SSCL-N-832

Performance Evaluation of Oxygen Sensors for Use in the Superconducting Super Collider Personnel Access Safety System

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1.0 *Introduction*

1.1 *Overview*

A test was performed to determine the response time, accuracy and repeatability of eight different sensors including the KE-50 (manufactured by Figaro) which is currently being used in the Accelerator Systems String Test (ASST) facility.

1.2 *Purpose*

The test was designed to characterize the different cells. Comparison of the results could lead to decisions on how to feasibly apply the cells, and determinations of which cell(s) to utilize.

1.3 *Description of Units under Test*

Sensor Name	Model #	Serial #	Manufacturer	Sensor Type
MSA	485105	485105	Mine Safety Appliances Company	Self Contained
Crowcon	RGD 90	S01-169	Crowcon Instruments LTD	Self Contained
General Monitors S720	S720	45060-2	General Monitors	Self Contained
General Monitors S721	S721	N/A	General Monitors	Self Contained
SMC	4101-3	91-C-2171	Sierra Monitor Corporation	Self Contained
City Technology	N/A	058256 071	City Technology LTD	O2 cell plus millivolt transmitter
KE-50	N/A	OXYFIG0010	Figaro	02 cell plus millivolt transmitter
Drager	18315230	18315230	Drager	Self Contained

2.0 *Test*

2.1 *Response Time*

2.1.1 *Methodology*

To test response time, a span gas of 19.5% oxygen was applied until the sensor read within + / - 0.2% of 19.5%. The time for the sensor to reach 19.5% was recorded. Then, the span gas was removed and the time for the sensor to reach ambient air was recorded. Ambient air was defined as within + / - 0.5% of 20.9% oxygen.

2.1.2 *Results*

The response time was broken into two readings: the number of seconds for the sensors to go from approximately 20.9% to approximately 19.5%, and the number of seconds required for the sensors to go from approximately 19.5% to approximately 20.9%.

2.1.2.1 *Response Time from 20.9% to 19.5% Oxygen*

Sensor Name	Response Time (sec)	Rank
General Monitors S720	7.81	1
General Monitors S721	14.85	2
SMC	27.35	3
Drager	27.87	4
Crowcon	28.2	5
City Technology	53.17	6
MSA	99.32	7
KE-50	125	8

2.1.2.2 *Response Time from 19.5% to 20.9% Oxygen*

Sensor Name	Response Time (sec)	Rank
General Monitors S720	7.2	1
General Monitors S721	13.12	2
SMC	15.94	3
Drager	16.36	4
Crowcon	18.67	5
City Technology	73.5	6
MSA	77.64	7
KE-50	157	8

2.1.2.3 *Response Time from 20.9% to 17% Oxygen*

Sensor Name	Response Time (sec)	Rank
KE-50	105	N/A

NOTE: The KE-50 was the only cell tested.

2.1.2.4 *Response Time from 17% to 20.9% Oxygen*

Sensor Name	Response Time (sec)	Rank
KE-50	117	N/A

NOTE: The KE-50 was the only cell tested.

2.2 *Accuracy*

2.2.1 *Methodology*

The accuracy of each sensor was determined by applying a span gas of

19.5% oxygen. The sensor was then allowed to stabilize and the value that the sensor reached was recorded. The test was repeated for 18% and 17% oxygen.

2.2.2 *Results*

2.2.2.1 *Accuracy for a span gas of 19.5% Oxygen*

Sensor Name	Accuracy	Rank
MSA	19.5	1(tie)
SMC	19.5	1(tie)
Drager	19.5	1(tie)
General Monitors S720	19.49	2
KE-50	19.55	3
City Technology	19.6	4
General Monitors S721	19.66	5
Crowcon	19.76	6

2.2.2.2. *Accuracy for a span gas of 18% Oxygen*

Sensor Name	Accuracy	Rank
SMC	18.03	1
Crowcon	18.09	2
Drager	18.1	3
MSA	18.14	4
City Technology	18.16	5
General Monitors S721	18.21	6
General Monitors S720	18.4	7
KE-50	18.64	8

2.2.2.3 *Accuracy for a span gas of 17% Oxygen*

Sensor Name	Accuracy	Rank
Drager	17	1
Crowcon	17.13	2 (tie)
SMC	16.87	2 (tie)
City Technology	17.13	2 (tie)
MSA	17.2	3
General Monitors S721	17.29	4
General Monitors S720	17.39	5
KE-50	Not Available	Not Available

2.3 *Repeatability*

2.3.1 *Methodology*

The repeatability of the sensors was defined as the difference between the ambient air value the sensors read initially and the ambient air value the

sensors read after 19.5% span gas was applied and removed. The ambient reading on the sensor was recorded. Then, a span gas of 19.5% oxygen was applied. The sensor was allowed to stabilize at 19.5%. The span gas was then removed and the sensor was allowed to return to ambient air. The final value of the sensor in ambient air was then recorded. The results were graphed so that the graph reflected the difference between initial value of the sensor and the final value of the sensor.

2.3.2 *Results*

Sensor Name	Initial Value	Final Value	Delta	Rank
MSA	20.77	20.77	0.00	1 (tie)
Crowcon	20.93	20.93	0.00	1 (tie)
General Monitors S720	20.63	20.63	0.00	1 (tie)
General Monitors S721	21.08	21.08	0.00	1 (tie)
City Technology	20.81	20.81	0.00	1 (tie)
Drager	20.7	20.7	0.00	1 (tie)
SMC	20.95	20.96	0.01	2
KE-50	20.51	20.54	0.03	3

2.4 *Cost*

Sensor Name	Cost per quantity 1	Rank
KE-50	$247.80	1
City Technology	$257.80	2
Crowcon	$495	3
Drager	$500	4
MSA	$690	5
SMC	$700	6
General Monitors S720	$910	7 (tie)
General Monitors S721	$910	7 (tie)

NOTE: The sensors were ranked from least expensive to most expensive.

