MEETING LOG
DIRECTORATE FOR ENGINEERING SCIENCES

SUBJECT: Presentation of Results of CO Alarm Testing Conducted by Mosaic Industries under Contract to the Gas Research Institute

PLACE: CPSC Headquarters

MEETING DATE: July 8, 2002

LOG ENTRY SOURCE: Donald W. Switzer DWS

ENTRY DATE: August 12, 2002

COMMISSION ATTENDEES:

Donald W. Switzer	ES
Richard Stern	CA
Joe Puskar	LS

NON-COMMISSION ATTENDEES:

Irwin Billick	WEC Consulting
Ted Williams	American Gas Association
Ed Godziszewski	Figaro USA, Inc.
Vince Mori	First Alert
Douglas Troutman	NEMA
Paul Clifford	Mosaic Industries, Inc.

MEETING SUMMARY

Mr. Clifford requested this meeting to present to the CPSC staff the results of recently completed CO alarm testing. Mr. Clifford's presentation is attached. CPSC staff told the meeting attendees that it would examine the final report when it is available, and will decide on the appropriate action at that time.

Presentation to the Consumer Product Safety Commission, July 8, 2002

Evaluating the Performance of Residential CO Alarms*

Presented by Paul K. Clifford, Ph.D.
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** Gas Research Institute Report GRI-02/0112*

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Evaluating the Performance of Residential CO Alarms

1. Review of prior performance tests
2. Methodology of the present study
3. Results
4. Implications for consumer safety

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Review of Prior Performance Tests

- Field Surveys
- Laboratory Tests
- Field Tests

Prior Performance Tests:

- Field Surveys:
  - **The majority of alarm activations occur at insignificant CO concentrations.**
  - **Per-year activation rates vary city-to-city from 13% to 39% (average 20%) in cities with mandatory installation.**
  - **Alarm activations are independent of CO levels or detector technology, but they strongly depend on the detector brand.**
  - **Most consumers ignore alarm activations -- consumer response to activation is uncertain and ineffective; consumer confidence in alarms is poor.**

Carbon Monoxide Response Survey Analyses: Utility Data, GRI-96/0409, GRI-97/0408
Residential Carbon Monoxide Alarm Population: Six Cities Study, GRI-98/0273, GRI-00/0014

Prior Performance Tests:

- Laboratory Tests:
  - **2 of 39 alarms did not alarm at any level of CO (12% failure at 90% CL), *Consumer Reports*, May 1994**
  - **4 of 19 brands were inadequately sensitive at 150 ppm at moderate humidity, *Consumer Reports*, October 2001**
  - **Late alarms and failures-to-alarm are more prevalent than early alarms and false alarms, *Chamber Tests of Residential CO Alarms*, GRI-98/0140**
  - **At humidity levels typical of northern climate homes in the winter, many units of three of four brands failed to alarm at UL test concentrations (58% and 67% for two brands). *Chamber Tests of Residential CO Alarms* (GRI-98/0140)**

Prior Performance Tests:

- Laboratory Tests (Performance Testing of Residential CO Detectors, GRI-98/0284):
  - **<u>Out-of-box failures</u>: Fifteen percent of all detectors purchased were nonfunctioning at the time of purchase.**
  - **<u>Uncontrolled CO Sensitivity</u>: When new, most detectors of eight of nine brands did not comply with UL 2034's sensitivity spec. After aging, only one brand had all detectors alarm within 2.5-10% COHb.**
  - **<u>Failures to alarm</u>: Five of nine brands affected by failures to alarm, and with three of those brands having a majority of their detectors failing to alarm at exposures greater than 10% COHb.**
  - **<u>Digital display accuracy</u>: Of four brands with digital displays one was grossly inaccurate with an average error of ±200% over a concentration range of 50 to 400 ppm, while the average errors of the others were ±17%, ±42% and ±51%.**

Prior Performance Tests:

- Field Tests (1999 UL Field Survey of Retail CO Alarms, Aug. 25, 1999 UL 2034 TAP Meeting):
  - **46% of detectors tested did not comply with the UL 2034 sensitivity requirement.**
  - **13% of tests of "biomimetic" detectors show no sensitivity to CO (up to the test limit of 20% COHb).**
  - **37% of all tests produced an "out-of-range" result.**
  - **All tests were performed at 50% relative humidity; they did not reveal which detectors fail at lower humidity.**

Prior Performance Tests:

