

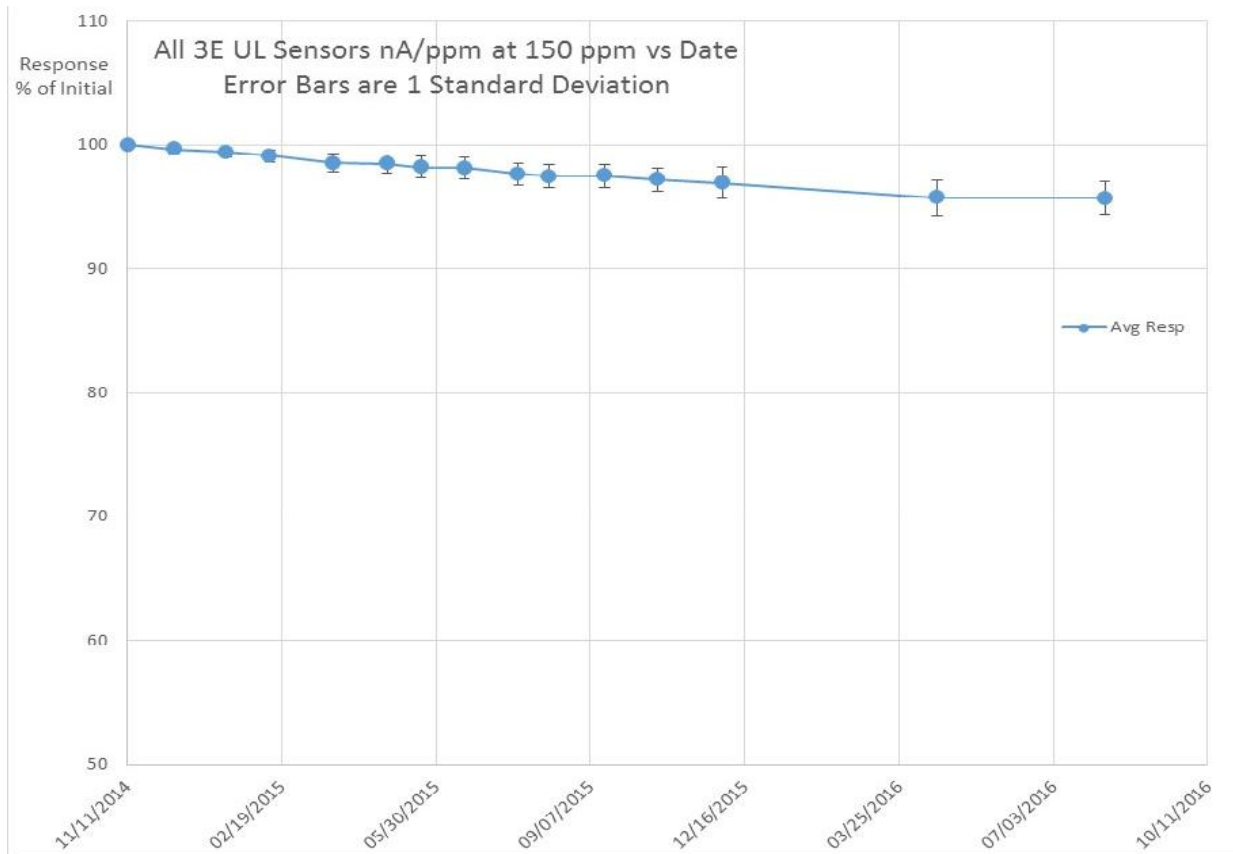
MTBF and FPMH per UL 2034 and UL 2075 for CO Sensor

Scope

This application note discusses Mean Time Between Failures (MTBF) and Failures per Million Hours (FPMH) Calculation and Procedure Per Standards UL 2034 and UL 2075. The testing began monthly as part of the 12 month CO Sensitivity Stability Testing for ETL and UL and has continued since then at approximately quarterly intervals. This report represents the current FPMH and MTBF calculations and 10-year failure rate estimates as of September 2016.

There were no failures during the 20 month (15185 hour) testing period. These results show that SPEC Sensors' CO sensor meets the UL 2034 and 2075 requirements for 10 year life.

The figure below shows the span/sensitivity drift over 20 months of the 3 electrode potentiostat configuration.



