U.S. Consumer Product Safety Commission

Staff

Status Report on Carbon Monoxide Alarm Testing

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The comments included in this report are those of the CPSC staff, have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

Summary

The U.S. Consumer Product Safety Commission (CPSC) stresses proper installation, use, and an annual service inspection of fuel burning appliances as the first lines of defense against residential carbon monoxide (CO) poisoning from consumer products. In addition, since 1992, the CPSC has supported the use of CO alarms in residences as a second line of defense against CO poisoning in the home.

In July 2002, CPSC staff received information that alleged that CO alarms did not perform adequately when tested at CO concentrations other than those specified in the Underwriters Laboratories, Inc. (UL) standard for CO alarms. The information also indicated alarms did not respond properly when challenged with rising CO concentrations as would be found in the home. CPSC staff undertook a test program to explore these allegations. The results indicate that, while the CO alarms we tested did not always respond strictly within the time limits required by the standard, with one exception, they did not alarm so late as to expose consumers to a significant heath risk. Based on what was learned from the testing, CPSC staff believes the UL standard for CO alarms should be strengthened. Recommendations to address several performance shortcomings in the standard are provided in this report.

Background

CPSC staff has participated in the development of the UL standard for CO alarms. In 1990 and 1991, CPSC staff and others requested that UL develop a voluntary performance standard for carbon monoxide alarms. In 1992, UL published the first edition of *UL Standard for Safety for Single and Multiple Station Carbon Monoxide Alarms* (UL 2034). There have, over time, been a number of modifications to the standard. The standard has been modified to address difficulties that occurred with alarms meeting the original specifications. For example, the standard was modified to raise the must not alarm level to 35 ppm for 30 days. This change was necessary to address alarm activations that occurred as a result of transient CO levels and temperature inversions where the outside CO concentration could be high enough to cause CO alarm activations, resulting in a high number of "false" alarms. In 1998 the must alarm set points were revised to their current levels (still consistent with the original exposure-based requirements). There have also been revisions in the requirements for test buttons, alarm selectivity, reliability, markings and shipping and storage tests.

Since 1992, the CPSC has supported the use of CO alarms in residences. Since that time, CPSC staff has worked with the National Fire Protection Association (NFPA) to develop a national installation standard for CO alarms. This work resulted in *NFPA 720, Recommended Practice for the Installation of Household Carbon Monoxide Warning Equipment.*

Since 1994, at the request of the CPSC Office of Compliance, CPSC's Directorate for Laboratory Sciences (LS) has, as part of official investigations, tested CO alarms that were alleged to operate improperly. In some cases the testing resulted in product recalls. Between 1994 and 2004, the Office of Compliance initiated 38 CO alarm investigations resulting from allegations of alarms failing to warn consumers of hazardous levels of CO. These investigations resulted in six recalls. In the remaining cases, LS testing indicated that the alarms performed reasonably well when tested to the CO sensitivity requirements of UL 2034. The standard's sensitivity concentrations and corresponding alarm response time requirements were chosen because they represent the widely recognized threshold for a diagnosis of CO poisoning of 10 percent

carboxyhemoglobin (COHb). At 10 percent COHb adverse health symptoms first become perceptible, yet the consumer still would have time to properly respond to rising CO levels.

In July 2002, the Gas Technology Institute (GTI) presented test data to CPSC staff that indicated some alarms might not function adequately under realistic in-home conditions. Specifically, GTI alleged that, 1) the alarms may not properly respond to CO concentrations at test points other than those specified in UL 2034, and 2) alarms may not adequately respond to rising CO levels, thus alarming at higher COHb levels than specified[1]. As a result of these assertions, LS evaluated previously tested CO alarms at intermediate CO concentrations or test points. Additional tests challenged the units with rising CO levels. This report summarizes the results of both sets of tests, discusses CPSC staff concerns, and provides recommendations for improvements to UL 2034.

Sensitivity Test Program

In the past, when CPSC received allegations that a CO alarm had failed to provide adequate CO poisoning protection, LS tested the sample to the conditions specified in the appropriate edition of UL 2034. The "must alarm" set points correspond to the length of time it would take a heavily exercising healthy active adult to achieve 10 percent carboxyhemoglobin (COHb) in their blood; that is, when the onset of perceptible symptoms of CO poisoning would first be expected to occur. In October 1998 the standard was modified, and the must alarm requirements were changed to certify performance at lower CO concentrations while still corresponding to 10 percent COHb (see Table 1). Therefore, alarms manufactured after October 1998 were tested to different requirements than pre-1998 models.

Table 1
Must Alarm Requirements in UL 2034

Requirements Prior to 1998		Requirements After 1998	
Concentration	Time to Alarm	Concentration	Time to Alarm
400 ppm CO	<15 min.	400 ± 10ppm CO	>4<15 min.
200 ppm CO	<35 min.	150± 5 ppm CO	>10<50 min.
100 ppm CO	<90 min.	70 ±5 ppm CO	>60<240 min.

False Alarm Resistance Requirements in UL 2034

no alarm below 30 ppm until after 30 days
no alarm below 70 ppm until 60 min.

The false alarm resistance specifications are included in the standard to prevent nuisance alarms. The 70 ppm for 1-hour requirement is to protect against alarms due to transient CO levels and the 30 ppm for 30 days is to protect against alarm activation due to temperature inversions

The UL 2034 "must alarm" sensitivity tests are conducted only at the three concentrations listed above. Currently, the standard specifies that the CO concentration in the test chamber be rapidly raised from 0 to the test concentration in 3 minutes. It is

[1] GRI-02/0112. "Evaluating the Performance of Residential CO Alarms", prepared by Mosaic Industries, Inc. for the Gas Technology Institute, June, 2002

therefore theoretically possible for a CO alarm to pass the sensitivity tests, but not respond adequately at concentrations between those of the "must alarm" points, such as 300-ppm CO.

Generally, CO levels in a house rise slowly because; 1) the source of CO is often "weak," and 2) the air change rate, measured in house volumes per hour (ACH), acts to remove CO from the home. This would suggest that the current 3-minute rise time specified in the standard may be too fast to adequately mimic in-home conditions. However, at the other extreme, the 3-minute rise time adequately imitates the conditions caused by engine-driven portable generators, which are becoming a popular consumer item. These products are predicted, under foreseeable conditions, to cause CO levels to rise very quickly to levels much higher than 400ppm, a scenario which is adequately covered in the current standard requirements. Therefore, CPSC staff believes that the standard should include both a new slower buildup performance requirement, more closely mimicking the CO buildup from a heating appliance, and the rapid rise time currently in the standard.

LS also developed new test procedures to investigate two GTI allegations (see LS report at Attachment 1) of CO alarm sensitivity shortcomings. These consisted of intermediate, near-static CO concentration tests and dynamic concentration tests.

Intermediate, Near Static Concentration Tests Results

LS staff conducted intermediate, near static concentration tests in September 2002. The eight test units were field samples that were alleged to have failed to alarm properly in consumers' homes. They subsequently performed satisfactorily when tested by LS staff at the UL test concentrations. They included both pre- and post-1998 units. The five pre-1998 units were tested at 300 ppm and 350 ppm CO. In these tests, the CO concentration was rapidly increased from 0 ppm to the target concentration within 3 minutes as specified in UL 2034. Time to alarm, alarm readout of CO concentration at time of alarm, laboratory CO analyzer reading at time of alarm, temperature, and relative humidity were recorded. Temperature was controlled at 23 °C for all tests and the humidity was between 48 and 55 percent relative humidity.

Results for pre-1998 units

Results for the five pre-1998 units are summarized in Table 2. When tested at 300 ppm, all five samples alarmed satisfactorily. The samples were then challenged with 350 ppm CO and all alarmed satisfactorily. Examination of Table 2 shows the digital displays on the three units with this feature were extremely inaccurate. One sample (see bold in Table 2) read low and showed 257 ppm when the chamber concentration was 310 ppm CO and 265 ppm when the chamber was at 352 ppm. Two others read much higher than the actual CO level and alarmed safely.

Results for post-1998 units

The alarm results for units made after October 1998 are presented in Table 3. None of these alarms had digital displays. With one exception, all of the alarms activated before the requirement for 400 ppm CO; COHb levels would therefore be below 10 percent. The exception alarmed at 20 and 26 minutes when challenged with 340 ppm and 275 ppm, respectively (see bold in table). These time/concentration points

TABLE 2
INTERMEDIATE TEST RESULTS FOR ALARMS MANUFACTURED BEFORE 10/98

Sample No.	Test CO Conc.	Alarm Time	Alarm Display Reading	Analyzer Reading	Std. for 400 ppm	Std. for 200 ppm
01-810-2260	300 ppm	12 min.	N/A	305 ppm	<15 min.	<35 min.
02-840-6197	300 ppm	3 min. 20 sec.	639 ppm	303 ppm	<15 min.	<35 min.
02-830-4296	300 ppm	8 min. 15 sec.	N/A	305 ppm	<15 min.	<35 min.
01-840-6328-01	300 ppm	5 min.	512 ppm	303 ppm	<15 min.	<35 min.
01-840-6328-02	**300 ppm**	**13 min. 30 sec.**	**257 ppm**	**310 ppm**	**<15 min.**	**<35 min.**
01-810-2260	350 ppm	8 min. 20 sec.	N/A	351 ppm	<15 min.	<35 min.
02-840-6197	350 ppm	3 min.	763 ppm	350 ppm	<15 min.	<35 min.
02-830-4296	350 ppm	7 min.	N/A	352 ppm	<15 min.	<35 min.
01-840-6328-01	350 ppm	5 min.	561 ppm	351 ppm	<15 min.	<35 min.
01-840-6328-02	**350 ppm**	**9 min. 30 sec.**	**265 ppm**	**352 ppm**	**<15 min.**	**<35 min.**

TABLE 3
INTERMEDIATE TEST RESULTS FOR ALARMS MANUFACTURED AFTER 10/98

Sample No.	Test CO Conc.	Alarm Time	Alarm Reading	Analyzer Reading	Std. for 400 ppm	Std. for 150 ppm
02-830-4054	340 ppm	4 min. 20 sec.	N/A	338 ppm	15 min.	50 min.
02-830-4635	**340 ppm**	**20 min.**	**N/A**	**343 ppm**	**15 min.**	**50 min.**
01-810-3004	340 ppm	7 min.	N/A	331 ppm	15 min.	50 min.
02-830-4054	275 ppm	5 min. 30 sec.	N/A	273 ppm	15 min.	50 min
02-830-4635	**275 ppm**	**26 min.**	**N/A**	**276 ppm**	**15 min.**	**50 min.**
01-810-3004	275 ppm	4 min. 55 sec.	N/A	272 ppm	15 min.	50 min.

correspond to 10.5 percent and 10.6 percent COHb, respectively, and would not pose a significant health hazard to consumers.