- Field Tests (British HSE Joint Industry Project on CO Issues: Long-term Reliability of Domestic CO Alarms, HSE Report 360/2001):
  - **Of 32 alarm models initially tested:**
    - **only 13 complied with the BS-7860 sensitivity requirement;**
    - **of those, only 6 of those remained commercially viable long enough for a field trial to be conducted;**
    - **of those, only 1 continued to meet the basic sensitivity requirement after a one year field trial.**
  - **Like the UL standard, neither the British nor the proposed EU (CENELEC) standard contains a reliability requirement.**
  - **There is no other reliability data available to demonstrate the field performance of residential CO alarms.**

- British HSE Report 360/2001 (cont.) :
  - **Extensive revision of UL2034 has not addressed its fundamental flaws; those flaws remain in order to accommodate the product with the major market share; the UK and draft CENELEC standards are inherently superior.**
  - **To become a useful standard UL2034 should include:**
    - **a requirement for long term in-service reliability;**
    - **a test for the effects of household substances, including cooking and smoking products;**
    - **a specified alarm recovery time;**
    - **alarm siting guidance.**

Methodology of the Present Study:

- Devices Tested
  - **Commercially available brands in Chicago and San Francisco.**
  - **Alarms under development.**
  - **Alarms withdrawn from the field owing to apparently poor performance.**
- Tests
  - **Sensitivity to the UL2034 test points.**
  - **Sensitivity to the UL2034 test points at low humidity.**
  - **Alarm actuation on exposure to gradually increasing CO levels.**
  - **Sensitivity to interference gases.**
  - **Digital display accuracy.**

Methodology: Devices Tested

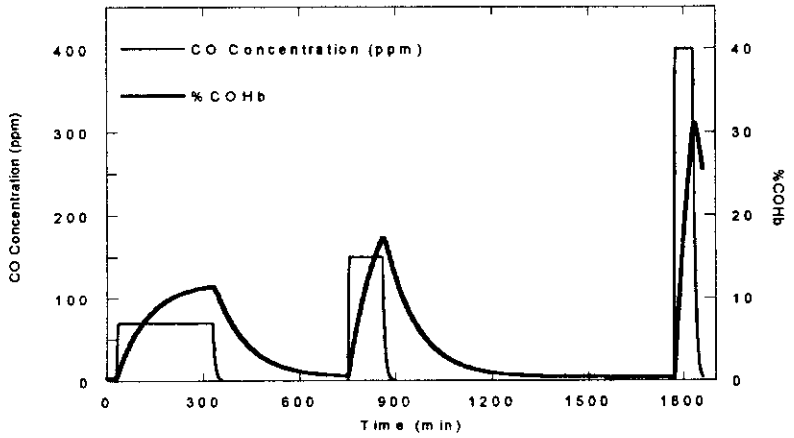
Brand	Type	Number	Technology	Plug-in	Battery Backup	Battery	Digital Display
A4	Retail	3	Semiconductor	--	Yes	--	Yes
	Field	1					
A11	Field	1	Semiconductor	Yes	--	--	--
A12	Research	6	Electrochemical	Yes	--	--	--
A13[1]	Retail	10	Electrochemical	--	--	Yes	Yes
A14	Research	7	Electrochemical	--	--	Yes	--
A15	Retail	9	Semiconductor	Yes	--	--	Yes
A16	Research	5	Electrochemical	Yes	--	--	--
A17	Retail	10	Electrochemical	--	--	Yes	--
A18	Retail	10	Electrochemical	Yes	--	--	Yes
A19[1,2]	Retail	13	Electrochemical	--	--	Yes	Yes
A20	Retail	10	Semiconductor	Yes	--	--	Yes
A21	Retail	8	Colorimetric	--	--	Yes	--
A22	Retail	6	Semiconductor	Yes	--	--	--
A23	Research	10	Electrochemical	--	--	Yes	--

[1] As of the writing of this report these brands A13 and A19 are no longer commercially available.

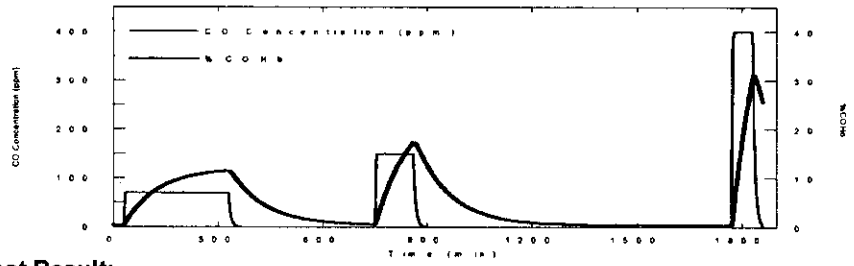
[2] All retail brands except A19 are certified to UL2034

