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LOG OF MEETING

Subject: Carbon Monoxide (CO) Alarms
Date: August 25, 1999
Location: Hyatt Regency Hotel, Bethesda, Maryland
Log Entry Date: September 14, 1999
Log Entry Source: Elizabeth W. Leland, EC
Attendees:

CPSC
Dwayne Davis, LSE
Sandra Inkster, HS
Elizabeth Leland, EC
Ronald Medford, EXHR
Warren Porter, LSE
Marcia Robins, EC
Richard Stern EXC
Donald Switzer, ES

Non- CPSC Attendees
Approximately 25 individuals (other than CPSC representatives) attended the meeting. The names of each of these individuals and their affiliation is not available at this time, but will be published by Underwriters Laboratories Inc. (UL). However, the groups and interested parties that sent representatives to the meeting are as follows:
Underwriters Laboratories Inc.
Gas Industry
various trade associations
Fire Services
CO Alarm Manufacturers
Sensor Manufacturers
UL may be able to provide the specific names of the individuals who attended the meeting. UL's telephone number is 847-272-8800.

Summary of Meeting

This meeting of the UL Technical Advisory Panel (TAP) for Carbon Monoxide (CO) Alarms was called by UL. The purpose of the meeting was to discuss the agenda items shown on the attached sheet. The meeting began at 8:30 a.m. and ended at approximately 2:15 p.m., with all items on the agenda having been discussed. The following hand-outs were distributed at the meeting and are attached to this meeting log: "Attachment 1 to the May 3-4, 1999 Meeting Minutes of the Interim CSA 6.19 Technical Committee for CO Detectors and Alarms", "Carbon Monoxide Field Survey", "GRI Recommendations to the Technical Advisory Panel for UL 2034".

Within a month of the meeting date, UL will publish a Meeting Report as well as specific proposals for changes to the UL 2034 standard. Comments on those proposals and on the Meeting Report will be solicited. A copy of the final meeting report will be attached to this meeting log.

TAP Meeting Agenda

UL2034 Single and Multiple Station Carbon Monoxide Alarms
August 25, 1999 Bethesda Maryland

1. Welcome
2. Introductions
3. Preliminary results of the field survey
4. Effects of Shipping and Storage Test
5. Selectivity Test
6. Accuracy requirements covering ppm displays
7. Enhancement of Factory Follow-Up Testing, and Manufacturer's QC
8. Modified Follow-Up inspection schedule to accommodate seasonal production
9. Tightened control schedules
10. Field Sampling as part of the Follow-Up program
11. User replaceable parts
12. Feasibility of requiring CO alarm sensors to be self-diagnosing
13. *Reliability requirements
14. *Minimum lifetime of alarms and alarm warranty
15. *Test ports for use in testing alarms
16. Additional items as time permits
17. Closing comments

CARBON MONOXIDE FIELD SURVEY

	All SAMPLES	Excluding Recall Models	7/99
Number of Listed Companies-----	11	10	
Number of Models ------------------	30	23	
Number of Samples Tested ----------	104	75	51
Sample Missed at Least One Test --	46.2%	25.3%	41.2%
Number of Tests – -------------------	474	309	219
Tests in-range -----------------------	63.3%	88.3%	81.2%
Early Response ------------------------	4.4%	6.8%	11.0%
Late Response -------------------------	14.6%	2.3%	5.5%
No Response, or After 20% COHb -	17.7% *	2.9% *	2.3%*
Response at or Below 20% COHb -	82.3%	97.4%	97.7%

* 70 and 100 ppm tests only.

Out-of Range By Concentration of CO

	All SAMPLES	Excluding Recall Models	7/99
70 ppm –	53.7%	21.4%	31.8%
100 ppm –	22.0%	17.8%	21.0%
150 ppm –	47.2%	7.1%	13.6%
200 ppm –	12.0%	10.6%	21.0%
400 ppm –	29.7%	6.8%	12.3%

CARBON MONOXIDE FIELD SURVEY

10/95 Edition Subtotal

	3/99	7/99
Number of Samples Tested	50	29
Number of Tests	150	87
Tests in-range	84.7%	78.3%
Early Response	6.0%	12.6%
Late Response	2.7%	4.6%
No Response, or After 20% COHb	6.7%	3.4%*
Response at or Below 20% COHb	93.3%	96.0%

* 100 ppm only

Out-of Range by concentration of CO

	3/99	7/99
70 ppm	NA	
100 ppm	22.0%	21.0%
150 ppm	NA	
200 ppm	12.0%	21.0%
400 ppm	10.0%	21.0%

CARBON MONOXIDE FIELD SURVEY

10/98 Edition Excluding Recall Models

	3/99	7/99
Number of Samples Tested	28	22
Number of Tests	168	132
Tests in-range	89.3%	82.5%
Early Response	7.1%	9.8%
Late Response	1.8%	6.1%
No Response, or After 20% COHb	1.8%	1.5%*
Response at or Below 20% COHb	98.2%	98.5%

* 70 ppm only

Out-of Range by concentration of CO

	3/99	7/99
70 ppm	21.4%	31.8%
100 ppm	NA	
150 ppm	7.1%	13.6%
200 ppm	NA	
400 ppm	5.4%	6.8%

Rationale:

Outgasing of packaging material has shown to negatively impact the performance of CO alarms. Accordingly, the following revision to Paragraphs 45.2.1 and 45.2.2 are proposed to address this issue.