Dynamic CO Concentration Testing Results

The GTI information alleged that currently certified CO alarms did not respond to rising CO levels in time to prevent exposure to harmful CO levels. In order to determine the validity of this allegation, LS staff developed a test plan simulating the buildup of CO in a home and tested 40 CO alarms to this plan (see LS test report, Attachment 1).

Of the 40 alarms, 32 of the units were previously included in the on-going long-term test program being conducted by LS. Eight units were samples from incident investigations. Table 4 lists the tested alarms, the technology used in the alarm sensor (where available), the manufacture date, and the program origin of the sample.

The 32 units from the long-term testing were previously tested in May and July 2002. Since then they were stored at LS while connected to their power source. The 8 incident sample alarms were previously tested in September 2002, and were stored in the un-energized condition at the CPSC warehouse. Because the histories of the tested alarms are not the same, the results for the two sets (i.e., the long-term units and the incident units) cannot be directly compared. However, observations about the

performance of individual units can be made. All units were preconditioned 48 hours in an energized state at 23°C and 50 percent relative humidity (RH) immediately before testing.

The dynamic concentration test program exposed the test samples to a slow CO buildup, less than 50 ppm/hr, which is comparable to what could be seen in a house with a malfunctioning combustion appliance. Time to alarm, digital display readout (alarm reading), CO concentration in the chamber at the time of alarm, chamber temperature and relative humidity were recorded. These data are presented in Table 5.

Thirteen of the alarms had digital readouts. Only one unit's display (99-830-4519-01) was within 10 percent of measured chamber concentration at time of alarm. Two units (00-792-0714-02 and 01-840-6328-01) were within 15 percent. The digital readouts on the remaining ten units with digital displays varied by 19 percent to 69 percent of actual chamber concentration, verifying the poor accuracy results from the previous near-static concentration tests. Because the CO concentration was increasing during the tests, the time to alarm results cannot be interpreted against the static CO concentrations specified in UL 2034. However, the results can be interpreted by modeling the COHb levels that would result from exposure to the conditions in the test.

The CO buildup rate (about 50 ppm/hr) data was combined with the data from Table 5 and analyzed by the Directorate for Health Sciences (HS) (see Attachment 2) to estimate the COHb level that would occur in an individual if exposed to the conditions of the tests. The HS analysis was done in two parts. First, HS did a screening calculation to determine which alarms should be examined more closely. For the screening calculation, HS assumed a worst case scenario, i.e., that the alarms had been exposed, from the start of the test to the alarm time, to a constant CO concentration equal to the CO concentration at the time of alarm. HS staff then calculated the COHb levels that would have occurred in a consumer exposed to the same conditions. HS staff also assumed that exposed individuals were engaged at a high activity level, corresponding to a respiration rate of 30L/min., as used in UL 2034. For those units which exceeded 10 percent COHb at 30 L/min, COHb levels were also calculated using a moderate respiration rate of 15 L/min (moderate activity level) and in some cases a very low activity respiration rate (sleeping) corresponding to 6 L/min. The screening tests identified 12 alarms that could possibly allow a CO exposure exceeding 10 percent COHb under the worst case conditions of the screening calculation. These units are termed "Check Alarms" and were further analyzed. Alarms that did not reach 10 percent COHb under the worst case scenario were dropped from further examination.

HS staff modeled more accurate COHb percentage estimates for the 12 "Check Alarms" using CO buildup data from the LS tests and a nonlinear form of the Coburn-Forster-Kane (CFK) equation. It is recognized as being more physiologically accurate than the linear form used in UL 2034. These calculations resulted in a much lower estimated COHb level than estimated in the screening calculations. The results of the more detailed calculations using the CFK equation and high, moderate and low activity levels are presented in Table 6. In Table 6, the section labeled High or Moderate or Low Activity (RMV=30L/min., 20L/min. or 10 L/min.) refers to the respiration rate of an individual exposed at the various activity levels. (The respiration rate of 10 L/min was

TABLE 4
TEST ALARMS
Dynamic CO Concentration Test

Sample No.	Sensor Type	Manufacture Date	Alarm Program
99-830-4517-4	Metal Oxide	Pre 10/98	Long Term
99-830-4517-9	Metal Oxide	Pre 10/98	Long term
99-830-4519-1	Metal Oxide	Nov 96	Long Term
99-830-4519-3	Metal Oxide	Nov 96	Long Term
00-792-0689-2		Pre 10/98	Long Term
00-792-0689-5		Pre 10/98	Long term
00-830-3472-2		2000	Long Term
00-830-3472-4		2000	Long Term
00-792-0681-1	Biomimetic	12/99	Long Term
00-792-0681-5	Biomimetic	1/00	Long Term
99-800-1314-4	Biomimetic	Pre 10/98	Long Term
99-800-1314-11	Biomimetic	Pre 10/98	Long Term
99-860-5821-1	Metal Oxide	Pre 10/98	Long Term
99-860-5821-8	Metal Oxide	Pre 10/98	Long Term
00-792-0677-3	Ionization	9/99	Long term
00-792-0677-5	Ionization	9/99	Long Term
00-792-0680-5	Metal Oxide	1/00	Long term
00-792-0680-6	Metal Oxide	1/00	Long Term
00-792-0751-1	Metal Oxide	1/00	Long Term
00-792-0751-3	Metal Oxide	1/00	Long Term
00-792-0685-1		1999	Long Term
00-792-0685-2		1999	Long Term
00-792-0686-3		2000	Long Term
00-792-0686-6		2000	Long term
00-792-0604-1	Biomimetic	Post 10/98	Long Term
00-792-0604-3	Biomimetic	Post 10/98	Long Term
99-792-0299-14	Metal Oxide	11/98	Long Term
99-792-0299-15	Metal Oxide	1/99	Long Term
00-792-0602-3	Electrochem.	2/99	Long Term
00-792-0602-4	Electrochem.	2/99	Long Term
00-792-0714-2	Electrochem.	3/99	Long Term
00-792-0714-6	Electrochem.	3/99	Long Term
02-830-4054-1		10/00	Incident
01-810-3004-1	Biomimetic	9/99	Incident
02-830-4296-1		Pre 10/98	Incident
01-810-2260-1		11/97	Incident
02-840-6197-1		9/97	Incident
01-840-6328-1		2/96	Incident
01-840-6328-2		2/96	Incident
02-830-4635-1		9/99	Incident

TABLE 5
ALARM RESULTS FOR SLOW CO BUILD-UP
Dynamic CO Concentration Tests

Sample No.	Time to Alarm (minutes)	Alarm Reading (ppm CO)	Chamber Conditions		
			CO (ppm)	Temp. (°C)	% RH
99-830-4517-4	111	N/A	90	23.3	19
99-830-4517-9	120	N/A	96	23	19
99-830-4519-1	129	111	103	23.3	20
99-830-4519-3	98	131	81	23.3	19
00-792-0689-2	129	N/A	92	23.2	49
00-792-0689-5	112	N/A	87	23.3	50
00-830-3472-2	156	57	103	23.3	24
00-830-3472-4	254	45	145	23.3	24
00-792-0681-1	90	N/A	74	23.2	27
00-792-0681-5	97	N/A	77	23.2	27
99-800-1314-4	101	N/A	85	23.1	35
99-800-1314-11	106	N/A	86	23.2	35
99-860-5821-1	115	N/A	87	23.3	50
99-860-5821-8	63	N/A	57	23.2	49
00-792-0677-3	176	N/A	137	23.2	19
00-792-0677-5	177	N/A	137	23.2	19
00-792-0680-5	179	95	141	23.1	12
00-792-0680-6	185	91	142	23.3	11
00-792-0751-1	159	96	123	23.3	18
00-792-0751-3	182	101	138	23.2	22
00-792-0685-1	89	N/A	72	23.4	23
00-792-0685-2	94	N/A	74	23.1	23
00-792-0686-3	155	N/A	103	23.3	24
00-792-0686-6	217	N/A	128	23.2	23
00-792-0604-1	118	N/A	89	23.2	34
00-793-0604-3	123	N/A	90	23.2	34
99-792-0299-14	180	N/A	139	23.1	19
99-792-0299-15	121	N/A	97	23.2	19
00-792-0602-3	167	N/A	96	23.1	29
00-792-0602-4	172	N/A	98	23.1	29
00-792-0714-2	141	98	88	23.1	29
00-792-0714-6	165	106	131	23.3	18
02-830-4054-1	110	N/A	80	23.1	33
01-830-3004-1	92	N/A	70	23.2	32
02-830-4296-1	75	N/A	59	23.2	32
01-810-2260-1	132	N/A	94	23.1	49
02-840-6197-1	90	97	82	23.2	19
01-840-6328-1	151	100	115	23.2	21
01-840-6328-2	314	64	204	23.2	19
02-830-4635-1	219	N/A	152	23.3	19