Test Conditions

- Temperature: $25 \pm 3^\circ \text{C}$
- Relative Humidity: $50 \pm 20\% \text{ RH}$
- ETL CO concentration for monthly test: 150 ppm for 15 minutes
- UL CO concentrations for monthly test: 0, 30, 70, 150, 400, 0 ppm for 15 minutes each step
- CO concentration of continuous exposure between monthly sensitivity tests: 15 ppm
- Test Duration: 20 months = 15,185 hours (much greater than 3,000 hour minimum requirement)
- Following UL and ETL testing for 12 months, sensors are stored under power in ambient air and tested quarterly: 0, 70, 150, 400, 0 ppm for 15 minutes each step.

Reliability Test Sample Size

The 12 month testing was done with 129 units of the 3SP-CO-1000 sensor element split into two packages:

- 70 units in the 3-electrode package
- 59 units in the 2-electrode package

Thus there are 3 sample populations to consider for the MTBF and FPMH determination.

Reliability Requirements of UL 2034 and UL 2075 Standards

- 1) Minimum test duration = 3,000 hours.
- 2) Predicted failure rate of not more than 2.5 FPMH when estimated using a 90% confidence interval. *Note: 2.5 FPMH corresponds to MTBF of 400,000 hours*
- 3) For unsupervised sensor systems, an MTBF of no less than 166,667 hours when estimated using 90% confidence interval.
- 4) At this failure rate, less than 14.6% failures over the devices' specified lifetime at a 90% confidence interval.

Chi-Squared Determination

Per MIL.217-F defined in the aforementioned UL and ETL standards, we use the inverse cumulative chi-squared distribution with a 90% confidence level and $(2 \times \text{\#failures} + 2)$ degrees of freedom to perform hypothesis testing.

This corresponds to the value of 4.605 found on the following table of critical values of the Chi-squared distribution at the intersection of

$$p = 1 - 90/100 = 0.1$$

$$df = 2$$

Critical Values of the χ^2 Distribution

df \ p	0.995	0.975	0.9	0.5	0.1	0.05	0.025	0.01	0.005	df
1	.000	.000	0.016	0.455	2.706	3.841	5.024	6.635	7.879	1
2	0.010	0.051	0.211	1.386	4.605	5.991	7.378	9.210	10.597	2
3	0.072	0.216	0.584	2.366	6.251	7.815	9.348	11.345	12.838	3
4	0.207	0.484	1.064	3.357	7.779	9.488	11.143	13.277	14.860	4
5	0.412	0.831	1.610	4.351	9.236	11.070	12.832	15.086	16.750	5
6	0.676	1.237	2.204	5.348	10.645	12.592	14.449	16.812	18.548	6
7	0.989	1.690	2.833	6.346	12.017	14.067	16.013	18.475	20.278	7
8	1.344	2.180	3.490	7.344	13.362	15.507	17.535	20.090	21.955	8
9	1.735	2.700	4.168	8.343	14.684	16.919	19.023	21.666	23.589	9
10	2.156	3.247	4.865	9.342	15.987	18.307	20.483	23.209	25.188	10
11	2.603	3.816	5.578	10.341	17.275	19.675	21.920	24.725	26.757	11
12	3.074	4.404	6.304	11.340	18.549	21.026	23.337	26.217	28.300	12
13	3.565	5.009	7.042	12.340	19.812	22.362	24.736	27.688	29.819	13
14	4.075	5.629	7.790	13.339	21.064	23.685	26.119	29.141	31.319	14
15	4.601	6.262	8.547	14.339	22.307	24.996	27.488	30.578	32.801	15

Reliability Hypothesis Testing

Using the test hours of 15,185 to calculate MTBF and FMPH using

$$\text{MTBF} = \text{sample size} * \text{test hours} * 2/4.605$$

$$\text{FPMH} = 1,000,000/\text{MTBF}$$

We have the following results.

	Sample Size	MTBF hours	FPMH
3 Electrode	70	461,633	2.166
2 Electrode	59	389,091	2.57
All sensors	129	850,724	1.175

Ten-Year Life Failure Estimates

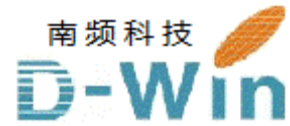
Using the FPMH of 2.57 and the smallest sample size of 59 (both from the 2-electrode configuration)

Considering that 10 years is $365 * 24 * 10 = 87,600$ hours.

$$\text{Max Failures in 10 years} = 2.57 * 87600 / 1000000 = 0.225$$

This corresponds to a

$$\text{Percent failure of } 100 * 0.225 / 59 = 0.382\%$$



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