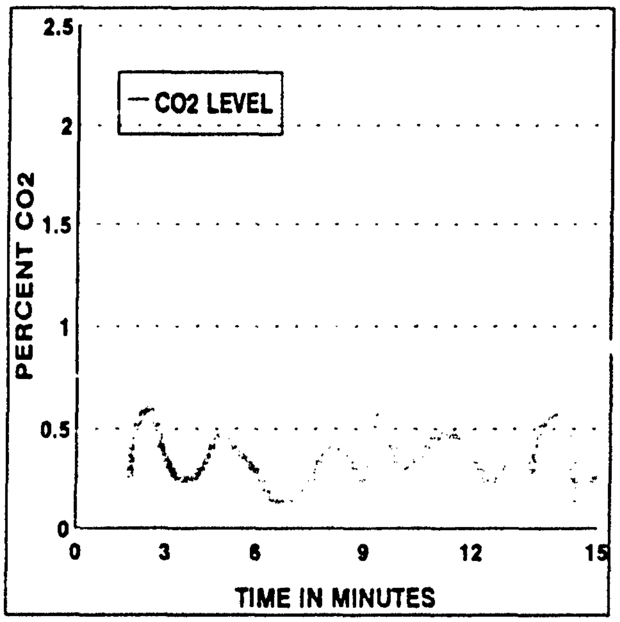


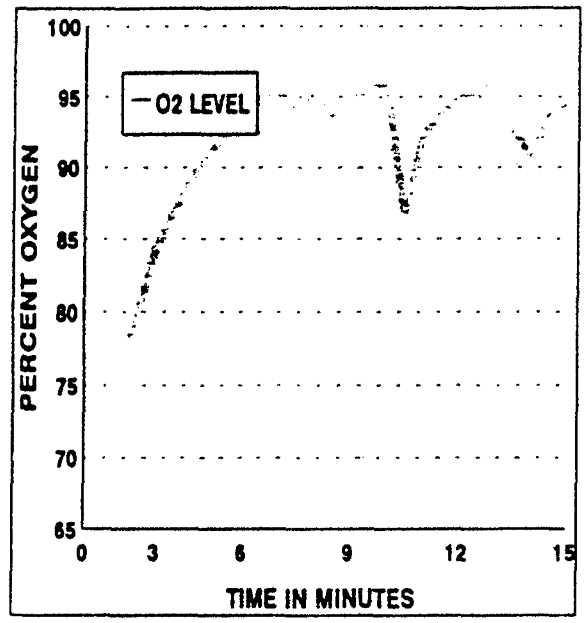


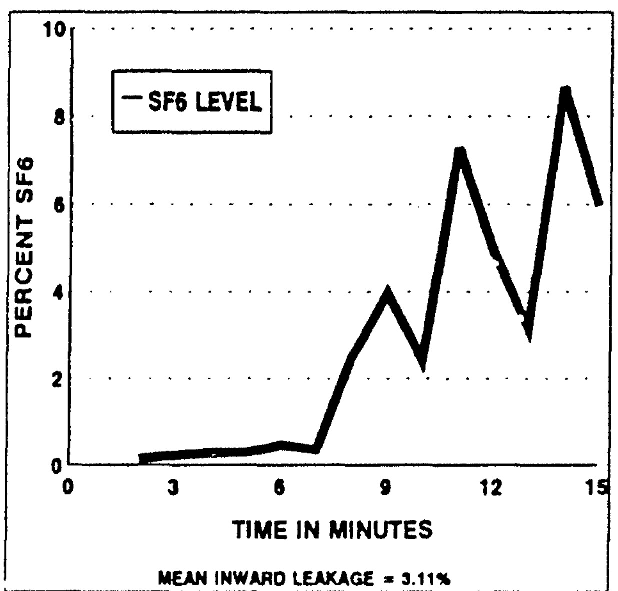