chosen as the lower level for these calculations because it is more conservative than the 6 L/min. sleeping rate.) This is important, as the respiration rate has a major effect on the rate that CO is absorbed to produce COHb. "Alarm Time" presents the time it took for the alarm to activate after being exposed to CO. The next column, "ppm CO at alarm," shows the concentration of CO in the chamber, measured by laboratory grade analytical instruments, when the alarm first sounded. "Lab Test I.D." identifies the test reference number. "%COHb re constant peak" represents the maximum estimated COHb level that could have been reached if a consumer was exposed to a constant CO level equal to "ppm CO at alarm" for the entire time of the test. "Time above 10% COHb (constant)" indicates the length of time an individual at the designated activity level would be above 10 percent COHb as a result of the exposure described in the preceding column. The most significant measure, "%COHb from profile," is the calculated COHb level that would result from exposure to the rising CO level (nominal 50 ppm/hr.) for the exposure time indicated in the column marked "Alarm Time." These COHb levels are lower than those calculated using a constant CO concentration at the peak level attained before the alarm activated. The length of "Time above 10 percent COHb (rising)" is also necessarily shorter for the COHb levels calculated using the rising CO concentrations. The last column "HS view" presents the judgment of the HS staff as to the seriousness of the risk of significant CO poisoning. "OK" indicates the estimated COHb level was below the 10 percent level, as specified in the standard. "TV-ok" (a technical violation) indicates the alarm exceeded the 10 percent COHb level required in the standard, but the exposure was short and was not sufficient to pose a serious risk of CO poisoning. "UA" (unacceptable) indicates unacceptable performance that would pose a serious hazard to the consumer.

For these 12 "Check Alarms," HS concluded that 11 of the 12 alarms were theoretically in violation of the 10 percent COHb threshold at the high activity level used in UL 2034. However, the amount by which these units exceeded 10 percent COHb was small, and the units alarmed before an individual's ability to react to the presence of CO would likely be compromised by the prevailing CO exposure conditions assumed in UL 2034. At the lower respiration rates more typical of most household activity levels, only one sample, 01-840-6328-2 (**in bold in the tables**), exceeded the 10 percent COHb level. Its performance is judged to be unacceptable because it would pose a serious risk of CO poisoning.

Standard Activities

The Underwriters Laboratories Standard "Single and Multiple Station Carbon Monoxide Alarms" (UL 2034) is the voluntary standard that applies to these products. UL 2034 is an accredited American National Standard Institute (ANSI) standard. The CPSC staff is a member of the Standard Technical Panel (STP) for this standard. The most recent meeting of the STP for UL 2034 was held January 31, 2003.

As the result of its testing, GTI made a number of recommendations to the STP in January 2003, to improve UL 2034. In general, the GTI proposals can be broken down into sensitivity test issues, which are the subject of the CPSC staff test programs, and miscellaneous proposals. CPSC staff shares many of GTI's concerns regarding shortcomings in the current standard. The CPSC staff test program, however, was undertaken to look at only two issues: 1) Do the alarms activate properly when challenged with CO concentrations between the test points specified in Section 38 of the

TABLE 6
HS ASSESSMENT OF 12 "CHECK ALARMS"

High Activity (RMV= 30L/min)									
sample #	Sub	**Alarm time (mins)**	**ppm CO at alarm**	Lab Test I.D.	**%COHb re: constant peak**	**time above 10% COHb (constant)**	**%COHb from CO profile**	**time above 10% COHb (profile)**	**HS view - OK?**
01-840-6328-02	**2**	**314**	**204**	**173**	**25.1**	**4h 40**	**22.45**	**164 min**	**UA**
02-830-4635	1	219	152	171	19.1	2h 40 min	15.5	65 min	TV-ok
00-830-3472	4	254	145	156	18.8	3h 20 min	14.8	80 min	TV-ok
00-792-0680-06	6	185	142	170	17.4	2h	12.9	35 min	TV-ok
00-792-0680-05	5	179	141	168	17.1	2h	12.62	30 min	TV-ok
99-792-0299	14	180	139	171	16.9	1h 40 min	12.58	30 min	TV-ok
00-792-0751-03	3	182	138	175	16.8	2h	12.37	77 min	TV-ok
00-792-0677	3	176	137	171	16.7	2h	12.58	30 min	TV-ok
00-792-0677	5	177	137	171	16.7	2h	12.58	30 min	TV-ok
01-792-0686	6	217	128	156	16.5	1.5h	12.9	45 min	TV-ok
00-792-0714	6	165	131	171	15.7	1h 40 min	11.31	15 min	TV-ok
00-792-0751-01	1	159	123	165	14.7	1.5h	10.61	10 min	TV-ok

Moderate Activity (RMV= 20L/min)									
sample #	Sub	**Alarm time (mins)**	**ppm CO at alarm**	Lab Test I.D.	**%COHb re: constant peak**	**time above 10% COHb (constant)**	**%COHb from CO profile**	**time above 10% COHb (profile)**	**HS view - OK?**
01-840-6328-02	**2**	**314**	**204**	**173**	**24**	**4h**	**20.24**	**134 min**	**UA**
02-830-4635	1	219	152	171	17.1	2h	12.8	35 min	TV-ok
00-830-3472	4	254	145	156	17.2	2h 20min	12.5	50 min	TV-ok
00-792-0680-06	6	185	142	170	16.1	1h	10.28	5 min	OK
00-792-0680-05	5	179	141	168	14.9	1h	10.12	5 min	OK
99-792-0299	14	180	139	171	14.7	1h	10.08	5 min	OK
00-792-0751-03	3	182	138	175	14.7	1h	9.94	NA	OK
00-792-0677	3	176	137	171	14.4	1h	10.08	5 min	OK
00-792-0677	5	177	137	171	14.4	1h	10.08	5 min	OK
01-792-0686	6	217	128	156	14.7	1h 20 min	10.7	11 min	OK
00-792-0714	6	165	131	171	13.4	30min	8.98	NA	OK
00-792-0751-01	1	159	123	165	12.5	15 min	8.38	NA	OK

TABLE 6 (CONT'D)
HS ASSESSMENT OF 12 "CHECK ALARMS"

Low Activity (RMV= 10L/min)									
sample #	Sub	Alarm time (mins)	ppm CO at alarm	Lab Test I.D.	%COHb re: constant peak	time above 10% COHb (constant)	%COHb from CO profile	time above 10% COHb (profile)	HS view - OK?
01-840-6328-02	**2**	**314**	**204**	**173**	**19**	**1h 45 min**	**14.25**	**60 min**	**UA**
02-830-4635	1	219	152	171	12	NA	8	NA	OK
00-830-3472	4	254	145	156	12.5	NA	8.4	NA	OK
00-792-0680-06	6	185	142	170	10.1	5 min	6.31	NA	OK
00-792-0680-05	5	179	141	168	9.9	NA	6.27	NA	OK
99-792-0299	14	180	139	171	9.8	NA	6.25	NA	OK
00-792-0751-03	3	182	138	175	9.8	NA	6.19	NA	OK
00-792-0677	3	176	137	171	9.5	NA	6.25	NA	OK
00-792-0677	5	177	137	171	9.5	NA	6.25	NA	OK
01-792-0686	6	217	128	156	10.2	NA	6.8	NA	OK
00-792-0714	6	165	131	171	10.4	NA	5.55	NA	OK
00-792-0751-01	1	159	123	165	8.1	NA	5.14	NA	OK

standard (sensitivity): and 2) Do CO alarms provide adequate protection when challenged with a rising CO level, as would be found in the field?

Alarm Sensitivity Issues

Response to Rising CO Levels and Intermediate CO Concentrations

The issue of CO alarms not responding at the levels specified in UL 2034 when exposed to rising CO levels was discussed at the January 31, 2003 STP meeting. GTI made a proposal to amend the standard to account for rising CO levels, supported by its conclusion that "Alarms don't alarm at safe levels. Recent tests of UL-certified CO alarms available at retail show that even for those models that do comply with UL Section 38's sensitivity specification, many often fail to alarm at 10% COHb when presented with realistic CO concentration profiles."[2] GTI suggests that this shortcoming could be overcome by using an integrating algorithm in the alarms to calculate COHb and to sound the alarm when the calculated COHb reaches 10 percent.

The results of both the intermediate CO concentration tests and the dynamic CO concentration tests performed by CPSC staff clearly show that many of the tested alarms did **not** meet the requirement of the sensitivity tests in UL 2034. However, the alarms tested by CPSC staff were all units that had been tested before or had been in use in the field for some period of time, thus possibly degrading their performance somewhat. Nevertheless, with one exception, the units CPSC staff tested, while not

[2] "Recommendation to the Standards Technical Panel for UL 2034," Clifford, P., January 21, 2003

always alarming at or before 10 percent COHb, did alarm before a consumer exposed to the conditions would be unable to take appropriate action to protect themselves from CO poisoning. Even though the alarms clearly provide a reasonable level of safety, the fact that the alarms do not meet the requirements of the standard diminishes the acceptability of CO alarms with code officials, fuel suppliers, and first responders. To improve the reputation and acceptability of CO alarms, CPSC staff agrees with the GTI recommendations to address this issue in the standard with additional test requirements.

Standardization of Integrating Logarithm

GTI presented the view that the test points in the standard do not adequately reflect the 10 percent COHb curve on which the standard is based. GTI recommended that the standard explicitly state that CO alarms must activate at or below 10 percent COHb. This could be accomplished by requiring CO alarms to use a standardized integrating algorithm to calculate COHb while it is being exposed to CO. The alarm would then be designed to alarm at or below 10 percent COHb when exposed to CO, regardless of the concentration-time profile. Some members of the STP expressed support for the "spirit of the proposal but indicated that it needs to include examples of exposures and an example of a CO presentation profile." The GTI agreed to re-write the proposal taking into consideration the issues raised during the meeting.

