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December 28, 2004

Dorothy Shimer
Research Division
Air Resources Board
P.O. Box 2815
Sacramento, California 95812

RE: Revised Draft Report to the California Legislature on Indoor Air Pollution

Dear Ms. Shimer:

Sempra Energy appreciates the opportunity to respond to the November 2004 revised draft AB 1173 Report. We submitted detailed technical comments on the first draft of the report, and do not agree with most of the responses provided by Air Resources Board (ARB) in the revised report. We recognize that ARB staff had to review and develop responses to a significant number of comments on the draft report and we hope that our comments will continue to receive further consideration during the peer review process. Although ARB staff did not accept many of our suggested changes, we do expect that our comments will be shared with the external scientific review panel for their consideration.

Sempra Energy does agree with statements made in the final paragraph of Section 7 of the Executive Summary such as: "The feasibility of individual measures, such as emission limits for a specific type of product, cannot be determined without substantial additional information."

Certain individual measures, such as amending building codes to ban the use of gas stoves, may have a profound economic and social impact on the state as a whole. Additional risk assessment studies need to be undertaken to assure that such a major change will achieve indoor air quality (IAQ) goals. As an example, we believe that a study would show that electrocution death rates from electric cooking appliances are nearly equal to death rates from Carbon Monoxide (CO) poisoning from all gas cooking appliances, mitigating any perceived death rate benefits by amending State building codes. If the issue then solely becomes injuries from CO poisoning related to gas fired appliances, significant work would have to be done to prove IAQ benefits due to the current lack of credible data related to CO injuries.

Sempra Energy agrees with the statement that "any emission limitations or other mitigation measures should be developed with continuous discussion and review by stakeholders, the public, and other state agencies." Because of Sempra Energy's long-standing efforts to study and understand the role of natural gas combustion on indoor air quality, we believe that we are a credible authority as well as a stakeholder, and we stand ready to assist in these efforts. We have attached a report conducted by the Consumer Product Safety Commission (CPSC) with the assistance of the National Institute of Standards and Technology (NIST) that specifically looked at CO emissions from the misuse of natural gas ranges. Even though they currently have regulatory authority over gas cooking appliances and could, by law, set new CO emission standards, they declined to take any such action based on their studies. It is not clear what ARB could add to this body of work to justify additional regulation or a ban on the use of these appliances.

Sempra Energy has reviewed several studies related to cooking activities and has concluded that the foods cooked and the specific type of cooking activity are much more important to IAQ than the energy source of the cooking appliance itself. Any consideration of controlling emissions from cooking appliances should include a full analysis of the impacts from all appliances, gas and electric. As an example, PAH's have no minimum threshold, so the fact that ARB's own cooking studies show that PAH's are emitted during cooking with an electric appliance as well as a gas appliance would seem to preclude the overt elimination of electric cooking as a source for PAH's, leading to the need for regulatory action in that area as well.

Sempra Energy agrees that Indoor Air Quality is an important issue, and we have been studying the impacts of natural gas combustion on IAQ since the early 1980's. We look forward to the development of sound and reasonable approaches to improving IAQ in homes and businesses.

We look forward to working with you on this important issue. Should you have any questions regarding these comments, please contact Lance DeLaura, National Codes/Standards and Emerging Technologies Manager for Sempra Energy Utilities at (213) 244-3678, or me at (916) 492-4244.

Sincerely

Bernie Orozco

Attachment

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

August 24, 2000

TO: Ron Jordan, Project Manager, Fire/Gas Codes and Standards, Directorate for Engineering Sciences,

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: Carbon monoxide (CO) emissions from residential gas ranges: projected consumer exposure and related health concerns.

Introduction

Several groups have suggested that use of unvented gas ranges may expose consumers to carbon monoxide (CO) levels of concern to health. As part of the U.S. Consumer Product Safety Commission's (CPSC) ongoing efforts to address the safety of combustion appliances, staff initiated a project to investigate this issue. Specifically, staff wanted to determine whether these concerns had any basis, and, if so, whether they needed to be addressed by recommendations to the appropriate standards setting authorities. The CPSC's Directorate for Laboratory Sciences (LS) recently issued a report concerning test data on carbon monoxide emissions from different models of residential gas ranges (Davis and Brown, 2000). Based on the CPSC staff's test data, National Institute of Standards and Technology (NIST) staff used a computer model to project indoor air levels of CO resulting from different consumer use patterns of gas ranges (Persily, 2000). Health Sciences (HS) staff was asked to determine whether these CO concentrations have any likely adverse impact on consumer health.

Background

The CPSC LS staff tested eight different models of residential gas ranges. Tests were conducted under different modes of operation which were intended to replicate consumer-use scenarios. Conditions ranged from normal bake or self-cleaning cycles to use as a space heater with partial to full occlusion of the ovens' vent holes by foil lining on the oven floor. CO emission rates were reported for each individual range unit, for up to ten different test conditions (Davis and Brown, 2000).

CPSC contracted with NIST to conduct modelling analyses to project indoor air levels of CO that consumers could be exposed to when using gas ranges, based on CO emission rates derived from CPSC's range test data. For each test on each individual range, CPSC staff provided NIST with the following three measures of CO emission rate: (1) an average emission rate over the entire test period, (2) an average emission rate for the period in which the range had reached steady state operation, and (3) the peak emission rate noted during the entire test period (see Table 2, Persily, 2000 and Appendix1 in this memorandum). For each operating condition, NIST staff calculated the average of all eight ranges for each category of emission rate, along with the respective standard deviation and minimum and maximum values (see Table 4, Persily, 2000). Together, CPSC and NIST staff defined four relevant range-operation modes for further analyses, i.e., (i) space heating 1 (4 hours on then 4 hours off); (ii) space heating 2 (1 hour on, then 7 hours off); (iii) baking (2 hours on, then 6 hours off); and (iv) self-cleaning (3 hours on, then 5 hours off). For the space heating mode, it was assumed that consumers would most likely operate ranges in the bake mode with the oven door open. Baking use reflected normal bake mode with the oven door closed, and self-cleaning use reflected operation of the ranges' automatic self-clean cycle. For both space heating and baking modes, test conditions employing 0%, 50%, and 100% occlusion of vent holes by foil-lining on the oven floor were considered relevant. Based on examination of the composite CPSC emissions test data, specific CO emission rates were selected as being broadly representative of low to extreme CO production for each of the four operation modes defined as relevant for modelling analyses. Table 1 is a composite of Table 6 from Persily, 2000, showing the CO emission rates selected for modelling, plus information on the number of individual ranges with steady state averages that reached selected CO emission rates in relevant tests, at different levels of vent occlusion by foil.

Table 1. CO Emission Rates Selected for NIST Modelling Analyses

Analysis Mode	CO Emission Rates Selected for Modelling Analyses			No. Ranges Reaching Selected CO Emission Rates Based on Steady State Average Test Data		
		mg/s	**cc/h**	**0% foil**	**50% foil**	**100% foil**
Space Heating 1 and 2	Low	0.32	1000	3/8	7/8	8/8
Bake/Open Door Mode:	Medium	0.48	2500	2/8	7/8	8/8
4 hours on/4 hours off or	High	3.18	10000	0/8	0/8	8/8
1 hour on/7 hours off	Extreme	23.86	75000	0/8	0/8	7/8
Baking	Low	0.32	1000	4/8	5/8	8/8
Bake/Close Door Mode:	Medium	0.64	2000	1/8	3/8	5/8
2 hours on/6 hours off	High	0.95	3000	0/8	1/8	2/8
	Extreme	2.39	7500	0/8	0/8	2/8
Self-cleaning	Low	0.16	500	7/8	NA	NA
Self Clean Cycle:	Medium	0.32	1000	5/8	NA	NA
3 hours on/5 hours off	High	0.48	1500	2/8	NA	NA

NA = not applicable (foil lining is not likely to be present during the oven self-clean cycle)

NIST staff used these specific CO emission rates in a single-zone mass balance computer model to estimate CO concentrations that could likely occur in residential areas at 1 hour and 8 hour durations, for each of the four defined operation modes. The NIST model allows both the room size and air change rate to be varied, as desired. Five room sizes (160, 400, 800, 1200, and 1600 m^3) and three air change rates (0.2, 035, and 0.7 h^{-1}) were used in modelling indoor CO concentrations for each combination of operation mode and emission rate (see NIST report for the basis of the selected variables). The results of the analyses were presented in tabular form, with CO concentration expressed as mg/m^3 (see Table 7, Persily, 2000).