Impact:

Testing of all currently Listed products.

45.2 Effect of shipping and storage

45.2.1 The sensitivity of an alarm shall not be impaired by exposure to high and low temperatures representative of shipping and storage, as well as storage in point-of-purchase packing.

45.2.1 revised October 15, 1997

45.2.2 Two alarms, in point-of-purchase packaging, at nominal sensitivity, are to be subjected, in turn, to a temperature of 70°C (158°F) @ 50 ± 30% RH for a period of 24 hours, allowed to cool to room temperature for at least 1 hour, exposed to a temperature of minus 40°C (minus 40°F) for at least 3 hours, and then permitted to warm up to room temperature for at least 3 hours. The same two samples are then to be subjected to 50 ± 3°C (122° ± 5°F) @ 50 ± 30% RH for 45 days. The alarms then are to be tested for sensitivity while connected to a source of supply in accordance with 34.3.1.

45.2.2 revised October 15, 1997

45.2.3 Sensitivity measurements shall be recorded, before and after the Effect of Shipping and Storage Test in 45.2 using the CO values listed in Table 38.1, Part A – Alarm, and Table 38.1, Part B – False alarm, except the 30 day test is to be conducted for 8 hours. All alarm samples tested as part of the Effect of Shipping and Storage Test in 45.2 shall comply with these requirements.

Revised 45.2.3 October 1, 1998

39 Selectivity Test

Rationale:

Additional gases commonly found in residences are applicable to the Selectivity Test.

Impact:

Retest of all currently Listed products.

Proposal:

Add

Substance	Concentration, ppm
Ammonia	100
Ethylene	200
Ethanol	200
Toluene	200
Trichloroethane	200

to Table 39.1.

Table 39.1
Gas and vapor concentrations

Revised Table 39.1 effective October 1, 1998

Substance	Concentration, ppm
Methane	500
Butane	300
Heptane	500
Ethyl acetate	200
Isopropyl alcohol	200
Carbon dioxide	5000

Add:

Substance	Concentration, ppm
Ammonia	100
Ethylene	200
Ethanol	200
Toluene	200
Trichloroethane	200

ATTACHMENT 1

TO THE MAY 3-4, 1999 MEETING MINUTES OF THE
(INTERIM CSA) 6.19 TECHNICAL COMMITTEE FOR
CO DETECTORS AND ALARMS

Note: These proposed revisions to standard CAN/CGA-6.19-M93 are based on CSA T.I.L No. R-03 (dated September 18, 1998). At its meeting of May 3-4, 1999 the (Interim CSA) 6.19 Technical Committee resolved that these proposed revisions, to amend and supplement the current edition of standard CGA 6.19-M93, be processed for adoption

(~~Deletions are shown with a strike-out~~, and <u>additions are underlined</u>.).

1. Scope

1.2 Carbon monoxide detectors covered by these requirements are intended to respond to the presence of carbon monoxide from sources such as, but not limited to, exhaust from internal-combustion engines, abnormal operation of fuel-fired appliances, and fireplaces. Carbon monoxide detectors are intended to detect carbon monoxide levels below those that could cause a loss of ability to react to the dangers of carbon monoxide exposure.

<u>1.2.1 Carbon monoxide alarms covered by this standard are not intended to activate the alarm when exposed to long-term, low-level carbon monoxide exposures or slightly higher short-term transient carbon monoxide exposure</u>

1.5 A product that contains features, characteristics, components, materials, or systems new or different from those in use when the standard was developed, and that involves a risk of fire, electric shock, or injury to persons shall be evaluated using the appropriate additional component and end-product requirements as determined necessary to maintain the level of safety for the user of the product as originally anticipated by the intent of this standard.

<u>1.6 Throughout this standard the term "carbon monoxide alarm" is used interchangeably for "carbon monoxide detector" and "carbon monoxide alarm".</u>

2) Extended operation of unvented fuel burning devices (range, oven, fireplace, etc.);

3) Temperature inversions which can trap exhaust gases near the ground;

4 Car idling in an open or closed attached garage, or near a home.

s) A minimum of two self adhesive labels with the information as described in Clause 70.1(d) shall be provided by the alarm manufacturer. Directions shall instruct the user of the alarm to add the telephone numbers of their emergency service provider and a qualified technician to the labels. Instructions shall be given for the user of the alarm to place one label next to the alarm, and the other label near a source of fresh air where they plan to gather after the alarm indicates the presence of carbon monoxide.