3.0 *Conclusions*

The sensor currently being used in the ASST is the KE-50 manufactured by Figaro. The KE-50 did poorly in the response time test, and finished last in both the accuracy (for 18% oxygen) and repeatability tests. The KE-50 finished well in the accuracy test for 19.5% oxygen. Notice that in the response time test for 17%, the KE-50 responded as quickly as it did to 19.5% oxygen (125 seconds for 19.5% versus 105 seconds for 17%). This is a very attractive feature and seems to suggest that the sensor's response could be equally quick in any level of oxygen. In the accuracy test, the KE-50 displayed excellent accuracy despite finishing last in the 18% oxygen category. Certainly, a deviation of 0.64% was acceptable. However, the accuracy could be improved if the cell were recalibrated. At the time of the test, the KE-50 was calibrated using an unapproved and untested calibration procedure. The KE-50 also finished last in the repeatability category with a delta of 0.03%. The Figaro cell had a very attractive claim of ten years life expectancy. The cell was also the least expensive sensor tested. The General Monitors S720 and S721 sensors did well in almost every category. The S720 and S721's most attractive feature was their response time (7.81 seconds for the S720 and 14.85 seconds for the S721). Response time is very important for a sensor, since the quicker the sensor detects a deficiency of

oxygen, the sooner a person can leave a hazardous area unharmed. This made the S720 and S721 very solid sensors. However, one thing not reflected by the tests is that the S720 and S721 could not be zero checked. This could cause offset errors that would skew sensor readings after a period of time. Also, the sensors did not offer flexibility as far as calibration is concerned. The sensors had to be calibrated using 20.9% span gas in order for them to be perfectly accurate. If there were not any 20.9% span gas available, the reliability of the sensor readings would be compromised. The S720 and S721 were also the most expensive sensors tested. These negatives made the S720 and S721 sensors unacceptable. The City Technology sensor was very similar to the KE-50 sensor. The City Technology sensor finished close to or better than the KE-50 in the tests. The City Technology data, in section 4.2, showed these cells have an average life expectancy of approximately 73 weeks, much less than the Figaro cells. The City Technology sensor was also slightly more expensive than the Figaro sensor. The SMC and Crowcon sensors were very similar and finished close to each other in every test. Both sensors were easy to calibrate and had above average accuracy, average response time and excellent repeatability. A big negative on both of these sensors was that they were bulky and costly and were therefore not recommended. The MSA sensor had average response time, good accuracy and excellent repeatability. However, it was a very bulky and costly sensor, but more important was that it was very difficult to calibrate. This made it an unacceptable choice. The last sensor was the Drager. It had a good response time, excellent accuracy and excellent repeatability. The sensor was very easy to calibrate and could be calibrated using any span gas (20.9%, 19.5%, 18%,etc.) which made it very flexible. The LCD that displayed the percent oxygen was very convenient and the sensor housing was durable and attractive. The only negative the sensor had was cost.

4.0 *Data*

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4.1 *Raw Data*
4.2 *Mean Time Between Failure Data*
4.3 *Graphs of Test Results*
4.4 *Test Data Tabulation*

4.1 Raw Data

Raw Data

Sensor Name: SMC (Sierra Monitor Corporation)

Response Time

	Time: 27.35 sec.		Time: 15.94 sec.	
% Oxygen	From	To	From	To
19.5	2.092v	1.95v	1.95v	2.092v
18	NA	NA	NA	NA
17	NA	NA	NA	NA

Accuracy of Sensor

% Oxygen	Start Reading	Low end reading	Time to return	Returned to
19.5	2.094v	1.95v	19.24 sec.	2.094v
18	2.093v	1.803v	25.82 sec.	2.093v
17	2.086v	1.687v	38.99 sec.	2.086v

Repeatability of Sensor

% Oxygen	Start Reading	Low end reading	Returned to
19.5	2.095v	1.953v	2.096v
18	NA	NA	NA
17	NA	NA	NA

Sensor Name: Crowcon

Response Time

NOTE: The readings in the table are the actual readings.
To obtain a percent oxygen reading from the table reading, subtract 0.57 from the reading. Then multiply the result by 5 and divide by 4. This procedure should only be used for the readings taken when 19.5% oxygen was used.

	Time: 28.20 sec.		Time: 18.67 sec.	
% Oxygen	From	To	From	To
19.5	17.28 ma	16.38 ma	16.38 ma	17.28 ma
18	NA	NA	NA	NA
17	NA	NA	NA	NA

Accuracy of Sensor Recalibrated for 18% Oxygen

% Oxygen	Start Reading	Low end reading	Time to return	Returned to
19.5	17.3 ma	16.38 ma	18.06 sec.	17.3 ma
18	167.2 mv	144.7 mv	1.41.46 min.	167.2 mv
17	167.7 mv	137 mv	2.14.36 min.	167.3 mv

Repeatability of Sensor

% Oxygen	Start Reading	Low end reading	Returned to
19.5	17.31 ma	16.39 ma	17.31 ma
18	NA	NA	NA
17	NA	NA	NA

Sensor Name: City Technologies

Response Time

	Time: 53.17 sec.		Time: 1.13.5 min.	
% Oxygen	From	To	From	To
19.5	16.64 ma	15.60 ma	15.60 ma	16.64 ma
18	NA	NA	NA	NA
17	NA	NA	NA	NA

Accuracy of Sensor

% Oxygen	Start Reading	Low end reading	Time to return	Returned to
19.5	16.64 ma	N/A	1.01.34 min.	16.64 ma
18	16.64 ma	14.53 ma	1.34.10 min.	16.64 ma
17	16.64 ma	13.70 ma	1.21.32 min.	16.64 ma

Repeatability of Sensor

% Oxygen	Start Reading	Low end reading	Returned to
19.5	16.65 ma	N/A	16.65 ma
18	NA	NA	NA
17	NA	NA	NA

Sensor Name: General Monitors S720

I calibrated the device using 19.5% oxygen instead of 20.9% oxygen. So I had to use an adjustment factor of 1.93. The readings in the tables are actual meter readings.
To convert the readings to % oxygen, subtract 1.93 from the table entry and multiply by 5, then divide by 4. This procedure only holds true for the 19.5% oxygen tests.