Health Sciences' Perspective

It is clearly established that CO interferes with oxygen uptake, delivery, and utilization by combining at least 200 times more avidly than oxygen with hemoglobin, the oxygen transport protein, to form carboxyhemoglobin (COHb). COHb formation is primarily a function of the CO level and duration of exposure. Before equilibrium conditions are reached, COHb formation is greatly influenced by an exposed individual's activity level which affects the amount of air and CO taken into the lungs. At high levels, CO can be a lethal asphyxiant. Levels above 20% COHb are generally considered to pose an immediate threat of death or permanent neurological impairment to all consumers. As a general rule, HS staff considers that keeping COHb levels from reaching 10% is protective of the majority of healthy consumers. The lowest exposure that can result in 10% COHb is about 65-70 ppm for at least 4-5 hours, depending on activity level. However, at lower levels, CO is reported to have more subtle effects on cardiac function, such as decreasing the onset times of exercise-induced electrocardiogram ST-segment changes and angina symptoms in some patients with coronary artery disease (CAD). These changes are indicative of myocardial ischemia, and can be associated with lethal myocardial infarcts. Thus, HS staff considers CAD patients to be the population most susceptible to adverse health effects of CO exposure (Burton, 1996).

CPSC staff believes that consumer exposure to CO should be kept to a minimum, whenever feasible. Staff develops recommendations for CO limits for specific consumer products on a case-by-case basis. Staff takes into consideration the intended use of the product, consumer use patterns, relevant affected populations, technical feasibility, and overall impact of their recommendations. Previously, in association with the unvented gas space heater (UVGSH) and kerosene heater (KH) projects, CPSC's HS staff recommended that indoor CO levels should be limited to 15 ppm for 8 hours, or 25 ppm for 1 hour, as time-weighted averages. These CO exposures can potentially elevate COHb levels to approximately 2.4%, about the level associated with the earliest subtle effects of CO on cardiac function in some CAD patients. The staff recommendations for indoor air CO limits associated with use of individual CO source products (such as UVGSHs and KHs) are more stringent than the limits for mandatory alarm activation of residential CO alarms[1]. The CPSC staff considers that the primary way to combat the CO hazard is to limit CO emissions from source products. CO alarms are considered a secondary means of protecting against the CO hazard. The higher limits for CO alarm activation reflect the fact that the CO alarm is not a source product, and, that in order to maintain confidence in CO alarms, consumers/emergency responders need to be able to readily trace and address the source of CO elevations that activate an alarm signal. The CO alarm will react to CO from all sources, thus, it needs to be able to resist activation by transient elevations in outdoor CO levels and/or CO emissions from more than one normally-operating CO source product.

Health Sciences' Evaluation of Gas Range CO Emissions

In order to assess the potential health impact of the projected indoor air concentrations of CO associated with use of unvented gas ranges, HS staff converted mg/m^3 CO concentrations

[1] Current voluntary standards (UL 2034 and IAS 696) specifications for CO alarm activation are 70 ppm for 189 minutes, 150 ppm for 50 minutes, and 400 ppm for 15 minutes. Alarm resistance is required at 30 ppm for 30 days, 70 ppm for 60 minutes, 150 ppm for 10 minutes, and 400 ppm for 4 minutes

provided by NIST to parts per million (ppm) of CO. In Table 2, HS staff has shaded the projected CO concentrations that would exceed the CO recommendations for UVGSHs and KHs. In Table 3, the same values are presented, but here, the shaded cells indicate concentrations that meet the voluntary standards criteria for mandatory CO alarm activation (i.e. where a CO alarm must activate an alarm signal).

Use of Gas Ranges as Space Heaters

As is readily apparent from Table 2, use of a gas range as a space heater is of greatest health concern to consumers. Examination of data from range use as a space heater shows that virtually all projected CO exposures associated with the most extreme CO emission rate (23.86 mg/s representative of bake-open door-100% vent occlusion by foil) are above 300 ppm/1h or 150 ppm for 8h, which can potentially result in permanent impairment or lethal endpoints (equivalent to about 20% COHb depending on activity level). Although the high CO emission rate of 3.18 mg/s also resulted in projected CO exposures that would exceed CPSC's recommended limits for UVGSH and KH, HS staff notes that only one individual range sample exceeded this value for either the test average, steady state average or peak test emission rate when the open door bake mode was used with less than 100% vent occlusion by foil (see Appendix 1). Room size greatly influenced projected CO exposures with the smallest room size being associated with highest exposure levels. If the smallest room sizes and the two highest emission rates used to model CO concentrations are removed from consideration, the data indicate that there is only a minor concern for adverse CO health effects when gas ranges are used as space heaters for up to 4 hours.

Use of Gas Ranges for Baking or Use of the Self Clean Cycle

When gas ranges are used as intended for baking, virtually all projected CO exposures above the recommendations for UVGSH or KH rate are confined to the extreme CO emission rate of 2.39 mg/s and/or the smallest room size. CO exposures of borderline health concern to highly susceptible populations (i.e., CAD patients) were noted in the next sized room (50 m^2, i.e., 400 m^3) at intermediate emission rates, but these exposure levels (between 16-38 ppm for 1-8 h) would be unlikely to result in perceptible health effects in healthy adults.

Regarding the self clean cycle of gas ranges, the highest projected CO levels were again confined to the highest emission rate (0.48 mg/s) or the smallest room volumes. However, even these highest levels are only of moderate concern for highly susceptible populations and are unlikely to have perceptible effects in healthy individuals.

Oven Use and CO Alarms

Staff did find that use of gas ranges as space heaters with foil occlusion of vents would be projected to generate CO levels sufficient to exceed the mandatory activation criteria for CO alarms (Table 3). However, during normal use of ranges for baking purposes, there is a very low likelihood that CO emissions would reach the mandatory activation threshold for CO alarms. Indeed, CPSC's "closed door/bake" steady state test data found that only one range exceeded 2.39 mg/s, the CO emission rate selected for "extreme" bake scenarios, even when the oven vents were 100% occluded by foil. HS staff acknowledges that there will be a few times annually, when the projected use of the oven for baking/roasting will probably exceed the 2 hour duration used in the bake cycle modelling scenario (e.g. Thanksgiving and other holidays) and that the indoor air levels of CO will likely be increased at these times. CO levels from use of the self clean cycle did not reach the mandatory criteria for CO alarm activation.

Conclusions

When used as intended, unvented gas ranges do not generally produce CO levels of consequence to healthy consumers, even if oven vents are up to 50% occluded. Even when used as a space heater for short durations, or when operated as intended by the manufacturers in small confined spaces, CO levels are not likely to be of health concern unless the oven vents are 100% occluded. Normal use of the self clean cycle is not of concern unless run in a confined space. Staff finds that use of a CO alarm should protect consumers from even the most extreme operating conditions. Staff cannot rule out the possibility that extremely susceptible consumers could be adversely impacted by use of unvented gas ranges in small spaces, but there is generally a low likelihood of adverse health effects associated with CO emissions from properly functioning unvented gas ranges.

