4.0 DISCUSSION

Data collected during this study addressed the following research objectives:

- Characterize emission rates and resultant indoor air concentrations and personal exposures for particulate matter (PM), carbon monoxide (CO), nitric oxide (NO), and nitrogen dioxide (NO_2) produced by residential cooking under typical and realistic worst-case conditions
- Characterize emission rates and resultant indoor air concentrations for other cooking pollutants such as PAHs, elements, and other potential marker compounds
- Measure the effectiveness of selected exposure reduction practices

As discussed in this section of the report, the data successfully addresses the objectives and provides a better understanding of the impact of cooking on exposures to occupants of residences. The results show that indoor concentrations of the air contaminants can be substantially elevated during certain types of cooking events, making a substantial contribution to the occupant's total exposure. The study also addressed selected reduction practices, demonstrating the impact on emissions of the various air contaminants.

The gas stove results, particularly those for CO, were clearly influenced by the fact that this unit was tuned and well cleaned before testing began. Routine maintenance of gas stoves in homes is the exception rather than the rule. Consequently, weatherization field workers and researchers have documented a common occurrence of dirty, maltuned gas stoves, which can produce indoor CO levels (Nelson et al., 1993, Tsongas 1994) that are over an order of magnitude higher than the levels found in this study. Higher PM, NO_2, and aldehyde emissions are also expected with maltuned stoves.

The following sub-sections summarize the results of the measurements during the cooking tests and discuss them as they relate to the project objectives. Summary tables presented in Section 3 are referenced in the discussion. The discussion addresses the pollutant concentrations and exposures during cooking; the impact of appliance type on indoor pollutant concentrations; the impacts of the cooking method, food type, and cooking vessel; and the impact of exposure reduction methods. The last section discusses the emission rates calculated for the different cooking tests.

There is a large amount of data available, and other analyses could be performed with the data collected in this study. As shown in Appendix D, the tuning of the stove-top burners greatly reduced CO emissions – indoor concentrations above the burners dropped from 35-59 ppm to 5 ppm. Results from the gas oven show a large drop-off in CO emissions as the oven began to heat. The ARB may find that further analyses of the data will be useful for more thorough understanding of the impact of cooking on indoor air quality and exposure.

4.1 Indoor Pollutant Concentrations and Exposures During Cooking

Pollutant concentrations were measured both indoors and outdoors during each test. For integrated samples collected on filters for gravimetric analysis, such as $PM_{2.5}$ and PM_{10}, the results represent the entire test period (the cooking period plus the one-hour post-cooking exposure period). As discussed in Section 2, data collected with the continuous monitors for CO, NO, NO_2, and PM with the ELPI were summarized by calculating average concentrations for the cooking period only and for the total exposure period, which included the one-hour post-cooking exposure period. Data are also broken out by cooking event for multiple event tests. It should be noted that exposure was not measured over long periods (24 hours), but only during the short cooking/eating/cleanup periods. The duration of the total exposure periods ranged from approximately 1.5 hours (bacon and stir frying) to over 5 hours (oven cleaning).

4.1.1 Particulate Matter Concentrations – Integrated Mass Measurements

Samples of PM mass were collected on Teflon® filters with size selective inlets, and mass was determined gravimetrically for the total exposure period of each cooking test. Samples were collected in the kitchen, living room, master bedroom, and outdoors. As discussed in Section 3.10, there was high variability in the mass measurements for samples collected concurrently, particularly for the $PM_{2.5}$ size fraction. The relative standard deviation for duplicate $PM_{2.5}$ samples ranged from 28 to 112%. The PM_{10} duplicates were in much better agreement, with only 2 of 8 pairs of duplicates having RSDs higher than 20%. In the following discussion, there are some cases where the reported $PM_{2.5}$ concentrations are higher than the PM_{10} concentrations, which is not possible because the PM_{10} size fraction collected with the PEMs and MS&T samplers includes the particles in the $PM_{2.5}$ size fraction. This may have occurred due to the high variability in the PM measurements, as discussed in Section 3.10 or due to differences in the collection efficiency for the different size particles, which in these tests consisted of both inorganic particles and oil droplets. As discussed below, there was also high variability of pollutant concentrations in replicate tests.

4.1.1.1 PM Concentrations during Typical Cooking Events with Gas and Electric Ranges

The results of the $PM_{2.5}$ mass measurements are listed in Table 3-4. The outdoor $PM_{2.5}$ concentrations during the 32 cooking tests ranged from below the detection limit to 13.6 $\mu g/m^3$ with a median concentration of 5.6 $\mu g/m^3$. At the three indoor locations, the concentrations of $PM_{2.5}$ ranged from below the detection limit to 3880 $\mu g/m^3$. The measurements show that for most cooking events, the cook and other individuals in the kitchen would be exposed to substantially higher $PM_{2.5}$ concentrations than individuals in other rooms of the house.

The concentrations of $PM_{2.5}$ measured at the outdoor and three indoor locations during seven tests with the gas range are presented in Figure 4-1 to show the variation in concentrations between the sampling locations. The concentrations were highest in the kitchen during all six cooking tests, but not during the oven-cleaning test when the concentration was higher in the living room. During some tests (e.g., stovetop stir fry), the concentrations were not dramatically different at the three indoor locations. But in other tests (e.g., oven cleaning and baking lasagna), there were large differences between rooms. The concentration of $PM_{2.5}$ in the kitchen during baking of a frozen lasagna dinner was 20 times higher than in the MBR. But when the oven was used to broil two batches of salmon steaks, the concentrations of $PM_{2.5}$ were nearly identical in the kitchen and MBR. The living room sample was not valid for the test during which the fish were broiled. As shown in the figure, the indoor concentrations were substantially higher than the outdoor concentrations.

A comparable set of seven cooking tests, using the same cooking protocols, was performed with the electric range. During these tests, depicted in Figure 4-2, $PM_{2.5}$ concentrations were highest in the kitchen in four of the seven tests. Although the concentrations were similar in the three rooms during stovetop stir-frying and preparation of French fries with the gas range top burner (Figure 4-1), the concentrations in the rooms differed substantially when the same cooking activities were performed with the electric range. The distribution of $PM_{2.5}$ concentrations in the three indoor locations was not similar for gas and electric tests.

The results of PM_{10} mass measurements were listed in Table 3-5. PM_{10} concentrations outdoors during the 32 cooking tests ranged from non-detectable to 19.3 $\mu g/m^3$. Indoor concentrations during the tests ranged from below the detection limit to 3660 $\mu g/m^3$. As in the case for $PM_{2.5}$, the cook and kitchen occupants would generally be exposed to higher concentrations than occupants of other rooms in the house.

Concentrations of PM_{10} during the seven typical cooking tests are depicted in Figures 4-3 and 4-4 for the gas and electric range, respectively. As shown in Figure 4-3, the highest indoor concentrations were measured during the oven-cleaning test with the gas range. During the test, the concentrations were above 2000 $\mu g/m^3$ in all three rooms of the house. The total duration of the test was 5 hours and 18 minutes, which would represent a significant exposure if the occupants were present in the house throughout the cleaning event. During the six cooking tests with a gas range, the highest concentration measured was 816 $\mu g/m^3$ in the master bedroom during broiling of fish. The total duration of this two-event cooking test was 3.2 hours.

The PM_{10} concentration differences between the rooms were not as great as those for $PM_{2.5}$ during the cooking tests with the gas range. During both tests involving use of the gas oven for cooking (broiling fish and baking lasagna), the concentrations indoors were highest in the bedroom.

Figure 4-1. $PM_{2.5}$ Mass Concentration Indoors and Outdoors During the Seven Standard Cooking Tests with the Gas Range

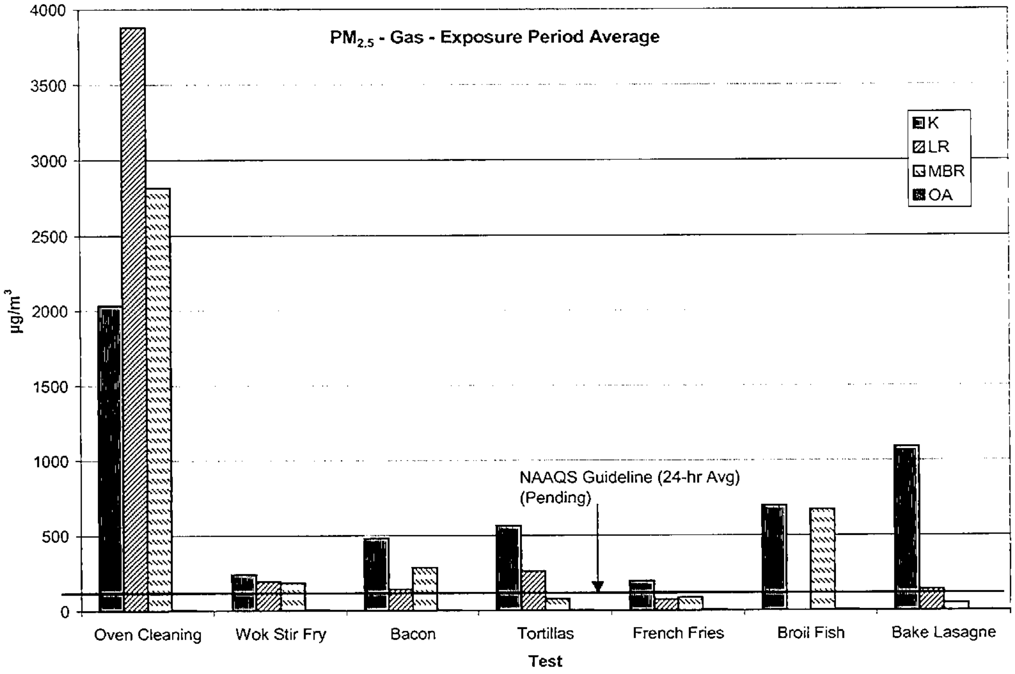


Figure 4-2. $PM_{2.5}$ Mass Concentration Indoors and Outdoors During the Seven Standard Cooking Tests with the Electric Range

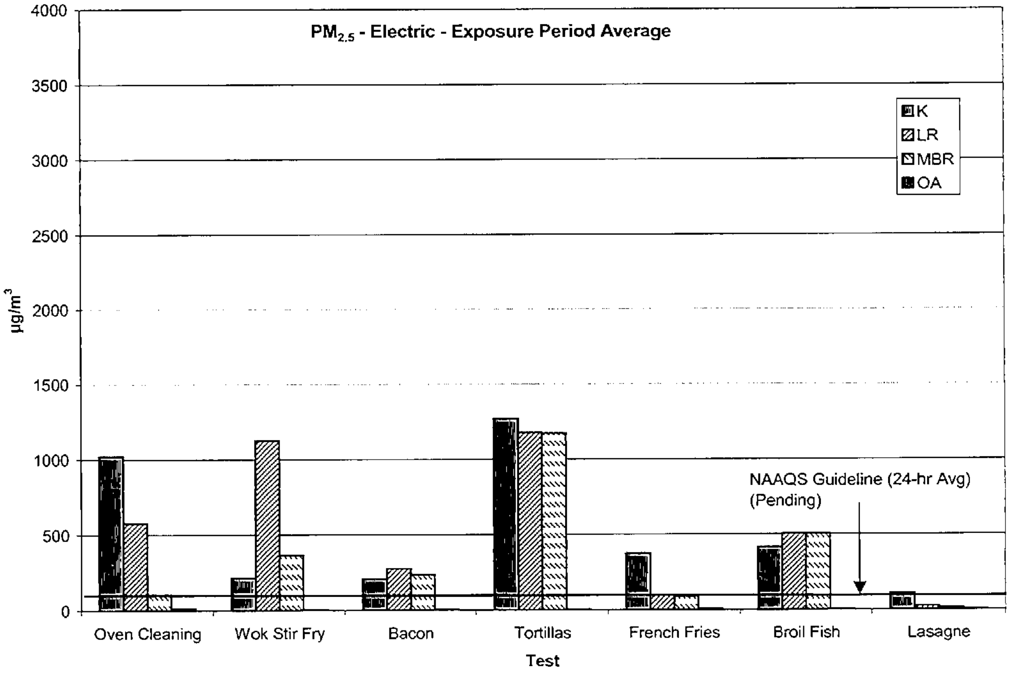


Figure 4-3. PM_{10} Mass Concentrations Indoors and Outdoors During the Seven Standard Cooking Tests with the Gas Range

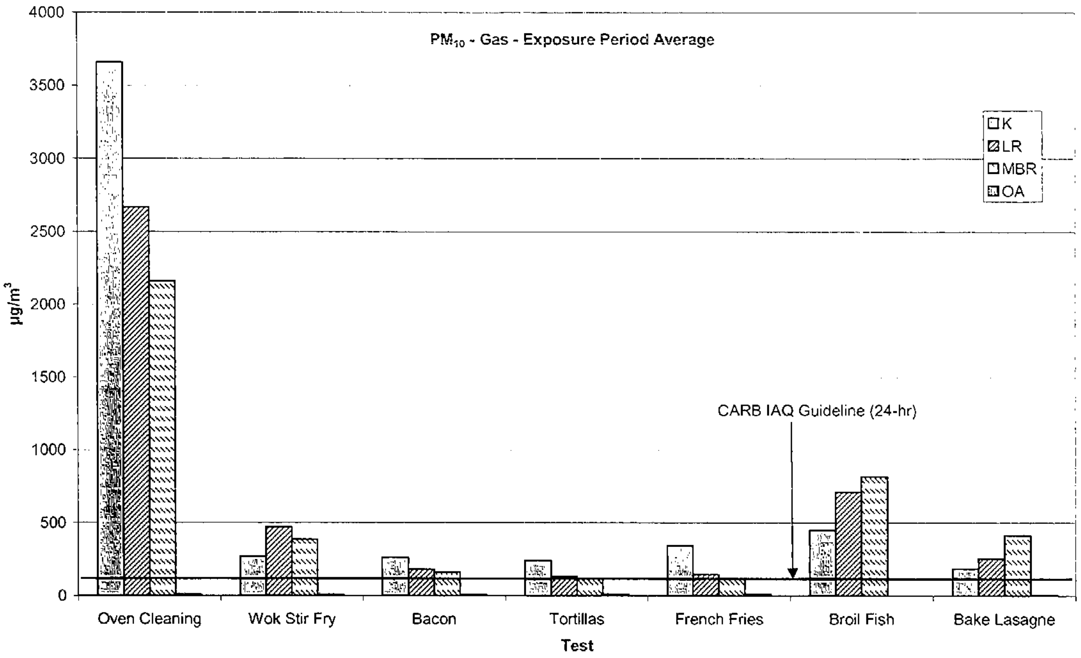
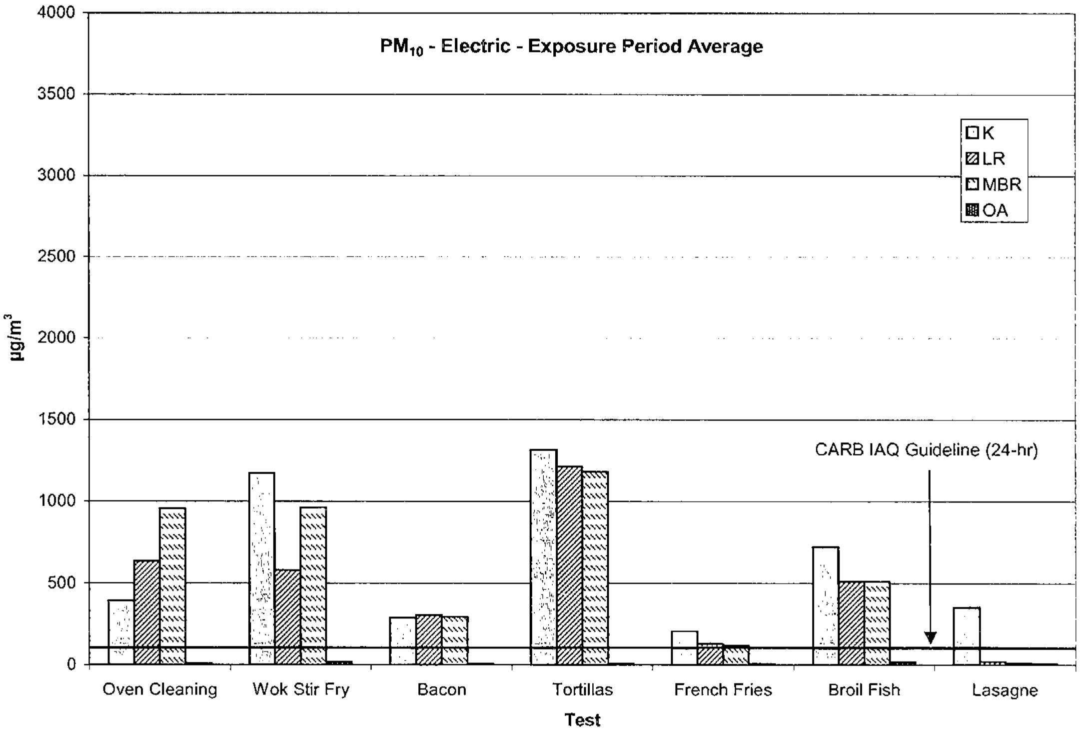


Figure 4-4. PM_{10} Mass Concentrations Indoors and Outdoors During the Seven Standard Cooking Tests with the Electric Range



During the same seven typical cooking activities with an electric range, the concentrations of PM_{10} were highest during the two-hour test involving frying of tortillas, with average concentrations above 1180 µg/m^3 in all three rooms. These concentrations were higher than those measured during the same type of cooking with the gas range and were higher than those measured during oven cleaning with the electric range. The concentrations during stovetop stir-frying were also high, with measurements of 1170, 580, and 960 µg/m^3 in the kitchen, living room, and MBR, respectively. The concentrations of PM_{10} during stovetop stir frying, frying tortillas, and broiling fish were higher during tests with the electric range than in the comparable tests with the gas range.