Response Time

	Time: 7.81 sec.		Time: 7.20 sec.	
% Oxygen	From	To	From	To
19.5	18.43 ma	17.53 ma	17.53 ma	18.44 ma
18	NA	NA	NA	NA
17	NA	NA	NA	NA

Accuracy of Sensor

The sensor was recalibrated using ambient air for the 18% and 17% oxygen tests.

% Oxygen	Start Reading	Low end reading	Time to return	Returned to
19.5	18.44 ma	17.52 ma	6.87 sec.	18.43 ma
18	17.40 ma	15.40 ma	13.91 sec.	17.40 ma
17	17.40 ma	14.59 ma	31.05 sec.	17.40 ma

Repeatability of Sensor

% Oxygen	Start Reading	Low end reading	Returned to
19.5	18.43 ma	17.52 ma	18.43 ma
18	NA	NA	NA
17	NA	NA	NA

Sensor Name: General Monitors S721

I calibrated the device using 19.5% oxygen instead of 20.9% oxygen. So I had to use an adjustment factor of 1.57. The readings in the tables are actual meter readings.
To convert the readings to % oxygen, subtract 1.57 from the table entry and multiply by 5, then divide by 4. This procedure holds true for the entire test.

Response Time

	Time: 14.85 sec.		Time: 13.12 sec.	
% Oxygen	From	To	From	To
19.5	18.30 ma	17.30 ma	17.30 ma	18.30 ma
18	NA	NA	NA	NA
17	NA	NA	NA	NA

Accuracy of Sensor

The sensor was recalibrated using ambient air for the 18% and 17% oxygen tests.

% Oxygen	Start Reading	Low end reading	Time to return	Returned to
19.5	18.30 ma	17.298 ma	14.51 sec.	16.73 ma
18	18.28 ma	16.13 ma	25.16 sec.	18.29 ma
17	18.29 ma	15.40 ma	25.24 sec.	18.29 ma

Repeatability of Sensor

% Oxygen	Start Reading	Low end reading	Returned to
19.5	18.43 ma	17.52 ma	18.43 ma
18	NA	NA	NA
17	NA	NA	NA

Sensor Name: MSA (Mine Safety Appliances)

Response Time

	Time: 1.39.32 min.		Time: 1.17.64 min.	
% Oxygen	From	To	From	To
19.5	16.54 ma	15.66 ma	15.66 ma	17.23 ma
18	NA	NA	NA	NA
17	NA	NA	NA	NA

Accuracy of Sensor

% Oxygen	Start Reading	Low end reading	Time to return	Returned to
19.5	17.29 ma	≈ 15.6 ma	2.16.04 min.	16.61 ma
18	17.15 ma	15.61 ma	2.44.78 min.	17.14 ma
17	17.15 ma	15.01 ma	2.12.86 min.	17.15 ma

Repeatability of Sensor

% Oxygen	Start Reading	Low end reading	Returned to
19.5	17.29 ma	16.53 ma	17.29 ma
18	NA	NA	NA
17	NA	NA	NA

Sensor Name: Drager

The Drager sensor is equipped with an LCD that displays the % oxygen 1 to 1. So, the values in the table are all % oxygen.

Response Time

	Time: 27.87 sec.		Time: 16.36 sec.	
% Oxygen	From	To	From	To
19.5	20.70%	19.50%	19.50%	20.70%
18	NA	NA	NA	NA
17	NA	NA	NA	NA

Accuracy of Sensor

% Oxygen	Start Reading	Low end reading	Time to return	Returned to
19.5	20.70%	19.50%	17.82 sec.	20.70%
18	20.60%	18.10%	23.07 sec.	20.60%
17	20.60%	17%	22.58 sec.	20.60%

Repeatability of Sensor

% Oxygen	Start Reading	Low end reading	Returned to
19.5	20.70%	19.50%	20.70%
18	NA	NA	NA
17	NA	NA	NA

Sensor Name: KE-50, manufactured by Figaro

Response Time

	Time:2.05 min.		Time: 2.37 min.	
% Oxygen	From	To	From	To
19.5	16.34 ma	15.63 ma	15.60 ma	16.34 ma

	Time: 1.45 min.		Time: 1.58 min.	
% Oxygen	From	To	From	To
17	16.37 ma	14.16 ma	14.16 ma	16.37 ma