References

Davis D, and Brown CJ, CPSC LS memo to Ron Jordan ES. Summary of Carbon Monoxide Emission Test Results of Gas Ranges with Self Cleaning Ovens (4/28/2000)

Persily AK, (NIST) Draft Letter report to CPSC. Estimation of Indoor Carbon Monoxide Levels due to Emissions From Residential Gas Ovens (7/00)

Burton LE, CPSC HS memo. Toxicity from Low Level Human Exposure to Carbon Monoxide (7/1/96)

Table 2: Projected Indoor CO Levels Associated with Unvented Gas Ranges under Specific Use Scenarios
Shaded cells show ppm values that reach 25 ppm/1h or 15 ppm/8h - recommended limits for UVGSHs and KHs

SPACE HEAT 1: 4 h on, 4 h off		Emission rates in mg/s (cc/h)							
		0.32 (1000)		0.80 (2500)		3.18 (10000)		23.86 (75000)	
		Carbon monoxide concentration ppm (mg/m^3 x 0.87336)							
	Averaging period	1 h	8 h	1 h	8 h	1 h	8 h	1 h	8 h
Room size	Air change rate (hr-1)								
20 m^2	0.2	54	36	136	89	544	355	4080	2663
(48 m^3)	0.35	43	25	107	64	424	254	3183	1906
	0.7	27	14	68	36	272	143	2035	1072
50 m^2	0.2	22	14	54	36	217	142	1632	1065
(120 m^3)	0.35	17	10	43	25	169	101	1273	762
	0.7	10	6	27	14	108	57	814	429
100 m^2	0.2	10	7	27	17	109	71	816	533
(240 m^3)	0.35	9	5	21	13	85	51	637	381
	0.7	5	3	14	7	54	29	407	215
150 m^2	0.2	7	4	18	12	72	47	544	355
(360m^3)	0.35	5	3	14	9	57	34	424	254
	0.7	3	2	9	4	36	19	272	143
200 m^2	0.2	5	3	14	9	54	36	408	266
(480 m^3)	0.35	4	3	10	6	43	25	319	190
	0.7	3	2	7	3	27	14	203	107

SPACE HEAT 2: 1 h on, 7 h off		Emission rates in mg/s (cc/h)							
		0.32 (1000)		0.80 (2500)		3.18 (10000)		23.86 (75000)	
		Carbon monoxide concentration ppm (mg/m^3 x 0.87336)							
	Averaging period	1 h	8 h	1 h	8 h	1 h	8 h	1 h	8 h
Room size	Air change rate (hr-1)								
20 m^2	0.2	17	10	43	24	172	100	1290	747
(48 m^3)	0.35	15	7	38	17	153	68	1143	508
	0.7	12	3	31	9	121	37	904	272
50 m^2	0.2	7	4	17	10	69	40	516	299
(120 m^3)	0.35	6	3	15	7	61	27	458	203
	0.7	5	2	12	3	48	15	362	109
100 m^2	0.2	3	2	9	5	34	20	258	149
(240 m^3)	0.35	3	2	8	3	31	14	229	101
	0.7	3	1	6	2	24	7	181	54
150 m^2	0.2	3	2	6	3	23	13	172	100
(360m^3)	0.35	2	1	5	3	20	9	153	68
	0.7	2	1	4	1	16	5	121	37
200 m^2	0.2	2	1	4	3	17	10	129	74
(480 m^3)	0.35	2	1	3	2	15	7	114	51
	0.7	1	0	3	1	12	3	91	27

SCENARIO BAKE: 2 h on, 6 h off		Emission rates in mg/s (cc/h)							
		0.32 (1000)		0.64 (2000)		0.95 (3000)		2.39 (7500)	
		Carbon monoxide concentration ppm (mg/m^3 x 0.87336)							
	Averaging period	1 h	8 h	1 h	8 h	1 h	8 h	1 h	8 h
Room size	Air change rate (hr-1)								
20 m^2	0.2	31	19	64	38	95	58	238	145
(48 m^3)	0.35	27	13	54	27	81	40	203	100
	0.7	20	7	40	15	59	22	149	54
50 m^2	0.2	13	8	25	16	38	24	95	58
(120 m^3)	0.35	10	5	22	10	32	16	81	40
	0.7	8	3	16	6	24	9	59	22
100 m^2	0.2	6	3	13	8	19	11	48	29
(240 m^3)	0.35	5	3	10	5	17	8	40	20
	0.7	4	2	8	3	12	4	30	10
150 m^2	0.2	4	3	9	5	13	8	31	19
(360m^3)	0.35	3	2	7	3	10	5	27	13
	0.7	3	1	5	2	8	3	20	7
200 m^2	0.2	3	2	6	3	10	6	24	15
(480 m^3)	0.35	3	2	5	3	8	4	20	10
	0.7	2	1	4	2	6	2	15	5

SELF CLEAN: 3 h on, 5 h off		Emission rates in mg/s (cc/h)					
		0.16 (500)		0.32 (1000)		0.48 (1500)	
		Carbon monoxide concentration ppm (mg/m^3 x 0.87336)					
	Averaging period	1 h	8 h	1 h	8 h	1 h	8 h
Room size	Air change rate (hr-1)						
20 m^2	0.2	22	14	44	28	66	42
(48 m^3)	0.35	18	10	36	19	54	30
	0.7	12	5	24	10	37	17
50 m^2	0.2	9	5	17	11	26	17
(120 m^3)	0.35	7	3	14	8	22	11
	0.7	5	2	10	4	15	6
100 m^2	0.2	4	3	9	5	13	9
(240 m^3)	0.35	3	2	7	3	10	6
	0.7	3	1	5	2	7	3
150 m^2	0.2	3	2	6	3	9	5
(360m^3)	0.35	3	1	4	3	7	3
	0.7	2	1	3	2	5	2
200 m^2	0.2	3	2	4	3	7	4
(480 m^3)	0.35	2	1	3	2	5	3
	0.7	1	1	3	1	3	2

Note: for all floor areas, the room ceiling height was set at 2.4 m

Table 3: Projected Indoor CO Levels Associated with Unvented Gas Ranges under Specific Use Scenarios
Shaded cells show ppm values that reach CO alarm voluntary standards criteria for mandatory alarm activation

SPACE HEAT 1: 4 h on, 4 h off		Emission rates in mg/s (cc/h)							
		0.32 (1000)		0.80 (2500)		3.18 (10000)		23.86 (75000)	
		Carbon monoxide concentration ppm (mg/m^3 x 0.87336)							
	Averaging period	1 h	8 h	1 h	8 h	1 h	8 h	1 h	8 h
Room size	Air change rate (hr-1)								
20 m^2	0.2	54	36	136	89	544	355	4080	2683
(48 m^3)	0.35	43	25	107	64	424	254	3183	1905
	0.7	27	14	68	36	272	143	2035	1072
50 m^2	0.2	22	14	54	36	217	142	1632	1065
(120 m^3)	0.35	17	10	43	25	169	101	1273	762
	0.7	10	6	27	14	108	57	814	429
100 m^2	0.2	10	7	27	17	109	71	816	533
(240 m^3)	0.35	9	5	21	13	85	51	637	381
	0.7	5	3	14	7	54	29	407	215
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(360 m^3)	0.35	5	3	14	9	57	34	424	254
	0.7	3	2	9	4	36	19	272	143
200 m^2	0.2	5	3	14	9	54	36	408	266
(480 m^3)	0.35	4	3	10	6	43	25	319	190
	0.7	3	2	7	3	27	14	203	107

SPACE HEAT 2: 1 h on, 7 h off		Emission rates in mg/s (cc/h)							
		0.32 (1000)		0.80 (2500)		3.18 (10000)		23.86 (75000)	
		Carbon monoxide concentration ppm (mg/m^3 x 0.87336)							
	Averaging period	1 h	8 h	1 h	8 h	1 h	8 h	1 h	8 h
Room size	Air change rate (hr-1)								
20 m^2	0.2	17	10	43	24	172	100	1290	747
(48 m^3)	0.35	15	7	38	17	153	68	1143	508
	0.7	12	3	31	9	121	37	904	272
50 m^2	0.2	7	4	17	10	69	40	516	299
(120 m^3)	0.35	6	3	15	7	61	27	458	203
	0.7	5	2	12	3	48	15	362	109
100 m^2	0.2	3	2	9	5	34	20	258	149
(240 m^3)	0.35	3	2	8	3	31	14	229	101
	0.7	3	1	6	2	24	7	181	54
150 m^2	0.2	3	2	6	3	23	13	172	100
(360 m^3)	0.35	2	1	5	3	20	9	153	68
	0.7	2	1	4	1	16	5	121	37
200 m^2	0.2	2	1	4	3	17	10	129	74
(480 m^3)	0.35	2	1	3	2	15	7	114	51
	0.7	1	0	3	1	12	3	91	27