71. REQUIRED TIME-OF-MANUFACTURE RELIABILITY

71.1 At the time of manufacture and after burn-in if applicable, devices shall have a total failure rate, for Supervised and Unsupervised Failures combined, of less than 1 % when estimated at a confidence level of 90 %.

71.2 Time-of-Manufacture Reliability shall be estimated by subjecting a suitable sample of devices to the Sensitivity Test, Section 34 and Table 34.1, for tests at CO concentrations of 70, 150 and 400 ppm, but excluding the test at 30 ppm.

71.3 Tests shall be conducted by the manufacturer, quarterly or for each major change in design, production or components, whichever comes first.

71.4 Samples for these tests shall be randomly selected from quarterly production or from each major change in production or components, whichever comes first.

71.5 The sample size for tests shall be determined according to widely accepted procedures for statistical quality control, as described in GRI-96/0055 (summarized in appendix "C" to this standard). A statistically significant sample of representative devices shall be randomly chosen to estimate the Required Time-of-Manufacture Reliability at the required confidence level.

72. MEASUREMENT OF IN-SERVICE RELIABILITY

72.1 Required In-Service Reliability

72.1.1 Reliability for Supervised Failures: CO detectors shall have a mean time between failure (MTBF) of no less than 100,000 hours when estimated at a 90% confidence level for Supervised Failures when averaged over the devices' lifetime. At this failure rate, the cumulative Supervised Failures over the devices' lifetime shall not exceed 23% at a 90%

confidence level.

72.1.2 Reliability for Unsupervised Failures: CO detectors shall have a mean time between failure (MTBF) of no less than 166,667 hours when estimated at a 90% confidence level for Unsupervised Failures when averaged over the devices' lifetime. At this failure rate, the cumulative Unsupervised Failures over the devices' lifetime shall not exceed 14.6% at a 90% confidence level.

72.2 Sample Frequency, and Sample Size

72.2.1 In-Service Reliability shall be estimated by subjecting a suitable sample of devices to the Sensitivity Test of Section 34 and Table 34.1, for tests at CO concentrations of 70, 150, and 400 ppm, but excluding the test at 30 ppm.

72.2.2 Reliability information on devices shall be collected quarterly using any of the following methods:

1. Life cycle testing at the manufacturer's facility;

2. Testing of devices installed in the field; or,

3. Laboratory testing of devices bought back from customers.

72.2.3 Prior to testing, devices shall be installed and operated in an actual or simulated residential environment for a period of sufficient duration to predict the average failure rate of the overall population over the devices' lifetime. During the installation period the alarms shall be tested and an upper bound on their failure rate at a 90% confidence level shall be determined at quarterly intervals. Installation times of less than the devices' lifetime, but not less than 3000 hours, may be used in this analysis, taking into account any other measurements that might be available demonstrating the applicability of the shorter installation period for estimating failure rates averaged over the devices' lifetime. The data from the shorter installation period shall be replaced with data from progressively longer duration, up to the devices' Lifetime, as it becomes available. If no data is available to demonstrate the applicability of the shorter duration data, it may still be used.

72.2.4 The sample size for tests shall be determined according to widely accepted procedures for statistical quality control, as described in GRI-96/0055 (summarized in Appendix "C"). A statistically significant sample of representative devices shall be randomly chosen to estimate the Required In-Service Reliability at the required confidence level.

72.3 Test Results and Record Keeping

The manufacturer shall maintain data and records of all tests performed to evaluate devices' conformance to the Required In-Service Reliability.

APPENDIX - C (to Standard CAN/CGA-6.19-M93)

SAMPLE SIZE DETERMINATION FOR TIME OF MANUFACTURE RELIABILITY TESTING

This Appendix is not a mandatory part of the standard.

The objective of this appendix is to assist manufacturers of CO alarming devices in identifying sample sizes for testing under section 71 of this standard. This discussion is a summary of the material provided in the GRI Report, "Test Protocols for Residential Carbon Monoxide Alarms, Phase 1," (GRI-96/0055), Section 6, "Target Reliabilities and the Number of Units Tested."

Preliminary Considerations

Sample size selection for time of manufacture reliability tests require the following assumptions:

- Selection of units from the population of a given CO alarming device after burn-in of 100% of all units produced and removal or repair of units failing normal burn-in operation. The remaining population of units is used in time of manufacture reliability testing. Failure during burn-in may be defined in terms of spontaneous alarm, failure to activate when the test button is depressed, or other obvious malfunctions indicative of a defective unit. Burn-in of 100% of all units is consistent with requirements of UL 2034 and with specifications of many component manufacturers including sensor manufacturers. If no burn-in procedures are implemented, if burn-in procedures are not applied to 100% of the population, or if failed units are not removed or repaired after burn-in, no units shall be removed from sampling for time of manufacture testing.