MEAN INWARD LEAKAGE = 4.38%

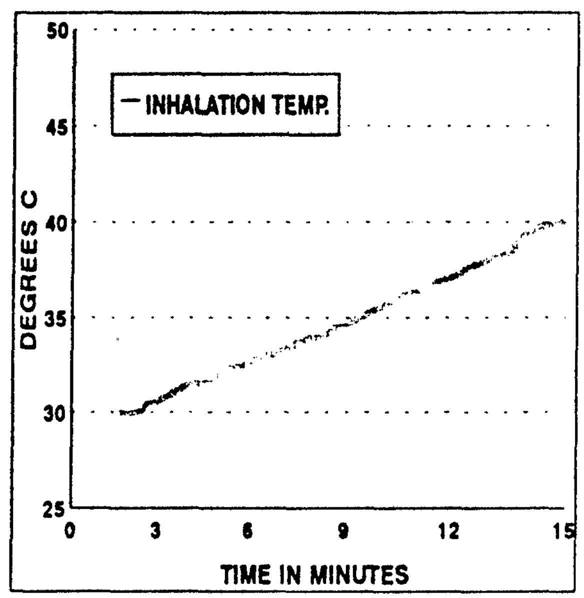


EEBD Tests: M4906

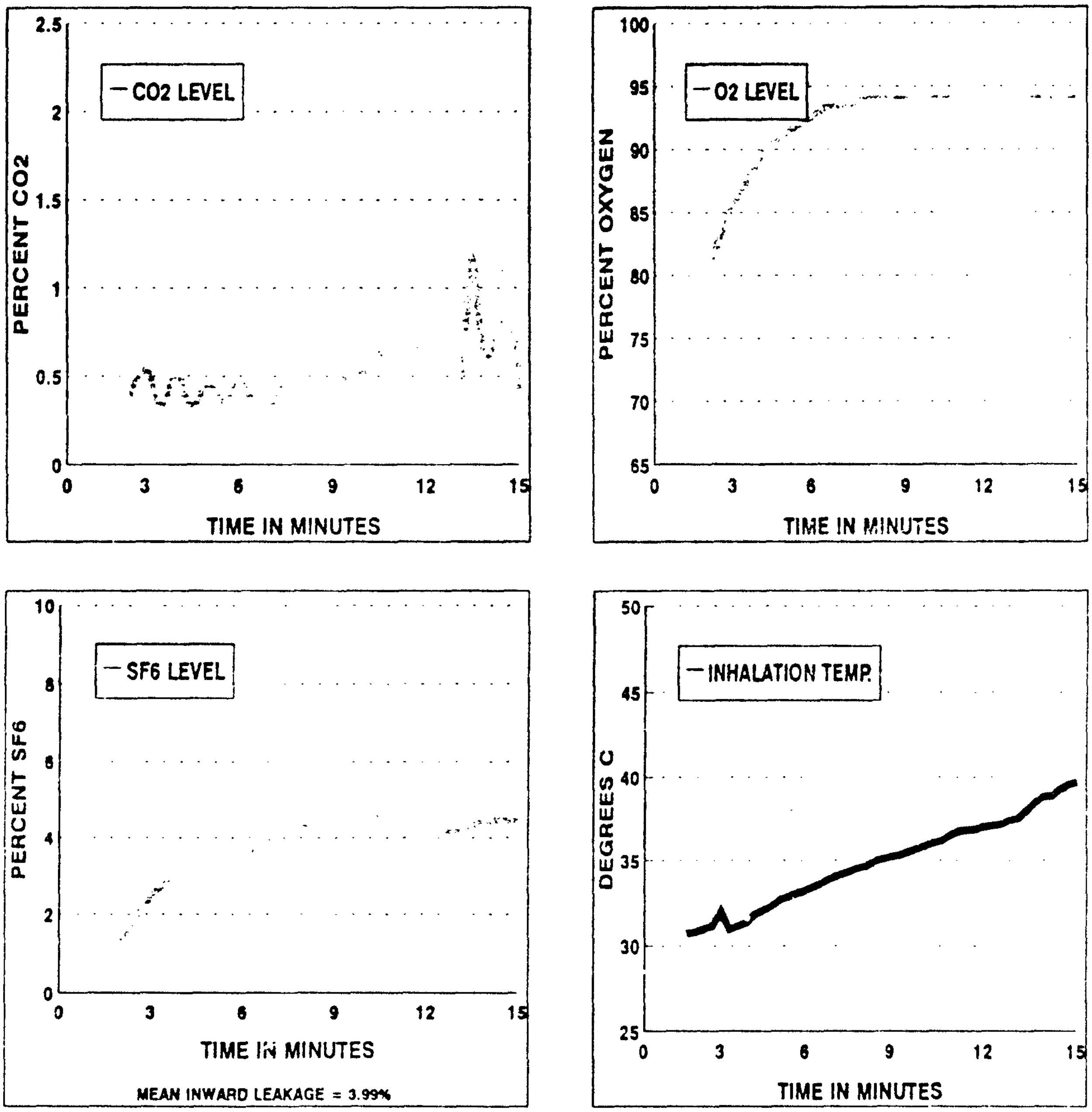




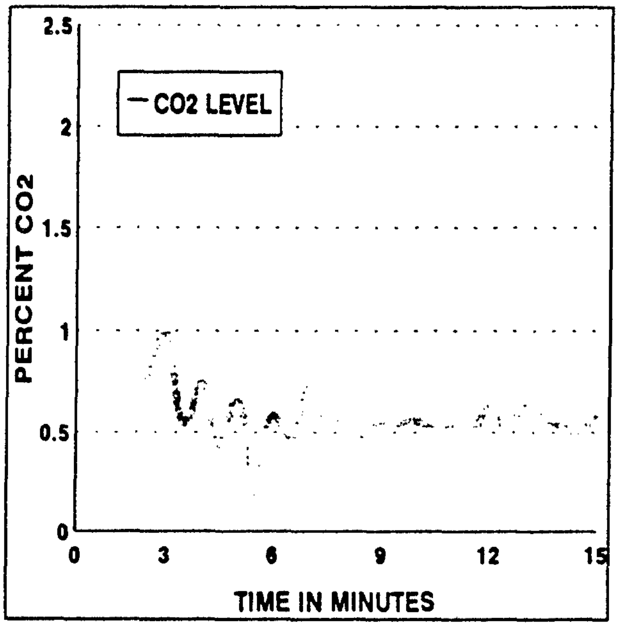


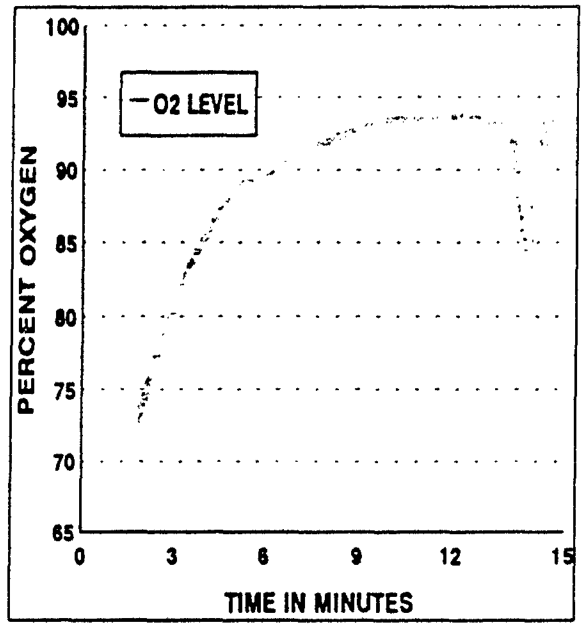