Methodology: UL2034 Sensitivity Tests

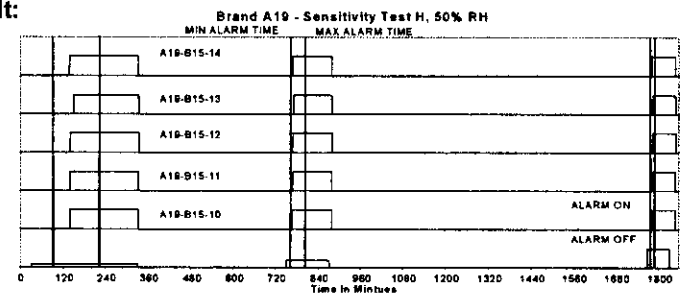
Do alarms activate within the UL-specified alarm times?



Sensitivity Test:



Test Result:



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Methodology: Sensitivity at Low Humidity Test

Do alarms activate at humidity levels typical of northern climate homes in the winter ?

Table 1 Humidity Range Required in Test

	UL 2034 Tests *		Current Tests	
	Controlled Condition	**Absolute Humidity**	**Controlled Condition**	**Absolute Humidity**
"Low" Humidity Level	15 ± 5 % RH at 0 °C	0.46 mmHg (603 ppm)	1320 ± 200 ppm at 22 °C	1.00 mmHg or (1320 ppm)
"High" Humidity Level	40 ± 10 % RH at 40 °C	44. mmHg or (57,900 ppm)	13,200 ± 1,000 ppm at 22 °C	10.0 mmHg or (13,200 ppm)

* UL 2034, Section 45.1.2

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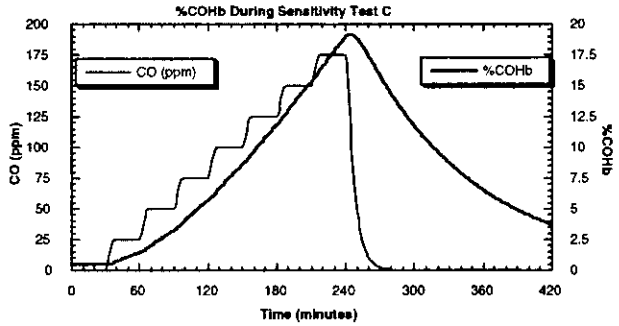
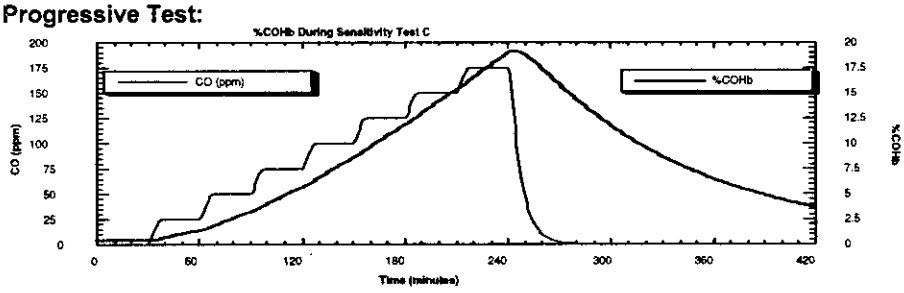
Methodology: Progressive Sensitivity Test

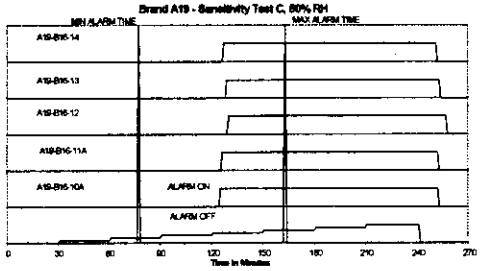
Do alarms activate in response to increasing CO concentrations?