Accuracy of Sensor

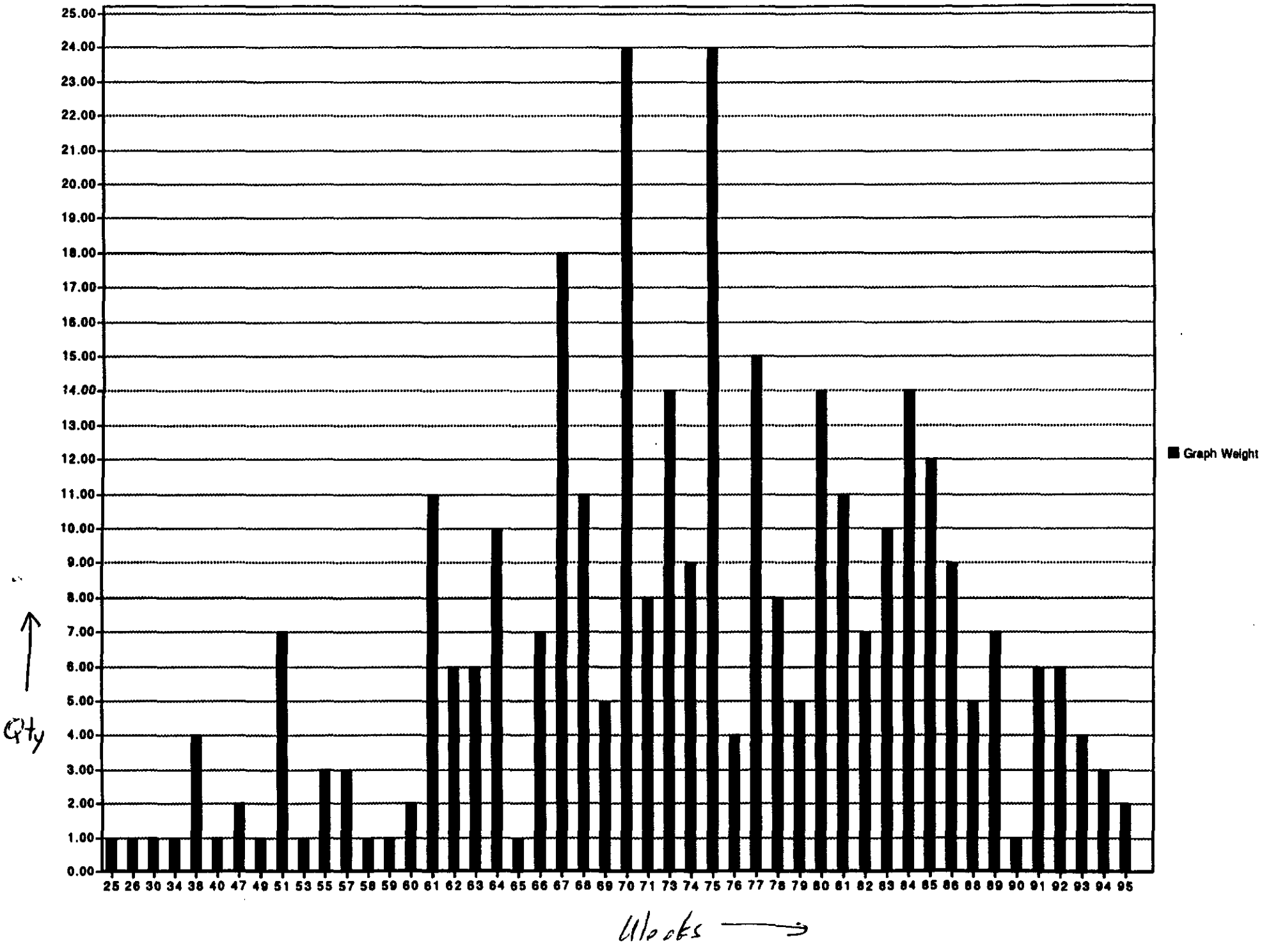
% Oxygen	Start Reading	Low end reading	Time to return	Returned to
19.5	16.34 ma	15.64 ma	1.12.60 min.	16.38 ma
18	16.43 ma	14.91 ma	1.41.79 min.	16.54 ma
17	N/A	N/A	N/A	N/A

Repeatability of Sensor

% Oxygen	Start Reading	Low end reading	Returned to
19.5	16.41 ma	15.70 ma	16.43 ma
18	NA	NA	NA
17	NA	NA	NA