SCENARIO BAKE: 2 h on, 6 h off		Emission rates in mg/s (cc/h)							
		0.32 (1000)		0.64 (2000)		0.95 (3000)		2.39 (7500)	
		Carbon monoxide concentration ppm (mg/m^3 x 0.87336)							
	Averaging period	1 h	8 h	1 h	8 h	1 h	8 h	1 h	8 h
Room size	Air change rate (hr-1)								
20 m^2	0.2	31	19	64	38	95	58	238	145
(48 m^3)	0.35	27	13	54	27	81	40	203	100
	0.7	20	7	40	15	59	22	149	54
50 m^2	0.2	13	8	25	16	38	24	95	58
(120 m^3)	0.35	10	5	22	10	32	16	81	40
	0.7	8	3	16	6	24	9	59	22
100 m^2	0.2	6	3	13	8	19	11	48	29
(240 m^3)	0.35	5	3	10	5	17	8	40	20
	0.7	4	2	8	3	12	4	30	10
150 m^2	0.2	4	3	9	5	13	8	31	19
(360 m^3)	0.35	3	2	7	3	10	5	27	13
	0.7	3	1	5	2	8	3	20	7
200 m^2	0.2	3	2	6	3	10	6	24	15
(480 m^3)	0.35	3	2	5	3	8	4	20	10
	0.7	2	1	4	2	6	2	15	5

SELF CLEAN: 3 h on, 5 h off		Emission rates in mg/s (cc/h)					
		0.16 (500)		0.32 (1000)		0.48 (1500)	
		Carbon monoxide concentration ppm (mg/m^3 x 0.87336)					
	Averaging period	1 h	8 h	1 h	8 h	1 h	8 h
Room size	Air change rate (hr-1)						
20 m^2	0.2	22	14	44	28	66	42
(48 m^3)	0.35	18	10	36	19	54	30
	0.7	12	5	24	10	37	17
50 m^2	0.2	9	5	17	11	26	17
(120 m^3)	0.35	7	3	14	8	22	11
	0.7	5	2	10	4	15	6
100 m^2	0.2	4	3	9	5	13	9
(240 m^3)	0.35	3	2	7	3	10	6
	0.7	3	1	5	2	7	3
150 m^2	0.2	3	2	6	3	9	5
(360 m^3)	0.35	3	1	4	3	7	3
	0.7	2	1	3	2	5	2
200 m^2	0.2	3	2	4	3	7	4
(480 m^3)	0.35	2	1	3	2	5	3
	0.7	1	1	3	1	3	2

Note: for all floor areas, the room ceiling height was set at 2.4m

Appendix 1: Individual Range CO Emissions Test Data Grouped by Test Type (from Table 2, Persily, 2000)

Oven	Test Condition	CO Emission Rates					
		Test average		Steady-state average		Test peak	
		mg/s	cc/h	mg/s	cc/h	mg/s	cc/h
A1	Closed Door, Bake	0.187	574	0.215	663	0.222	683
A2	Closed Door, Bake	0.163	501	0.207	636	0.215	661
B1	Closed Door, Bake	0.605	1863	0.691	2127	0.709	2182
B2	Closed Door, Bake	0.353	1087	0.456	1403	0.476	1465
C1	Closed Door, Bake	0.242	744	0.27	832	0.286	879
C2	Closed Door, Bake	0.197	607	0.225	691	0.254	783
D1	Closed Door, Bake	0.292	900	0.321	987	0.332	1021
D2	Closed Door, Bake	0.275	847	0.337	1037	0.343	1057
A1	Closed Door, Bake, 50 % Foil	0.177	544	0.085	261	0.402	1236
A2	Closed Door, Bake, 50 % Foil	0.233	717	0.267	821	0.282	869
B1	Closed Door, Bake, 50 % Foil	1.223	3764	1.106	3405	1.747	5376
B2	Closed Door, Bake, 50 % Foil	0.766	2357	0.891	2743	0.957	2945
C1	Closed Door, Bake, 50 % Foil	0.043	132	0.452	1391	0.497	1530
C2	Closed Door, Bake, 50 %Foil	0.481	1480	0.284	873	1.085	3340
D1	Closed Door, Bake, 50 % Foil	0.518	1595	0.581	1790	0.604	1860
D2	Closed Door, Bake, 50 % Foil	0.805	2477	0.927	2853	0.978	3009
A1	Closed Door, Bake, 100 % Foil	3.728	11474	0.749	2306	11.552	35556
A2	Closed Door, Bake, 100 % Foil	0.319	982	0.33	1015	0.452	1391
B1	Closed Door, Bake, 100 % Foil	5.37	16527	7.37	22685	18.698	57551
B2	Closed Door, Bake, 100 % Foil	1.644	5061	1.513	4656	2.333	7181
C1	Closed Door, Bake, 100 % Foil	0.873	2686	0.53	1631	1.711	5267
C2	Closed Door, Bake, 100 % Foil	1.344	4137	0.641	1973	2.563	7889
D1	Closed Door, Bake, 100 % Foil	0.378	1163	0.55	1692	0.683	2102
D2	Closed Door, Bake, 100 % Foil	2.997	9224	2.706	8329	5.131	15793
A1	Open Door, Bake	0.165	506	0.196	604	0.204	629
A2	Open Door, Bake	0.172	529	0.211	649	0.218	672
B1	Open Door, Bake	0.602	1853	0.795	2447	0.829	2552
B2	Open Door, Bake	0.392	1206	0.562	1731	0.588	1809
C1	Open Door, Bake	0.234	719	0.342	1052	0.353	1086
C2	Open Door, Bake	0.267	823	0.338	1041	0.349	1075
D1	Open Door, Bake	0.126	387	0.162	497	0.173	534
D2	Open Door, Bake	0.161	496	0.216	664	0.234	721
A1	Open Door, Bake, 50 % Foil	0.533	1641	0.909	2798	1.043	3209
A2	Open Door, Bake, 50 % Foil	0.247	760	0.208	641	0.35	1076
B1	Open Door, Bake, 50 % Foil	1.698	5227	2.266	6974	2.347	7223
B2	Open Door, Bake, 50 % Foil	1.973	6073	2.971	9145	3.144	9677
C1	Open Door, Bake, 50 % Foil	1.552	4776	2.939	9045	3.169	9755
C2	Open Door, Bake, 50 % Foil	1.69	5201	3.057	9410	3.314	10200
D1	Open Door, Bake, 50 % Foil	0.706	2174	0.77	2370	0.886	2727
D2	Open Door, Bake, 50 % Foil	0.747	2300	0.81	2494	1.124	3459
A1	Open Door, Bake, 100 % Foil	16.39	50446	20.661	63592	28.384	87364
A2	Open Door, Bake, 100 % Foil	13.523	41623	20.72	63773	21.443	65999
B1	Open Door, Bake, 100 % Foil	25.124	77329	33.246	102326	33.55	103263
B2	Open Door, Bake, 100 % Foil	25.04	77071	33.328	102579	35.258	108518
C1	Open Door, Bake, 100 % Foil	6.897	21228	9.659	29729	9.766	30058
C2	Open Door, Bake, 100 % Foil	9.53	29332	14.581	44878	14.813	45592
D1	Open Door, Bake, 100 % Foil	6.899	21236	10.063	30971	10.243	31527
D2	Open Door, Bake, 100 % Foil	21.399	65863	28.499	87717	28.773	88561
A1	Self-Clean	0.316	973	0.351	1081	0.36	1106
A2	Self-Clean	0.134	413	0.105	323	0.262	805
B1	Self-Clean	0.737	2269	0.576	1773	1.176	3618
B2	Self-Clean	0.362	1113	0.291	894	0.575	1770
C1	Self-Clean	0.212	653	0.313	964	0.366	1126
C2	Self-Clean	0.312	960	0.352	1083	0.392	1206
D1	Self-Clean	0.521	1604	0.379	1167	0.998	3072
D2	Self-Clean	0.503	1547	0.481	1480	0.755	2322