- No changes in production methods, designs, components, production consistency (other than random variability) or other factors that could alter the reliability, in terms of failure rate, for a given population of CO alarming devices. Statistical methods underlying time of manufacture reliability testing assume a constant time of manufacture failure rate for the CO alarming device. Any changes in manufacture and handling of components or finished goods that alter this failure rate (either raising it or lowering it) would violate this assumption and define a new, unique population for reliability testing purposes. As a result, sampling and testing must be restarted for all such changes in the product. Likewise, systematic (non-random) changes in product quality and consistency over time due to learning curve efficiencies or other effects would violate the assumption of a constant failure rate and bias the sampling of finished goods off the production line, which is needed for time of manufacture reliability testing.

Statistical Design

Time of manufacture testing suggests the use of classical statistical methods for binomial experiments, which have the following properties:

- The experiment consists of N repeated trials.
- Each trial results in an outcome that may be classified as a "pass" or a "fail."
- The probability of success, P, remains constant from trial to trial.
- The repeated trials are independent.

Using classical statistical methods for binomial experiments, a large number of statistical tools can be applied including hypothesis testing and sample size selection. However, use of these simple classical methods becomes unworkable for reliability testing where the size of the population, N, is unknown or cannot be specified and where testing must proceed over a changing (growing) population. In this case, statistical methods must be able to use a tally of observed failures (incidents of noncompliance with a given set of performance specifications) to extrapolate a *maximum failure rate* for the entire population at a *chosen confidence level.* Such approaches, commonly used in statistical literature on reliability testing but rarely explained in full, are *independent of population size.*

The number of units needed for testing is estimated as follows. The goal of testing is to establish an upper bound for the population failure rate, r_f, at a given confidence level (e.g., 60%, 80%, or 90%) by testing a sample of only N units. However, the sample size N must be sufficiently large to confidently place an upper bound on the failure rate. The number of units *expected* to fail a test, $<N_f>$, is given by the size of the sample tested times the population failure rate:

$$<N_f> = Nr_f \qquad \text{Eq. 1.}$$

Although $<N_f>$ is the expected number of failures, the actual number of failures, N_f, observed in any sample may be more or less, with a 50% probability of observed failures being more than the expected and a 50% probability of them being less. Unfortunately, one cannot statistically estimate r_f from sample testing in this type of experiment.

Instead, one can make an assumption for r_f and calculate the cumulative probability of observing *more* than the actual number of failures as a likelihood of, or confidence level for, being correct when using the assumed value for r_f as an upper bound for the true r_f. Consequently, if the expected number of failures given an assumed failure rate r_f were actually to be observed (i.e., $<N_f> = N_f$), the test would have established that the failure rate is truly less than or equal to r_f with a confidence level of 50%. If the observed number of failures were found to be much less than the number expected, one would have a high confidence that the actual failure rate is less than or equal to the assumed failure rate and a high confidence in assumed failure rate r_f as an upper bound.

To establish an upper bound on the failure rate, one must consider the probability distribution for observing differing numbers of failures given a particular population failure rate. This distribution is given by the binomial probability distribution. The probability of observing a particular number, N_f, or fewer failures, $P(\leq N_f)$, is given by one minus the cumulative binomial probability for observing more than N_f failures with a probability of r_f each in a sample of N units and is related to the incomplete beta function, $I_r(N_f+1, N-N_f)$, as:

$$P(\leq N_f) = 1 - \sum_{j=N_f+1}^{N} [N!/j!(N-j)!]\, r_f^j (1-r_f)^{N-j} = 1 - I_r(N_f+1, N-N_f) \qquad \text{Eq. 2.}$$

Unfortunately, tables for the incomplete beta function are not as commonly available as those of the gamma or chi-squared functions so it is preferable to approximate the above in terms of those distributions. This may be done by assuming that the number of observed failures is much less than that total number of units tested, $N_f \ll N$, so that the Poisson distribution may be used as an approximation for the binomial distribution. The probability that the number of observed failures, N_f, is equal or fewer than the expected number, $<N_f>$, is given by the cumulative Poisson distribution function, $P(N_f \leq <N_f>)$, which in turn is given by the complement of the incomplete gamma function, GAMMAQ, or the chi-squared function as:

$$P(N_f \leq <N_f>) = \mathrm{GAMMAQ}(N_f + 1, <N_f>) = P\chi^2(2<N_f>, 2N_f+2) \qquad \text{Eq. 3.}$$