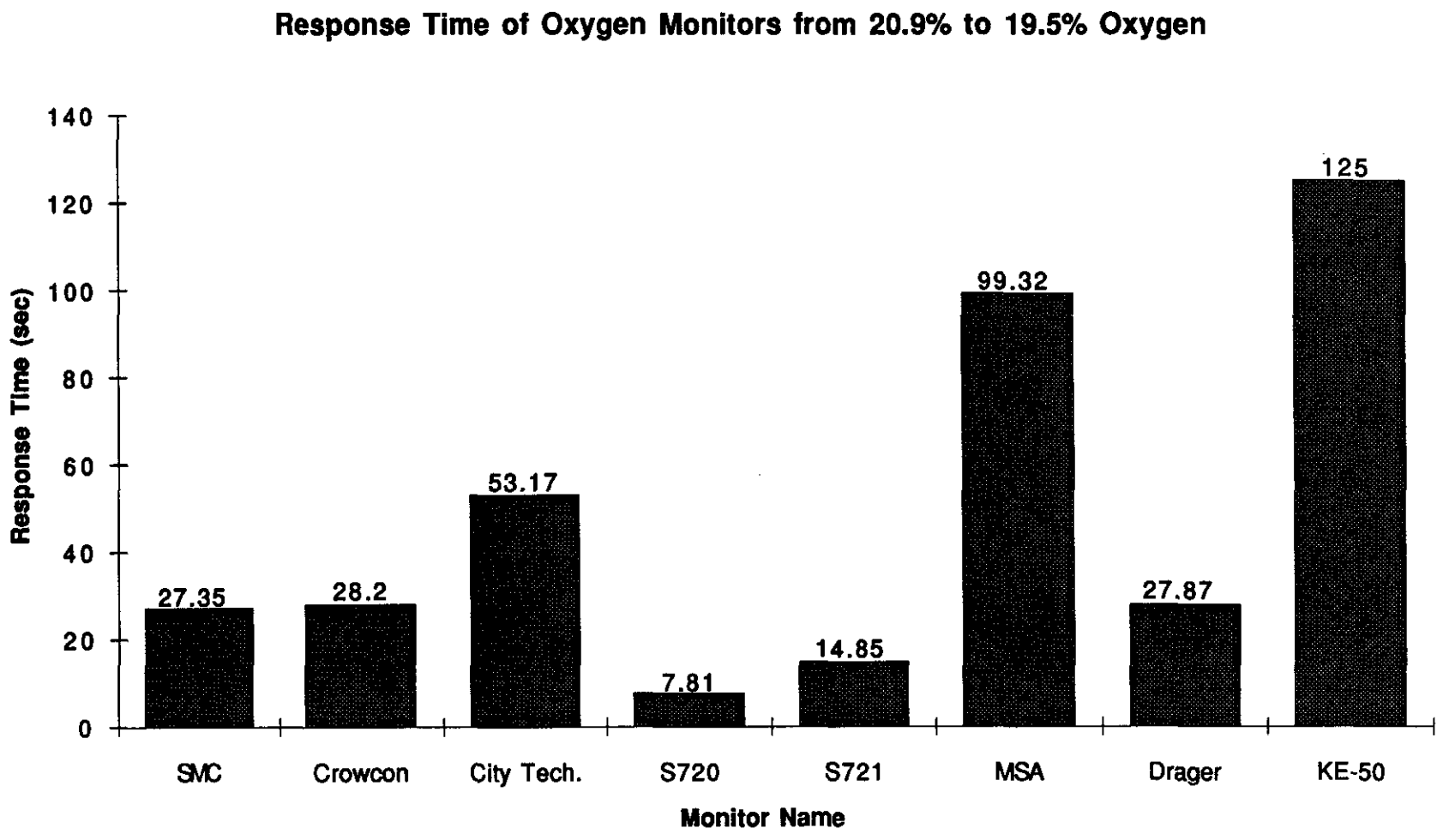
4.2 Mean Time Between Failure Data

327 City Tech Cells

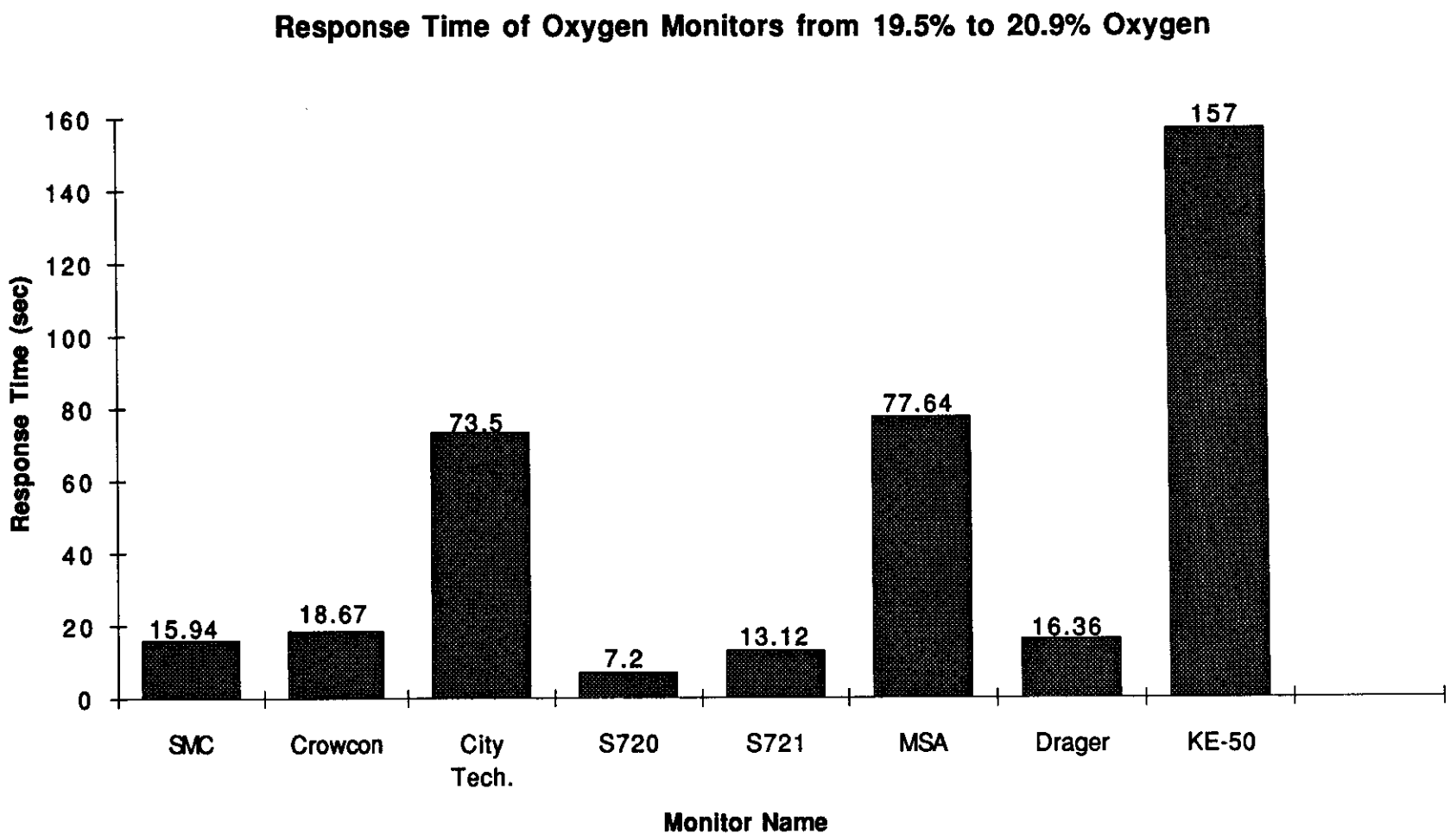


4.3 Graphs of Test Results

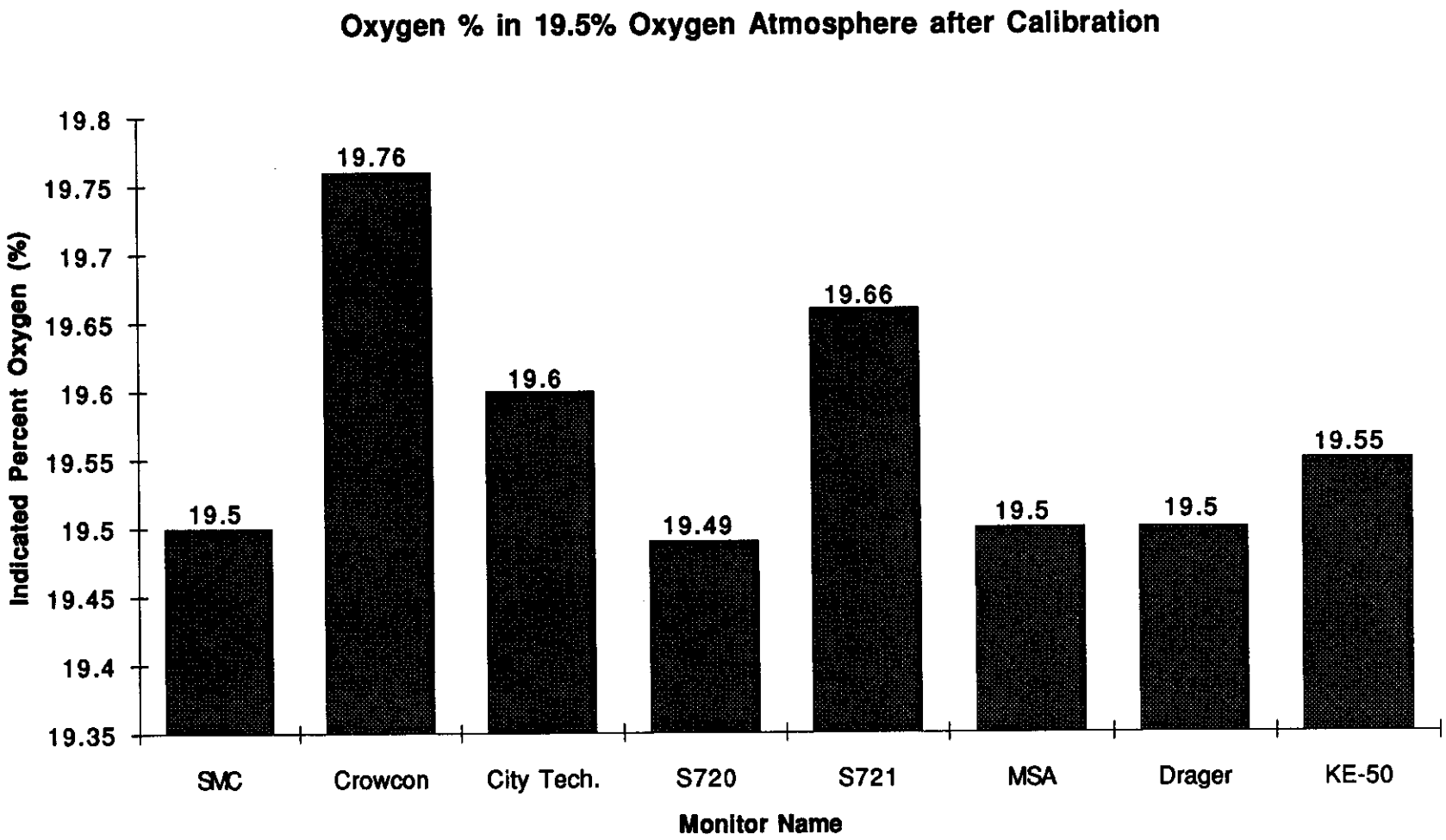
Graph 4.1


Response Time of Oxygen Monitors from 20.9% to 19.5% Oxygen
Response Time (sec)
140
120
100
80
60
40
20
0
27.35
28.2
53.17
7.81
14.85
99.32
27.87
125
SMC
Crowcon
City Tech.
S720
S721
MSA
Drager
KE-50
Monitor Name