CPSC staff supports this approach. In 1996, CPSC staff recommended that the alarms activate at or below 10 percent COHb. At that time staff believed that if the alarms activated at or below the "must alarm" points in the standard, which are based on 10 percent COHb, then they would properly activate at intermediate concentrations, regardless of the concentration-time profile. The most recent CPSC staff testing clearly shows that this is not the case and that CO alarm model performance varies widely. Staff agrees with GTI that if a standardized integrating algorithm is used in the alarm, consistent alarm performance could be achieved between different models, which would be beneficial to consumers and particularly to first responders.

Test Conditions

GTI also was concerned that the test conditions in the UL standard's sensitivity tests do not appropriately protect the population that is being exposed to the CO. GTI bases this concern on the fact that the COHb curve used in the standard is based on the respiration rate of heavily exercising young men who would have a respiration rate much higher than a consumer in their home.

CPSC staff does not believe that the way the high respiration rate is used to calculate COHb in the standard puts consumers at risk. To the contrary, the way the COHb is calculated offers a margin of safety to less active individuals because the rate of COHb formation in the blood increases with increasing respiration rate.

Miscellaneous Concerns

End of Life Failure Concerns

The CPSC staff continues to be very concerned about the long-term reliability of CO alarms, particularly "end of life" failures of CO alarms currently in consumer use. Although CPSC staff has not found any CO alarms that have failed to alarm due to old

age, staff believes it is inevitable that this will occur. The sensors incorporated in CO alarms have a finite life, after which they will no longer respond adequately. End of life failures can either be a failure of the alarm to respond at all, or calibration drift such that the alarm does not sound soon enough to prevent death or injury. UL 2034 does not require any type of warning or signal when the sensor becomes inoperable. Because of this concern, in 2000, the CPSC staff initiated a long-term reliability test program to ascertain how CO alarms respond over their life.[3] The results of the long-term testing are not included in this report because, to date, that testing has not been of long enough duration to provide meaningful results.

The issue of the lack of notification that the alarm has become unresponsive due to age (unsupervised end of life failure) was discussed at the January 2003 STP meeting. The author of the GTI report that prompted the CPSC staff CO alarm test program submitted a proposal[2] to amend UL 2034 to "require either 1) permanent marking of a replacement date on the detector, or 2) an end-of-life signal coupled with a stick-on replacement date marking."

The STP members objected to the concept of a marking because it would have to be small to fit on the device; the consumer would have difficulty seeing the label; and ".... therefore such a marking should also appear on the product packaging. There were also concerns expressed regarding the marking of a specific date on the product due to issues involving packaging, shipping, and shelf time for various types of products. It was suggested that a number of months be indicated, rather than a specific date."[4] The GTI agreed to re-write the proposal taking into consideration the issues raised at the STP meeting.

The CPSC staff agrees with part of the proposal. UL 2034 should include an "end of life" signal requirement. However, staff does not believe that a permanent marking specifying a "replace by date" on the product is an acceptable alternative to having an "end of life" signal that actuates at a predetermined date corresponding to the expected useful life of the product. Because CO alarms are physically small devices, a label would necessarily be small. If the alarm were mounted on the ceiling, it would be very difficult for the consumer to see the label after installation. An audible and visual "end-of-life" signal that activates as the result of a continuous "self check" for proper calibration would be the best solution. Alternatively, an "end of life" signal that activates at a predetermined manufacturer-specified date (based on expected calibration drift as determined by the manufacturer) would be an acceptable method to warn consumers that the alarm may no longer be functioning as designed.

Inaccurate Digital Displays

The digital displays on CO alarms performed poorly in the CPSC staff's dynamic CO concentration tests. Thirteen of the alarms had digital readouts. Only one unit's display (99-830-4519-01) was within 10 percent of measured chamber concentration at time of alarm. Two units (00-792-0714-02 and 01-840-6328-01) were within 15 percent. The accuracy of the remaining ten units with digital displays

[3] 2003 Budget and Performance Plan (Operating Plan), page 37, March 2003
[4] "Report of the Meeting of the Standards Technical Panel of UL for Carbon Monoxide Alarms and Gas Detectors"; Underwriters Laboratories, March 14, 2003.

varied from 19 percent to 69 percent of actual chamber concentration, verifying the poor accuracy results from the previous near-static concentration tests. GTI recommended that UL 2034 specify that an alarm must have an accuracy of +/- 5 ppm for concentrations less than 33 ppm and +/- 15% of actual value for greater CO concentrations. CPSC staff believes that if the CO alarms have a digital readout, there must be a strong correlation between the CO concentration and the readout on the alarm. UL agreed to prepare a proposal for alarm accuracy. Based on the results of its testing, CPSC staff supports this action.

Conclusions and Recommendations

CPSC staff believes that CO alarms that are certified to UL 2034 offer a level of safety to the consumer. The results of the most recent CO alarm testing programs reveal that further improvement in the standard is desirable. When challenged with rising CO concentrations typical of the conditions found in a home, 12 of the 40 CO alarms exceeded the 10 percent COHb level prescribed in UL 2034. However, because of the safety margin built into the standard and when the COHb is calculated using a more physiologically accurate version of the Coburn-Forster-Kane equation, only one sample would have put the consumer at risk of significant health effects. Nevertheless, staff believes that the following recommended changes to UL 2034 could improve alarm performance:

1. The alarms should activate at or before a 10 percent COHb level regardless of the concentration-time profile. This would assure that the products would properly activate when faced with rising CO levels in the home.

2. A sensitivity test should be included that incorporates a rising CO level to certify performance to the requirement to alarm at or before 10 percent COHb, as recommended above.

3. Alarms should include standardized integrating algorithms to insure that all manufacturers use appropriate coding in their products.

4. Alarms should have a warning signal that alerts consumers when the sensor in the product is nearing end-of-life to insure that out of calibration or inoperative CO alarms are removed from service.

5. A minimum digital readout accuracy should be specified for alarms incorporating this feature.

CPSC staff plans to submit recommendations to amend UL 2034 in accordance with these findings.

Attachment 1

United States
Consumer Product Safety Commission
Washington, D.C. 20207

MEMORANDUM **DATE:** December 19, 2003

To: Donald Switzer, Engineering Sciences
Through: Andrew G. Stadnik, P.E., Associate Executive Director, Directorate for Laboratory Sciences
Through: James C. Hyatt, P.E., Director, Mechanical Engineering Division
From: Joseph J. Puskar, Mechanical Engineering Division

Subject: Slow Carbon Monoxide Buildup Testing of Carbon Monoxide Alarms

SUMMARY: The time to alarm for forty carbon monoxide (CO) alarms was determined when the CO concentration was slowly increased in the CPSC Laboratory's CO alarm test chamber. The CO buildup rate was less than 50 parts per million (ppm) per hour. The digital readout on 13 CO alarms, that had a digital readout feature, was also compared to the measured CO concentration in the test chamber.

BACKGROUND: The Underwriters Laboratory (UL) Standard UL-2034 "Single and Multiple Station Carbon Monoxide Alarms" specifies a maximum response time for CO alarms when tested at three different concentrations of carbon monoxide. For CO alarms manufactured before October 1, 1998, the test concentrations and maximum response times are:

1. 100 ppm - 90 minutes
2. 200 ppm - 35 minutes
3. 400 ppm - 15 minutes

For CO alarms manufactured after October 1, 1998, the test concentrations and maximum response times are:

1. 70 ±5 ppm - 60 to 189 minutes
2. 150 ±5 ppm - 10 to 50 minutes
3. 400 ±10 ppm - 4 to 15 minutes

UL bases these test points on the 10 percent Carboxyhemoglobin (COHb) curve in Figure 38.1 of the UL Standard. Carboxyhemoglobin is the result of CO binding to the hemoglobin in the bloodstream when the body is exposed to CO. Percent carboxyhemoglobin (%COHb) indicates the level to which the oxygen-carrying capacity of the blood is blocked because of the CO binding to

the hemoglobin in the bloodstream. Carboxyhemoglobin concentrations under 10% are not acutely poisonous. Higher concentrations of COHb increase the chance of permanent brain damage or even death as shown in Figure 38.1 of the UL Standard.

The UL-2034 Standard specifies that the test CO concentration listed above be attained in the test chamber within three minutes after placing the alarm in the chamber and sealing the chamber. The test CO concentration is then maintained in the chamber and the alarm response time to the test CO concentration is noted. Because the UL Standard tests the alarms at a few constant concentrations, it may be possible for a manufacturer to program the alarm to alarm at the test CO levels. If a situation occurs in which the CO concentration builds up slowly, the CO alarm may not alarm before the COHb reaches the desired 10% limit. In real life, the CO alarm would probably experience a slow buildup of CO (as from a malfunctioning furnace or heater) rather than a fixed concentration of CO as found in the UL tests. In this testing, the response times of the CO alarms were determined when the alarms were subjected to a slow CO buildup (under 50 ppm CO per hour).

TEST ALARMS: Forty CO alarms were tested. Thirty-two alarms were from the "Long-term Carbon Monoxide Alarm/Detector Testing" program started in FY 2002 for the Recalls and Compliance Division. These units were tested between May, 2002, and July, 2002, to the applicable UL 2034 Compliance Standard Test CO concentrations. The alarms were then stored in the energized condition at the CPSC Lab.

The remaining eight alarms were incident samples sent to Compliance. These alarms were also previously tested to the UL-2034 Standard by LS Staff. After testing in 2002, these eight alarms were stored de-energized at the CPSC Warehouse. Table 1 lists the 40 alarms tested.