ESTIMATION OF INDOOR CARBON MONOXIDE LEVELS DUE TO EMISSIONS FROM RESIDENTIAL GAS OVENS

Letter Report to U.S. Consumer Product Safety Commission

December 12, 2000

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ABSTRACT

The U.S. Consumer Product Safety Commission (CPSC) is evaluating the emissions of carbon monoxide (CO) from residential gas-fired ovens under various conditions of consumer use. CPSC staff performed measurements of CO emissions from eight ovens in a single-zone test chamber. Using the emission rates measured by CPSC, the National Institute of Standards and Technology (NIST) estimated the levels of CO that could reasonably be expected to occur in U.S. residences under selected operating conditions. These estimates are based on a single-zone mass balance analysis and include several simplifying assumptions. This letter report describes the analysis approach employed and the results of the calculations of indoor CO levels.

Keywords: carbon monoxide, gas appliances, indoor air quality, ovens.

This project was funded by the Consumer Product Safety Commission (CPSC). The content of the publication does not necessarily reflect the views of the Commission, nor does mention of trade names, commercial products, or organizations imply endorsement by the Commission.

INTRODUCTION

Based on incident investigations, information from outside organizations and concerns from state health departments, the U.S. Consumer Product Safety Commission (CPSC) evaluated the production of carbon monoxide (CO) from gas ranges and ovens in residential buildings. CPSC's interest is based in part on the use of ranges and ovens as space heaters and the practice on the part of some consumers to line the bottoms of ovens with aluminum foil. CPSC implemented an emissions testing program to understand the performance of ranges and ovens under various use patterns. The purpose of the CPSC testing program was to investigate whether gas ovens generate high levels of CO during certain consumer uses and to make recommendations to revise the voluntary standard for gas ovens if appropriate. The CPSC testing focused on range top burner and oven burner emissions from eight freestanding gas ranges and ovens, which were tested in an emissions measurement chamber at CPSC's laboratories.

In order to relate the measurements of emission rates to expected indoor CO levels in residential buildings, CPSC entered into an interagency agreement with the National Institute of Standards and Technology (NIST). The objective of the study covered by this agreement is to estimate indoor CO emissions for a variety of conditions in residential buildings based on the CPSC emissions test results. This study employs a simple, single-zone analysis approach that is not expected to precisely predict indoor CO levels, but rather to estimate the range of concentrations that might be expected to exist under a reasonable range of building sizes and air change rates.

CPSC EMISSIONS TEST DATA

The emission measurements conducted by CPSC are described elsewhere (Davis 2000). In the measurement program, CPSC purchased eight new gas ranges with self-cleaning ovens from retail vendors in the Washington DC metropolitan area. The ranges were selected by CPSC to represent a random selection of models covering a range of costs from four major manufacturers. The units are designated by CPSC, and in this report, as A1, A2, B1, B2, C1, C2, D1 and D2. The CO emissions were measured in a 27.3 m^3 (965 ft^3) environmental chamber at CPSC's laboratories. In these tests, CPSC monitored CO levels in the chamber during appliance operation and calculated the CO emission rates over time based on the chamber air change rate. Air change rates were measured by tracer gas decay after the appliance stopped operating. Each test lasted about 60 min to 90 min, depending on the chamber air change rate. Each appliance was tested once under the conditions listed in Table 1.

Table 1 Appliance Operating Conditions During Emissions Tests

Appliance Operation	Door Position	Percent Foil on Oven Bottom
Bake	Closed	0
Bake	Open	0
Bake	Closed	50
Bake	Open	50
Bake	Closed	100
Bake	Open	100
Broil	Closed	0
Broil	Open	0
Broil	Closed	50
Broil	Open	50
Broil	Closed	100
Broil	Open	100
Self-clean	Closed	0

Not all conditions are reported for all appliances due to some tests being eliminated by CPSC due to instrument failure or some other problem.

Table 2 contains the CO emission test results provided to NIST by CPSC. The first column of the table lists the oven to which the results apply, and the second column is the test condition, specifically door position and the presence of foil on the oven bottom. The next six columns present three different emission rates, in units of mg/s and cc/h. (The emission rates provided by CPSC were in units of cc/h. These were converted to mg/s based on the density of CO at 101.3 kPa and 25 °C, i.e., 1.145 kg/m^3.) The first emission rate is the average rate over the entire test. The second value is the average emission rate after the appliance has achieved "steady-state" operation, that is, after initial transients have dissipated. And the third value is the peak emission rate measured over the entire test.

The emission rates in Table 2 were calculated by CPSC as part of their experimental effort and provided to NIST at the beginning of this project. The emission rates were provided to NIST with no value of the associated uncertainty. Given the lack of an uncertainty value, these rates are presented in the tables that follow to the nearest 0.001 mg/s (1 cc/h).

Table 2 Carbon Monoxide Emission Rates Measured by CPSC

		CO Emission Rate					
		Test average		Steady-state average		Test peak	
Oven	Test Condition	mg/s	cc/h	mg/s	cc/h	mg/s	cc/h
A1	Closed Door, Broil	0.196	603	0.215	661	0.265	814
	Open Door, Broil	0.058	180	0.084	260	0.092	284
	Closed Door, Bake	0.187	574	0.215	663	0.222	683
	Open Door, Bake	0.165	506	0.196	604	0.204	629
	Self-Clean	0.316	973	0.351	1081	0.360	1106
	Closed Door, Bake, 50 % Foil	0.177	544	0.085	261	0.402	1236
	Closed Door, Bake, 100 % Foil	3.728	11474	0.749	2306	11.552	35556
	Open Door, Bake, 50 % Foil	0.533	1641	0.909	2798	1.043	3209
	Open Door, Bake, 100 % Foil	16.390	50446	20.661	63592	28.384	87364
	Closed Door, Broil, 100 % Foil	0.162	500	0.202	623	0.210	645
A2	Closed Door, Broil	0.116	358	0.161	495	0.167	516
	Open Door, Broil	0.053	164	0.057	177	0.088	271
	Closed Door, Bake	0.163	501	0.207	636	0.215	661
	Open Door, Bake	0.172	529	0.211	649	0.218	672
	Self-Clean	0.134	413	0.105	323	0.262	805
	Closed Door, Bake, 50 % Foil	0.233	717	0.267	821	0.282	869
	Closed Door, Bake, 100 % Foil	0.319	982	0.330	1015	0.452	1391
	Open Door, Bake, 50 % Foil	0.247	760	0.208	641	0.350	1076
	Open Door, Bake, 100 % Foil	13.523	41623	20.720	63773	21.443	65999
B1	Closed Door, Broil	0.195	600	0.172	530	0.257	792
	Open Door, Broil	0.076	233	0.094	288	0.099	305
	Closed Door, Bake	0.605	1863	0.691	2127	0.709	2182
	Open Door, Bake	0.602	1853	0.795	2447	0.829	2552
	Self-Clean	0.737	2269	0.576	1773	1.176	3618
	Closed Door, Bake, 50 % Foil	1.223	3764	1.106	3405	1.747	5376
	Closed Door, Bake, 100 % Foil	5.370	16527	7.370	22685	18.698	57551
	Open Door, Bake, 50 % Foil	1.698	5227	2.266	6974	2.347	7223
	Open Door, Bake, 100 % Foil	25.124	77329	33.246	102326	33.550	103263
	Closed Door, Broil, 100 % Foil	0.127	392	0.118	363	0.159	489