Progressive Test:

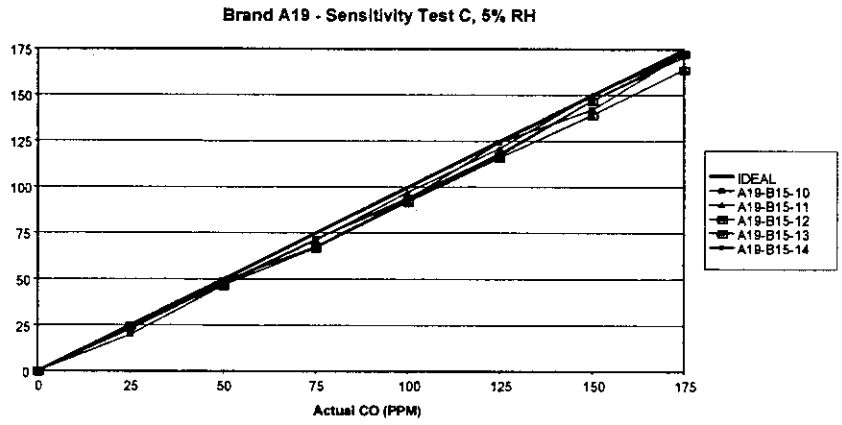


Test Result:



Methodology: Digital Display Accuracy Test

How accurate are digital displays ?



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Methodology: Interference Gas Test

Do alarms actuate on exposure to interference gases ?

Interference Test		
Gas or Vapor	Concentration (ppm)	Duration (minutes)
i-Butane	300	120
Methane	500	120
Ammonia	50	120
Methanol	200	120
Ethanol	200	120
i-Propanol	200	120
Ethyl-acetate	200	120
n-Heptane	500	120
Toluene	200	120

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Results

- Overall Poor Reliability
- Insufficient Sensitivity at Low Humidity
- Poor Integration of CO Exposure
- Digital Display Inaccuracy

Results:Overall Poor Reliability

- 4% of retail alarms false alarmed in clean air.
- A significant portion of seven of ten retail brands failed to alarm at hazardous CO levels.
- 35% of retail alarms failed to actuate at UL test points or during the progressive concentration test.
- 37% of retail alarms failed to actuate at low humidity.

Results:Overall Poor Reliability

Numbers of Detectors Exhibiting Failure Under Each Condition

Brand ID	Number Tested	Supervised Failures	False Alarms in Clean Air	Failures to Alarm 5% RH	Failures to Alarm 50% RH	Alarms with Interference Gas	Display Reading at 100 ppm CO
A4	4	0	1	4	0	--	25 - 160
A11	1	0	0	1	0	--	35 - 142
A13	10	0	0	0	0	0	100 - 145
A15	9	0	1	1	9	9	0 - 400
A17	10	0	0	0	10	0	
A18	10	1	0	0	0	0	85 - 138
A19	13	4	0	0	0	0	92 - 100
A20	10	0	1	10	8	1	0 - 65
A21	8	0	0	8	1	0	
A22	6	0	0	6	0	0	
Total Retail Alarms	81	5	3	30	28	10	
Failure Rate/Retail Alarms		**6.2 %**	**3.7 %**	**37 %**	**35 %**	**12 %**	
Upper Bound at 90% CL		**12 %**	**8.3 %**	**46 %**	**43 %**	**19 %**	

Overall Reliability

Well Performing vs. Poorly Performing Brands

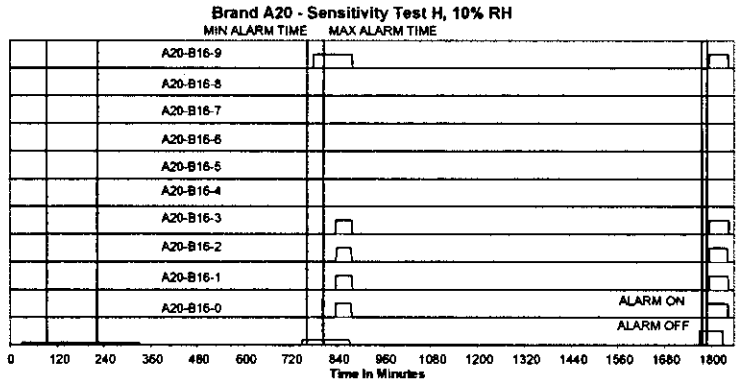
Detector Failure Rates of Well Performing vs. Poorly Performing Brands					
Brand Cohort	**Supervised Failures**	**False Alarms in Clean Air**	**Failures to Alarm 5% RH**	**Failures to Alarm 50% RH**	**Alarms with Interference Gas**
Well Performing Brands [1]					
Observed Failure Rate	15 %	0 %	0 %	0 %	0 %
Lower – Upper Bound at 90% CL	7.3 – 28 %	0 – 7 %	0 – 7 %	0 – 7 %	0 – 7 %
Poorly Performing Brands [2]					
Observed Failure Rate	0 %	8 %	79 %	47 %	30 %
Lower – Upper Bound at 90% CL	0 – 6 %	3 – 18 %	63 – 100 %	34 – 66 %	16 – 39 %

[1] Well performing brands comprise 33 detectors from three brands (Brands A13, A18, and A19).