There was no clear trend in the distribution of PM_{10} in the three rooms during the seven cooking activities with the electric range. During oven cleaning, the concentrations were highest in the bedroom. In tests with bacon, tortillas, and French fries, there was little difference between the concentrations in the kitchen and the other two rooms where integrated PM samples were collected. But when lasagna was baked in the oven, there was a substantial difference between the kitchen concentrations (350 µg/m^3) and the LR (19.9 µg/m^3) and MBR (13.9 µg/m^3). The distribution of PM_{10} in the rooms during cooking with the electric range differed substantially from that observed with the gas range (Figure 4-3). These differences may be related to different temperature and pressure gradients that are created due to heat output from the different ranges. Although, the cooking protocols were the same, the technician activities that affected mixing may also have differed slightly between the tests.

4.1.1.2 Variability of PM Concentrations in Replicate Cooking Tests

Four tests were performed in duplicate to assess the variability of air contaminant concentrations in the house during cooking tests. Room air concentrations of $PM_{2.5}$ and PM_{10} mass are depicted in Figures 4-5 and 4-6, respectively. Tests 5 and 22 and 7 and 23 were true replicates, using the same cooking protocol and approximately the same amount of food. Test 24R was a repeat of Test 24, during which there was a problem with the data acquisition system. To obtain the CO, NO, and NO_2 data, test 24 was repeated facilitating replication of the test for the PM mass samples. The cooking protocol and amount of food were the same in the two tests. Test 21 was originally planned as a replicate of Test 2, but a decision was made to change the protocol from a single event to two events to produce more contaminant mass for this cooking activity because PAHs were planned for collection during the test. Therefore, although not a true replicate, it is included in the figure, and the differences are discussed below.

As shown in Figure 4-5, the concentrations of $PM_{2.5}$ were similar in all three rooms during the replicate tests with the French fries. The concentrations in the first test (195, 72, and 83 µg/m^3) differed by less than 25% from the concentrations in the replicate test (162, 92, and 70 µg/m^3). The PM_{10} concentrations during the replicate French fries cooking test had relative differences of 61, 25, and 10% in the kitchen, living room, and bedroom. The lowest variability was observed in the two beef frying tests with relative differences in the living room and bedroom of 11 and 2% for $PM_{2.5}$ and 2 and 18% for PM_{10}. But the variability was substantially higher in the kitchen in the beef tests with relative differences for the replicate tests of 99% for $PM_{2.5}$ and 63% for PM_{10}. The highest variability was observed in the replicate tests involving baking of lasagna in the gas oven. The relative differences were 100, 103 and 6% for $PM_{2.5}$

Figure 4-5. $PM_{2.5}$ Gravimetric Mass Measurements in Replicate Tests with the Gas Range

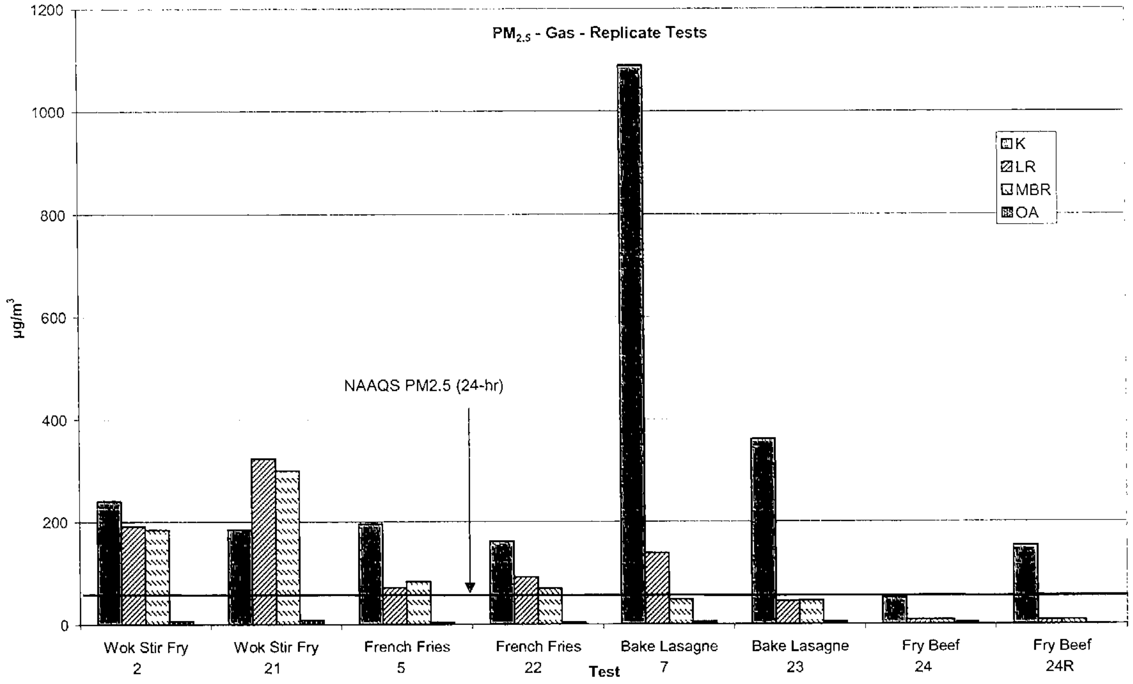
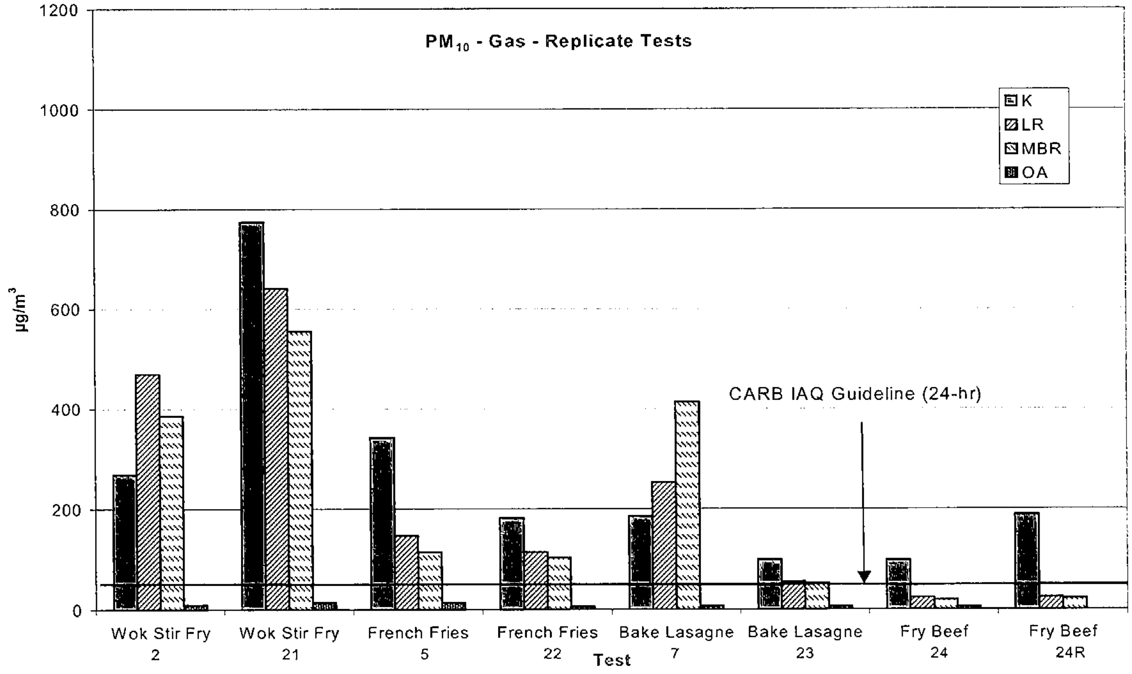


Figure 4-6. PM_{10} Gravimetric Mass Measurements in Replicate Tests with the Gas Range



concentrations and 61, 129, and 155% for PM_{10} in the kitchen, living room, and bedroom, respectively. It was interesting that this cooking activity had the highest variability because it involved the least food preparation activity by the cook. The reason for high variability could not be determined in this study. However, as discussed in a following subsection, the concentrations of the combustion gases were also highly variable in the replicate tests.

The variability between replicate tests was also assessed by estimating the emissions using the mass balance model. The results for the eight tests depicted in Figures 4-5 and 4-6 are summarized in Table 4-1. During the two French fries tests, the emissions of $PM_{2.5}$ differed by less than 35%, if normalized to either the mass of food cooked (source strength) or the energy use (power-specific emission factor). The emissions of PM_{10} were slightly more variable, but in reasonable agreement. The variation between the replicate beef frying tests was greater than the French fries test. The $PM_{2.5}$ emissions, normalized to the energy use, differed by nearly 81%. The PM_{10} emissions differed by about 20% when normalized to either the amount of food or the energy use. The differences were higher for the test involving baking of lasagna. The emission rates for $PM_{2.5}$ differed by 68% in the two tests, and the PM_{10} emission rates were almost two times higher in the first test than in the replicate test.

As discussed above, although Tests 2 and 21 were planned as replicates, the cooking protocol was changed in Test 21 to cook twice as much food in order to increase the pollutant mass. The emission rate was higher in Test 21 than in Test 2, although the difference was not twice as high. When normalized to the amount of food cooked, the relative difference between the tests was only 52% for $PM_{2.5}$ and 88% for PM_{10}. The results of the replicate tests suggest that emissions of particles may be highly variable during cooking. This high variability needs to be addressed in the design of future studies of emissions and resultant exposures due to cooking.

Table 4-1. $PM_{2.5}$ and PM_{10} Emission Rates during Replicate Tests

Test No	**Type**	**Range**	**Conditions**	**Emission Rate**	**Source Strength (per gram of food)**	**Food-specific Emission Factor**	**Power-specific Emission Factor**
				mg/hr	**µg/g**	**µg/g/hr**	**µg/BTU**
$PM_{2.5}$							
2	Stovetop Stir Fry	Gas	Standard	201.5	69.5	198.6	25.2
21	Stovetop Stir Fry	Gas	Test 2 Replicate	92.4	33.4	51.3	11.3
5	French Fries	Gas	Standard	65.9	15.3	13.5	8.5
22	French Fries	Gas	Test 5 Replicate	46.2	13.0	8.9	6.1
7	Bake Lasagna	Gas	Standard	251.2	452.8	215.6	51.8
23	Bake Lasagna	Gas	Test 7 Replicate	89.0	153.5	76.1	16.6
24	Fry Beef	Gas	Cast Iron Pan	43.4	16.6	47.5	9.7
24R	Fry Beef	Gas	Cast Iron Pan	74.9	28.8	41.2	17.4
PM_{10}							
2	Stovetop Stir Fry	Gas	Standard	318.3	109.8	313.6	39.8
21	Stovetop Stir Fry	Gas	Test 2 Replicate	571.7	206.4	317.6	70.1
5	French Fries	Gas	Standard	177.0	41.2	36.3	22.9
22	French Fries	Gas	Test 5 Replicate	82.6	23.2	15.8	10.8
7	Bake Lasagna	Gas	Standard	70.7	127.4	60.7	14.6
23	Bake Lasagna	Gas	Test 7 Replicate	39.4	68.0	33.7	7.4
24	Fry Beef	Gas	Cast Iron Pan	117.4	44.9	128.4	26.3
24R	Fry Beef	Gas	Cast Iron Pan	134.6	51.8	73.9	31.2

4.1.1.3 PM Concentrations During Worst Case Tests

Three tests were performed that were designed to measure emissions during cooking events that would be considered realistic, but worst case conditions. For example, in Test No. 17, the oil in the stovetop was heated to a higher temperature causing some smoke and the foods were cooked longer. Results of this test can be compared to the results from Test No. 2, a typical cooking test with the gas range. In Test No. 18, the bacon was fried extra crispy for comparison to Test No. 3. Test No. 19, for comparison to Test No. 6, was designed to burn the salmon steaks, a not uncommon occurrence during broiling. However, due to a technician error, the window in the MBR was left open during Test No. 19. As a result, worst-case conditions may have existed in the kitchen, but not in the bedroom.

The $PM_{2.5}$ mass measurements during the typical and worst-case tests are compared in Figure 4-7. During the stovetop stir-fry test and the bacon frying test, the $PM_{2.5}$ gravimetric mass concentrations were substantially higher in all three rooms during the worst-case tests. The concentrations were nearly four times higher in the worst-case stovetop stir frying test than in the typical test in all three rooms. During the worst case test involving broiling of fish in the oven, the concentrations in the master bedroom, where the window was left open, were not substantially higher than in the typical cooking test. The concentration of $PM_{2.5}$ was lower in the kitchen during the worst case test. This may have been due to temperature and pressure gradients in the house resulting from the heat output from the gas range and the open window at the other end of the house. Air exchange rate during test 19 was 4.7 times greater than the average house air exchange rate for the standard tests.

The PM_{10} gravimetric mass measurements during the worst case tests are compared to the typical cooking tests in Figure 4-8. The PM_{10} concentrations were higher in all three rooms during the stovetop stir-fry and bacon tests. In the broil fish test, concentrations were higher in the kitchen and only slightly higher in the living room. The PM_{10} concentrations in the bedroom were apparently impacted by the open window because the concentrations were similar in the worst case and typical cooking tests. The results of all three tests indicate higher indoor concentrations due to the worst case cooking event.

4.1.1.4 Comparison of PM Concentrations to Standards, Guidelines, and Other Studies

The typical cooking tests performed to compare concentrations during use of the gas and electric ranges included six cooking tests and the self-cleaning oven test. The highest concentrations of $PM_{2.5}$ and PM_{10} were measured during oven cleaning with the gas range. With the electric range, the self-cleaning oven did not produce nearly as high concentrations. Oven cleaning is, however, a relatively rare activity that does not represent a routine or consistent source of exposure to PM. The other six typical cooking tests represent actual cooking activities that may contribute to routine, repeated exposures to PM. The averages, standard deviations, and medians should not be interpreted as representative for cooking in this test house or any other house.