This probability equals one minus the confidence level that the failure rate is actually less than or equal to the value responsible for the expected number of failures, $<N_f>$. In the above equation, $P\chi^2(2<N_f>, 2N_f+2)$ represents the probability that an observed chi-squared, χ^2, will exceed a value of $2<N_f>$ by chance with $2N_f+2$ degrees of freedom. Note that the standard interpretation of this distribution in terms of chi-squared and degrees of freedom is not particularly meaningful in this application. Rather, the chi-squared distribution is used for its availability; it is the most widely tabulated form of the gamma function. Even so, the chi-squared distribution is usually tabulated not as probability as a function of squared error, $P\chi^2$, but rather as a reduced chi-squared as a function of probability, χ^2_v (where χ^2_v is χ^2 divided by the number of degrees of freedom). Recast in these terms, Equation 3 becomes:

$$Nr_f = <N_f> \leq (N_f + 1)\, \chi^2_v(1 - C, 2N_f+2) \qquad \text{Eq. 4.}$$

Thus, the failure rate is bounded for a given confidence level as:

$$r_f \leq (N_f + 1)\, \chi^2_v(1 - C, 2N_f + 2) / N \qquad \text{Eq. 5.}$$

where,

N is the number of units undergoing test

r_{f} is the hypothesized population failure rate

N_f is the actual number of failures observed in a test of N units

C is the degree of confidence in the bound of the failure rate

$\chi^2_\nu(1 - C, 2N_f + 2)$ is the reduced chi-squared distribution at a significance of 1 - C and with $\nu = 2N_f + 2$ degrees of freedom.

Using these equations, upper bounds on the expected number of failures can be established for various confidence levels and numbers of failures observed during testing. For example, the following table shows this relationship for a 90% confidence level:

UPPER BOUNDS ON THE EXPECTED NUMBER OF FAILURES AT 90% LEVEL OF CONFIDENCE FOR GIVEN NUMBERS OF OBSERVED FAILURES

Number of Failures Observed	Upper Bound on Expected Failures
0	2.3
1	3.9
2	5.3
3	6.7
4	8.0
5	9.3
6	11
8	13
10	15
20	27
50	60

Choosing the Sample Size

Using the table above or similar tables developed for other confidence levels of interest, sample size can be selected to help ensure that product time of manufacture failure rates will not exceed a target population failure rate. Consider an example in which the target failure rate is less than 1% with a 90% confidence level. The table shows that even if no failures are observed during testing, one could expect that at most 2.3 failures might occur in any sample. For this number of failures, N_f, to correspond to a failure rate, r_f, of 1%, one must choose the sample size, N, to be at least 230 according to Equation 1:

$$N = N_f / r_f = 2.3 / 0.01 = 230$$

Consequently, if one tests 230 units without observing a failure, he/she can be 90% confident that the population failure rate is less than 1%. If one failure is observed in the 230 unit sample, the table entry 3.9 must be used in Equation 1, and the upper bound on the failure rate for this example would be 1.7%:

$$N = 230 = 3.9 / r_f;\ r_f = 0.017 \text{ or } 1.7\%$$

Since failures are assumed to be randomly distributed throughout the population, sampling can be expanded when failures are observed to ensure compliance with a failure rate of less than 1% using the same information. For example, if one failure is observed in an initial sample of 230, the sample can be expanded to 390. Provided no additional failures occur, compliance with the criterion of less than 1% failure rate with 90% level of confidence can still be met:

$$N = N_f / r_f = 3.9 / 0.01 = 390$$

If additional failures are observed, testing can be again expanded using the associated values for upper bound on expected failures. However, at some point, it may become more efficient to evaluate the reasons for failure rather than continue expanding testing. Although relaxing either the target failure rate or the confidence level would achieve favorable results in tests where failures are observed, these criteria are intended to be set external to the process of product testing and should not be altered once agreed upon.

Random Sampling

These procedures are applicable and appropriate only where the assumptions stated above hold and where random sampling is conducted. Manufacturers using these approaches should exercise care in establishing approaches for developing random samples. Such approaches, out of necessity, will be highly specific to the manufacturer. For example, the practical difficulty in randomly sampling 230 units from a production run of 100,000 units is greater than for a production run of 1,000 units. However, in spite of efforts to avoid bias in time of manufacture testing discussed in the assumptions, remaining systematic bias in product quality can be minimized by random sampling techniques.

GRI Recommendations to the Technical Advisory Panel for UL 2034

Submitted by,
Gas Research Institute
Contact: Steve Wiersma, 773-399-8126

August 25, 1999

Recommendation 1: Uniquely identify butane and heptane in Section 39, butane as either i-butane or n-butane (whichever is truly intended), and heptane as n-heptane.

Discussion:

Among the gases listed for the Selectivity Test in the current Standard are butane and heptane. These are inadequately identified; there are two different chemical species called "butane", n-butane and i-butane, and many isomers for heptane. The intended species should be uniquely identified so that manufacturers and others can reproduce the tests.