[2] Poorly performing brands comprise 38 detectors from six brands (Brands A4, A11, A15, A20, A21, and A22).

Results: Insufficient Sensitivity at Low Humidity

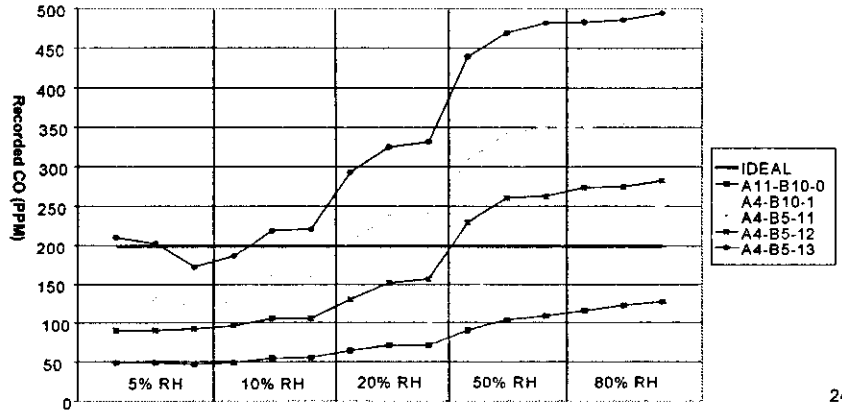
Failures to Alarm



Insufficient Sensitivity at Low Humidity

Physical Cause: The CO sensitivity of semiconductor sensors is directly proportional to absolute humidity concentration.

Brands A4 & A11 - Sensitivity Test F



Insufficient Sensitivity at Low Humidity

Remedy: Compensate CO sensitivity with a measurement of absolute humidity.

Table 15 Temperature/Humidity Uncompensated vs Compensated CO Measurement

Actual	Measured	
	Uncompensated	Compensated
30 ppm	12-70 ppm	28-42 ppm
100 ppm	32-163 ppm	69-97 ppm
300 ppm	125-603 ppm	255-340 ppm

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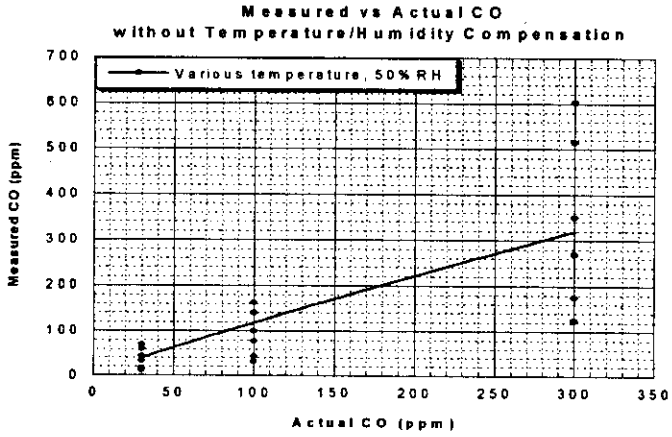
Insufficient Sensitivity at Low Humidity

The CO response of an uncompensated semiconductor sensor.



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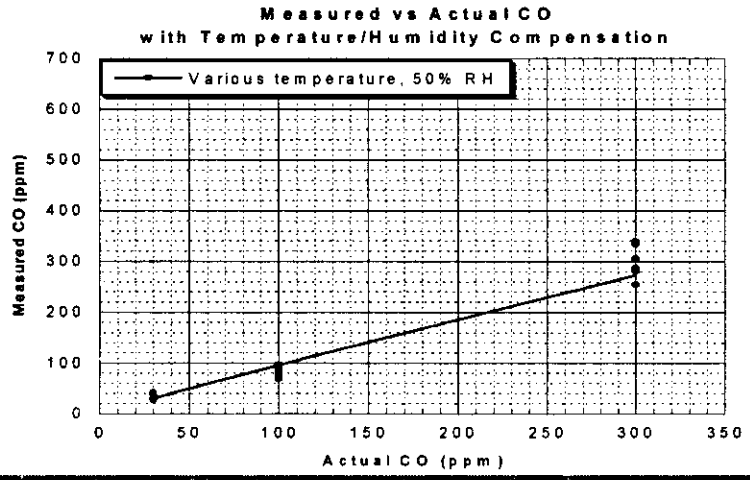
Insufficient Sensitivity at Low Humidity

The CO response of a humidity/temperature compensated semiconductor sensor.