Figure 4-7. $PM_{2.5}$ Mass Measurements in Standard and Worst Case Tests

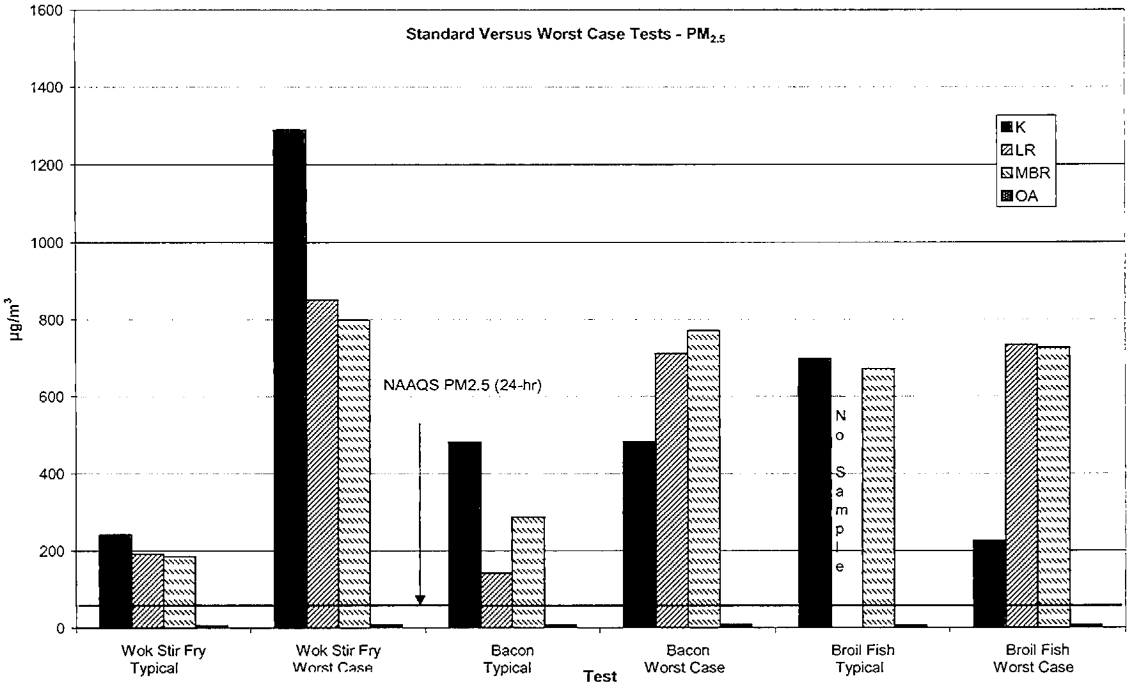
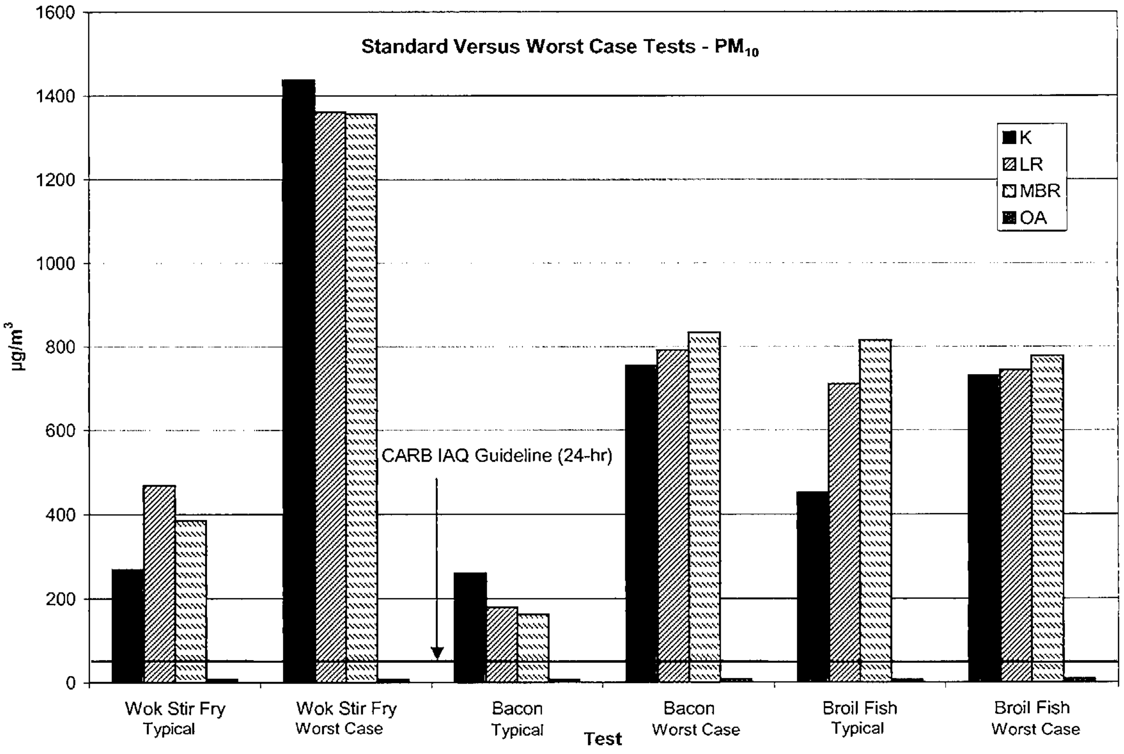


Figure 4-8. PM_{10} Mass Measurements in Standard and Worst Case Tests



The average and median $PM_{2.5}$ and PM_{10} concentrations measured during the exposure periods of the six standard cooking tests with the gas and electric ranges are summarized in Table 4-2. The table shows that both the average and median concentrations of the cooking activities were greater than 134 $\mu g/m^3$ for $PM_{2.5}$ in all three rooms of the test house for both gas and electric tests. The average and median PM_{10} concentrations were greater than 216 $\mu g/m^3$ in all three rooms. The median concentration of $PM_{2.5}$ in the kitchen during the six tests with the gas range was 524 $\mu g/m^3$, which was higher than the median concentration of 294 $\mu g/m^3$ in the kitchen during the six tests with the electric range. But the median concentrations of $PM_{2.5}$ were higher in the living room and bedroom during tests with the electric range. For PM_{10}, the median concentrations measured in all three rooms during six tests with the electric range were substantially higher than those measured during tests with the gas range.

Table 4-2. Average and Median $PM_{2.5}$ and PM_{10} Concentrations during the Six Standard Cooking Activities

	Gas (Test Nos. 2 through 7)			**Electric (Test Nos. 9 through 14)**		
	Kitchen	**LR**	**MBR**	**Kitchen**	**LR**	**MBR**
$PM_{2.5}$						
Minimum	195	71.9	48.7	112	23.8	13.1
Maximum	1090	260	673	1269	1175	1173
Average	545	161	226	432	533	397
Std. Deviation	328	70	236	425	506	420
Median	524	142	134	294	391	300
PM_{10}						
Minimum	185	129	112	206	19.9	13.9
Maximum	451	711	816	1315	1213	1182
Average	292	315	334	676	459	513
Std. Deviation	93	230	272	475	427	469
Median	265	216	274	538	407	402

Both the average and median concentrations measured during the six standard cooking tests were substantially higher than the ARB IAQ Guideline for PM_{10} of 50 $\mu g/m^3$ over 24 hours. The average and median $PM_{2.5}$ concentrations also exceeded the pending Federal National Ambient Air Quality Standard (NAAQS) of 65 $\mu g/m^3$ for $PM_{2.5}$ (24-hr average). The total exposure periods during the seven standard tests performed with both the gas and electric ranges had durations that ranged from 1.65 hours (stovetop stir frying) to over 5 hours for oven cleaning.

The elevated indoor concentrations during these short exposure periods would have significant impacts on the personal exposures of occupants in the home. The results are consistent with observations by Wallace (1996) and others (e.g. Kamens et al., 1991; Brauer et al., 2000) that cooking is one of the most important indoor sources of particles. Brauer et al. (2000) reported $PM_{2.5}$ concentrations in a range of 24 to 201 $\mu g/m^3$ in residential kitchens with frying. They also reported peak $PM_{2.5}$ concentrations above 400 $\mu g/m^3$ in kitchens. Brauer et al. and Wallace (1998) have consistently identified cooking as a major source of fine and coarse particles indoors. The PTEAM study demonstrated that homes and persons associated with HOUSE WORK had significantly higher mean aerosol levels than those not indicating HOUSE

WORK (Clayton et al., 1993). Ozkaynak et al. (1996) estimated that cooking added about 12 – 26 $\mu g/m^3$ to indoor PM_{10} concentrations. They reported that homes with cooking averaged 20 $\mu g/m^3$ higher levels of PM_{10} than homes without cooking. Wallace (1996) estimated that cooking accounted for 4 – 5% of the particle mass indoors based on the PTEAM data. Kamens et al. (1991) estimated that 5 to 18% of an 8-hr personal particle exposure could be attributed to cooking one meal in one of three homes that they studied. Results from the tests reported here suggest that the contribution could be much higher.

4.1.2 Continuous PM Measurement Results

Particle concentrations and size distributions were measured during each test with the ELPI. The results were summarized in Tables 3-6 through 3-12. The summary statistics for particle concentrations and the estimated particle mass are presented in Tables 4-3 and 4-4. The data are for the average values measured during the cooking period for all cooking events performed during the main study. Median particle concentrations were 66,000; 32,000; and 13,000 particles/cm^3 in the three smallest size fractions (0.04, 0.08, and 0.13 µm geometric diameter). There were very few particles measured in the three largest size fractions.

The number concentrations measured with the ELPI in the smallest size fractions are consistent with data reported by Wallace. He reported number concentrations for the 0.01 to 0.4 µm size fraction that ranged from 10,000 to 190,000 particles/cm^3 in cooking tests performed in a townhouse (Wallace, 1998). He reported number concentrations of 190,000; 140,000; and 32,000 for three tortilla frying tests. In the current study, particle concentrations of 203,000 and 414,000 particles/cm^3 were measured in the two tortilla frying tests. Wallace reported a concentration of 22,000 particles/cm^3 during preparation of popcorn. During this study, preparation of popcorn in a microwave resulted in a concentration of 22,000 particles/cm^3.

The mass estimates from the ELPI data are summarized in Table 4-4. The median mass concentrations in the nine channels for the smallest particles were less than 15 $\mu g/m^3$ for the 48 measurement periods. Maximum concentrations, however, were up to 3070 in the 0.5 µm size fraction. Because of the small number of particles in the larger size fractions, the accuracy of the mass estimate using the ELPI data is likely to be poor for these size fractions. No published statistical data exist for the ELPI sampler relating particle counts to instrument precision and accuracy. It is known, however, that small particle counts result in unreliable mass and concentration data.

Table 4-3. Summary Statistics for Average Concentrations of Particles Measured with the ELPI during the Cooking Period (Particles/cm^3)

Size (μm)	N	Minimum	Maximum
0.04	48	0	460280
0.08	48	271	250981
0.13	48	97	184203
0.21	48	60	101825
0.32	48	0	73510
0.51	48	0	44320
0.81	48	0	1921
1.29	48	0	124
2.02	48	0	40
3.18	48	0	25
5.24	48	0	21
8.38	48	0	26
pm 2.5	48	822	805499
pm 10	48	825	805536

Table 4-4. Summary Statistics for Average Particle Mass Concentrations (μg/m^3) of Particles Measured with the ELPI during the Cooking Period

Size (μm)	N	Minimum	Maximum
0.04	48	0	18
0.08	48	0	66
0.13	48	0	228
0.21	48	0	491
0.32	48	0	1291
0.51	48	0	3069
0.81	48	0	534
1.29	48	0	139
2.02	48	0	176
3.18	48	0	417
5.24	48	0	1568
8.38	48	0	8061
pm 2.5	48	4	5862
pm 10	48	4	15907

The particle size distribution is important because it impacts exposure and the associated health risks. Figures 4-9 and 4-10 depict the particle concentration size distribution for the seven standard cooking tests with the gas range and electric range. Figures 4-11 and 4-12 depict the mass distribution based on particle size. For all figures, the data presented are the average values during the cooking tests. Figures for the gas range also depict the distributions during operation of the oven only and range top burner only without cooking of food.

Figure 4-9. Particle Size Distribution During Gas Range Cooking Tests and Baseline Measurements

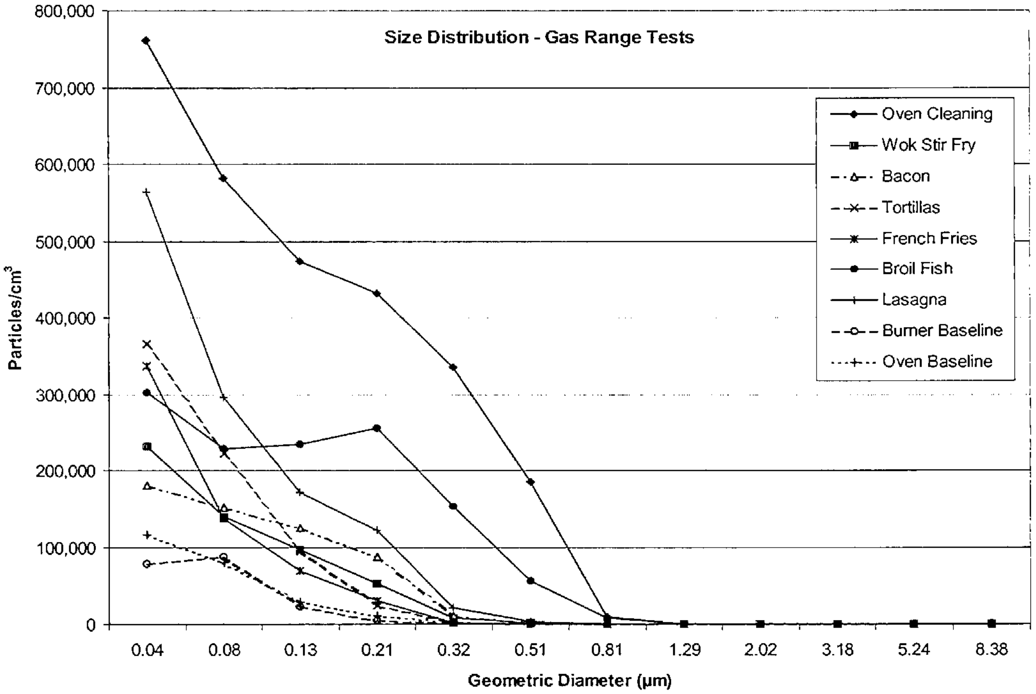


Figure 4-10. Particle Size Distributions During the Standard Cooking Tests with the Electric Range

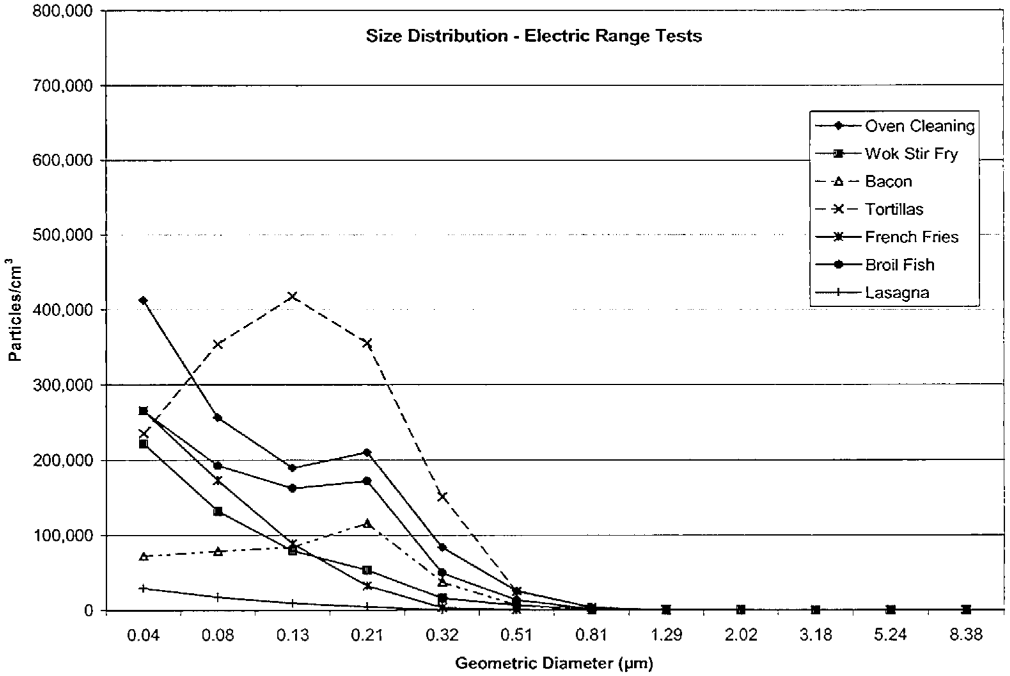


Figure 4-11. Particle Mass Distributions during the Standard Cooking Tests with the Gas Range