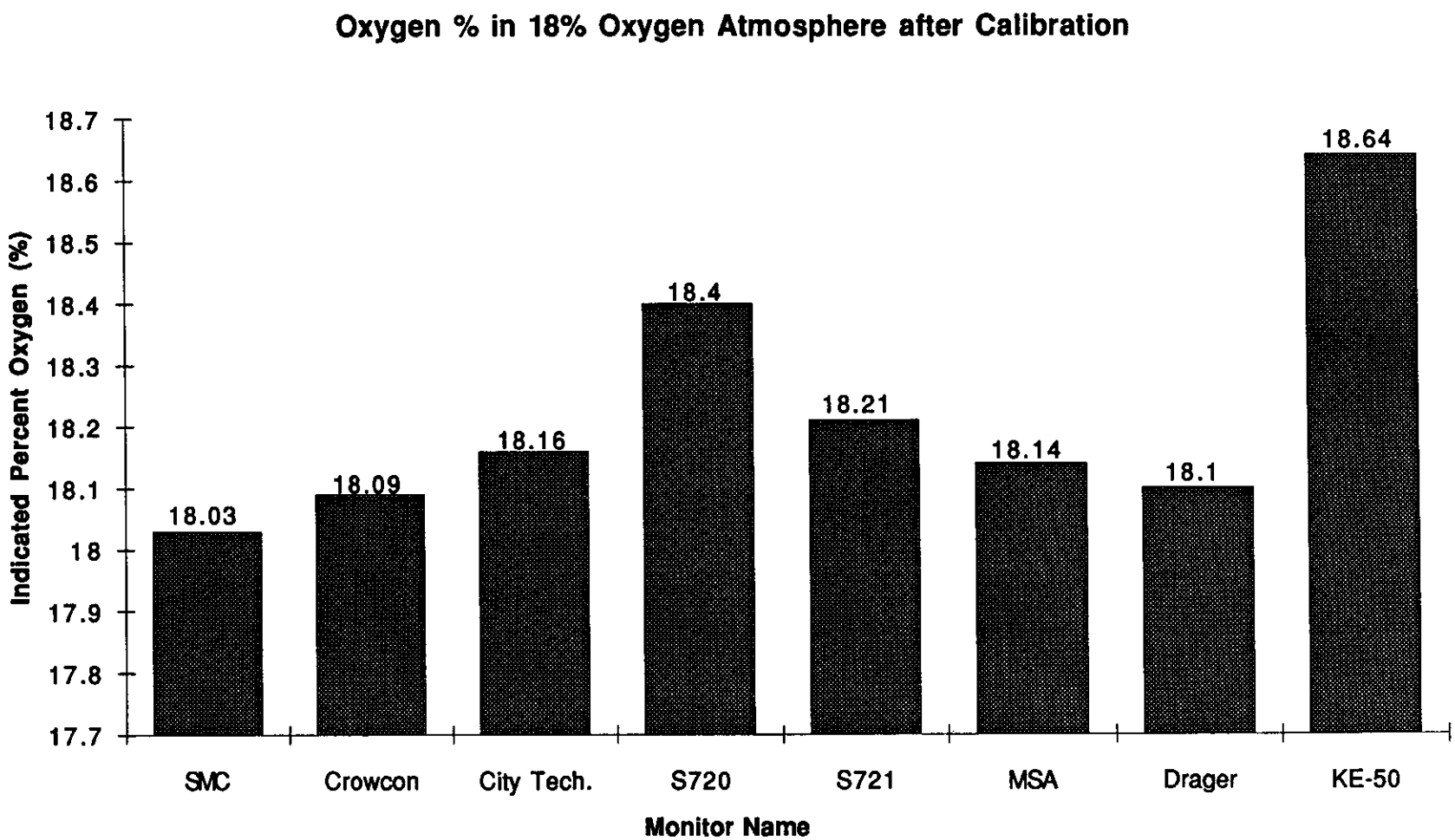
Graph 4.2


Response Time of Oxygen Monitors from 19.5% to 20.9% Oxygen
Response Time (sec)
160
140
120
100
80
60
40
20
0
15.94
18.67
73.5
7.2
13.12
77.64
16.36
157
SMC
Crowcon
City Tech.
S720
S721
MSA
Drager
KE-50
Monitor Name

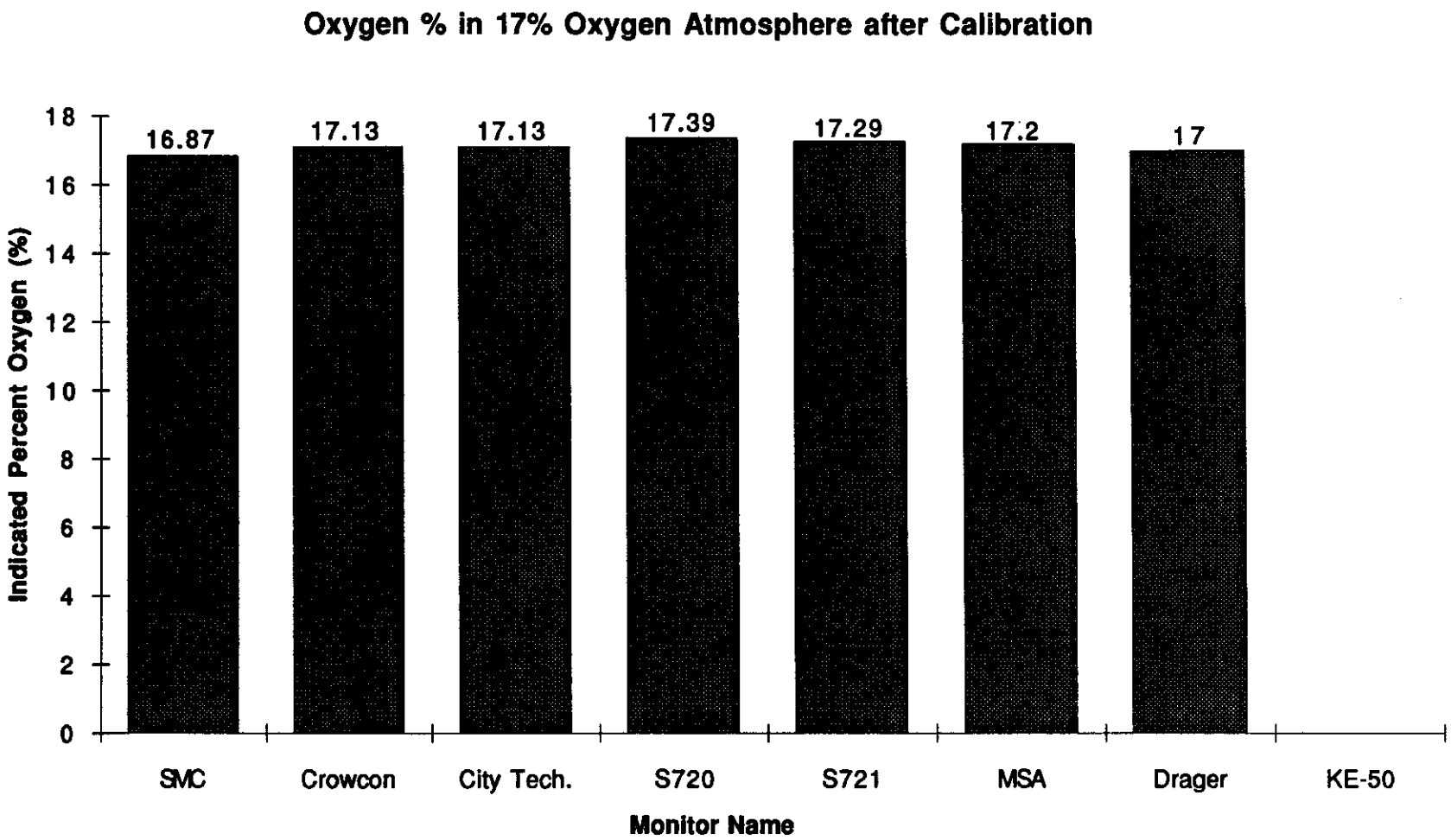
Graph 4.3


Oxygen % in 19.5% Oxygen Atmosphere after Calibration
Indicated Percent Oxygen (%)
19.8
19.75
19.7
19.65
19.6
19.55
19.5
19.45
19.4
19.35
19.5
19.76
19.6
19.49
19.66
19.5
19.5
19.55
SMC
Crowcon
City Tech.
S720
S721
MSA
Drager
KE-50
Monitor Name