TABLE 1
TEST ALARMS

Sample No.	Sub No.	Alarm Type	Manufacture Date	Alarm Program
99-830-4517	4	Metal Oxide	Pre 10/98	Long Term
99-830-4517	9	Metal Oxide	Pre 10/98	Long term
99-830-4519	1	Metal Oxide	Nov 96	Long Term
99-830-4519	3	Metal Oxide	Nov 96	Long Term
00-792-0689	2		Pre 10/98	Long Term
00-792-0689	5		Pre 10/98	Long term
00-830-3472	2		2000	Long Term
00-830-3472	4		2000	Long Term
00-792-0681	1	Biomimetic	12/99	Long Term
00-792-0681	5	Biomimetic	1/00	Long Term
99-800-1314	4	Biomimetic	Pre 10/98	Long Term
99-800-1314	11	Biomimetic	Pre 10/98	Long Term
99-860-5821	1	Metal Oxide	Pre 10/98	Long Term
99-860-5821	8	Metal Oxide	Pre 10/98	Long Term
00-792-0677	3	Ionization	9/99	Long term
00-792-0677	5	Ionization	9/99	Long Term
00-792-0680	5	Metal Oxide	1/00	Long term
00-792-0680	6	Metal Oxide	1/00	Long Term
00-792-0751	1	Metal Oxide	1/00	Long Term
00-792-0751	3	Metal Oxide	1/00	Long Term
00-792-0685	1		1999	Long Term
00-792-0685	2		1999	Long Term
00-792-0686	3		2000	Long Term
00-792-0686	6		2000	Long term
00-792-0604	1	Biomimetic	Post 10/98	Long Term
00-792-0604	3	Biomimetic	Post 10/98	Long Term
99-792-0299	14	Metal Oxide	11/98	Long Term
99-792-0299	15	Metal Oxide	1/99	Long Term
00-792-0602	3	Electrochem.	2/99	Long Term
00-792-0602	4	Electrochem.	2/99	Long Term
00-792-0714	2	Electrochem.	3/99	Long Term
00-792-0714	6	Electrochem.	3/99	Long Term
02-830-4054	1		10/00	Incident
01-810-3004	1	Biomimetic	9/99	Incident
02-830-4296	1		Pre 10/98	Incident
01-810-2260	1		11/97	Incident
02-840-6197	1		9/97	Incident
01-840-6328	1		2/96	Incident
01-840-6328	2		2/96	Incident
02-830-4635	1		9/99	Incident

The "alarm type" information listed in Table 1 was taken from previous LS test reports, from information printed on the alarm, or from the literature supplied with the alarm. Blank spaces in the "alarm type" column indicate that the alarm type could not be determined from the information that was available. No disassembly of the alarms was performed.

TEST PROGRAM: Prior to testing, each alarm was conditioned for at least 48 hours in the Hotpack Chamber located in Building A at the CPSC Lab. The alarms were conditioned in the energized state (either battery power or 110 VAC). The Hotpack was maintained at a temperature of 23 +/- 3 degrees Centigrade (73.4 +/- 5 degrees Fahrenheit) and 50 +/- 20 % Relative Humidity. After conditioning the alarm was placed in a sealed plastic bag and carried to Building G for testing. A Lunaire Environmental Steady State Test Chamber, Model CE0932W-4, is used by LS for testing CO alarms. See Photograph 1. The chamber has a volume of 0.9 m^3 (32 ft^3). Heating, cooling, and humidity in various combinations can be maintained in the chamber to meet the desired test requirements. A Munters MG 90 dehumidifier is also installed on the chamber to dehumidify the chamber air. The procedures outlined in the "Chamber Operating Procedure for Testing CO Detectors" (May 2002) were followed with some modifications in this testing.

Photograph 1 – CO Alarm Test Setup - Data Acquisition System (Computer), Front of Instrument Rack, and Front of Lunaire Test Chamber.

The test chamber was maintained at 23 +/- 3 degrees Centigrade during the slow CO buildup tests. In this testing it was decided to test some of the alarms at low humidity. The Munters MG 90 dehumidifier was not operational for these tests. Since the tests were run during the winter, when the building heating system was operating and the outside humidity was low, the chamber ran at or below 50% RH. Neither the humidifier nor the dehumidifier systems were used. See Table 2 below for the chamber and Building G relative humidity during each test.

The fine CO injection system installed on the chamber was used to inject the CO into the chamber. A needle valve was used to further control the CO buildup to keep it slightly under 50 ppm per hour. A Rosemount Model 880A CO gas analyzer was used to measure the CO buildup in the chamber. The output from the Rosemount gas analyzer was sent to a computer and recorded using the Labtech Notebook Data Acquisition System. Figure 1 shows a typical CO slow buildup test.

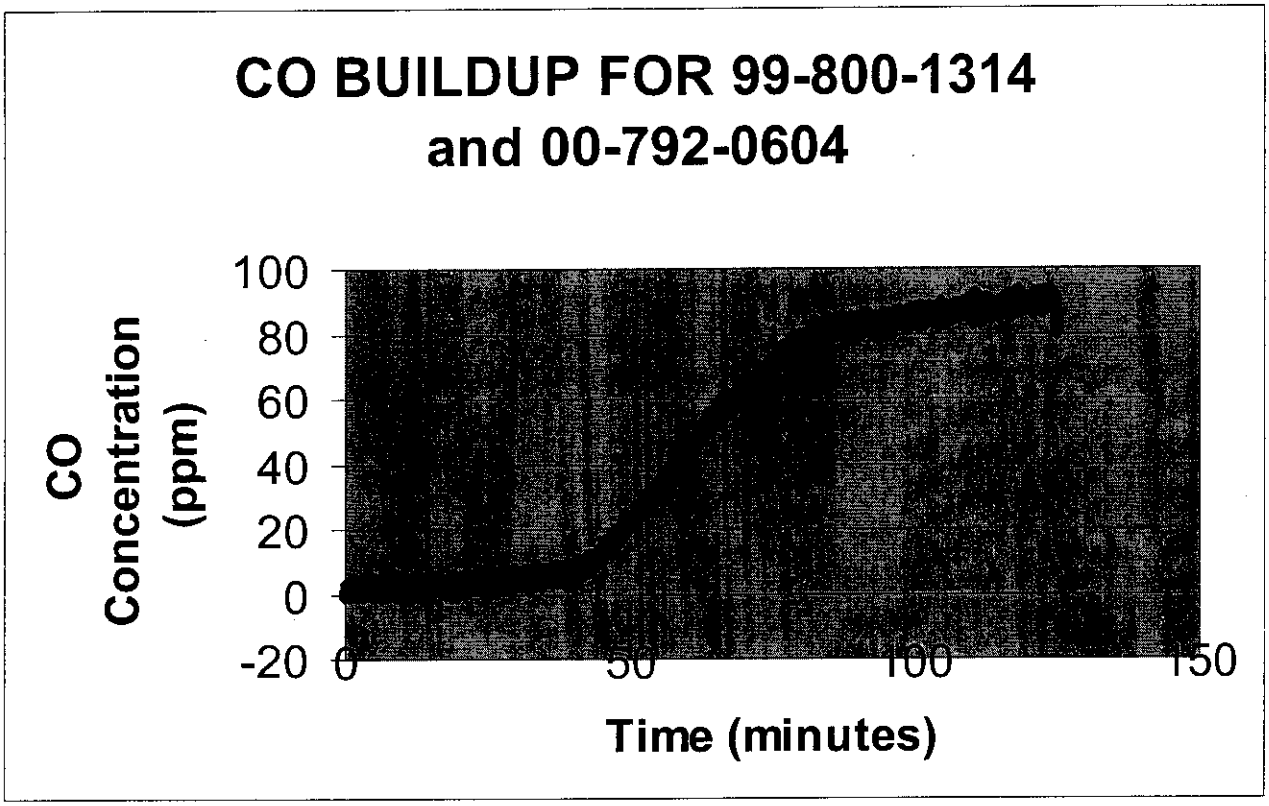

Figure 1 – Typical slow buildup test.

RESULTS/DISCUSSION: The alarm times for the slow CO buildup for each alarm and the chamber CO concentration at alarm are presented in Table 2.

TABLE 2
ALARM RESULTS FOR SLOW CO BUILDUP

Sample No.	Sub. No.	Time to Alarm (minutes)	Alarm Type	Alarm Reading (ppm CO)	Chamber Conditions		
					CO (ppm)	Temp. (°C)	% RH
99-830-4517	4	111	Metal Oxide	N/A	90	23.3	19
99-830-4517	9	120	Metal Oxide	N/A	96	23	19
99-830-4519	1	129	Metal Oxide	111	103	23.3	20
99-830-4519	3	98	Metal Oxide	131	81	23.3	19
00-792-0689	2	129		N/A	92	23.2	49
00-792-0689	5	112		N/A	87	23.3	50
00-830-3472	2	156		57	103	23.3	24
00-830-3472	4	254		45	145	23.3	24
00-792-0681	1	90	Biomimetic	N/A	74	23.2	27
00-792-0681	5	97	Biomimetic	N/A	77	23.2	27
99-800-1314	4	101	Biomimetic	N/A	85	23.1	35
99-800-1314	11	106	Biomimetic	N/A	86	23.2	35
99-860-5821	1	115	Metal Oxide	N/A	87	23.3	50
99-860-5821	8	63	Metal Oxide	N/A	57	23.2	49
00-792-0677	3	176	Ionization	N/A	137	23.2	19
00-792-0677	5	177	Ionization	N/A	137	23.2	19
00-792-0680	5	179	Metal Oxide	95	141	23.1	12
00-792-0680	6	185	Metal Oxide	91	142	23.3	11
00-792-0751	1	159	Metal Oxide	96	123	23.3	18
00-792-0751	3	182	Metal Oxide	101	138	23.2	22
00-792-0685	1	89		N/A	72	23.4	23
00-792-0685	2	94		N/A	74	23.1	23
00-792-0686	3	155		N/A	103	23.3	24
00-792-0686	6	217		N/A	128	23.2	23
00-792-0604	1	118	Biomimetic	N/A	89	23.2	34
00-793-0604	3	123	Biomimetic	N/A	90	23.2	34
99-792-0299	14	180	Metal Oxide	N/A	139	23.1	19
99-792-0299	15	121	Metal Oxide	N/A	97	23.2	19
00-792-0602	3	167	Electrochem.	N/A	96	23.1	29
00-792-0602	4	172	Electrochem.	N/A	98	23.1	29
00-792-0714	2	141	Electrochem.	98	88	23.1	29
00-792-0714	6	165	Electrochem.	106	131	23.3	18
02-830-4054	1	110		N/A	80	23.1	33
01-830-3004	1	92	Biomimetic	N/A	70	23.2	32
02-830-4296	1	75		N/A	59	23.2	32
01-810-2260	1	132		N/A	94	23.1	49
02-840-6197	1	90		97	82	23.2	19
01-840-6328	1	151		100	115	23.2	21
01-840-6328	2	314		64	204	23.2	19
02-830-4635	1	219		N/A	152	23.3	19