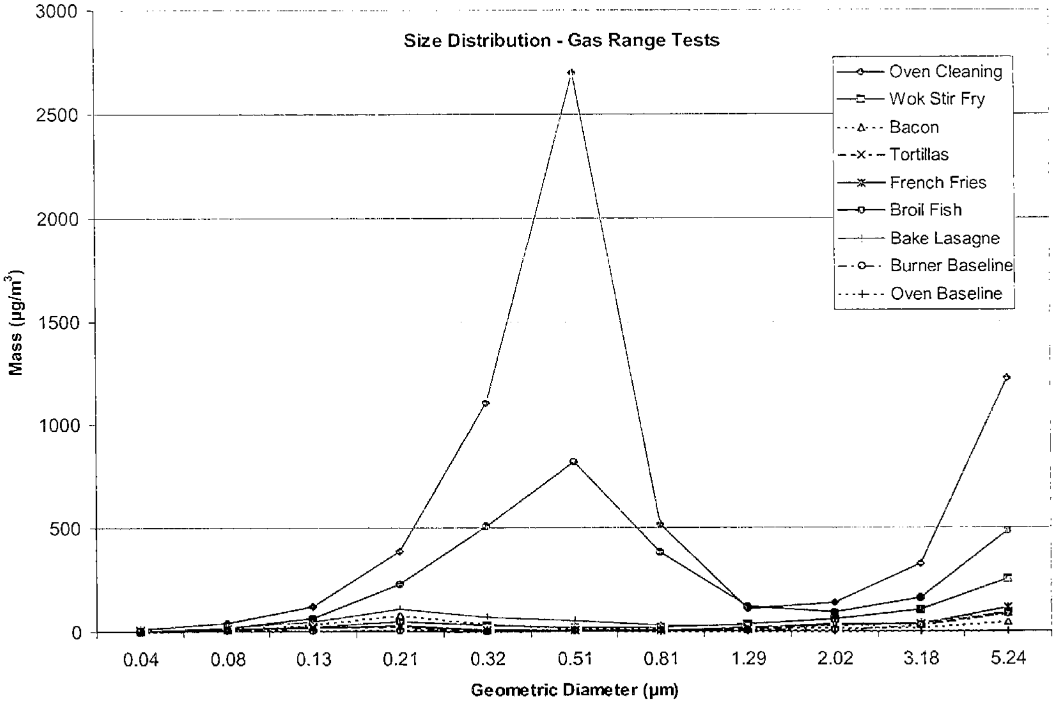
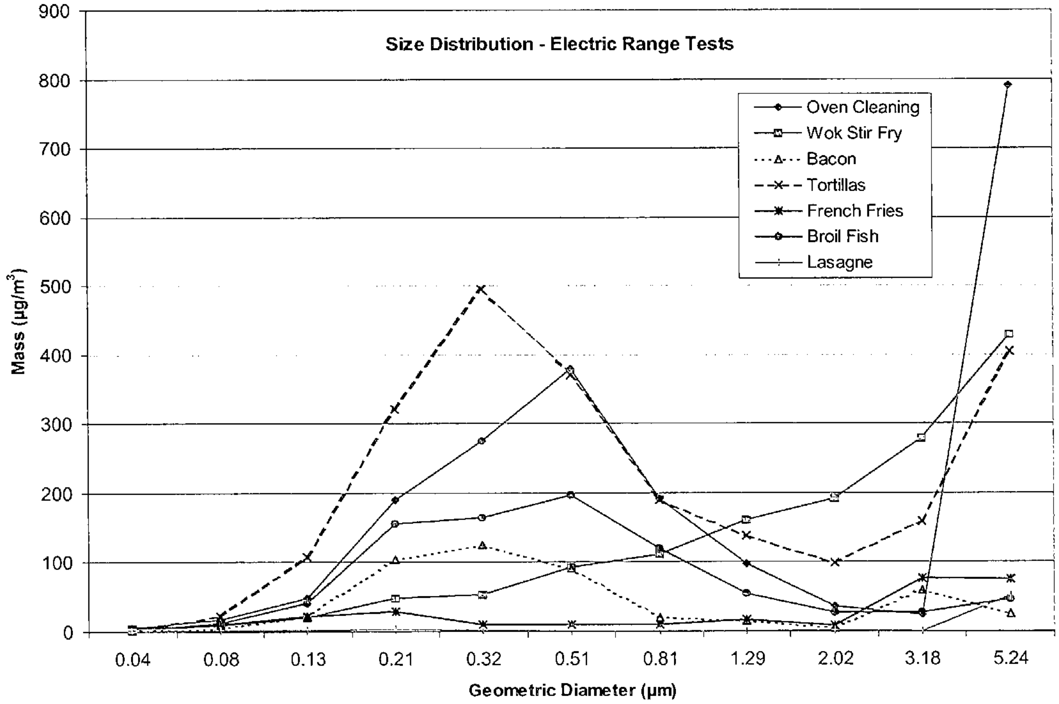


Figure 4-12. Particle Mass Distributions during the Standard Cooking Tests with the Electric Range



For both the gas and electric ranges, there were relatively few particles in the size fractions above 0.8 µm. The results show that the particles emitted during cooking are predominantly in the fine and ultra-fine size fractions, consistent with observations by Wallace (1998) and Li et al. (1993) who reported that 60 to 70% of the cooking particles were in the ultrafine size fraction. During the tests with the gas range, the particles were predominantly in the size fractions less than 0.21 µm during baseline measurements with the burner and oven. The largest particles occurred during oven cleaning and during use of the oven to broil fish. In the other cooking tests, the particles were predominantly smaller than 0.32 µm. The ELPI did not measure the peak particle size, as indicated in the figures.

During tests with the electric range, the particle sizes were somewhat larger, although still predominantly less than 0.51 µm diameter. During the two tests with the electric range that involved frying food in cooking oil, the peak particle size was measured. For frying tortillas, the peak particle size was 0.13 µm. For French fries, it was 0.21 µm. As discussed earlier, the tortillas frying on the electric range generated higher indoor air concentrations than the same cooking performed with the gas range. Although the reasons for the differences in concentrations and size distributions of the particles could not be determined in this study, a possible cause might be splattering of the oil during cooking and contact of oil droplets on the electric range top burner during cooking.

The mass distributions depicted in Figure 4-11 show that the mass was predominantly in the 0.21 to 1.29 µm size fractions for the oven cleaning and broiling fish tests with the gas range. For the other tests, it was predominantly in the larger size fraction. Data were not included in the figure for the largest size fraction because of the small number of particles in that fraction, making the mass estimate less accurate. For the tests with the electric range, the mass appears to be predominantly in the 0.21 to 0.81 µm size fractions for oven cleaning, broiling fish, tortillas, and bacon frying. But, the mass was primarily in the larger size fractions for stovetop stir frying, consistent with the different distribution of the particle concentrations (Figure 4-10).

The mass distributions depicted in Figure 4-11 show that the mass was predominantly in the 0.21 to 1.29 µm size fractions for the oven cleaning and broiling fish tests with the gas range. For the other tests, it was predominantly in the larger size fraction. Data were not included in the figure for the largest size fraction because of the small number of particles in that fraction, making the mass estimate less accurate. For the tests with the electric range, the mass appears to be predominantly in the 0.21 to 0.81 µm size fractions for oven cleaning, broiling fish, tortillas, and bacon frying. But, the mass was primarily in the larger size fractions for stovetop stir frying, consistent with the different distribution of the particle concentrations (Figure 4-10).

The particle concentrations increased rapidly after the start of a cooking event. Examples of the time series of particle mass concentrations are depicted in Figures 4-13 through 4-25 for the seven standard cooking tests with the gas range and the two gas range background tests (rangetop burner and oven) without cooking. Data displayed in Figures 4-13 through 4-21 are the estimated concentrations for the particles of less than 2.5 µm, as calculated with the ELPI. The ELPI results were generally higher than the gravimetric measurements, as discussed previously. It should be noted that the figures are not depicted using the same concentration scale.

Figure 4-13. $PM_{2.5}$ Mass Measured with the ELPI during Self-cleaning of the Gas Oven (SC = Start cooking period; EC = End cooking period; ET = End total exposure period)

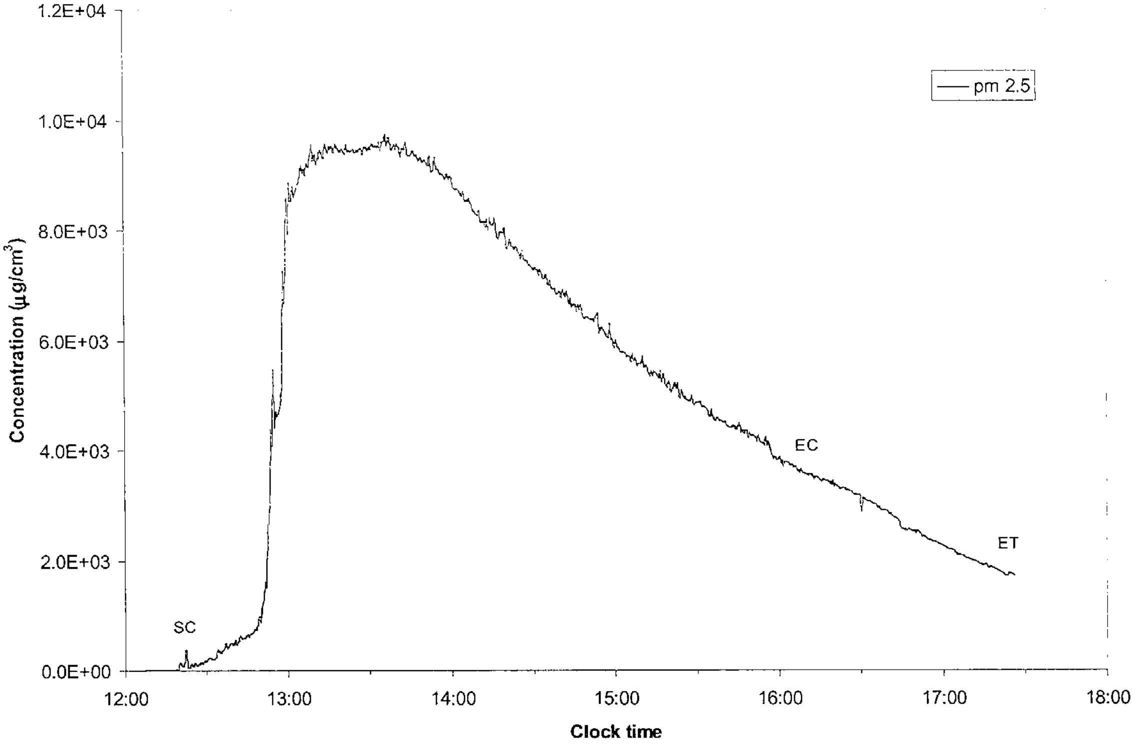


Figure 4-14. $PM_{2.5}$ Mass Measured with the ELPI during the Wok Stir Fry Test on the Gas Range (SC = Start cooking period; EC = End cooking period; ET = End total exposure period)

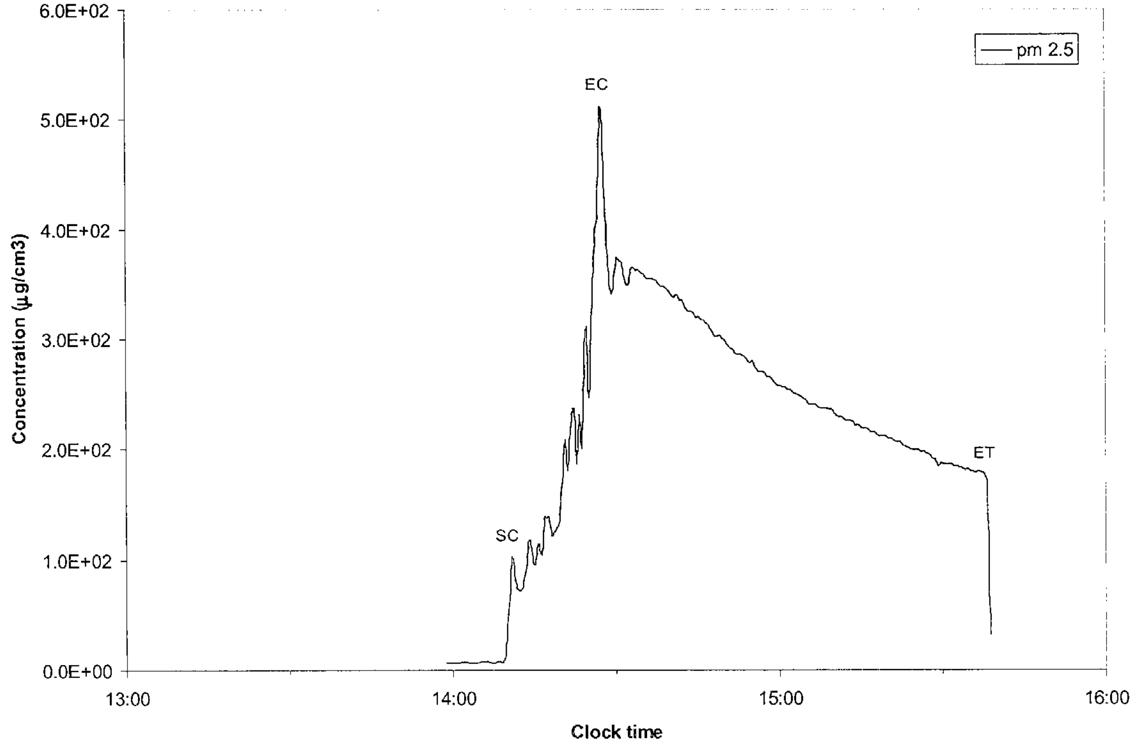


Figure 4-15. $PM_{2.5}$ Mass Measured with the ELPI during the Bacon Tests on the Gas Range (SC = Start cooking period; EC = End cooking period; ET = End total exposure period)

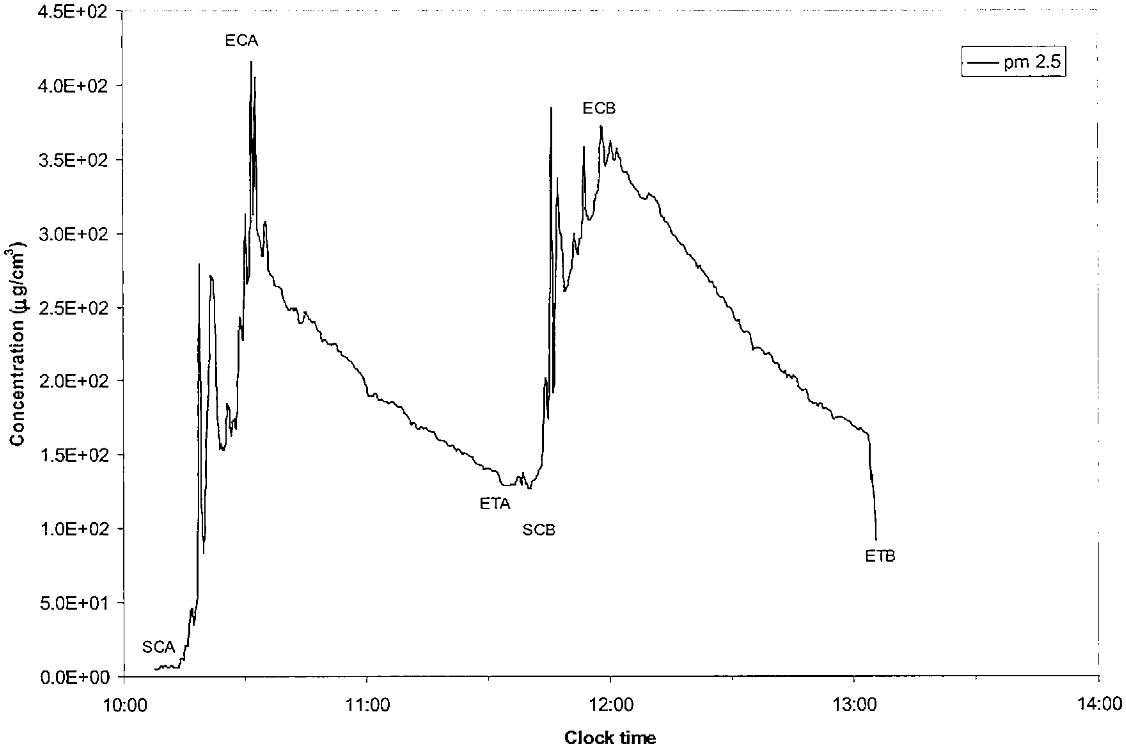


Figure 4-16. $PM_{2.5}$ Mass Measured with the ELPI during the Tortillas Test on the Gas Range