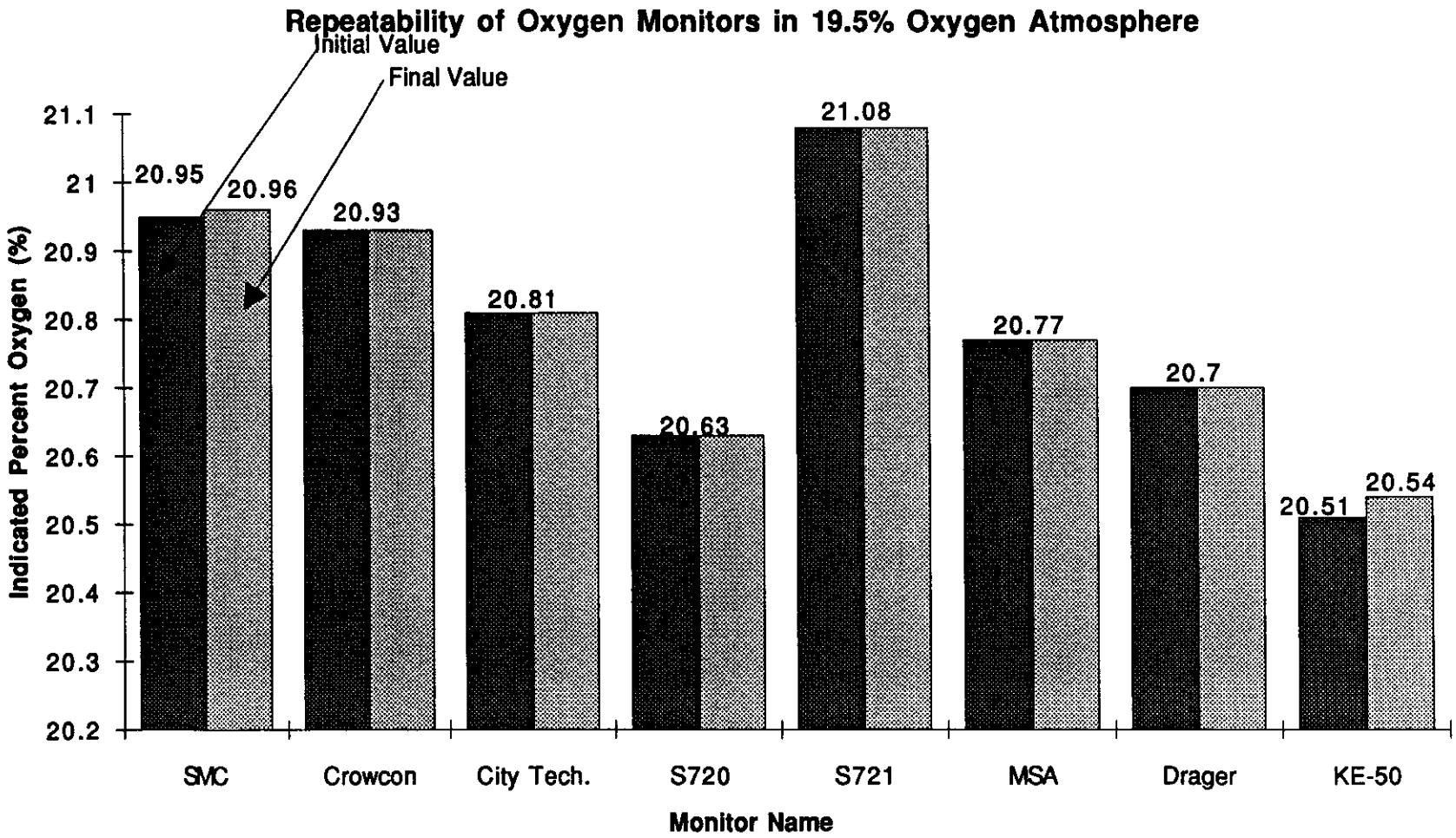
Graph 4.4


Oxygen % in 18% Oxygen Atmosphere after Calibration
Indicated Percent Oxygen (%)
18.7
18.6
18.5
18.4
18.3
18.2
18.1
18
17.9
17.8
17.7
18.03
18.09
18.16
18.4
18.21
18.14
18.1
18.64
SMC
Crowcon
City Tech.
S720
S721
MSA
Drager
KE-50
Monitor Name

Graph 4.5


Oxygen % in 17% Oxygen Atmosphere after Calibration
Indicated Percent Oxygen (%)
18
16
14
12
10
8
6
4
2
0
16.87
17.13
17.13
17.39
17.29
17.2
17
SMC
Crowcon
City Tech.
S720
S721
MSA
Drager
KE-50
Monitor Name

Graph 4.6


Repeatability of Oxygen Monitors in 19.5% Oxygen Atmosphere
Initial Value
Final Value
Indicated Percent Oxygen (%)
21.1
21
20.9
20.8
20.7
20.6
20.5
20.4
20.3
20.2
20.95
20.96
20.93
20.81
20.63
21.08
20.77
20.7
20.51
20.54
SMC
Crowcon
City Tech.
S720
S721
MSA
Drager
KE-50
Monitor Name

4.4 Test Data Tabulation

Response Time - from 20.9% to 19.5%		
SMC	27.35	
Crowcon	28.2	
City Tech.	53.17	
S720	7.81	
S721	14.85	
MSA	99.32	
Drager	27.87	
KE-50	125	
Response Time - from 19.5% to 20.9%		
SMC	15.94	
Crowcon	18.67	
City Tech.	73.5	
S720	7.2	
S721	13.12	
MSA	77.64	
Drager	16.36	
KE-50	157	
Response Time - from 20.9% to 17%		
20.9 to 17	105	
17 to 20.9	118	
Accuracy - for 19.5% Oxygen		
SMC	19.5	
Crowcon	19.76	
City Tech.	19.6	
S720	19.49	
S721	19.66	
MSA	19.5	
Drager	19.5	
KE-50	19.55	

Accuracy - for 18% Oxygen		
SMC	18.03	
Crowcon	18.09	
City Tech.	18.16	
S720	18.4	
S721	18.21	
MSA	18.14	
Drager	18.1	
KE-50	18.64	
Accuracy - for 17% Oxygen		
SMC	16.87	
Crowcon	17.13	
City Tech.	17.13	
S720	17.39	
S721	17.29	
MSA	17.2	
Drager	17	
KE-50	N/A	
Repeatability - 19.5% Oxygen		
SMC	20.95	20.96
Crowcon	20.93	20.93
City Tech.	20.81	20.81
S720	20.63	20.63
S721	21.08	21.08
MSA	20.77	20.77
Drager	20.7	20.7
KE-50	20.51	20.54

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