Health Sciences (HS) staff did a preliminary assessment of the corresponding %COHb for the CO concentration listed in Table 2 at which each unit alarmed. The HS preliminary assessment data is presented in Table 3. (Table 3 is taken from a January 6, 2004 memo from S. Inkster to D. Switzer.) In this memo HS staff states that "HS ran some %COHb predictions for the test data on 40 alarm samples. For each result, HS calculated the %COHb that would be expected at the recorded alarm time. HS assumed there had been constant exposure to the CO level that was recorded at the time of the alarm and used a high activity level of the exposed consumer (air intake of 30 L/min as used in UL2034 CO Alarm Standard, i.e. worst case scenario). If HS felt the estimated COHb level exceeded 10% for a relatively long time or by a relatively large amount, HS estimated the COHb level assuming a moderate activity level of 15 L/min air intake. In some cases HS also estimated COHb at a rest/sleep air intake level of 6 L/min. HS gave each alarm sample a preliminary assessment to determine if HS needed to make a more accurate assessment %COHb at alarm time using the time course data from the testing".

Table 3 shows the data ranked by the HS level of concern with the more worrisome alarms listed first. HS felt that the first 12 samples listed in Table 3 needed more accurate COHb assessments. HS felt that the remaining 28 samples alarmed properly. The following legend is used in Table 3: OK = no health hazard, TV-ok = potential technical violation but no health hazard, check = do more accurate COHb profile, NA = Not Analyzed (time above 10% COHb level could not be analyzed because COHb at alarm was below 10%). Blank spaces in the "Moderate" and "Rest" activity level columns indicate that no COHb assessment was needed because the unit alarmed under 10% COHb at the "High" activity level.

TABLE 3
HS PRELIMINARY COHb ASSESSMENT

Activity Level (Respiratory minute volume)				High (30 L/min)		Moderate (15L/min)		Rest (6L/min)		HS
		Alarm Time	ppm CO	% COHb	~Time above	% COHb	~Time above	% COHb	~Time above	view
Sample #	Sub	(mins)	at alarm	at alarm	10% COHb	at alarm	10% COHb	at alarm	10% COHb	OK?
01-840-6328	2	314	204	25.1	4h 40	22.4	4h	13.4	1h 45 min	check
02-830-4635	1	219	152	19.1	2h 40 min	15.2	2h	8.1	NA	check
00-830-3472	4	254	145	18.8	3h 20 min	15.5	2h 20min	8.6	NA	check
00-792-0680	6	185	142	17.4	2h	13.1	1h	10.2	5 min	check
00-792-0680	5	179	141	17.1	2h	12.9	1h	6.6	NA	check
99-792-0299	14	180	139	16.9	1h 40 min	12.7	1h	6.5	NA	check
00-792-0751	3	182	138	16.8	2h	12.6	1h	6.5	NA	check
00-792-0677	3	176	137	16.7	2h	12.5	1h	6.4	NA	check
00-792-0677	5	177	137	16.7	2h	12.5	1h	6.4	NA	check
01-792-0686	6	217	128	16.5	1.5h	12.9	1h 20 min	6.9	NA	check
00-792-0714	6	165	131	15.7	1h 40 min	11.5	30min	5.8	NA	check
00-792-0751	1	159	123	14.7	1.5h	10.6	15 min	5.4	NA	check
01-840-6328	1	151	115	13.6	1h 15 min	9.7	NA	4.9	NA	TV-ok
00-830-3472	2	156	103	12.4	1h	8.9	NA			TV-ok
01-792-0686	3	155	103	12.3	1h	8.9	NA			TV-ok
00-792-0602	4	172	98	12.2	1h 10min	9	NA			TV-ok
00-792-0602	3	167	96	11.9	1h	8.7	NA			TV-ok
99-830-4519	1	129	103	11.6	40 min	8	NA			TV-ok
00-792-0714	2	141	88	11.1	45 min	7.3	NA			TV-ok
01-810-2260	1	132	94	10.7	20 min	7.5	NA			TV-ok
99-792-0299	1	121	97	10.7	20 min	7.3	NA			TV-ok
99-830-4517	9	120	96	10.5	10 min					TV-ok
00-792-0689	2	129	92	10.4	14 min					OK
00-792-0604	3	123	90	10	NA					OK
00-792-0604	1	118	89	9.8	NA					OK
99-860-5821	1	115	87	9.4	NA					OK
00-792-0689	5	112	87	9.3	NA					OK
99-800-1314	11	106	86	9	NA					OK
99-800-1314	4	101	85	8.7	NA					OK
99-830-4517	4	111	90	8.7	NA					OK
02-830-4054	1	110	80	8.6	NA					OK
99-830-4519	3	98	81	8.2	NA					OK
02-840-6197	1	90	82	8	NA					OK
00-792-0681	5	97	77	7.8	NA					OK
00-792-0681	1	90	74	7.3	NA					OK
00-792-0685	2	94	74	7.2	NA					OK
00-792-0685	1	89	72	7.1	NA					OK
01-810-3004	1	92	70	7	NA					OK
02-830-4296	1	75	59	5.4	NA					OK
99-860-5821	8	63	57	4.8	NA					OK

The time versus CO concentration test data for the 12 alarms marked "check" in Table 3 were sent to HS for a more accurate assessment for %COHb at alarm time. The HS assessment for these 12 alarms is presented in Table 4. (Table 4 is from the January 6, 2004 memo from S. Inkster to D. Switzer and J. Puskar.)

The following legend is used in Table 4: UA = unacceptable, Tv-ok = potential technical violation but no health hazard, OK = no health hazard.

TABLE 4
HS ASSESSMENT FOR 12 "CHECK" ALARMS

				High Activitiy (RMV= 30L/min)				HS
Sample #	Sub	Time (mins)	ppm CO at alarm	%COHb re constant pk	time above 10% COHb	%COHb from CO profile	time above 10% COHb	view OK?
01-840-6328	2	314	204	25.1	4h 40	22.45	164 min	UA
02-830-4635	1	219	152	19.1	2h 40 min	15.5	65 min	Tv-ok
00-830-3472	4	254	145	18.8	3h 20 min	14.8	80 min	Tv-ok
00-792-0680	6	185	142	17.4	2h	12.9	35 min	Tv-ok
00-792-0680	5	179	141	17.1	2h	12.62	30 min	Tv-ok
99-792-0299	14	180	139	16.9	1h 40 min	12.58	30 min	Tv-ok
00-792-0751	3	182	138	16.8	2h	12.37	77 min	Tv-ok
00-792-0677	3	176	137	16.7	2h	12.58	30 min	Tv-ok
00-792-0677	5	177	137	16.7	2h	12.58	30 min	Tv-ok
01-792-0686	6	217	128	16.5	1.5h	12.9	45 min	Tv-ok
00-792-0714	6	165	131	15.7	1h 40 min	11.31	15 min	Tv-ok
00-792-0751	1	159	123	14.7	1.5h	10.61	10 min	Tv-ok

				Moderate Activitiy (RMV= 20L/min)				HS
Sample #	Sub	Time (mins)	ppm CO at alarm	%COHb re constant pk	time above 10% COHb	%COHb from CO profile	time above 10% COHb	view OK?
01-840-6328	2	314	204	24.0	4h	20.24	134 min	UA
02-830-4635	1	219	152	17.1	2h	12.8	35 min	Tv-ok
00-830-3472	4	254	145	17.2	2h 20min	12.5	50 min	Tv-ok
00-792-0680	6	185	142	16.1	1h	10.28	5 min	OK
00-792-0680	5	179	141	14.9	1h	10.12	5 min	OK
99-792-0299	14	180	139	14.7	1h	10.08	5 min	OK
00-792-0751	3	182	138	14.7	1h	9.94	NA	OK
00-792-0677	3	176	137	14.4	1h	10.08	5 min	OK
00-792-0677	5	177	137	14.4	1h	10.08	5 min	OK
01-792-0686	6	217	128	14.7	1h 20 min	10.7	11 min	OK
00-792-0714	6	165	131	13.4	30min	8.98	NA	OK
00-792-0751	1	159	123	12.5	15 min	8.38	NA	OK

				Low Activitiy (RMV= 10L/min)				HS
				%COHb re	time above	%COHb from	time above	view
Sample #	Sub	Time (mins)	ppm CO at alarm	constant pk	10% COHb	CO profile	10% COHb	OK?
01-840-6328	2	314	204	19.0	1h 45 min	14.25	60 min	UA
02-830-4635	1	219	152	12.0	NA	8	NA	OK
00-830-3472	4	254	145	12.5	NA	8.4	NA	OK
00-792-0680	6	185	142	10.1	5 min	6.31	NA	OK
00-792-0680	5	179	141	9.9	NA	6.27	NA	OK
99-792-0299	14	180	139	9.8	NA	6.25	NA	OK
00-792-0751	3	182	138	9.8	NA	6.19	NA	OK
00-792-0677	3	176	137	9.5	NA	6.25	NA	OK
00-792-0677	5	177	137	9.5	NA	6.25	NA	OK
01-792-0686	6	217	128	10.2	NA	6.8	NA	OK
00-792-0714	6	165	131	10.4	NA	5.55	NA	OK
00-792-0751	1	159	123	8.1	NA	5.14	NA	OK

For these 12 alarms, HS staff concluded that "while most all alarms were theoretically in violation of the 10% COHb threshold at high activity level used in UL2034/CSA standards, only the first listed sample (01-840-6328-02) experienced significantly delayed alarm activation that could likely result in serious CO poisoning in exposed healthy adults engaged at high or moderate levels." Alarm Sample No. 01-840-6328-01 was the same type and manufacture as 01-840-6328-02. Alarm 01-840-6328-01 alarmed properly. HS also concluded that "delayed alarming of Alarms 02-830-4635 and 00-830-3472-04 could result in a relatively low severity CO exposure" (memo from S. Inkster to D. Switzer, January 6, 2004).