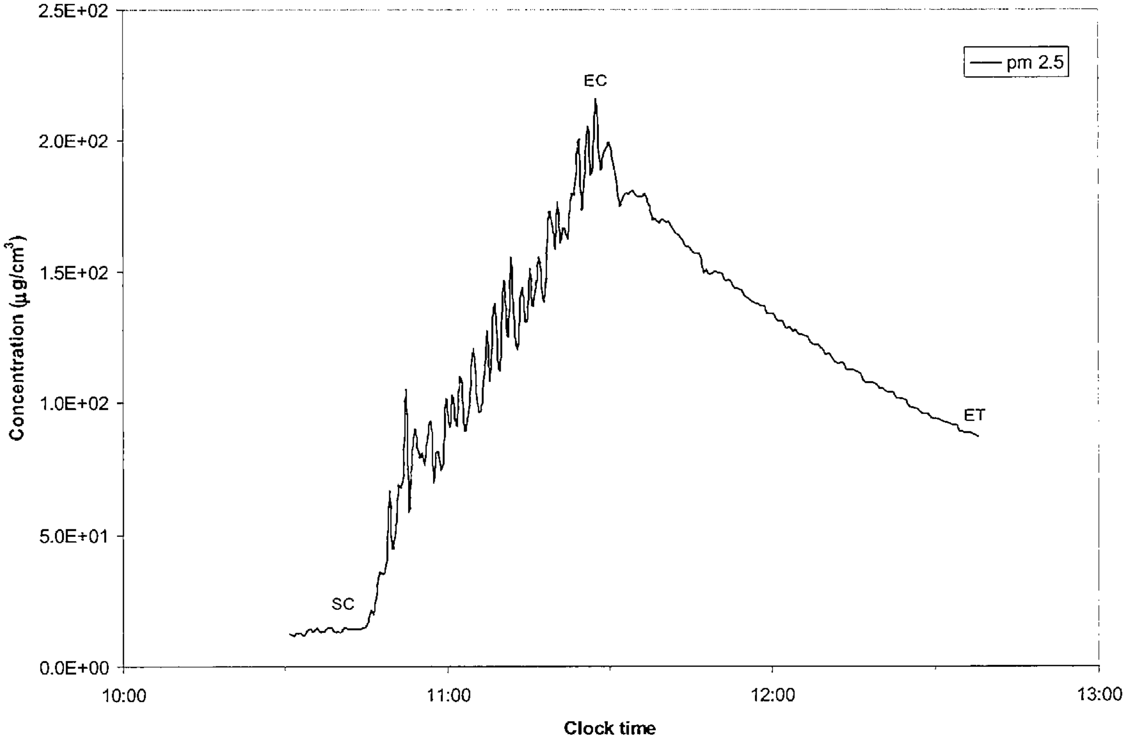


Figure 4-17. $PM_{2.5}$ Mass Measured with the ELPI during the French Fry Test on the Gas Range (SC = Start cooking period; EC = End cooking period; ET = End total exposure period)

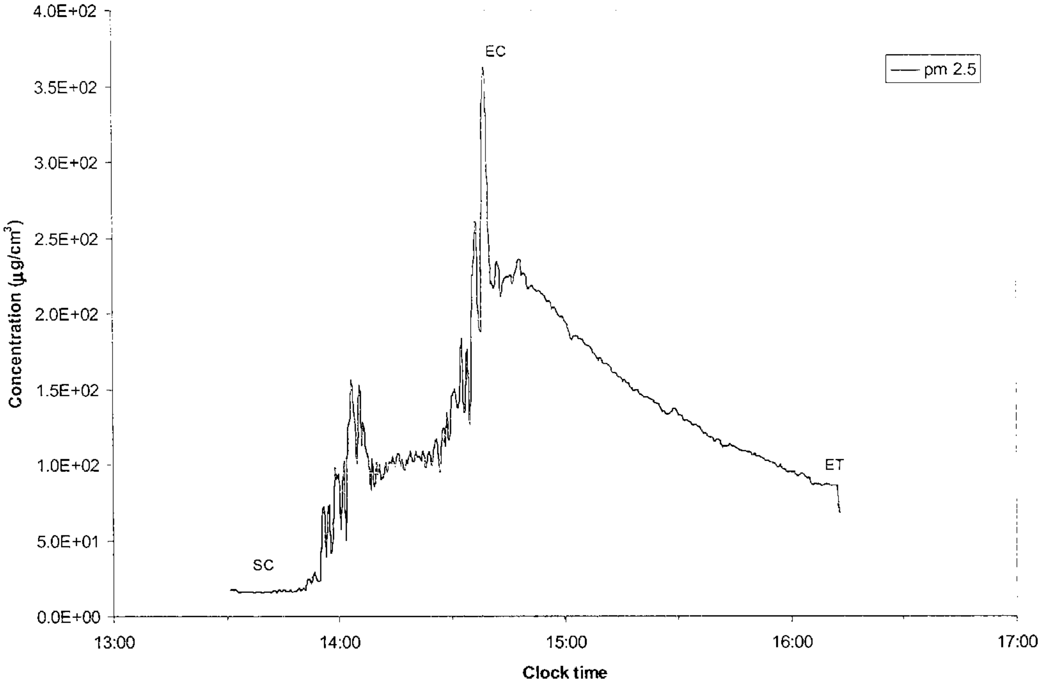


Figure 4-18. $PM_{2.5}$ Mass Measured with the ELPI during the Broil Fish Tests with the Gas Oven (SC = Start cooking period; EC = End cooking period; ET = End total exposure period)

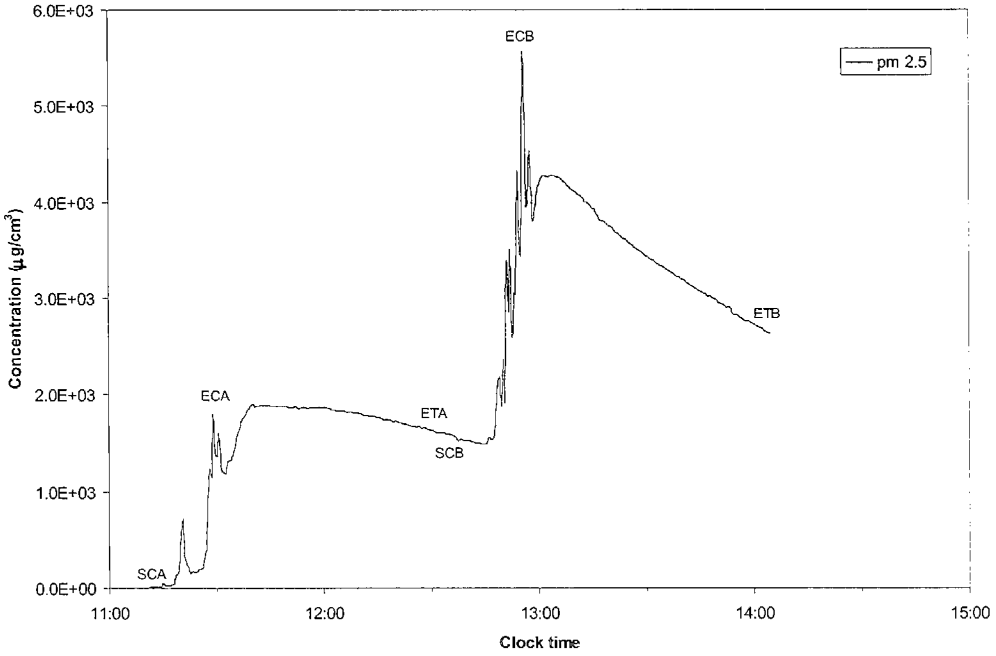


Figure 4-19. PM$_{2.5}$ Mass Measured with the ELPI during the Bake Lasagna Test with the Gas Oven (SC = Start cooking period; EC = End cooking period; ET = End total exposure period)

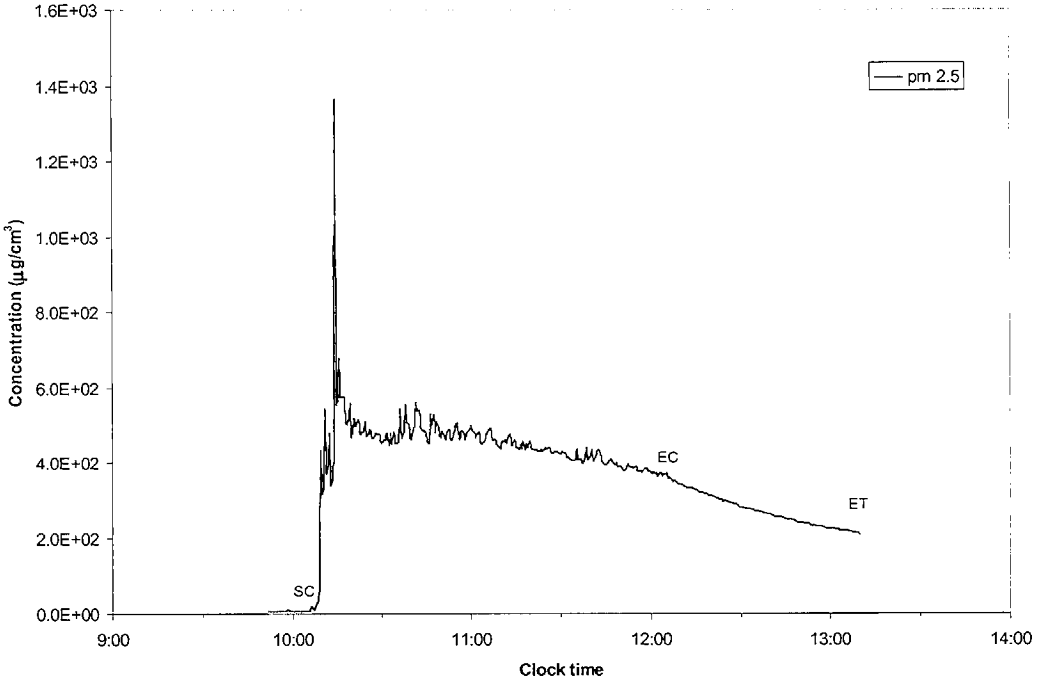


Figure 4-20. PM$_{2.5}$ Mass Measured with the ELPI during the Gas Range Top Burner Baseline Test (SC = Start cooking period; EC = End cooking period; ET = End total exposure period)

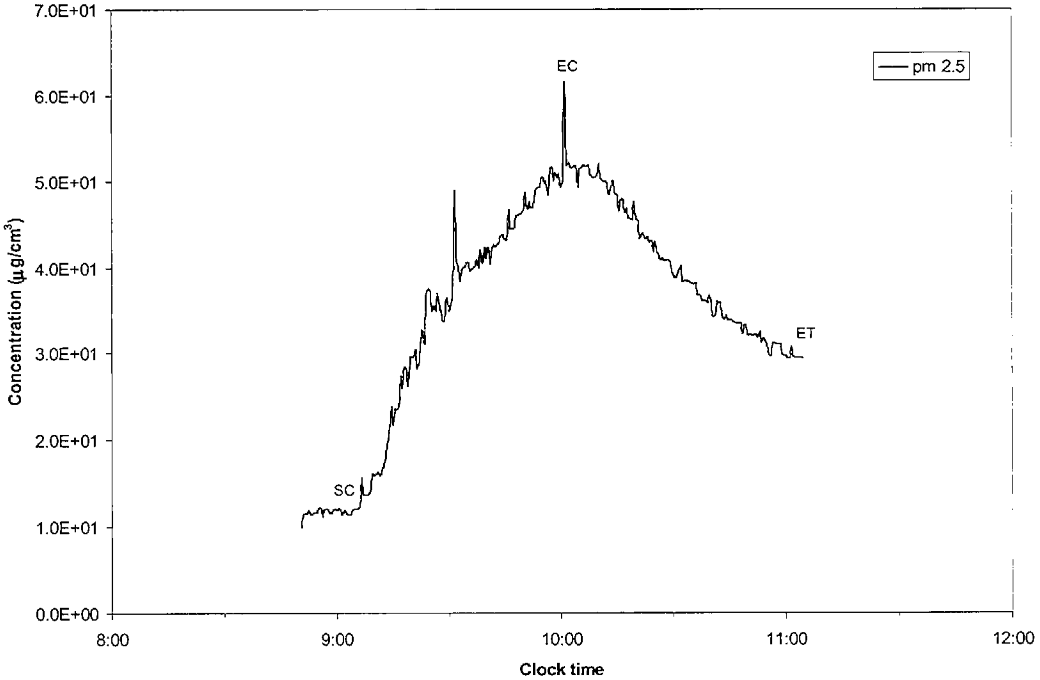


Figure 4-21. $PM_{2.5}$ Mass Measured with the ELPI during the Gas Oven Baseline Test

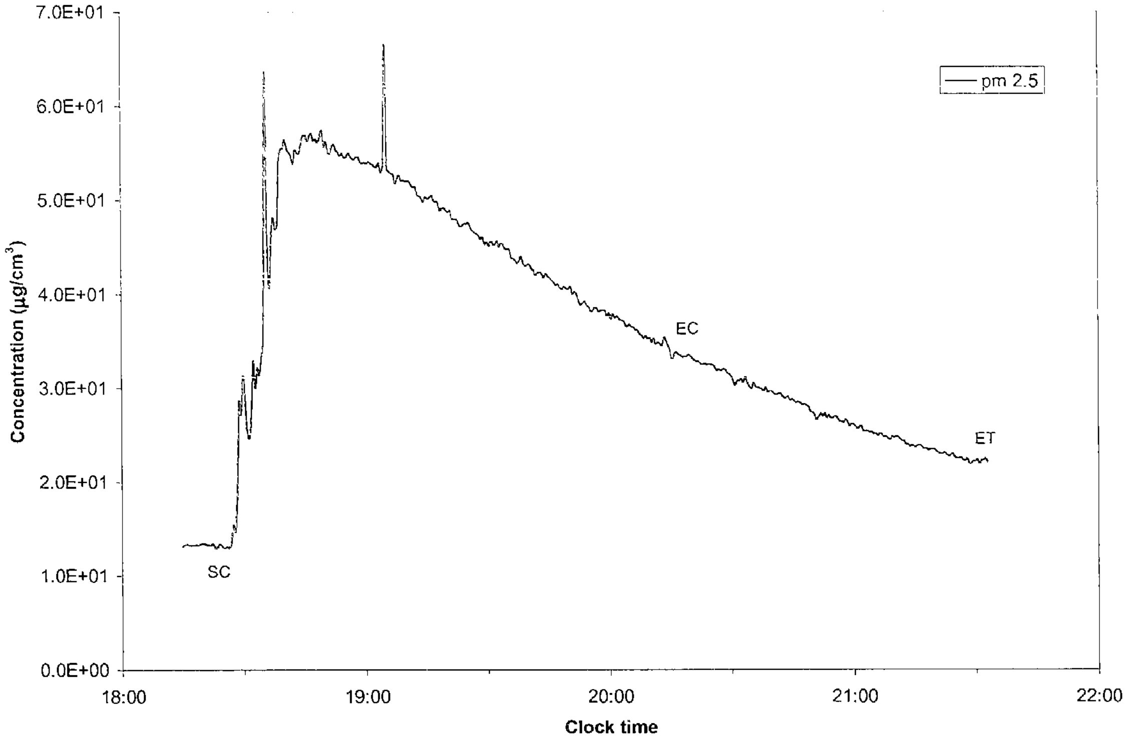


Figure 4-22. Particle Mass Distribution during the Gas Range Wok Stir Fry Test (No. 2)

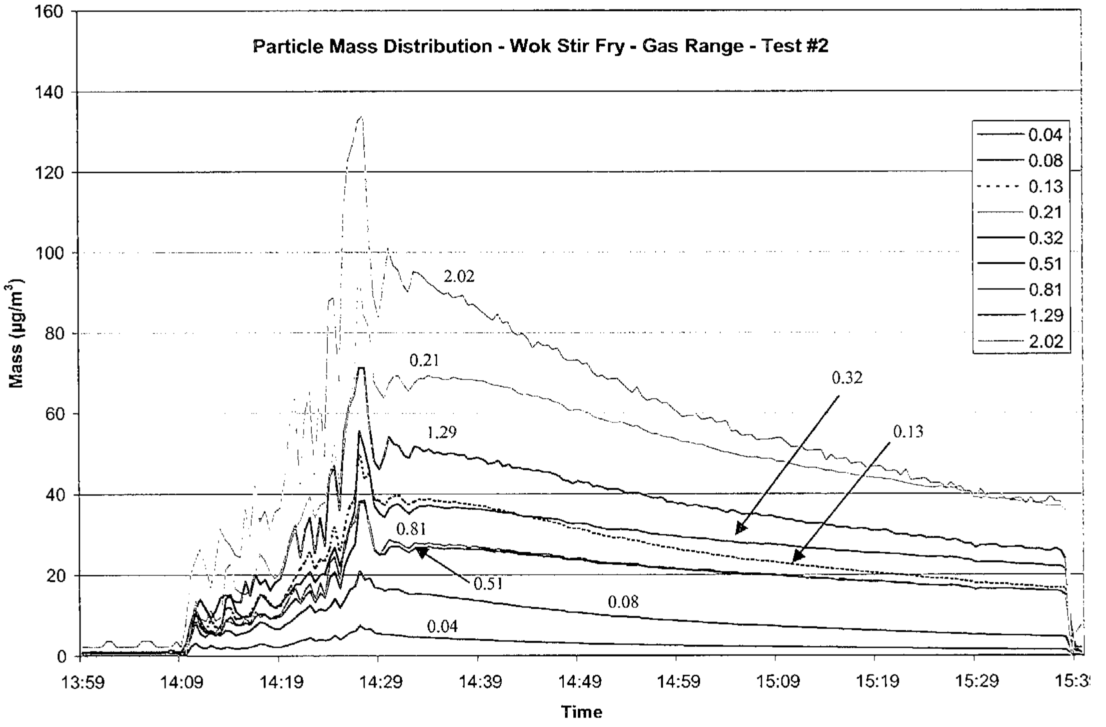


Figure 4-23. Particle Mass Distribution during the Electric Range Wok Stir Fry Test (No. 9)