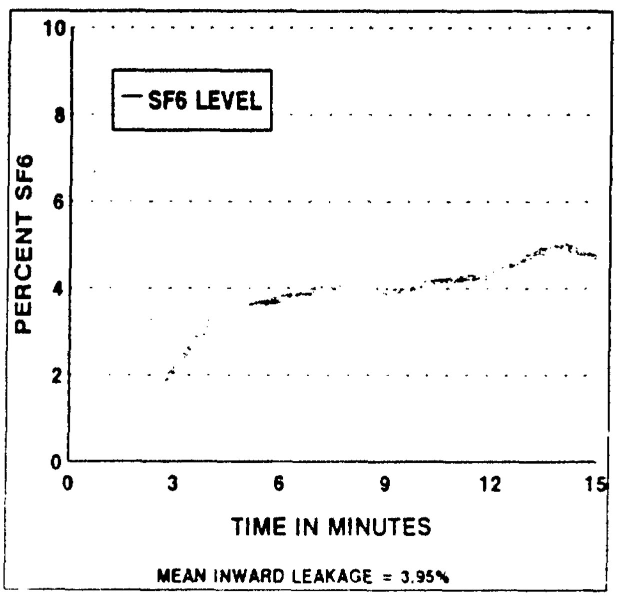
EEBD Tests: D5968

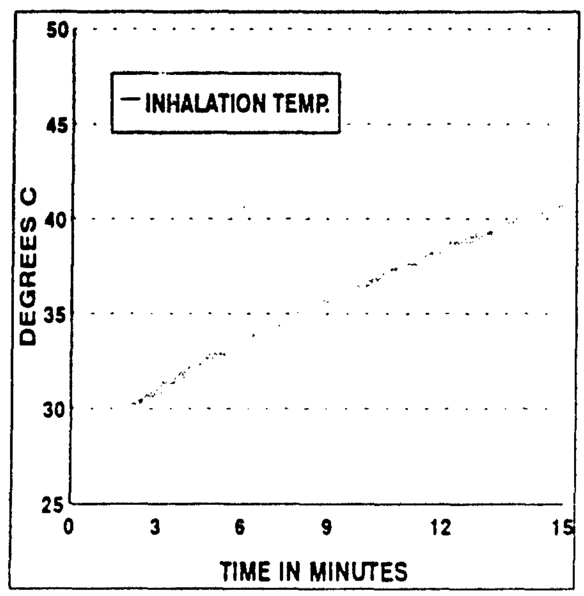


EEBD Tests: H9454



