# Application Note AN-109

September 2016

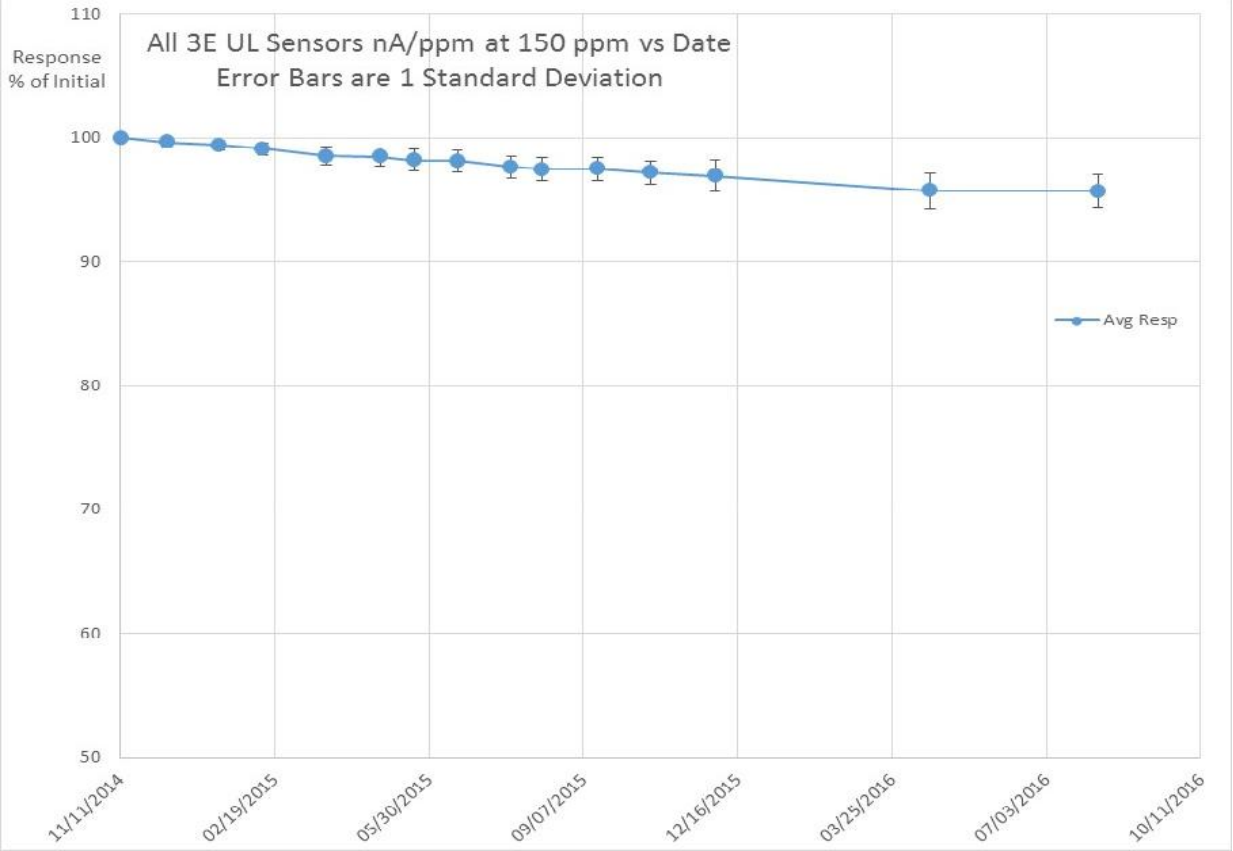
## MTBF and FPMH per UL 2034 and UL 2075 for CO Sensor

### 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 ± 3° C
- Relative Humidity: 50 ± 20 % 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*#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 $\chi^2$ 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

MTBF = sample size * test hours * 2/4.605

FPMH = 1,000,000/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.

Max Failures in 10 years = 2.57*87600/1000000 = 0.225

This corresponds to a

Percent failure of 100*0.225/59 = 0.382%