Table 2 Carbon Monoxide Emission Rates Measured by CPSC (continued)

		Test average		Steady-state average		Test peak	
Oven	Test Condition	mg/s	cc/h	mg/s	cc/h	mg/s	cc/h
B2	Closed Door, Broil	0.181	556	0.177	546	0.232	713
	Open Door, Broil	0.169	519	0.176	541	0.210	647
	Closed Door, Bake	0.353	1087	0.456	1403	0.476	1465
	Open Door, Bake	0.392	1206	0.562	1731	0.588	1809
	Self-Clean	0.362	1113	0.291	894	0.575	1770
	Closed Door, Bake, 50 % Foil	0.766	2357	0.891	2743	0.957	2945
	Closed Door, Bake, 100 % Foil	1.644	5061	1.513	4656	2.333	7181
	Open Door, Bake, 50 % Foil	1.973	6073	2.971	9145	3.144	9677
	Open Door, Bake, 100 % Foil	25.040	77071	33.328	102579	35.258	108518
	Closed Door, Broil, 100 % Foil	0.181	558	0.128	393	0.327	1005
C1	Closed Door, Broil	0.181	558	0.179	551	0.228	702
	Open Door, Broil	0.155	478	0.180	553	0.189	582
	Closed Door, Bake	0.242	744	0.270	832	0.286	879
	Open Door, Bake	0.234	719	0.342	1052	0.353	1086
	Self-Clean	0.212	653	0.313	964	0.366	1126
	Closed Door, Bake, 50 % Foil	0.043	132	0.452	1391	0.497	1530
	Closed Door, Bake, 100 % Foil	0.873	2686	0.530	1631	1.711	5267
	Open Door, Bake, 50 % Foil	1.552	4776	2.939	9045	3.169	9755
	Open Door, Bake, 100 % Foil	6.897	21228	9.659	29729	9.766	30058
	Closed Door, Broil, 100 % Foil	0.120	370	0.122	374	0.144	445
C2	Closed Door, Broil	0.409	1258	0.402	1238	0.491	1511
	Open Door, Broil	0.282	868	0.333	1025	0.340	1047
	Closed Door, Bake	0.197	607	0.225	691	0.254	783
	Open Door, Bake	0.267	823	0.338	1041	0.349	1075
	Self-Clean	0.312	960	0.352	1083	0.392	1206
	Closed Door, Bake, 50 %Foil	0.481	1480	0.284	873	1.085	3340
	Closed Door, Bake, 100 % Foil	1.344	4137	0.641	1973	2.563	7889
	Open Door, Bake, 50 % Foil	1.690	5201	3.057	9410	3.314	10200
	Open Door, Bake, 100 % Foil	9.530	29332	14.581	44878	14.813	45592
D1	Closed Door, Broil	0.114	351	0.071	217	0.210	646
	Open Door, Broil	0.172	530	0.176	543	0.260	800
	Closed Door, Bake	0.292	900	0.321	987	0.332	1021
	Open Door, Bake	0.126	387	0.162	497	0.173	534
	Self-Clean	0.521	1604	0.379	1167	0.998	3072
	Closed Door, Bake, 50 % Foil	0.518	1595	0.581	1790	0.604	1860
	Closed Door, Bake, 100 % Foil	0.378	1163	0.550	1692	0.683	2102
	Open Door, Bake, 50 % Foil	0.706	2174	0.770	2370	0.886	2727
	Open Door, Bake, 100 % Foil	6.899	21236	10.063	30971	10.243	31527
	Closed Door, Broil, 100 % Foil	0.091	281	0.032	97	0.248	763

Table 2 Carbon Monoxide Emission Rates Measured by CPSC (continued)

		Test average		Steady-state average		Test peak	
Oven	**Test Condition**	**mg/s**	**cc/h**	**mg/s**	**cc/h**	**mg/s**	**cc/h**
D2	Closed Door, Broil	0.164	504	0.117	360	0.287	882
	Open Door, Broil	0.053	162	0.057	174	0.064	197
	Closed Door, Bake	0.275	847	0.337	1037	0.343	1057
	Open Door, Bake	0.161	496	0.216	664	0.234	721
	Self-Clean	0.503	1547	0.481	1480	0.755	2322
	Closed Door, Bake, 50 % Foil	0.805	2477	0.927	2853	0.978	3009
	Closed Door, Bake, 100 % Foil	2.997	9224	2.706	8329	5.131	15793
	Open Door, Bake, 50 % Foil	0.747	2300	0.810	2494	1.124	3459
	Open Door, Bake, 100 % Foil	21.399	65863	28.499	87717	28.773	88561

Table 3 summarizes the measured emission rates based on test condition. For each operating condition, the table contains the mean value of the average emission rate over each test, the mean of the average under "steady-state" operation, and the mean of the peak emission rate over each test. In addition to these mean values, the table presents the standard deviation, maximum and minimum of the emission rates for each operating condition. The highest emission rates for these ovens occur with foil on the bottom in the bake mode. Increased foil coverage and an open door are also associated with higher emissions.

Table 3 Summary of Emission Rates by Test Condition

	CO Emission Rate							
	Mean		Standard deviation		Maximum		Minimum	
Condition	mg/s	cc/h	mg/s	cc/h	mg/s	cc/h	mg/s	cc/h
Test Average								
Broil, closed door, no foil	0.194	598	0.092	285	0.409	1258	0.114	351
Broil, open door, no foil	0.127	392	0.082	252	0.282	868	0.053	162
Bake, closed door, no foil	0.289	890	0.142	437	0.605	1863	0.163	501
Bake, open door, no foil	0.265	815	0.160	493	0.602	1853	0.126	387
Self clean	0.387	1192	0.193	593	0.737	2269	0.134	413
Bake, closed door, 50 % foil	0.531	1633	0.390	1200	1.223	3764	0.043	132
Bake, closed door, 100 % foil	2.082	6407	1.795	5526	5.370	16527	0.319	982
Bake, open door, 50 % foil	1.143	3519	0.653	2010	1.973	6073	0.247	760
Bake, open door, 100 % foil	15.600	48016	7.622	23460	25.124	77329	6.897	21228
Broil, closed door, 100 % foil	0.137	420	0.036	110	0.181	558	0.091	281
Steady-state Average								
Broil, closed door, no foil	0.187	575	0.098	300	0.402	1238	0.071	217
Broil, open door, no foil	0.145	445	0.093	286	0.333	1025	0.057	174
Bake, closed door, no foil	0.340	1047	0.164	505	0.691	2127	0.207	636
Bake, open door, no foil	0.353	1086	0.220	678	0.795	2447	0.162	497
Self clean	0.356	1096	0.138	425	0.576	1773	0.105	323
Bake, closed door, 50 % foil	0.574	1767	0.367	1129	1.106	3405	0.085	261
Bake, closed door, 100 % foil	1.799	5536	2.382	7331	7.370	22685	0.330	1015
Bake, open door, 50 % foil	1.741	5359	1.184	3643	3.057	9410	0.208	641
Bake, open door, 100 % foil	21.344	65696	9.613	29588	33.328	10257	9.659	29729
Broil, closed door, 100 % foil	0.120	370	0.060	186	0.202	623	0.032	97
Test Peak								
Broil, closed door, no foil	0.267	822	0.097	300	0.491	1511	0.167	516
Broil, open door, no foil	0.168	517	0.099	303	0.340	1047	0.064	197
Bake, closed door, no foil	0.355	1092	0.166	511	0.709	2182	0.215	661
Bake, open door, no foil	0.369	1135	0.229	704	0.829	2552	0.173	534
Self clean	0.610	1878	0.335	1030	1.176	3618	0.262	805
Bake, closed door, 50 % foil	0.819	2521	0.476	1466	1.747	5376	0.282	869
Bake, closed door, 100 % foil	5.390	16591	6.465	19898	18.698	57551	0.452	1391
Bake, open door, 50 % foil	1.922	5916	1.203	3701	3.314	10200	0.350	1076
Bake, open door, 100 % foil	22.779	70110	10.218	31449	35.258	10851	9.766	30058
Broil, closed door, 100 % foil	0.218	669	0.074	226	0.327	1005	0.144	445

DESCRIPTION OF ANALYSIS

Based on the emission rates provided by CPSC, NIST performed analyses to calculate the indoor CO levels that could exist in residential buildings. The analyses were based on a single-zone mass balance analysis of CO, which can be expressed as follows:

$$V dC/dt = G + C_{out}Q - C(t)Q \qquad (1)$$

where

V = space volume, (m^3)
$C(t)$ = indoor CO concentration at time t, (mg/m^3)
C_{out} = outdoor CO concentration, (mg/m^3)
Q = airflow rate into (and out of) the space, (m^3/s)
t = time, (s)
G = CO emission rate, (mg/s)

The key assumption in this equation is that the CO concentration in the volume is represented by a single value C. In addition, density differences between the indoor and outdoor air are neglected.