Results: Poor Integration of CO Exposure

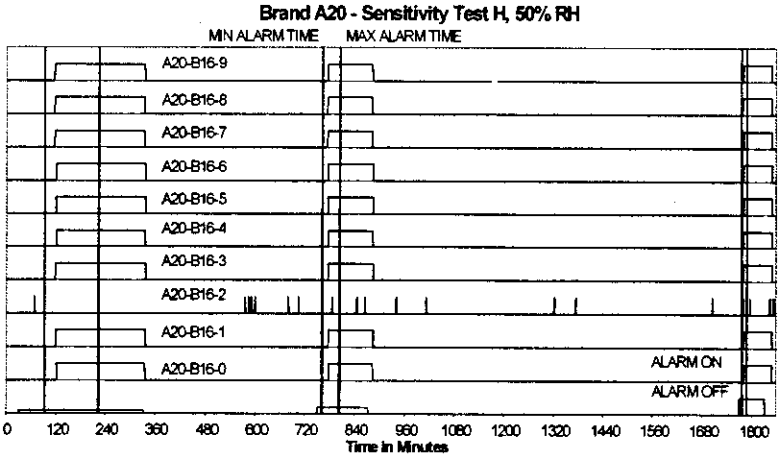
- Even when alarms actuate at the UL test concentrations they do not necessarily actuate on exposure to other life-threatening CO concentrations.
- Of 14 brands tested seven were significantly less sensitive to varying CO concentrations as opposed to fixed concentrations.
- Alarms that integrate CO exposure actuate reliably whatever the time course of CO exposure.
- Alarms that use timer/counter algorithms do not actuate reliably.

Results: Poor Integration of CO Exposure

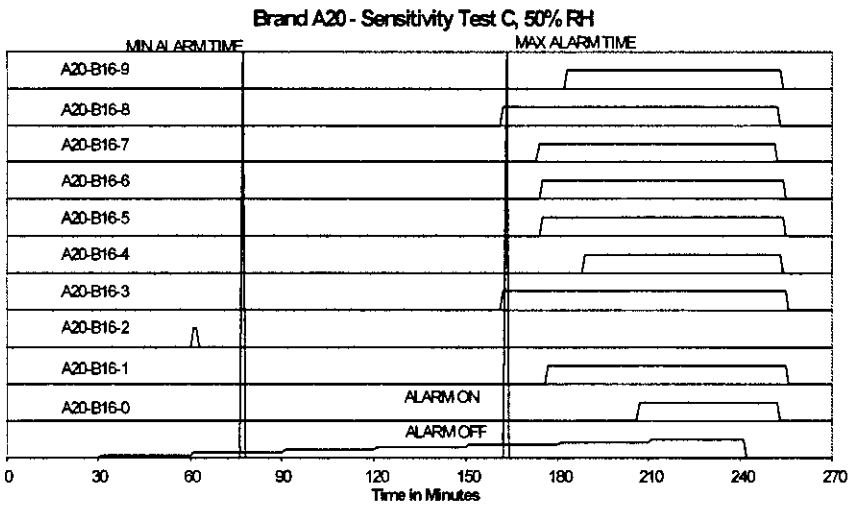
"... protection of consumers can be enhanced without altering the alarm thresholds of UL2034 by the deployment of genuine time integrating detector algorithms. The overall level of protection by using such algorithms can be enhanced from a possible maximum exposure of 20% COHb to a consistent alarm at 10% COHb. It is recommended that UL2034 be modified so that detectors are designed so as to interpolate between the alarm threshold points consistent with the 10% COHb exposure curve."

-- "Contribution to US CPSC Hearings on Residential Carbon Monoxide Detectors, February 1996: Realistic Technology Improvements Reducing Alarm COHb Levels", P. McGeehin of Capteur Sensors & Analysers Ltd., Abingdon, UK

CO Alarms that do (predominantly) alarm within the UL 2034 specification ...