Recommendation 2: For the Selectivity Test of Section 39, adopt the following additional gases and concentrations:

Acetone	**200 ppm**
Ammonia	**100 ppm**
Ethanol	**200 ppm**
Ethylene	**200 ppm**
Toluene	**200 ppm**
Trichloroethane	**200 ppm**

Discussion:

In addition to the gases listed in the meeting agenda (dated Aug. 11, 1999) this list includes acetone. Acetone is a common solvent frequently found in residences and has been recommended for the Selectivity Test in the past by both GRI and the CPSC (CPSC Recommendation 11 of Oct. 1996).

We recognize that the concentrations listed in the table for some of these gases are significantly greater than would likely be found in a residence for a sustained two hours. However, in the absence of an accelerated lifetime exposure test, the interference test serves two purposes. It tests the alarms' false alarm resistance to interferences, and it also tests their immunity to a drift in characteristics caused an accumulated dose of potentially reactive gases and vapors. To fulfill this second function it is important that after the interference test the alarms be retested for their sensitivity to CO. The doses of these interference gases are still only a small fraction of expected cumulative dosages over a presumptive three year lifetime.

Recommendation 3: For the Selectivity Test of Section 39, specify a recovery time between presentations of each of the interference gases and vapors of two hours exposure to clean air.

Discussion:

Many CO alarms incorporate a filter to remove solvent vapors before they reach the active sensor. Increasing the number of interference gases required in the Selectivity Test also increases the total capacity demanded of the filter, perhaps beyond a reasonable design specification. Providing a modest recovery time between gas and solvent presentations allows the filter greater time to desorb the gases and will help prevent premature breakthrough.

Recommendation 4: Solicit technical recommendations for appropriate concentrations and exposure times for interference gas tests to SO_2, NO_X, hydrogen sulfide (H_2S), and hexamethyldisiloxane (HMDS). We suggest the following as appropriate concentrations for two hour exposures:

SO_2	**5 ppm**
NO_X	**5 ppm**
H_2S	**5 ppm**
HMDS	**10 ppm**

Discussion:

The response to CO of some alarms may be inhibited by other products of combustion, specifically SO_2 and NO_X. HMDS is a known poison of some technologies. Consequently, tests to these gases are required by the proposed CENELEC TC 216 Standard. H_2S is a known long term poison for some sensors; in the absence of an accelerated lifetime exposure test it may be wise to include it in an interference test.

Recommendation 5: Consider requiring an accelerated lifetime exposure test to gases and vapors representative of the chemical families of gases known to be present in the residential environment.

Discussion:

Certification should include an accelerated lifetime exposure test and require technical justification for lifetime claims. A cumulative-exposure type accelerated lifetime test would include exposures to the gases and vapors expected in indoor air. In this test alarms are exposed in a short time to a cumulative dose equivalent to that which they would experience during a presumptive three year lifetime.

Simplifying assumptions must be made to create a set of tests that can be economically performed. Not all substances to which a detector might be exposed are known, so those that are known to occur in the greatest concentrations in the indoor environment should be chosen, whether or not they are known to have a strong influence on the sensor technologies used. In addition, gases that are known to be reactive or poisonous to the sensors now in use should be included. Whenever there is a choice of gas species, those that can be inexpensively delivered, or surrogates for those that can not be practically delivered, should be chosen. While some gases known to be present in indoor air can be chosen now, in the future more precise estimates of indoor pollutant levels may be available so that a more inclusive set of test gases may be used.

Not all indoor pollutants can be tested. Instead, a small subset should be chosen to represent pollutants from each of the major chemical families and known sensor poisons. Fifteen such test gases were recommended in the GRI report, *Test Protocols for Residential Carbon Monoxide Alarms, Phase 1*, GRI-96/0055 and are shown in the following table:

Accelerated Lifetime Test Gases and Exposures		
Class	**Test Gas**	**Test Exposure (ppm-days)**
Alkanes	i-Butane	700.
Alkenes	Ethylene	350.
Amines	Ammonia	650.
Aromatics HCs	Toluene	70.
Halogenated HCs	Trichloroethane	200.
Alcohols	Ethanol	900.
Aldehydes	Formaldehyde	1000.
Ketones	Acetone	500.
Carboxylic Acids	Acetic acid	600.
Hydrogen	Hydrogen	550.
Mineral Acids	Hydrogen chloride	143.
	Sulfur dioxide	41.
Oxidants	Nitric oxide	1400.
	Chlorine	40.
Catalyst Poisons	Hexamethyldisilazane	10.
Thiols	Hydrogen sulfide	33.