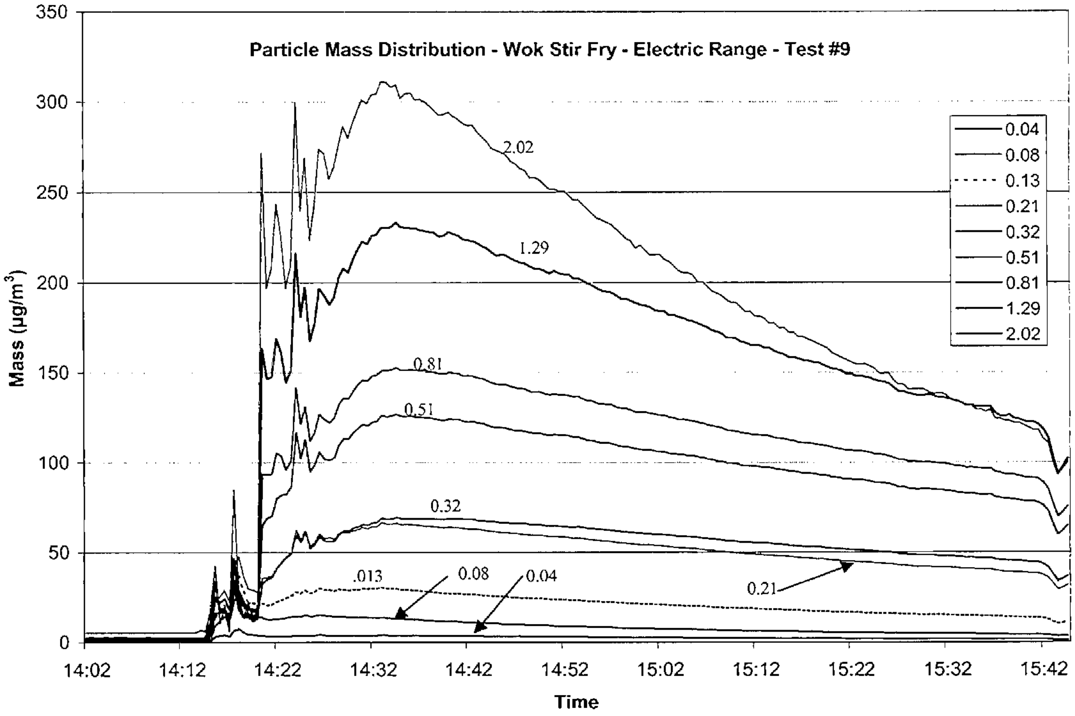


Figure 4-24. Particle Mass Distribution during the Electric Range Tortillas Test (No. 11)

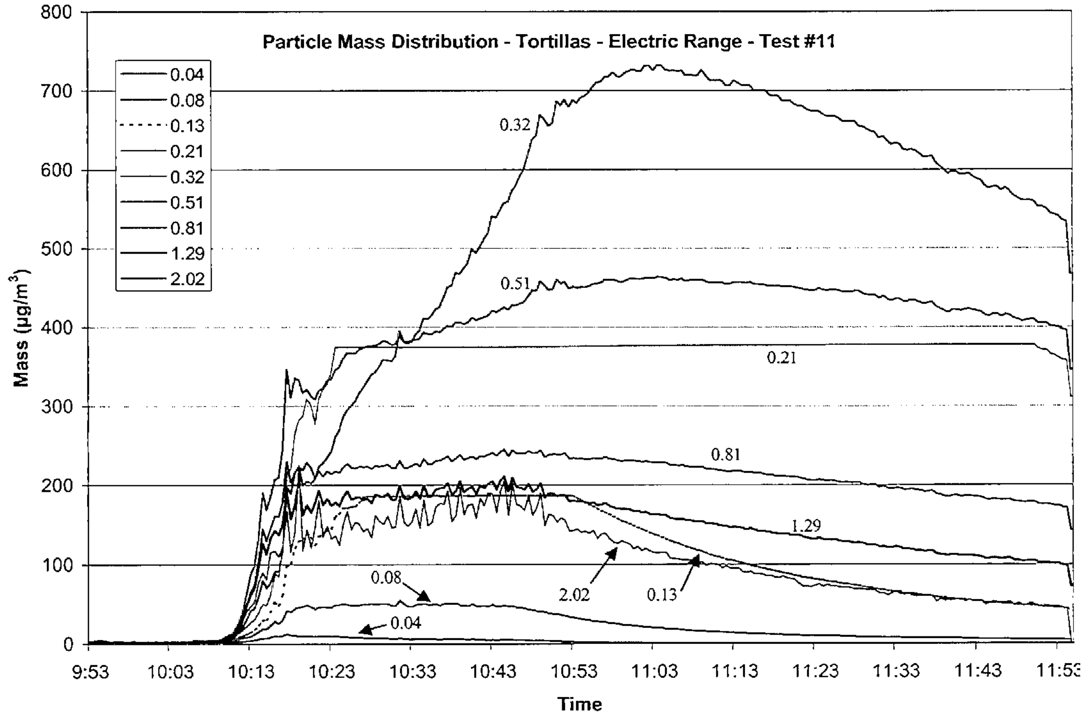
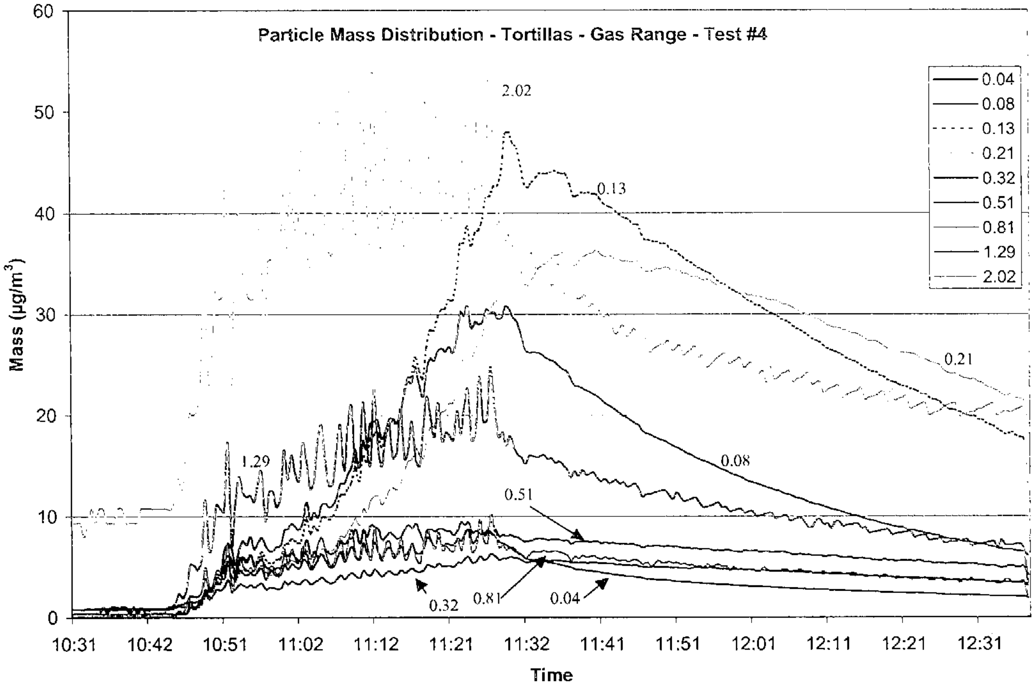


Figure 4-25. Particle Mass Distribution during the Gas Range Tortilla Test (No. 4)



The ELPI measurements show the impact of different types of cooking on the PM levels in the kitchen. For the self-cleaning oven test, the concentrations of particles increased quickly and stayed at a high concentration for approximately one hour. But apparently, the majority of the food was burned off the surface during the first hour, and then the concentrations of PM in the kitchen decreased. During stovetop stir-frying, the concentrations rose steadily during the short cooking event. The concentrations dropped dramatically after the cooking was completed, then decreased slowly during the one-hour post-cooking exposure period. The dramatic decrease at the end of the test was due to opening of doors and windows in preparation for another test on that day. The data in Figure 4-15 show two cooking events with frying of bacon, each followed by a one-hour post-cooking exposure period. In the French fry test depicted in Figure 4-17, two batches of French fries were cooked sequentially with no break between the two batches. But in the test with fish broiled in the gas oven, one large salmon steak was broiled for 24 minutes, and the oven was turned off. However, as shown Figure 4-18, the concentration of the $PM_{2.5}$ did not decrease substantially during the one-hour post-cooking exposure period. As a result, when the second salmon steak was cooked, the concentration peaked at nearly 6 mg/m^3, as measured with the ELPI. During the two-hour cooking period required to bake the large frozen lasagna, there was an initial large peak in PM followed by a relatively constant concentration of PM in the kitchen. But the concentration during the lasagna test was an order of magnitude higher than when the oven was operated without cooking of food (Figure 4-21), indicating the impact of the food cooking on the $PM_{2.5}$ concentrations. It should be noted that the intent of these figures is to depict the peak concentrations and the trends of the changes in PM concentrations. The actual concentrations appear to be unrealistically high in some cases and should not be compared to the gravimetric data.. A complete set of charts for particles/cm^3 and mass is included for all tests in an electronic database accompanying this report.

Figures 4-22 through 4-25 are examples of changes in the mass concentrations in individual size fractions during four tests. The figures show that, in general, the changes in concentrations are similar for the smaller size fractions. In both the stovetop stir fry tests depicted in the figures, the peak concentrations occur at approximately the same time for the six smallest size fractions. The figures also show the differences in the decay of the particles following termination of cooking. During the tortilla cooking test with the electric range (Figure 4-24), there were substantial differences in the decay rates for the different size fractions. Figure 4-25 rather dramatically shows the impact of cooking on the fine PM emissions, with each peak representing placement of an individual tortilla in the oil for frying.

4.1.3 Comparison of Cook Personal PM Exposures and Kitchen PM Area Samples

The gravimetric PM samples were collected at a fixed location in the kitchen using size selective inlets. For most tests, the cook did not wear a personal sampler. The samplers were place on a tripod located in front of the range and to the side of the cook. Samplers were located at breathing height. The ELPI was located directly behind the tripod so that the gravimetric and ELPI measurements were collocated. This approach was taken to allow greater freedom of movement for the cook, to avoid the potential personal cloud effect (Wallace, 1996), and to facilitate measurements with the ELPI at the same location as the PM gravimetric samples. The cook's personal exposure may be lower than the concentrations measured in the kitchen air because the cook may move from room to room or even outdoors. Or, the cook's exposure may be impacted, either positively or negatively, due to closer proximity to the source, different air flow patterns, and mixing at the breathing zone of the cook due to body heat and/or heat from cooking.

During two tests with stovetop stir-frying, concentrations of PM measured in the kitchen air were compared to concentrations measured with personal samplers worn by the cook. The results are summarized in Table 4-5. In test 17, the $PM_{2.5}$ concentration for the personal sample was approximately four times higher than the kitchen air concentration and over two times higher than the living room concentration. During test 30, the personal $PM_{2.5}$ concentration was nearly six times higher than the kitchen air concentration. However, during both tests, the PM_{10} concentration in the personal sample was less than half of the room air concentrations.

Table 4-5. Comparison of Cook Personal Exposure and Room Air Measurements of $PM_{2.5}$ and PM_{10}

Sampling Location	**Stir Fry – Worst Case (Test 17)**		**Stir Fry – Vegetable Oil (Test 30)**	
	μg/m^3		**μg/m^3**	
	$PM_{2.5}$	**PM_{10}**	**$PM_{2.5}$**	**PM_{10}**
Cook - Personal	2050^a	532^a	2350	291
Kitchen	531	1440^b	392	913^c
LR	850	1360	294	587
MBR	798	1360	303	606

^{a}Final flow 20% low
^{b}Final flow 35% low
^{c}Final flow 28% low

The results of the measurements suggest that the room air concentrations may underestimate the cook's exposure to $PM_{2.5}$ and overestimate the exposure to PM_{10}. The reason for the differences between the personal exposure measurements for $PM_{2.5}$ and PM_{10} are not known, but may be related to particle agglomeration and deposition. The fine particles, which may be predominantly grease droplets, may agglomerate to form larger particles. This is suggested by the higher PM_{10} concentrations in the room air samples compared to the personal samples. PM_{10} concentrations were also generally highest in the kitchen and lower in the MBR, which was the most distant room from the source.

4.1.4 PM Element Concentrations

The element concentrations measured in the PM_{10} mass samples were summarized in Tables 3-13 and 3-14. The compounds identified in the samples were typical of those in ambient air samples, including silicon, aluminum, calcium, phosphorous, and sulfur. The samples also contained sodium and chlorine, probably originating from sea salt due to the proximity of the house to the ocean. Average and median indoor concentrations and median outdoor concentrations are presented in Table 4-6.

The concentrations of many of the elements were elevated relative to the outdoors during the self-cleaning oven tests, particularly with the gas oven. The concentrations of many of the elements were an order of magnitude higher in the kitchen than in the outdoor sample during oven cleaning. The chromium concentration of 1220 ηg/m^3 was nearly two orders of magnitude higher than in the outdoor sample. The silicon, phosphorous, sulfur, chlorine, potassium, and bromine concentrations were all substantially higher in the indoor sample during oven cleaning. The differences in concentrations between indoors and outdoors were not as dramatic during the self-cleaning oven test with the electric oven. Nickel and zinc were also higher indoors than outdoors during self-cleaning with both the gas and electric ovens.

Similar differences were observed during the tests involving frying of loose ground beef in a pan on the gas rangetop burner. The concentrations of titanium, chromium, zinc, sodium, magnesium, aluminum, silicon, phosphorous, sulfur, chlorine, calcium, and bromine were all higher indoors than outdoors. Even larger differences were observed between indoors and outdoors when the full meal was cooked. As in the self-cleaning oven tests, chromium and zinc were elevated with respect to outdoors.

Copper concentrations were always higher indoors than outdoors. This, however was an artifact related to the sampling equipment. Pumps were located in the house for collection of the integrated air samples. It is likely that they were the source of the copper.

The median concentrations measured indoors and outdoors in 16 samples collected in this study are compared in Table 4-6 to median concentrations measured in PTEAM. The median concentrations measured in outdoor air samples during this study were substantially lower than in PTEAM for all elements except chlorine. The element concentrations in the indoor air samples were also quite low, with chlorine and bromine being the only elements with median concentrations higher than the PTEAM medians. However, it should be recognized that the

PTEAM data were collected nearly ten years ago in Riverside, CA, an area with substantially poorer air quality than that which currently exists in Rohnert Park, CA.

Table 4-6. Element Concentrations (ηg/m^3) in this Study Compared to PTEAM

Element	Cooking Indoor Average	Cooking Indoor Median	Cooking Outdoor Median	PTEAM Indoor - Daytime	PTEAM Outdoor - Daytime
Sodium	380	310	250	--	--
Magnesium	160	100	52	--	--
Aluminum	230	170	35	1900	2500
Silicon	2300	860	110	4900	6800
Phosphorous	1000	160	6.0	--	--
Sulfur	850	320	160	1600	1600
Chlorine	1200	720	390	280	160
Potassium	740	150	59	880	1000
Calcium	340	340	46	2700	2700
Titanium	22	17	5.5	150	180
Vanadium	24	23	3.4	--	--
Chromium	190	31	1.3	--	--
Manganese	0.0[a]	0.0[a]	0.6	30	46
Iron	100	100	66	1400	2100
Cobalt	3.7	3.5	0.7	16	14
Nickel	12	3.3	0.6	--	--
Copper	100	92	4.0	--	--
Zinc	49	58	6.8	68	63
Arsenic	3.9	4.2	0.2	--	--
Selenium	4.6	4.6	0.6	--	--
Bromine	430	18	1.9	11	10
Strontium	3.4	2.9	0.7	13	17
Molybdenum	17	16	2.2	--	--
Palladium	13	13	7.5	--	--
Silver	54	550	2.3	--	--
Cadmium	63	48	6.5	--	--
Tin	10	10	3.6	--	--
Antimony	0.0[a]	0.0[a]	4.5	--	--
Barium	310	260	9.2	--	--
Gold	27	26	0.9	--	--
Mercury	22	22	1.6	--	--
Lead	18	15	1.2	23	27

[a] – Blank filter correction resulted in a zero or negative value.