Thirteen of the forty alarms had a digital readout feature of the CO concentration that the alarm was measuring. Table 2 lists the digital readout of the alarms at the time the unit alarmed. When the alarm digital readout is compared to the CO readout recorded by the Rosemount CO analyzer, only one alarm (99-830-4519-01) had a digital readout that was within 10% of the readout on the Rosemount analyzer. Two samples (00-792-0714-02 and 01-840-6328-01) had digital readouts that were within 15% of the CO level measured by the Rosemount analyzer. The CO readout of the other ten digital alarms differed by 19% to 69% from the CO concentration recorded by the Rosemount analyzer at the time the unit alarmed.

CONCLUSIONS: In this testing, most CO alarms were found to alarm properly when exposed to a slow buildup of carbon monoxide. Only one out of the forty alarms tested gave an alarm time that could result in serious CO poisoning. Two other alarms gave alarm times that could result in a low severity CO exposure. The remaining units gave acceptable alarm times.

The thirteen alarms with the digital readout feature gave poor correlation with the chamber CO level. The two best performing alarms had digital readouts that were within 15% of the actual chamber reading. The other alarms were off by 19% to 69%.

Attachment 2

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

January 6, 2004

TO: Donald Switzer, Directorate for Engineering Sciences (ES)

Through: Mary Ann Danello, Ph.D., Associate Executive Director for Health Sciences (HS)
Lori E Saltzman, M.S., Division Director, HS

FROM: Sandra E. Inkster, Ph.D., Pharmacologist, HS

SUBJECT: Summary hazard assessment of potential health effects associated with carbon monoxide (CO) exposure consequent to delayed alarm activation of CO alarms subjected to slow build up of CO levels to UL 2034 CO mandatory alarm thresholds.

Introduction

This memorandum is written in response to a request from Don Switzer (ES) for Health Sciences (HS) staff to provide an official record and explanation of its earlier informal health hazard assessment concerning performance of CO alarms in certain tests conducted by staff in CPSC's Directorate for Laboratory Sciences (LS).

Background

External parties have raised concerns that the test methodology employed in Underwriter's Laboratories (UL) voluntary standard for CO alarms (UL 2034, *Single and Multiple Station Carbon Monoxide Alarms*) overlooks likely field use situations that might result in consumers experiencing harmful CO exposures. Specifically, UL's test method, employing rapid build up (within 3 minutes) of CO to mandatory alarm test points, has been criticized as not preventing extended CO exposure to sub-alarm thresholds. It is believed by some that this can allow exposed individuals to experience adverse health effects associated with elevated carboxyhemoglobin (COHb) levels above the 10% COHb threshold on which UL 2034's mandatory alarm test points are based.

To investigate the basis of these concerns, LS investigated performance of various CO alarm models (40 different samples) during slow CO buildup to mandatory alarm exposure test points (rate of buildup <50 ppm CO/hour), with exposure maintained until alarm activation. Full details of the test methodology, samples tested, results, and conclusions are provided in the final LS report (memorandum from J. Puskar to D. Switzer, dated May 15, 2003). Tables 3 and 4 of the LS report detail input provided by HS staff. For reference purposes, these tables are repeated in the appendix attached to this current memorandum.

Health Sciences Assessment

Prior to writing its final report, LS staff presented the summary results of these CO alarm tests to HS staff. HS staff provided an informal preliminary assessment of potential health

concerns for each sample. The assessments were based on rough estimates of blood carboxyhemoglobin levels (% COHb) calculated[1] for the reported alarm times, assuming the hypothetical worst case scenario of constant exposure to the CO level at the time of alarm [03/13/03 email from S. Inkster to D. Switzer (ES) and J. Puskar (LS)]. HS staff's preliminary assessment reported the following:

- 18 samples alarmed appropriately.
- 10 samples appeared to have slightly delayed alarms that could be considered technical violations of UL 2034, but which, in HS staff's opinion, did not constitute a health hazard. (HS reasoned that since the predicted COHb levels, which only slightly exceeded 10% COHb, were calculated using a hypothetical worst case exposure, they would drop below 10% COHb "threshold" if calculated using the more accurate time-course profile of CO buildup to the time of alarm activation.)
- 12 samples had delayed alarm activations of concern, for which HS recommended that more accurate estimates of % COHb levels be calculated using relevant time-course profiles of CO buildup to the time of alarm activation.

Subsequently, HS staff modeled more accurate % COHb estimates for these latter 12 samples of concern, using test data on CO buildup provided by LS staff. As expected, this resulted in much lower maximum % COHb estimates than the hypothetical worst case scenario approach. HS staff's assessment of the potential hazard associated with these 12 CO alarm samples of concern was provided to ES and LS staff in an email dated 4/29/03. HS staff concluded that while performance of 11 samples could be considered in technical violation of UL 2034 alarm criteria, only one sample (#01-840-6328) had an unacceptable alarm performance. Note: the aforementioned LS final report contains tables provided by HS staff, detailing all predicted % COHb levels, assuming exposed individuals would be engaged in high, moderate or low level activity.

Explanation of HS Assessment

According to the scope of UL 2034, Section 1.1 ***"Carbon monoxide alarms are intended to alarm at carbon monoxide levels below those that could cause a loss of ability to react to the dangers of carbon monoxide exposure."*** The mandatory alarm criteria in UL 2034 are based on plotted limits of the 10% COHb curve, as specified in section 38.1. Currently, specific test points at which mandatory alarm activation is required are as follows:

Carbon monoxide concentration versus time for alarm test points based on 10 % COHb *	
Carbon monoxide concentration and response time	
Concentration, ppm	Maximum response time, minutes
70 ± 5	60-240
150 ± 5	10-50
400 ± 10	4-15

*From Section 38, UL 2034, Second Edition, 10/29/96, including subsequent revisions up to 6/2/99

[1] CPSC HS staff typically calculates % COHb estimates using a non-linear form of the Coburn-Forster-Kane equation. The non-linear form of the CFK is widely recognized as being more physiologically accurate than the simplified linear CFK equation used by UL.

The rate of formation of COHb in the bloodstream is greatly influenced by an exposed individual's activity level. As activity level increases, breathing rate generally increases; therefore, at fixed ambient CO concentrations, the amount of CO inhaled per unit time is greater in active individuals compared to sedentary persons, so they form COHb, and approach equilibrium COHb levels, more rapidly. It should be noted that the UL 2034 alarm criteria are based on the 10% COHb curve **assuming exposure of a healthy adult who is engaged in heavy activity** (equivalent to a breathing rate, or respiratory minute volume [RMV] of 30 liters/minute). UL's alarm criteria are conservative in that less active individuals would have much lower COHb levels at these same test point CO exposures.

When applying UL 2034's specified threshold of 10% COHb criteria to evaluate the performance of the CO alarms, HS noted that performance of several samples could be considered as being in technical violation of the standard. HS staff notes that the blood level of COHb serves as a useful **approximation** of CO poisoning severity (as shown in Table 2 below) and that perceptible adverse health effects are unlikely to occur <10% COHb. However, the relationship between symptom severity and % COHb is not absolute and HS staff notes that CO poisoning severity is a function of **both the maximum % COHb level attained and the profile and duration of the COHb elevation,** and also influenced by an exposed individual's health status.

Table 2. Approximate Correlation Between % COHb Level and Symptoms in Healthy Adults

% COHb	Symptoms
<10%	No perceptible ill effects*
10-20	Mild headache, labored breathing, decreased exercise tolerance
20-30	Throbbing headache, mild nausea
30-40	Severe headache, dizziness, nausea, vomiting, cognitive impairment
40-50	Confusion, unconsciousness, coma, possible death
50-70	Coma, brain damage, seizures, death
>70	Typically fatal

* Some studies have reported adverse health effects in some cardiac patients at 2-5% COHb (from Burton, 1996)

Therefore, to assess the health risk associated with delayed CO alarm activation, HS staff applied its professional judgement to evaluate **likely maximum % COHb levels attained and the profile and duration of the COHb elevation.** The influence of activity levels was also considered in deciding whether technical violations would likely ***"cause a loss of ability to react to the dangers of carbon monoxide exposure."*** (By this, HS staff means that it is certainly likely that consumers will engage in high level activity in their homes, but it considers that most are unlikely to sustain high activity for periods longer than an hour or so).