... do not necessarily protect against > 10 %COHb



Results: Poor Integration of CO Exposure

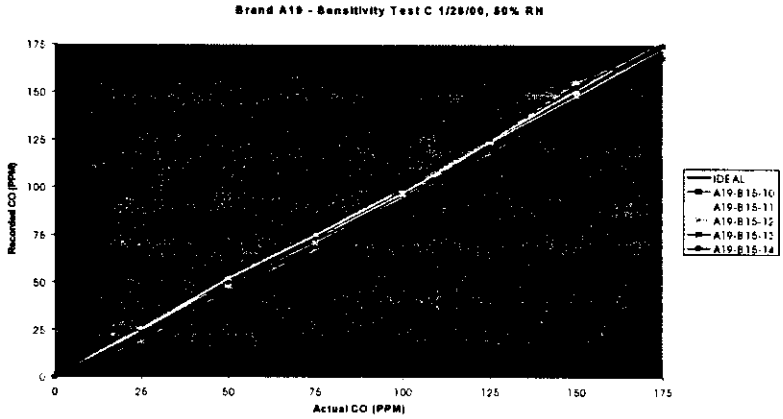
Solution:

- Implement integrating detection algorithms:

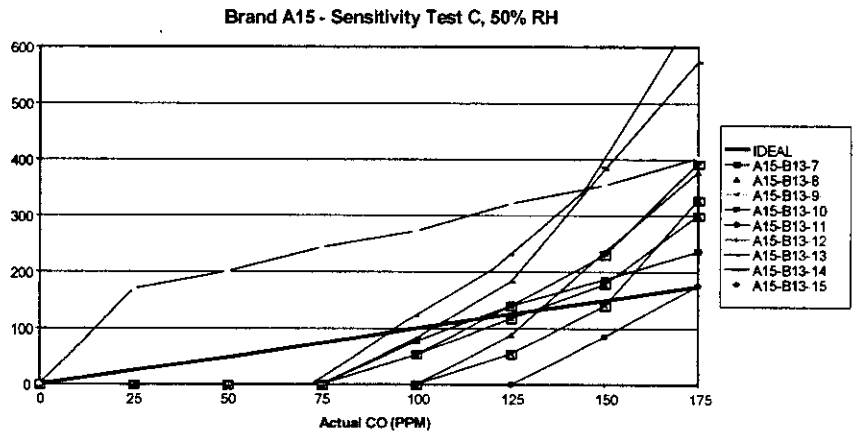
  $$\%COHb_{t+\Delta t} = \%COHb_t\ \beta + (\%COHb_e + \alpha_o\ CO_{ppm})(1-\beta)$$

- Incorporate into UL2034 the CPSC recommendation that alarms always actuate at less than 10% COHb.

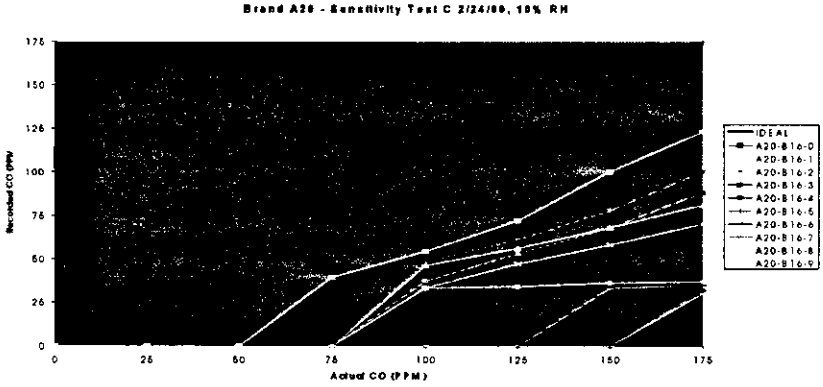
Digital Display Accuracy: The Best Brand



Digital Display Accuracy: A Typical Brand



Digital Display Accuracy: A Poor Brand



Results: Summary

- Many models fail to perform satisfactorily according to the sensitivity criteria of UL 2034.
- For many models, times to alarm depend unpredictably on the time course of CO exposure.
- At low but realistic ambient relative humidity, alarms lose sensitivity, with some becoming unresponsive to CO.
- CO alarm brands holding significant shares of the CO alarm market continue to have serious performance problems; they do not provide the protection consumers expect and pay for.
- Alarm performance is unrelated to their UL certification; certified brands range in performance from "mediocre" to "dismal", while the best performing brand is uncertified.
- Two of the three well-performing brands are no longer available.