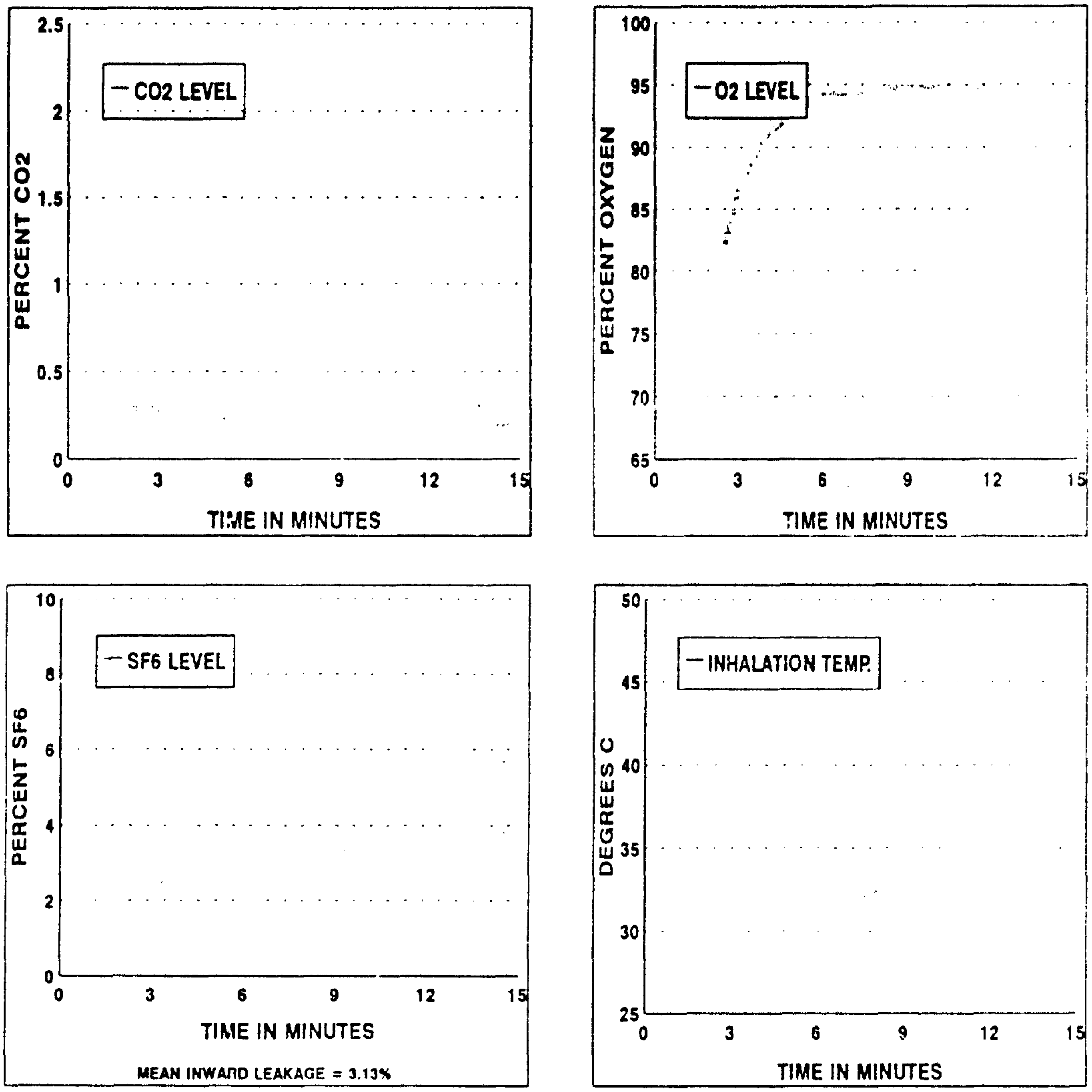






APPENDIX C. PHASE II. EEBD TEST PARAMETERS

EEBD Tests: M6128