Under conditions of constant Q and G, the solution to Equation (1) is as follows:

$$C(t) = C_{init}\exp(-Qt/V) + C_{out}[1 - \exp(-Qt/V)] + (G/Q)[1 - \exp(-Qt/V)] \qquad (2)$$

where

C_{init} = indoor CO concentration at time t=0, (mg/m^3)

Equation (2) was used to calculate CO concentrations over an 8 h period for four different modes of operation: two heating modes, baking and self-cleaning. For each mode, the oven was assumed to start operating at t=0 for a fixed period of time and to emit CO at a constant rate during this period of time. The emission rate was then reduced to zero after operation ceased and through the end of the 8 h analysis period. At the point in time when the oven was assumed to stop operating, G was set equal to zero in Equation 2 and C_{init} was set to the concentration at the time operation ceased. Time was also reset to zero in the calculations.

Based on discussions with CPSC, four modes of operation were defined as follows:

Space Heating 1: 4 h on followed by 4 h off
Space Heating 2: 1 h on followed by 7 h off
Baking: 2 h on followed by 6 h off
Self-cleaning: 3 h on followed by 5 hours off.

The two "space heating" modes correspond to the use of the oven for heating with the oven door open. The second space heating mode, with only 1 h of oven operation, was included based on concerns that some spaces might overheat over a 4 h operating period. The "baking" mode corresponds to using the appliance in the bake mode with the door closed. And the "self-cleaning" mode is the automated operation of the oven in that mode with the door closed. A broiling mode was not considered since the emission rates were generally lower in that mode of operation and the oven would not be expected to operate for very long in the broil mode.

To carry out these analyses, values were needed for C_{init}, C_{out}, Q, V and G. Both C_{init} and C_{out} were assumed to equal 0 mg/m^3 (0 ppm(v)) throughout the analysis period. While there is typically a nonzero background level of CO in the ambient air, it is generally on the order of only 1 mg/m^3 (1 ppm(v)). Because the objective of this analysis is simply to estimate indoor CO levels and because these estimates are not expected to be accurate to within 1 mg/m^3 (1 ppm(v)), the ambient CO concentration was neglected.

The values of the space ventilation rate Q were calculated from an assumed air change rate multiplied by the space volume V discussed below. Three values of air change rate were used to calculate Q. These values are 0.2 h^{-1}, 0.35 h^{-1}, and 0.70 h^{-1}. The middle value, 0.35 h^{-1}, is included as a baseline value based on it being the residential ventilation requirement contained in ASHRAE Standard 62-1999. The lower value of 0.2 h^{-1} was included as a low air change rate, though residential air change rates can be significantly lower. The high air change rate, 0.70 h^{-1}, is based on twice the ASHRAE residential requirement.

Five values of space volume were used in the analysis based on a ceiling height of 2.4 m (8 ft) and five values of floor area: 20 m^2 (220 ft^2), 50 m^2 (540 ft^2), 100 m^2 (1080 ft^2), 150 m^2 (1610 ft^2), and 200 m^2 (2200 ft^2). The smaller floor areas (volumes) were included to represent kitchens with very limited exchange of air with the rest of a residence. Without multizone airflow modeling, it is not possible to calculate concentrations in a kitchen, and therefore a small volume was used in the analysis to obtain a conservative estimate of the concentrations that could occur in a kitchen that has limited airflow communication with the rest of the residence. The three higher floor areas are intended to represent small, medium and large residences. In the single-zone analysis employed, the use of these three floor areas assumes that the CO generated in the kitchen is uniformly dispersed through the residence, i.e., the concentration in the kitchen is the same as the rest of the house. Therefore, the use of the two smaller "kitchen" volumes is somewhat conservative in terms of mixing, while the three larger values are less so.

The CO generation rates for the analysis were based on the measured values provided by CPSC. To determine reasonable values, NIST considered the test conditions from CPSC in the context of the four modes of operation that were simulated. The specific associations are presented in Table 4.

Table 4 Analysis Modes and Relevant CPSC Test Conditions

Analysis Mode	Relevant test conditions from CPSC tests
Space Heating 1 and 2	Bake, open door, no foil
	Bake, open door, 50 % foil
	Bake, open door, 100 % foil
Baking	Bake, closed door, no foil
	Bake, closed door, 50 % foil
	Bake, closed door, 100 % foil
Self-cleaning	Self-clean

For each of the Analysis Modes, the measured emission rates were examined to determine a range of values that represent the test condition. Based on this examination, the generation rates in Table 5 were selected for the analysis. Note that the low and extreme generation rates do not reflect the absolute lowest and highest rates measured. Also note that the same emission rates were used for the two space heating modes; only their oven operation times differed.

Table 5 Carbon Monoxide Generation Rates Used in the Analysis

Analysis Mode		**CO Generation Rate**	
		mg/s	**cc/h**
Space Heating 1 and 2	Low	0.32	1000
	Medium	0.80	2500
	High	3.18	10000
	Extreme	23.86	75000
Baking	Low	0.32	1000
	Medium	0.64	2000
	High	0.95	3000
	Extreme	2.39	7500
Self-cleaning	Low	0.16	500
	Medium	0.32	1000
	High	0.48	1500

For each combination of analysis mode, space volume (floor area), air change rate, and CO generation rate, indoor CO concentrations were calculated over 8 h. The results of each analysis are presented in terms of the highest 1 h average concentration over the analysis period and as the average concentration over the entire 8 h analysis period.

ANALYSIS RESULTS

Figure 1 presents a sample of the analysis results, that is, the predicted CO concentrations in mg/m^3 over 8 h. This case is under the first space heating mode, where the oven operates for 4 h and then is off for 4 h. For this particular case, the CO emission rate is 3.18 mg/s (10000 cc/h), the air change rate is $0.35\ h^{-1}$, and the floor area is $100\ m^2$.