4.1.5 CO, NO, and NO_2 Measurement Results

4.1.5.1 CO, NO, and NO_2 Air Concentrations During Standard Cooking Tests

CO, NO, and NO_2 concentrations were measured in the kitchen, living room, master bedroom, and outdoors during each cooking test. The results were summarized in Tables 3-19 through 3-24. The distributions of the average CO concentrations in the house during the seven typical cooking tests with gas and electric ranges are presented in Figures 4-26 and 4-27. CO concentrations outdoors ranged from 0.1 to 1.1 ppm during the tests. Indoor concentrations ranged from 0.4 to 20 ppm (peak concentration), with the highest concentrations occurring during the oven cleaning tests with the gas range. The second highest concentrations of CO occurred during oven cleaning with the electric range, but they were only about half that with the gas oven cleaning. The CO emissions during self-cleaning with the electric oven were likely due to combustion of the food materials on the surfaces of the oven. Elevated levels of CO during use of electric broilers for commercial food preparation were reported by Gerstler et al. (1998).

Figure 4-26. CO Concentrations During Cooking and in Baseline Measurements with the Gas Range

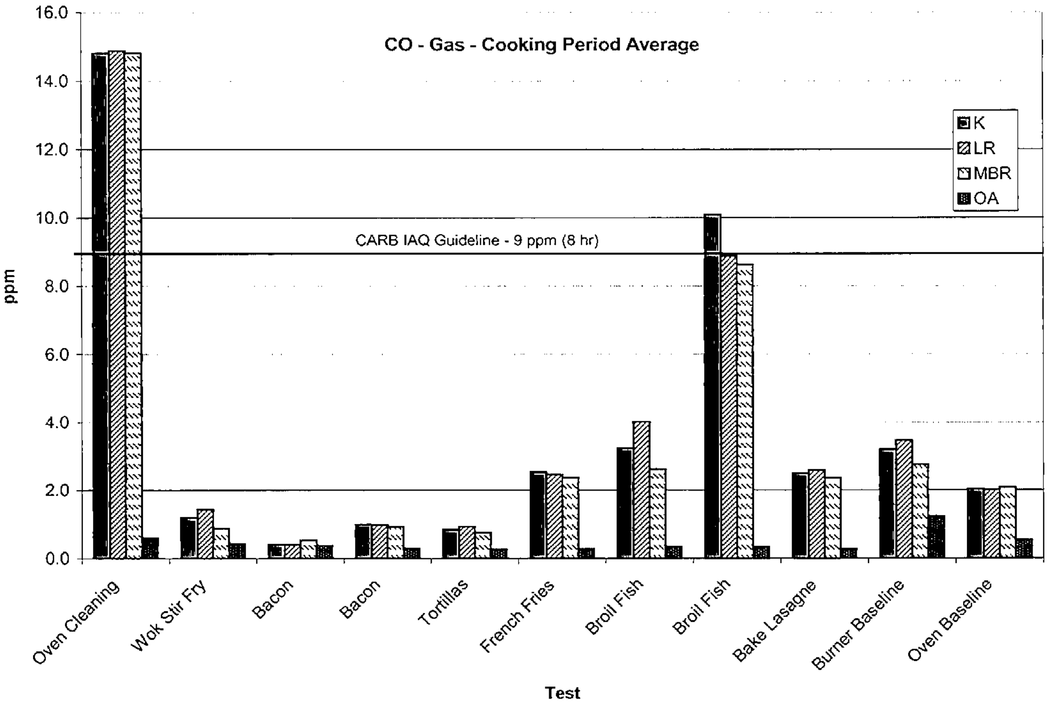
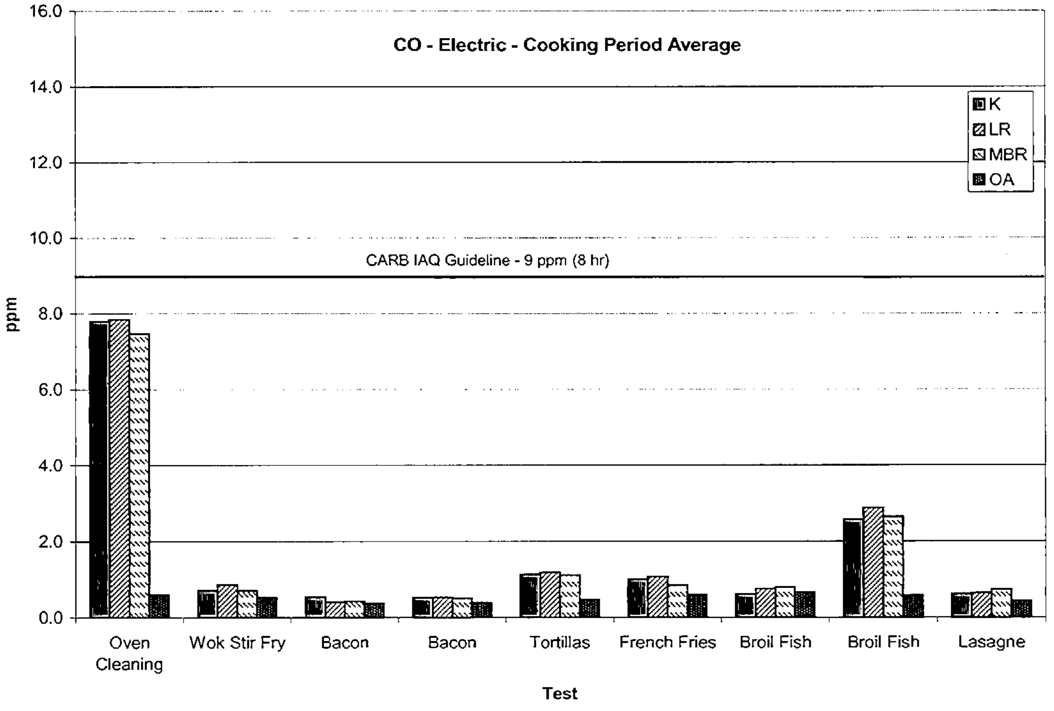


Figure 4-27. CO Concentrations During Cooking Tests With the Electric Range



During the cooking tests, CO concentrations peaked at 9.5 ppm during cooking of the full meal and 11.4 ppm when broiling the fish with the gas range. Average concentrations during the cooking period were highest for broiling fish, both with the gas and electric ovens. The CO concentrations during the total exposure period were generally below 4 ppm, and the median concentrations were 1.3, 1.3 and 1.2 ppm for the three indoor locations during 32 tests.

The baseline CO concentration during operation of the range top burner for one hour peaked at 5.1 ppm and averaged 3.2 ppm in the kitchen. During two hours of oven operation at 350 °F with no food being cooked, the average CO concentration was 2.0 ppm with a peak of 3.0 ppm in the kitchen. These values suggest that the range top and oven burners were reasonably well tuned. The results are similar to those reported by Koontz and Nagda (1989) for well-tuned gas ranges in test houses. They reported peak CO concentrations of 5 and 5.4 ppm and 8-hr average concentrations of 2.1 and 2.5 ppm during operation of a gas range burner with ranges in two test houses. Higher baseline concentrations have been measured in other studies. Nelson et al. (1993) reported measuring a CO concentration of 183 ppm in the oven vent during self cleaning of an oven, resulting in a kitchen air concentration of 6 ppm after only 10 minutes. Tsongas (1994) reported a study in which 25 of 62 homes had kitchen air concentrations greater than 9 ppm due to operation of gas ovens.

The average concentrations of CO during the tests were similar in the three indoor locations, as shown in Figures 4-26 and 4-27. These uniform concentrations, for this inert gas, suggest that the house was very well mixed during the tests. Although there were no fans operating in the house during the tests, heat gradients and technician activity may have facilitated good mixing.

NO concentrations during the tests ranged from non-detectable to 44 ppb outdoors, with an average of 27 ppb during the 32 tests (Table 3-22). Indoor concentrations during the 32 cooking tests ranged from 1.7 to 1000 ppb. Results for the seven standard cooking tests are depicted in Figures 4-28 and 4-29 for the gas and electric ranges, respectively. The reader should note that the concentration scales are different on the two figures. As was the case for CO, the highest concentrations occurred during oven cleaning, with average concentrations of approximately 700 ppb during cleaning period in all three rooms with the gas range and 150 ppb with the electric range. As shown in Figure 4-28, NO concentrations were also high during preparation of French fries and baking lasagna. However, the average concentrations while cooking these foods were no higher than the baseline concentrations for the range top burner and the oven operated without cooking of food. Concentrations of NO were below 20 ppb during all six standard cooking tests with the electric range.

The NO_2 concentrations during the total exposure periods of the cooking tests ranged from 3.0 to 48 ppb outdoors and 7.0 to 670 ppb indoors during the cooking tests. Average concentrations during the seven standard cooking tests are depicted in Figures 4-30 and 4-31 for tests with the gas and electric range, respectively. The reader should note that the concentration scales are not the same on the two figures. As shown in the figures, the concentrations of NO_2 in the house did not exceed 45 ppb during the tests with the electric range. The average concentrations of NO_2 in the rooms during cooking tests with the electric range were not substantially different from the outdoor concentrations.

Figure 4-28. NO Concentrations During Cooking and Baseline Measurements with the Gas Range

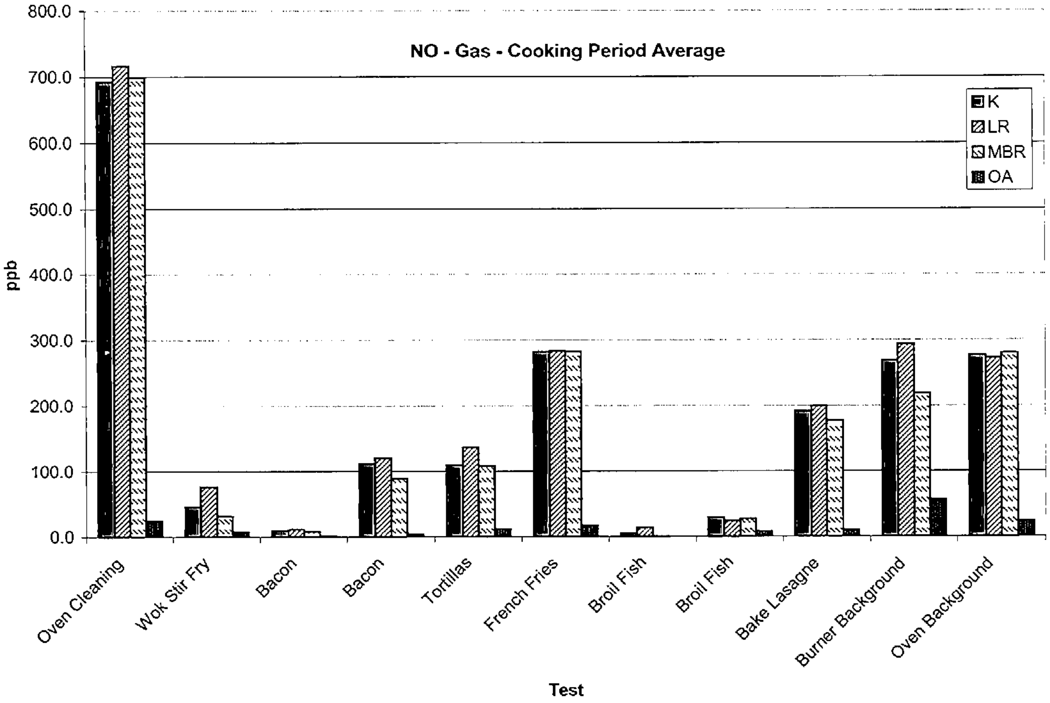


Figure 4-29. NO Concentrations During Cooking With the Electric Range

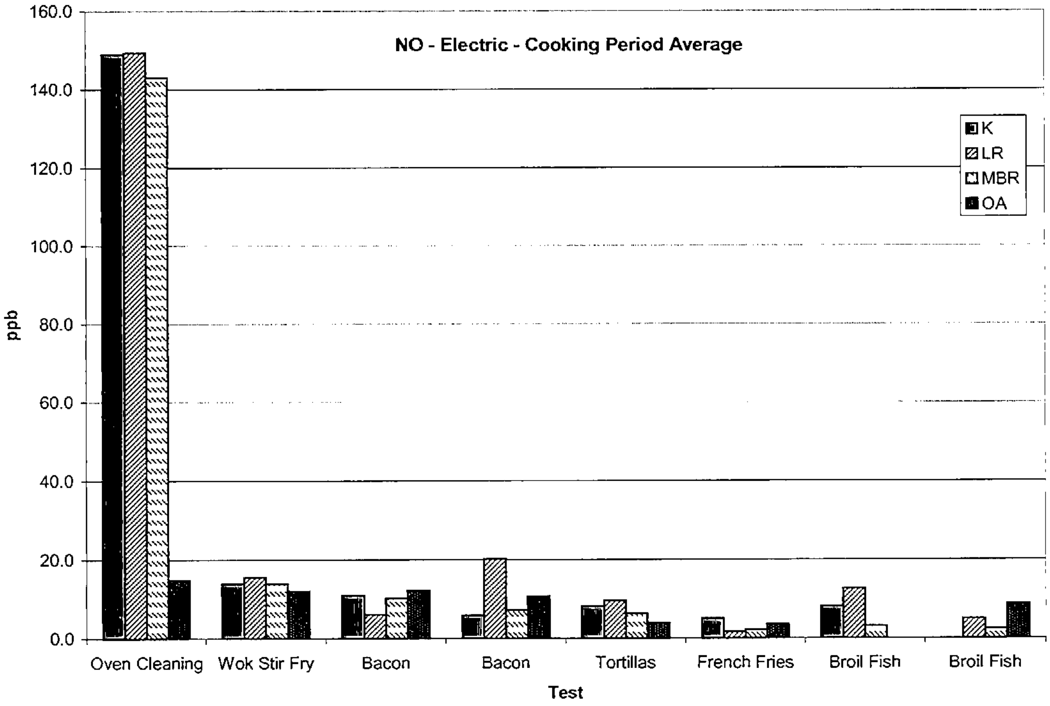


Figure 4-30. NO_2 Concentrations During Cooking and Baseline Measurements with the Gas Range