A Comparison of the Best and Worst Brands

The "Best" Brand:

- **Alarmed within the UL sensitivity specification at purchase, at moderate and low relative humidity, and after exposure to interference gases.**
- **Always alarmed at less than 10% COHb, even when presented with steadily increasing CO concentrations.**
- **Was immune to all interference gases tested.**
- **Digital displays were accurate to ±5%.**
- **Many supervised failures when purchased, with one third of detectors displaying error messages.**
- **Not UL certified! No longer available. (Two of the three "well-performing" brands identified by this study are now no longer available.)**

A Comparison of the Best and Worst Brands

The "Worst" Brand:

- **Sufficiently sensitive at the UL test points at 50% RH, but less sensitive at lower humidity, becoming unreliable below 20% RH. At 5% RH all detectors are completely insensitive to CO!**
- **Even at 50% RH eight of ten detectors failed to alarm at less than 10% COHb when presented with steadily increasing CO concentrations.**
- **At 50% RH digital displays read low by 30% to 55% over a 50-175 ppm CO range, failing to meet the error specification stated in the user's manual of +100% to -40% of reading. At 10% RH displays read low by 30% to 100%, and at 5% RH all displays fail completely.**
- **This inexpensive, UL-certified alarm is widely available retail and likely accounts for the greatest share of installed alarms.**

Implications for Consumer Safety

- Are residential CO alarms safe?
- What are the causes of the overall poor performance of residential CO alarms?
- The deficiencies of UL2034.
- Recommendations: How can the performance of CO alarms be improved?

Are CO Alarms Safe ?

- The results of this and prior studies shows that many CO alarm brands do not protect the public from the most common and likely CO poisoning incidents; i.e, incidents that involve steadily increasing CO concentrations, and incidents that occur during the winter.
- Their notoriously poor performance has destroyed public and responder confidence in alarms -- most consumers do not take CO alarm actuations seriously.
- The ready availability of cheap, nonfunctioning CO alarms discourages consumers from taking the simple, effective measures needed to guard against CO poisoning.
- The performance of CO alarms has not improved over the years; instead, the best performing brands have been driven from the market by the worst.
- Consumers have no way to distinguish the better performing brands from the junk -- most carry the UL mark.

What are the causes of the poor performance of residential CO alarms ?

- The specific failings of devices have technical causes, and they also have technical solutions – unimplemented solutions that have been available for years.
- These solutions have not been implemented because Underwriters Laboratories policies, and the UL2034 standard, penalize manufacturers who burden their product with the costs of quality assurance, time-of-manufacture calibration, and in-service reliability.
- CO alarm brands that function well, but are burdened with the costs of quality assurance, must compete with those that function so poorly as to be incapable of protecting consumers from CO poisoning. Consumers may believe the UL certification mark assures them of a minimum, safe level of functionality. These tests show that it does not.

The Deficiencies of UL2034

- UL2034 was developed solely by UL, in a closed process uninformed by the needs of consumers or knowledge of the technical capabilities and limitations of the sensing technologies involved.
- Despite the repeated recommendations of manufacturers, the CPSC, GRI, and others, UL2034 does not include basic requirements for:
  - **alarm actuation at or before 10% COHb is attained in an exposed person;**
  - **minimum lifetime;**
  - **time-of-manufacture quality assurance through actual testing;**
  - **digital display accuracy; or,**
  - **in-service reliability.**
- The lack of a reliability component in the UL2034 standard, and UL's continued certification of devices that do not even meet the most basic requirements of UL2034, have had the effect of promoting the least reliable products and driving the most reliable products out of the marketplace.

Recommendations

How can the performance of CO alarms be improved?

- UL2034 should adopt CPSC's recommendations of October, 1996:
  - **alarms' sensors should be subject to the alarms' performance criteria;**
  - **alarms should actuate at or below the 10% COHb level;**
  - **expand the selectivity test;**
  - **test 100% of product at the time-of-manufacture to actual CO gas;**
  - **perform long term stability and reliability testing using defined failure rate criteria and lifetime; and,**
  - **assure that digital displays do not differ greatly from the actual CO levels.**
- Six years after these recommendations were made, UL2034 has not adopted them. But the CSA 6.19-01 Standard, through an open standards process, has adopted most of them. The public interest would be best served if CPSC were to recommend that consumers only purchase alarms certified to the CSA Standard.

Conclusions

- **The performance, reliability and lifetime of currently installed CO alarms is poor. Some detector models do provide consumer protection, but other popular models are so egregiously unreliable as to present a public hazard. Consumers have no way to distinguish the two.**
- **Unfortunately, certification to the UL standard is not a predictor of alarm reliability. Several poorly functioning detector models are UL certified, while the best functioning model is not.**
- **The CSA 6.19-01 Standard represents a broad consumer and industry consensus for the need for requirements for time-of-manufacture and in-service reliability. While UL2034 has not incorporated most of the CPSC recommendations of October 1996, the CSA Standard has.**
- **The performance and reliability of alarms offered to the public is diminishing as the best functioning alarms lose market share and retail availability.**