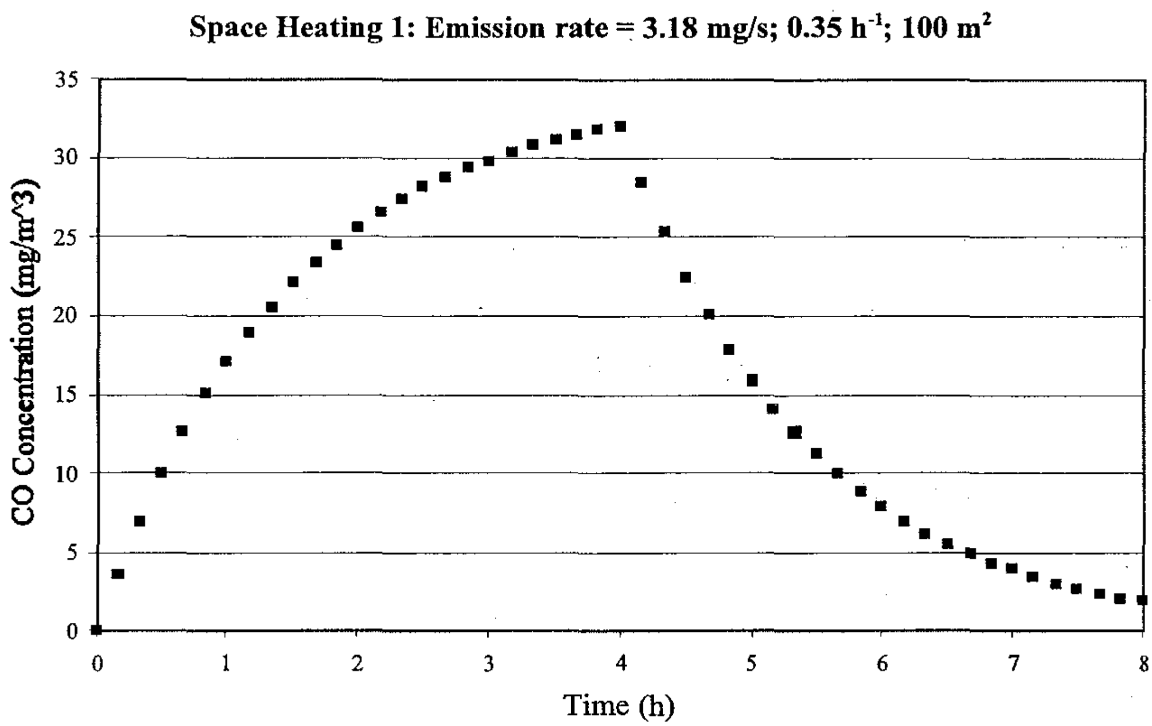

Figure 1 Sample Carbon Monoxide Concentrations over 8 Hour Analysis Period (to convert concentrations from mg/m^3 to ppm(v), divide by 1.145)

The results of the analyses are presented in Table 6. The table presents the maximum 1 h and the 8 h mean CO concentrations calculated for each combination of floor area, air change rate and emission rate for the four oven operation scenarios, that is, space heat 1 and 2, bake and self-clean. As expected the indoor concentrations are higher for lower floor areas, lower air change rates and higher emission rates. For the same emission rate, the longer operating period yields higher concentrations as expected.

Table 6 Analysis Results

SCENARIO	Floor area (m^2)	Air change rate (hr^{-1})							
SPACE HEAT 1: 4 h on, 4 h off			**Emission rates in mg/s (cc/h)**						
			0.32 (1000)		0.80 (2500)		3.18 (10000)		23.86 (75000)	
			Carbon monoxide concentration (mg/m³)*						
Averaging period			1 h	8 h	1 h	8 h	1 h	8 h	1 h	8 h
	20	0.20	62	41	156	102	623	407	4672	3049
		0.35	49	29	122	73	486	291	3645	2181
		0.70	31	16	78	41	311	164	2330	1228
	50	0.20	25	16	62	41	249	163	1869	1220
		0.35	19	12	49	29	194	116	1458	873
		0.70	12	7	31	16	124	65	932	491
	100	0.20	12	8	31	20	125	81	934	610
		0.35	10	6	24	15	97	58	729	436
		0.70	6	3	16	8	62	33	466	246
	150	0.20	8	5	21	14	83	54	623	407
		0.35	6	4	16	10	65	39	486	291
		0.70	4	2	10	5	41	22	311	164
	200	0.20	6	4	16	10	62	41	467	305
		0.35	5	3	12	7	49	29	365	218
		0.70	3	2	8	4	31	16	233	123
SPACE HEAT 2: 1 h on, 7 h off			**Emission rates in mg/s (cc/h)**						
			0.32 (1000)		0.80 (2500)		3.18 (10000)		23.86 (75000)	
			Carbon monoxide concentration (mg/m³)*						
Averaging period			1 h	8 h	1 h	8 h	1 h	8 h	1 h	8 h
	20	0.20	20	11	49	28	197	114	1477	855
		0.35	17	8	44	19	175	78	1309	582
		0.70	14	4	35	10	138	42	1035	311
	50	0.20	8	5	20	11	79	46	591	342
		0.35	7	3	17	8	70	31	524	233
		0.70	6	2	14	4	55	17	414	125
	100	0.20	4	2	10	6	39	23	295	171
		0.35	3	2	9	4	35	16	262	116
		0.70	3	1	7	2	28	8	207	62
	150	0.20	3	2	7	4	26	15	197	114
		0.35	2	1	6	3	23	10	175	78
		0.70	2	1	5	1	18	6	138	42
	200	0.20	2	1	5	3	20	11	148	85
		0.35	2	1	4	2	17	8	131	58
		0.70	1	0	3	1	14	4	104	31

To convert concentrations from mg/m³ to ppm(v), divide by 1.145.

Table 6 Analysis Results (continued)

SCENARIO	Floor area (m^2)	Air change rate (hr^{-1})								
BAKE: 2 h on, 6 h off			**Emission rates in mg/s (cc/h)**							
			0.32 (1000)		0.64 (2000)		0.95 (3000)		2.39 (7500)	
			Carbon monoxide concentration (mg/m^3)*							
Averaging period			1 h	8 h	1 h	8 h	1 h	8 h	1 h	8 h
	20	0.20	36	22	73	44	109	66	273	166
		0.35	31	15	62	31	93	46	232	114
		0.70	23	8	46	17	68	25	171	62
	50	0.20	15	9	29	18	44	27	109	66
		0.35	12	6	25	12	37	18	93	46
		0.70	9	3	18	7	27	10	68	25
	100	0.20	7	4	15	9	22	13	55	33
		0.35	6	3	12	6	19	9	46	23
		0.70	5	2	9	3	14	5	34	12
	150	0.20	5	3	10	6	15	9	36	22
		0.35	4	2	8	4	12	6	31	15
		0.70	3	1	6	2	9	3	23	8
	200	0.20	4	2	7	4	11	7	27	17
		0.35	3	2	6	3	9	5	23	11
		0.70	2	1	5	2	7	2	17	6
SELF CLEAN: 3 h on, 5 h off			**Emission rates in mg/s (cc/h)**							
			0.16 (500)		0.32 (1000)		0.48 (1500)			
			Carbon monoxide concentration (mg/m^3)*							
Averaging period			1 h	8 h	1 h	8 h	1 h	8 h		
	20	0.20	25	16	50	32	76	48		
		0.35	21	11	41	22	62	34		
		0.70	14	6	28	12	42	19		
	50	0.20	10	6	20	13	30	19		
		0.35	8	4	16	9	25	13		
		0.70	6	2	11	5	17	7		
	100	0.20	5	3	10	6	15	10		
		0.35	4	2	8	4	12	7		
		0.70	3	1	6	2	8	4		
	150	0.20	3	2	7	4	10	6		
		0.35	3	1	5	3	8	4		
		0.70	2	1	4	2	6	2		
	200	0.20	3	2	5	3	8	5		
		0.35	2	1	4	2	6	3		
		0.70	1	1	3	1	4	2		

To convert concentrations from mg/m^3 to ppm(v), divide by 1.145.

SUMMARY AND DISCUSSION

The analysis presented in this letter report is based on a simplified single zone mass balance, which limits its accuracy. Other limitations of this analysis are the lack of consideration of weather impacts and of CO mixing within the kitchen and the rest of the building. In addition, the accuracy of the analysis depends on the emission rates provided to NIST and the other specific values used in the analysis. Nonetheless, the results provide a reasonable estimate of the range of indoor CO concentrations that could result from the ovens tested by CPSC. More precise estimates of the indoor concentrations resulting from these emission rates would require consideration of weather-induced infiltration, mixing within the kitchen and the residence, and variations in emission rates over time. Such detailed analyses can be performed using multizone airflow and contaminant dispersal modeling in which a residential building is represented as a multizone airflow system.

ACKNOWLEDGMENTS

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Davis, D. 2000. Summary of carbon monoxide emission test results of gas ranges with self-cleaning ovens. U.S. Consumer Product Safety Commission, Directorate of Laboratory Sciences.