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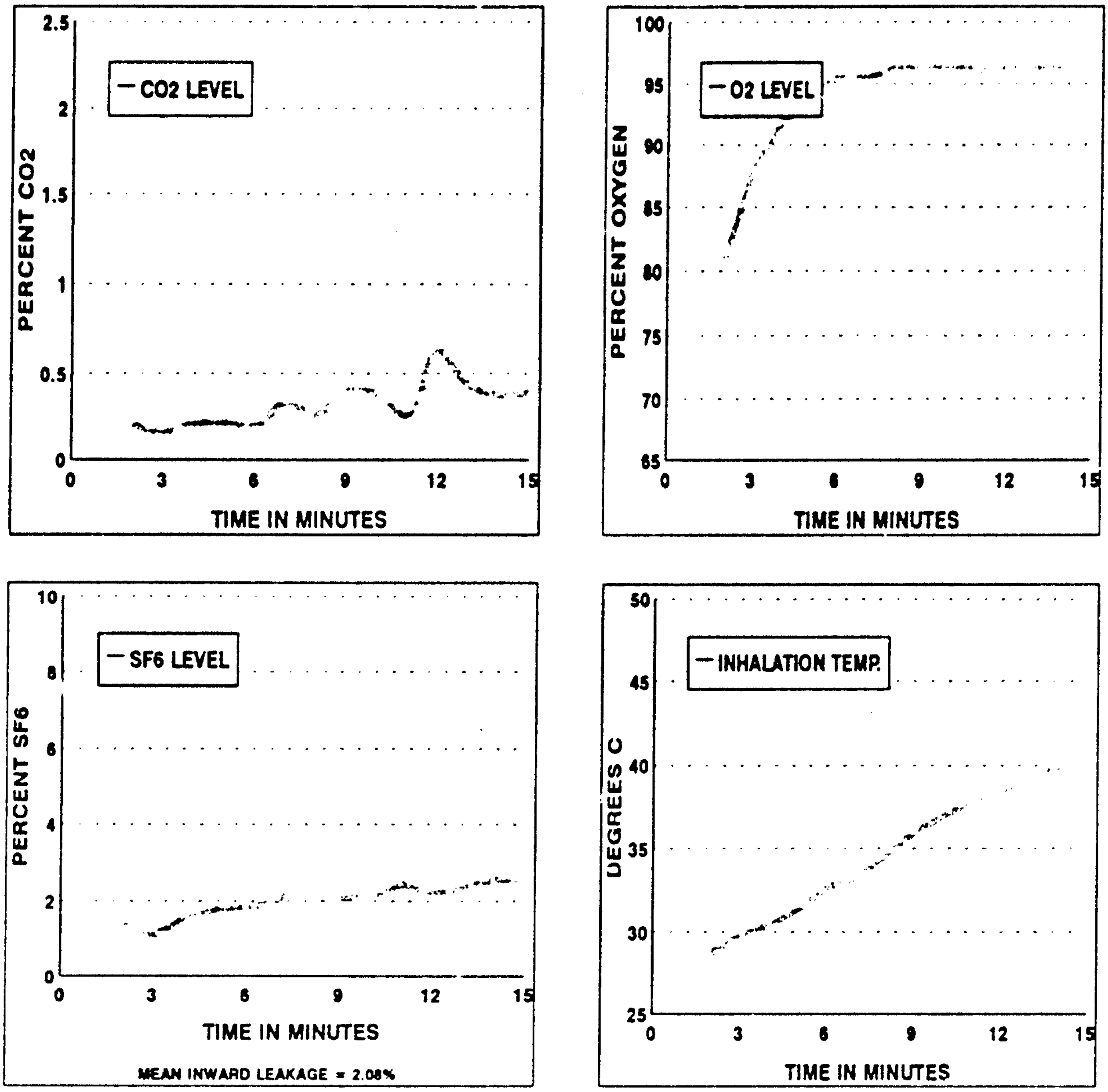
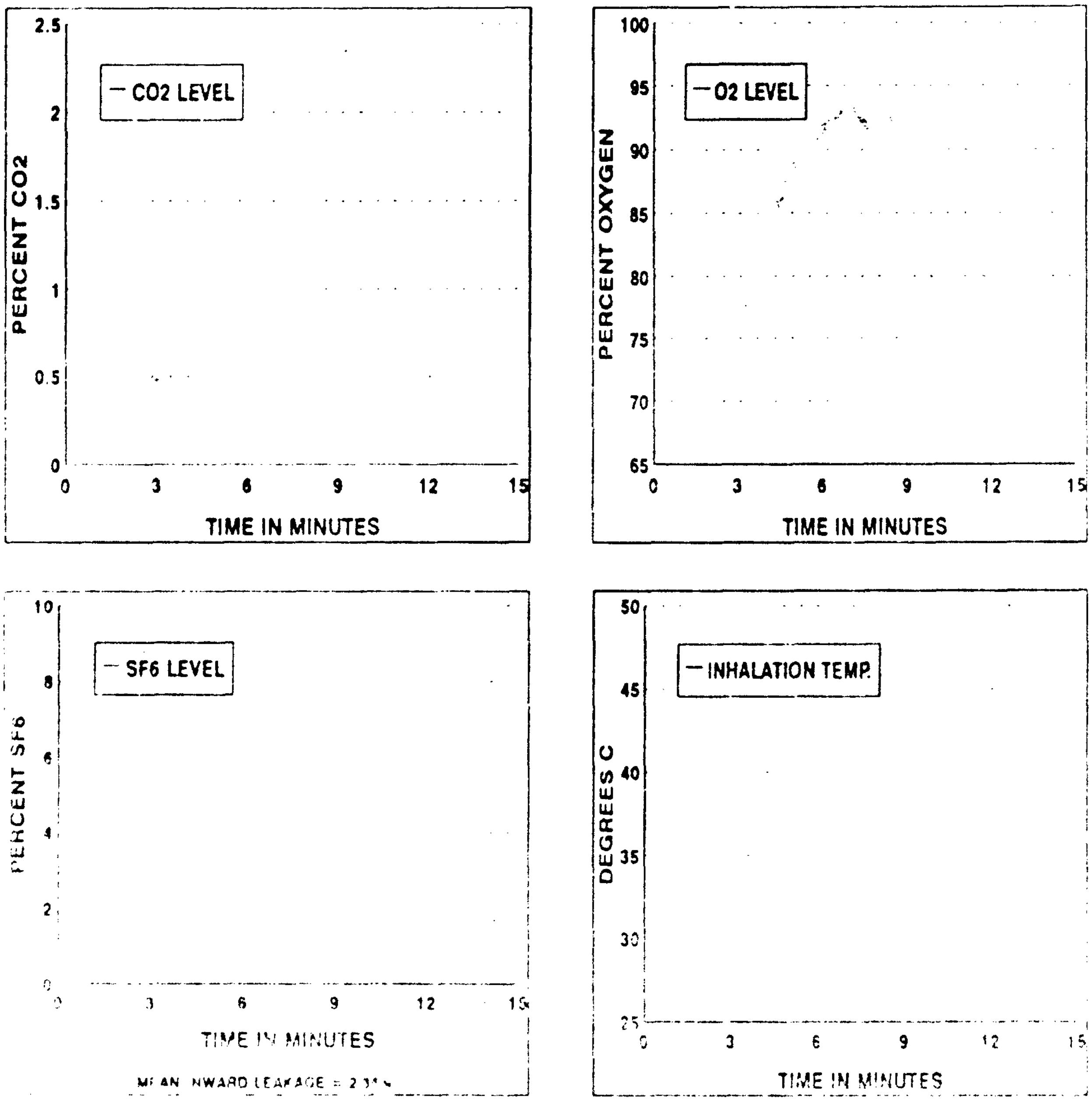