HS Conclusions

HS staff found that only sample **01-840-6328** would allow COHb levels to reach and exceed 20% COHb, a level at which a realistic concern exists for the potential of serious delayed neurological sequelae (DNS) symptoms due to CO exposure. According to HS calculations, performance of this sample would allow COHb levels to reach approximately 22.45% or 20.24%, assuming exposed individuals were engaged in high or moderate level activity, respectively (i.e., RMVs of 30 and 20 liters/min, respectively). Corresponding duration of COHb elevations above 10% were calculated to be 164 and 134 minutes, respectively. HS staff considers performance of this sample as unacceptable in terms of potential adverse impact on consumers' health and ability to react to the potentially hazardous CO environment.
Note: Examination of the test data for this sample indicates that it failed to meet UL's test point requiring alarm activation at 150 ppm within 50 minutes, allowing exposure to continue for 110 minutes after the level exceeded 150 ppm, and continuing to rise to 314 ppm.

Regarding the performance of the remaining 11 samples of concern, HS calculated that in highly active individuals, all units would allow short-lived elevations (range of 10-80 minutes, average duration 41 minutes) above 10 % COHb (range of 10.61-15.5% COHb, average peak level of 12.8% COHb). Applying a moderate activity level, HS found that 8/11 would allow shortlived elevations (range of 5-50 minutes, average duration 15 minutes) above 10% COHb (range of 10.1-12.8% COHb, average peak level of 10.8% COHb). Using a low activity level, none of the samples allowed COHb levels to exceed 10%. HS staff considers that, although alarm activation was slightly delayed, all 11 samples provided adequate notification of a developing, potentially hazardous CO environment before an individual's ability to react was likely to be compromised by the prevailing CO exposure conditions.

References

Puskar, JJ, CPSC Memorandum to D. Switzer, Slow carbon monoxide buildup testing of carbon monoxide detectors, dated May 15, 2003.

Burton, LE, CPSC Report, Toxicity from low level human exposure to carbon monoxide, dated July 1, 1996.

Underwriter's Laboratories (UL) voluntary standard for CO alarms (UL 2034, *Single and Multiple Station Carbon Monoxide Alarms*), Second Edition, 10/29/96, including subsequent revisions up to 6/2/99.

Appendix

Recapture of Data in Tables 3 and 4 of LS final report

Appendix 1a. HS PRELIMINARY COHb ASSESSMENT*										
Activity Level (Respiratory minute volume)				High (30 L/min)		Moderate (15L/min)		Rest (6L/min)		HS
sample #	sub	Alarm time (mins)	ppm CO at alarm	% COHb at alarm	~Time above 10% COHb	% COHb at alarm	~Time above 10% COHb	% COHb at alarm	~Time above 10% COHb	view OK?
01-840-6328-02	2	314	204	25.1	4h 40	22.4	4h	13.4	1h 45 min	check
02-830-4635	1	219	152	19.1	2h 40 min	15.2	2h	8.1	NA	check
00-830-3472	4	254	145	18.8	3h 20 min	15.5	2h 20min	8.6	NA	check
00-792-0680-06	6	185	142	17.4	2h	13.1	1h	10.2	5 min	check
00-792-0680-05	5	179	141	17.1	2h	12.9	1h	6.6	NA	check
99-792-0299	14	180	139	16.9	1h 40 min	12.7	1h	6.5	NA	check
00-792-0751-03	3	182	138	16.8	2h	12.6	1h	6.5	NA	check
00-792-0677	3	176	137	16.7	2h	12.5	1h	6.4	NA	check
00-792-0677	5	177	137	16.7	2h	12.5	1h	6.4	NA	check
01-792-0686	6	217	128	16.5	1.5h	12.9	1h 20 min	6.9	NA	check
00-792-0714	6	165	131	15.7	1h 40 min	11.5	30min	5.8	NA	check
00-792-0751-01	1	159	123	14.7	1.5h	10.6	15 min	5.4	NA	check
01-840-6328-01	1	151	115	13.6	1h 15 min	9.7	NA	4.9	NA	TV-ok
00-830-3472	2	156	103	12.4	1h	8.9	NA			TV-ok
01-792-0686	3	155	103	12.3	1h	8.9	NA			TV-ok
00-792-0602	4	172	98	12.2	1h 10min	9	NA			TV-ok
00-792-0602	3	167	96	11.9	1h	8.7	NA			TV-ok
99-830-4519	1	129	103	11.6	40 min	8	NA			TV-ok
00-792-0714	2	141	88	11.1	45 min	7.3	NA			TV-ok
01-810-2260	1	132	94	10.7	20 min	7.5	NA			TV-ok
99-792-0299	1	121	97	10.7	20 min	7.3	NA			TV-ok
99-830-4517	9	120	96	10.5	10 min					TV-ok
00-792-0689	2	129	92	10.4	14 min					OK
00-792-0604	3	123	90	10	NA					OK
00-792-0604	1	118	89	9.8	NA					OK
99-860-5821	1	115	87	9.4	NA					OK
00-792-0689	5	112	87	9.3	NA					OK
99-800-1314	11	106	86	9	NA					OK
99-800-1314	4	101	85	8.7	NA					OK
99-830-4517	4	111	90	8.7	NA					OK
02-830-4054	1	110	80	8.6	NA					OK
99-830-4519	3	98	81	8.2	NA					OK
02-840-6197	1	90	82	8	NA					OK
00-792-0681	5	97	77	7.8	NA					OK
00-792-0681	1	90	74	7.3	NA					OK
00-792-0685	2	94	74	7.2	NA					OK
00-792-0685	1	89	72	7.1	NA					OK
01-810-3004	1	92	70	7	NA					OK
02-830-4296	1	75	59	5.4	NA					OK
99-860-5821	8	63	57	4.8	NA					OK

Note: %COHb estimates assume constant exposure to CO level at alarm time for alarm time duration.

HS view: OK; TV-ok = technical violation but okay; check= do COHb time course profile

****HS input captured as Table 3 in J. Puskar (LS) final report dated May 15, 2003***

Appendix 1b. HS FINAL COHb ASSESSMENT FOR 12 CO ALARM SAMPLES OF CONCERN*								
High Activity (RMV= 30L/min)								
sample #	sub	Alarm time (mins)	ppm CO at alarm	%COHb re: constant peak	time above 10% COHb	%COHb from CO profile	time above 10% COHb	HS view - OK?
01-840-6328-	2	314	204	25.1	4h 40	22.45	164 min	UA
02-830-4635	1	219	152	19.1	2h 40 min	15.5	65 min	TV-ok
00-830-3472	4	254	145	18.8	3h 20 min	14.8	80 min	TV-ok
00-792-0680-	6	185	142	17.4	2h	12.9	35 min	TV-ok
00-792-0680-	5	179	141	17.1	2h	12.62	30 min	TV-ok
99-792-0299	14	180	139	16.9	1h 40 min	12.58	30 min	TV-ok
00-792-0751-	3	182	138	16.8	2h	12.37	77 min	TV-ok
00-792-0677	3	176	137	16.7	2h	12.58	30 min	TV-ok
00-792-0677	5	177	137	16.7	2h	12.58	30 min	TV-ok
01-792-0686	6	217	128	16.5	1.5h	12.9	45 min	TV-ok
00-792-0714	6	165	131	15.7	1h 40 min	11.31	15 min	TV-ok
00-792-0751-	1	159	123	14.7	1.5h	10.61	10 min	TV-ok

Moderate Activity (RMV= 20L/min)								
sample #	sub	Alarm time (mins)	ppm CO at alarm	%COHb re: constant peak	time above 10% COHb	%COHb from CO profile	time above 10% COHb	HS view - OK?
01-840-6328-	2	314	204	24	4h	20.24	134 min	UA
02-830-4635	1	219	152	17.1	2h	12.8	35 min	TV-ok
00-830-3472	4	254	145	17.2	2h 20min	12.5	50 min	TV-ok
00-792-0680-	6	185	142	16.1	1h	10.28	5 min	OK
00-792-0680-	5	179	141	14.9	1h	10.12	5 min	OK
99-792-0299	14	180	139	14.7	1h	10.08	5 min	OK
00-792-0751-	3	182	138	14.7	1h	9.94	NA	OK
00-792-0677	3	176	137	14.4	1h	10.08	5 min	OK
00-792-0677	5	177	137	14.4	1h	10.08	5 min	OK
01-792-0686	6	217	128	14.7	1h 20 min	10.7	11 min	OK
00-792-0714	6	165	131	13.4	30min	8.98	NA	OK
00-792-0751-	1	159	123	12.5	15 min	8.38	NA	OK

Low Activity (RMV= 10L/min)								
sample #	sub	Alarm time (mins)	ppm CO at alarm	%COHb re: constant peak	time above 10% COHb	%COHb from CO profile	time above 10% COHb	HS view - OK?
01-840-6328-	2	314	204	19	1h 45 min	14.25	60 min	UA
02-830-4635	1	219	152	12	NA	8	NA	OK
00-830-3472	4	254	145	12.5	NA	8.4	NA	OK
00-792-0680-	6	185	142	10.1	5 min	6.31	NA	OK
00-792-0680-	5	179	141	9.9	NA	6.27	NA	OK
99-792-0299	14	180	139	9.8	NA	6.25	NA	OK
00-792-0751-	3	182	138	9.8	NA	6.19	NA	OK
00-792-0677	3	176	137	9.5	NA	6.25	NA	OK
00-792-0677	5	177	137	9.5	NA	6.25	NA	OK
01-792-0686	6	217	128	10.2	NA	6.8	NA	OK
00-792-0714	6	165	131	10.4	NA	5.55	NA	OK
00-792-0751-	1	159	123	8.1	NA	5.14	NA	OK

profile data

HS view: OK; TV-ok = technical violation but okay; UA = unacceptable

****HS input captured as Table 4 in J. Puskar (LS) final report dated May 15, 2003***