Isobutane is chosen to represent aliphatic hydrocarbons because it is generally more reactive than methane. Its concentration is chosen to provide a total exposure equivalent on an atomic carbon basis to the combined presence of all paraffinic hydrocarbons and unspecified VOCs in the indoor environment. Likewise, ethylene is chosen as representative of all alkenes. For the amines, ammonia is used because it appears in much greater concentration in the indoor environment than any of the others. Similarly, the aromatic hydrocarbon most likely to be found in the greatest concentration, toluene, is used. Its test concentration is chosen to provide a molecular loading equal to the sum total of all aromatic hydrocarbons that may be found in the indoor environment. For the halogenated hydrocarbons, the species that occurs

in the greatest concentration is chosen as representative, with a concentration calculated to provide a total chlorine loading equivalent to the combined presence of all of the halogenated species. Nitric oxide is taken to represent itself, NO_2, and ozone. Hydrogen is included because MOS sensors are quite sensitive to it and it is often used for accelerated lifetime testing of methane-sensitive MOS sensors. Hydrogen chloride is included because of its potential importance in the indoor environment. It is, however, difficult to deliver. Finally, chlorine is included as a strong corrosive, hexamethyldisilazane (HMDS) as a quintessential poison, and hydrogen sulfide to represent all reduced sulfurs. The total doses listed for chlorine, HMDS, and hydrogen sulfide are comparable to those used by others in poisoning studies of catalytic bead gas sensors. Further justification for the choice of these gases and cumulative loads may be found in GRI-96/0055.

An accelerated lifetime exposure test would consist in exposing the alarms to the cumulative doses of these gases. The exposures should be provided over an exposure time that keeps the concentrations well below the concentration for each gas that might be expected to cause a prompt false alarm. In order to minimize the duration and cost of the tests the test gases may be grouped and combined so that as many as possible are delivered simultaneously to the detectors without chemically competing in their influence on the detectors. A recommended grouping is the following:

Gas Groups for Accelerated Lifetime Exposure Tests

Reducing Gases	Acid Gases	Oxidants	Catalyst Poisons
Hydrogen i-Butane Toluene Ethanol Ammonia Formaldehyde Ethylene Acetone	Acetic acid Hydrogen chloride Sulfur dioxide	Nitric oxide Chlorine	HMDS Hydrogen Sulfide Trichloroethane

Recommendation 6: Fully incorporate the newly proposed reliability requirements of the Canadian Standards Association CAN/CGA-6.19-M93 Technical Committee for CO Detectors and Alarms. These are the reliability requirements of IAS 6-96 Rev. June 1998.

Discussion:

For years now there has been growing public concern over the reliability of CO alarms. This concern must be forthrightly addressed if CO alarms are to attain their potential as life saving

devices. Presently, the sections of UL 2034 pertaining to reliability are confusing and ambiguous:

- Section 4.1 appears to require an overall failure rate of fewer than 3.5 or 4.0 failures per million hours, but it does not define what is meant by failure.
- Section 4.2d removes from the failure rate calculation of section 4.1 any component that "is evaluated by specific performance tests included in the standard" and cites as examples "the audible signal appliance, test switch, and battery contacts". Is the sensor, the alarm's most critical component from which its overall reliability derives, included in this category? If so, does section 4.2d really intend to remove the sensor from the reliability analysis? Citing other components while remaining silent on the sensor, which is the most conspicuous component "evaluated by specific performance tests" only adds to the confusion. Is it wise to waive a genuine reliability requirement in lieu of single-time performance tests which are not designed to determine the reliability of the alarm?
- Section 4.5 seems to clarify the reliability requirements for the sensor by requiring reliability data developed using MIL.217-F. But MIL.217-F provides no reliability data for any kind of chemical sensor, nor guidance for developing any. Further, while Section 4.5 requires a failure rate of less than 2.5/million hours, it does not define "failure". For a device that drifts, failure can only mean a drift of device specifications so great that the entire detector no longer operates within a required sensitivity specification.
- Likewise, it is not clear if Section 34.4 (Component Reliability Data) is meant to include or exclude the sensor.
- There seems to be some confusion over what "sensitivity calibration" means in Section 74. Must all alarms be tested to actual CO gas at their time of manufacture?

Adopting the clear and explicit reliability requirements of CAN/CGA-6.19-M93 would resolve all of these ambiguities. In addition, CAN/CGA-6.19-M93 provides the following essential components of a reliability standard:

- A definition of lifetime and a specified lifetime;
- Definitions of what is meant by failure for supervised and unsupervised failures;
- Target reliability (as an upper bound on the failure rate) for alarms at their time of manufacture; and,
- Target Mean-Times-Between-Failure (MTBF) for supervised and unsupervised failures over the lifetime of the alarms.

If the reliability requirements of CAN/CGA-6.19-M93 were not to be adopted, forging a credible reliability requirement within UL 2034 would still mean implementing each of these components.

Adopting the reliability requirements of CAN/CGA-6.19-M93 would address the CPSC request (CPSC Recommendation 14 of Oct. 1996) that production quality test requirements be clarified. In particular, CPSC recommended that:

> *UL require each manufacturer to perform long term stability and reliability testing on each UL-listed detector model...* [the criteria] *including:*
>
> - *Minimum sample size;*

- *Acceptable failure rate criteria;*
- *Requirement to test detectors periodically for a total time period not less than the expected life of the detector; and,*
- *Suitable UL oversight and inspection procedures.*

CPSC recommended that manufacturers perform actual long term testing for reliability, saying that they *"do not believe that designing to a predicted failure rate ensures detector reliability in the field."* Each of these CPSC concerns is fully addressed by the proposed reliability requirements of CAN/CGA-6.19-M93.