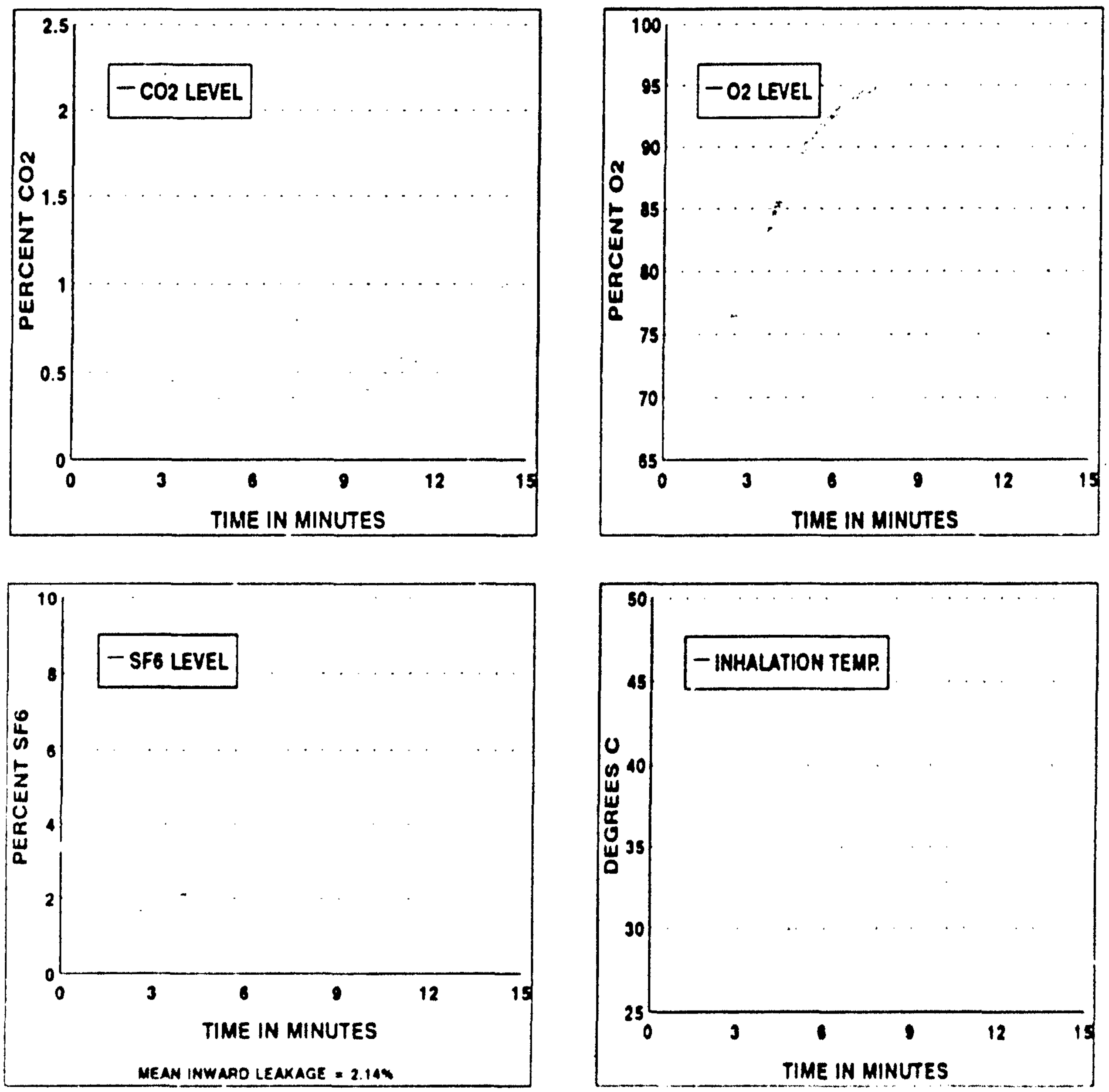


EEBD Tests: L0161



EEBD Tests: M6279



*U.S.GPO:1992-661-063/40077