The proposed reliability requirements require statistical sampling of a production run, testing to actual CO concentrations, and withholding a statistical sample for quarterly testing throughout the lifetime of the alarm. It is not necessary to test every alarm to CO, as presently seems to be required by Section 74. Instead, only a sufficient statistical sample of alarms needs to be tested at the time of manufacture.

The adoption of the proposed reliability requirements of CAN/CGA-6.19-M93 will also advance the eventual harmonization of the two standards.

Recommendation 7: Require a test port on each alarm to simplify and lower the cost of automated testing. This test port may be implemented as a direct electrical connection, or it may use the preexisting alarm LED to signal an alarm, and for detectors with digital displays, the displayed concentration.

Discussion:

Testing CO alarms is presently an expensive, laborious and time-consuming task. Automating the recording of alarm activations would simplify testing and decrease its cost. Some testing laboratories do this by automatically detecting the sound created by the alarms. However, this is not a wholly reliable method, as it requires considerable finesse in microphone placement, and in some cases it requires modifying the alarm's enclosure. A test port would enable reliable automated recording of the alarm signal and concentration.

A test port could take several forms. It could be implemented as a direct electrical connection conveying an analog or digital signal. Or it could be implemented by modulating the alarm's LED indicator, requiring no additional hardware cost.

A disadvantage of electrical or optical connection is that it does not test the alarm's piezoelectric sounder. Fortunately, the sounder's functionality can be independently tested by pressing the test button before and after any gas sensitivity tests.

Recommendation 8: Clarify alarm response by fully specifying recovery times between test gas presentations.

Discussion:

Because the present standard says little about recovery time, different alarm brands may implement quite different algorithms and still meet the standard's sensitivity specification. Consequently, different alarm brands may behave very differently in their response to varying CO concentrations, and this has consequences both for their performance in the field and for reliability testing.

In the field, CO concentrations are not likely to appear abruptly and remain constant, as during a test of the device. Instead, CO concentrations vary and often appear and disappear episodically. Tests of alarms to varying CO concentrations reveals that alarm brands with different recovery times may activate their alarms at the same, or vastly different %COHb levels, depending on the temporal profile of the CO exposure. To reliably alarm at consistent COHb levels all brands should have similar response *and* recovery times.

Testing CO alarms is simplified when they are allowed to recover from test exposures on their own, without operator intervention. Operator intervention is expensive and goes against the grain of automated testing, and sometimes it is not even possible. For some alarm brands an instantaneous de-integration is evoked by pressing a reset button, but other brands are inherently integrating and not capable of an electrical reset. Fair treatment of all brands then necessitates that there be sufficient time between test gas presentations for alarms to fully recover. However, recovery times now vary from brand to brand by as much as a factor of ten.

Consequently, specifying recovery times as well as activation times would assure that different models all activate within the required %COHb range in the face of varying CO concentration, and it would simplify testing.

Such a specification could be achieved by stating within the Section 38 of the standard that the alarms are intended to provide an integrated response to CO with equal integration and de-integration time constants (ie., to follow the Coburn equation). Section 38 should also then specify a sufficient recovery time between test gas presentations for the presumptive %COHb to decay to within 0.5% of baseline.

Recommendation 9: Require that digital readouts, if allowed in an alarm under UL 2034, be accurate to ±5 ppm for concentrations less than 50 ppm and ±10% for concentrations greater than 50 ppm, provide no indication at less than 15 ppm, and be subject to the same lifetime and reliability requirements as the alarms as a whole, with a digital reading outside of the specified tolerance considered as an unsupervised failure. Additionally, the digital readout should not indicate concentrations of the interfering gases of Section 39 at greater than 10% of their actual concentrations.

Discussion:

Tests reveal that the digital readouts of some brands are quite accurate while those of other brands are highly inaccurate. For this reason CPSC recommended (Recommendation 15 of Oct. 1996) that UL specify the accuracy of digital readouts, if they are incorporated in a detector.

We recommend the following:

- A not-to-be-exceeded (NTBE) tolerance should be specified as ±5 ppm for CO concentrations less than 50 ppm and ±10% for concentrations greater than 50 ppm;
- No readout should occur at a concentration less than three times the NTBE tolerance, i.e., no display below 15 ppm; and,
- The digital displays should be held to the same reliability standard as unsupervised errors in the proposed reliability requirements of CAN/CGA-6.19-M93, that is, no more than 1% of alarms manufactured would be allowed to exceed the NTBE tolerance at the time of manufacture, and the cumulative fraction of alarms that could exceed these tolerances over a presumptive 3 year lifetime would be limited to 14.6% (at a 90% confidence level).