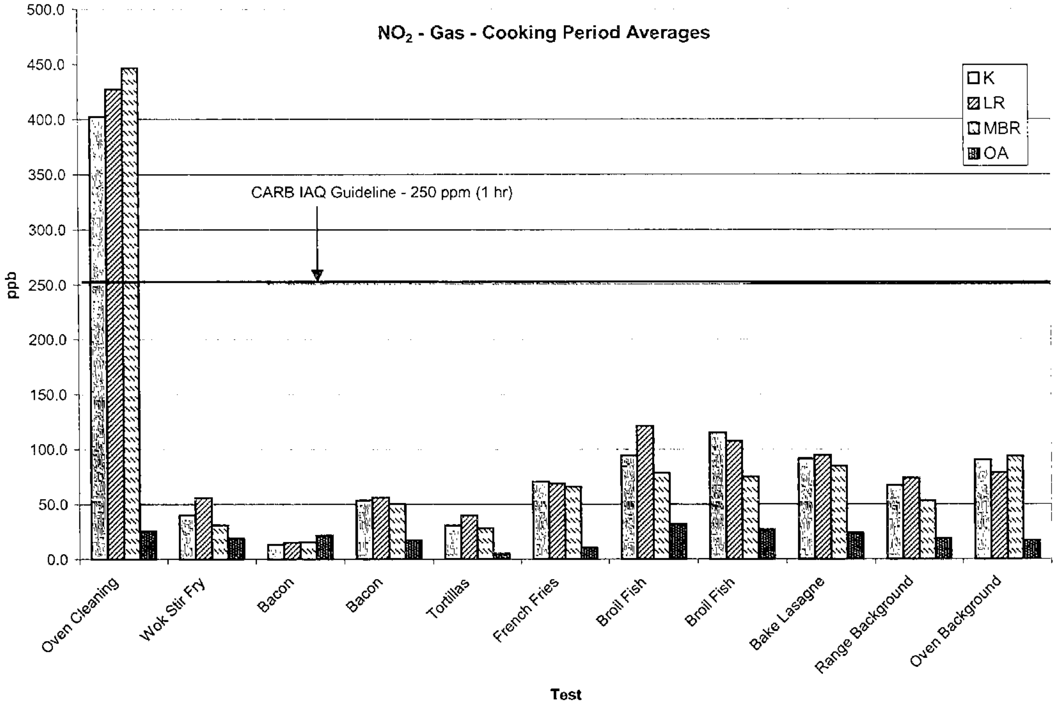
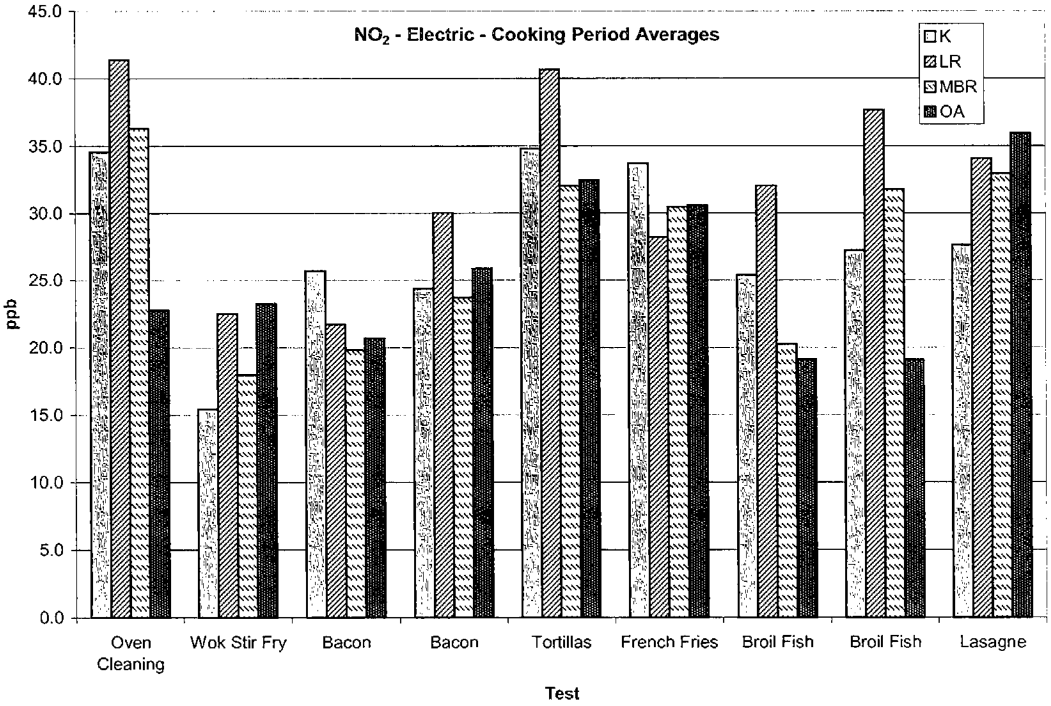


Figure 4-31. NO_2 Concentrations During Cooking with the Electric Range



During the tests with the gas range, the average NO_2 concentrations were above 400 ppb in all three rooms during the five-hr long self-cleaning oven test. The average NO_2 concentrations during the cooking period for the six typical cooking tests with the gas range were from 13 ppb for bacon frying to 115 ppb for broiling fish. The highest concentrations during the six typical cooking tests with the gas range were measured during broiling fish, with peak concentrations in the kitchen as high as 145 ppb. NO_2 concentrations were also high, above 85 ppb in all three rooms during the other test with the oven, baking lasagna. Peak concentrations during the lasagna test were 113, 131, and 103 ppb in the kitchen, living room, and bedroom. The average and peak NO_2 concentrations were substantially lower during the tests with the range top burner. The results suggest that elevated exposures to NO_2 may occur due to use of the oven. This is an especially important observation because the oven is generally operated for longer time periods than range top burners, resulting in exposure to higher peak concentrations and longer exposures.

Figures 4-28 and 4-29 also show that, like CO, the concentrations of NO were very similar in the three rooms of the house. The NO data show that there was good mixing in the house during the tests.

The range top burner and oven were operated without cooking to determine baseline NO_2 concentrations. The average NO_2 concentrations during one hour of operation of the range top burner with a pot of water were 67, 108, and 98 ppb in the K, LR, and MBR. The peak concentration was 108 ppb in the kitchen. During two hours of oven operation with no food, the concentrations were 90, 79, and 94 ppb in the K, LR, and MBR with a peak of 129 ppb in the kitchen. The average room air concentrations during cooking of the foods were not substantially different from the NO_2 concentrations measured during the baseline tests. Koontz and Nagda (1989) reported peak concentrations of 50 and 58 ppb for the gas ranges used in two test houses. The peak concentrations measured in this study were somewhat higher, but were reasonable considering that the emissions are expected to vary between ranges due to different burner design, adjustment of the burner, and combustion characteristics.

NO_2 concentrations were generally lower in the bedroom than in the kitchen and living room. This was consistent with the fact that NO_2 is a reactive gas and that deposition and reactions may occur during transport from the source to the bedroom. The concentrations in the kitchen and adjacent living room were not substantially different.

Examples of the changes in the concentrations of combustion pollutants are depicted in Figures 4-32 through 4-37. All figures depict NO, NO_2, and CO concentrations in the kitchen during cooking with the gas range. Figures 4-32 and 4-33 show the steady rise in the concentrations of the combustion pollutants during the 1 hour and 8 minute period during which French fries were cooked in oil on the range top. NO_2 concentrations peaked at approximately 100 ppb and declined slowly after cooking ended. Figure 4-34 shows an example of a test with two cooking events separated by a one-hour post-cooking exposure period. During this test, when salmon steaks were broiled in the oven, the concentration of NO_2 was substantially higher than the NO concentration. After the first salmon steak was broiled, the concentrations decreased nearly 50% in the following hour. The second peak reflected the higher background in the kitchen at the start of the second cooking event. Concentrations of NO_2 dropped quickly after cooking ended. The dramatic drop after 1400 (2:00 p.m.) represented the end of the test, when the room was ventilated in preparation for another test on the same day. Figures 4-36 and 4-37 depict the concentrations of the combustion pollutants during the test when a full meal was cooked. This test, which involved preparation of baked potatoes, fried chicken, boiled vegetables and rolls, involves a two hour and twenty minute period during which both the range top burners and oven were used. The NO_2 concentration peaked at 375 ppb. NO reached the maximum of the instrument range of 1000 ppb. CO reached a maximum of 9.4 ppm and averaged 4.7 ppm during the total exposure period of 7.25 hours during which the test was performed.

4.1.5.2 Variability of CO, NO, and NO_2 Concentrations During Replicate Tests

The variability of CO, NO, and NO_2 concentrations, measured in three replicate cooking tests, is summarized in Table 4-7. Average and peak concentrations are listed along with the relative difference between the replicate tests. The results of the three replicate tests can be summarized as follows:

- Average CO concentrations in the three tests, in the three rooms, varied by 5 to 53%
- Peak CO concentrations varied by 18 to 49%
- Average NO concentrations in the three tests, in the three rooms, varied by 3 to 64%
- Peak NO concentrations varied by 4 to 61%
- Average NO_2 concentrations in the three tests, in the three rooms, varied by 4 to 52%
- Peak NO_2 concentrations varied by 3 to 59%
- Concentrations of CO and NO_2 were most variable during the French fries tests
- Peak NO_2 concentrations were the least variable in the bedroom

The results suggest that concentration differences of less than 50% may not be significant when comparing results from different tests. The high variability in the concentrations of the combustion gases is also consistent with the high variability in the particle measurements, suggesting that cooking tests may be difficult to perform reproducibly. Alternatively, the variability may be due to a variety of other factors during the semi-controlled tests conducted in the test house. These include variations in temperature, relative humidity, internal air flows, and the impact of pollutant sinks. However, the high variability for the inert gases, CO and NO, suggest that the sinks may not be a major contributor to the variability.

Figure 4-32. NO and NO_2 Concentrations During French Fries Test with the Gas Range

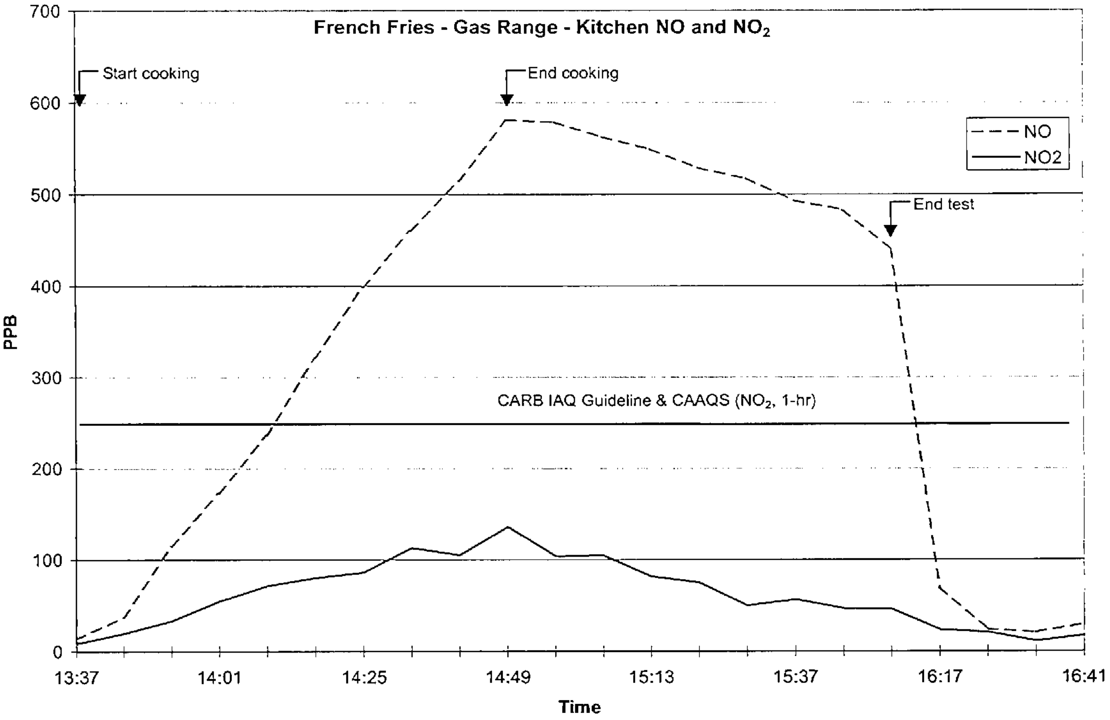


Figure 4-33. CO Concentrations During the French Fries Test with the Gas Range

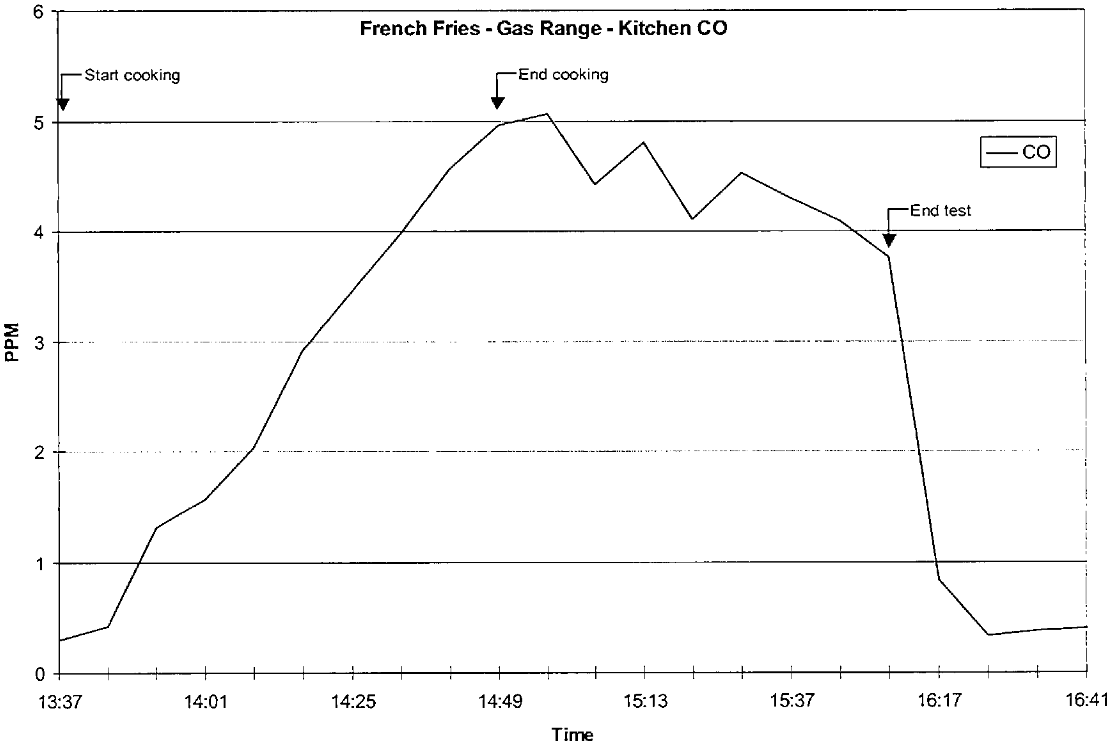


Figure 4-34. NO and NO_2 Concentrations During the Broil Fish Test with the Gas Range

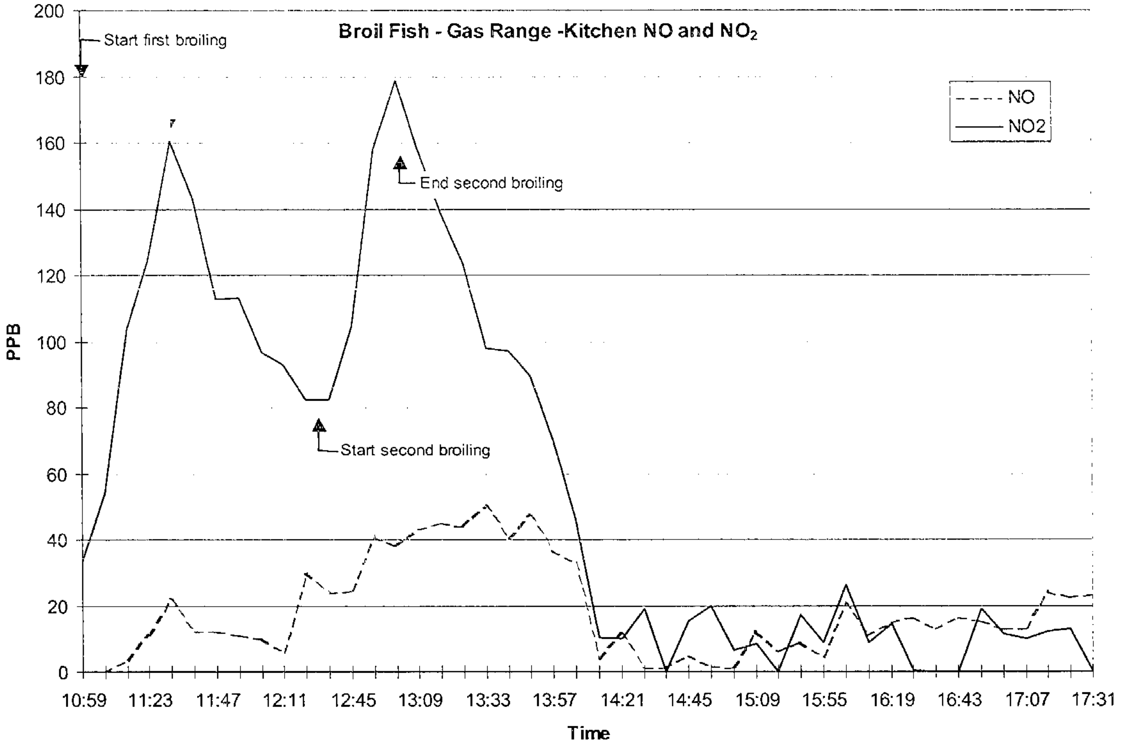


Figure 4-35. CO Concentrations During the Broil Fish Test with the Gas Range

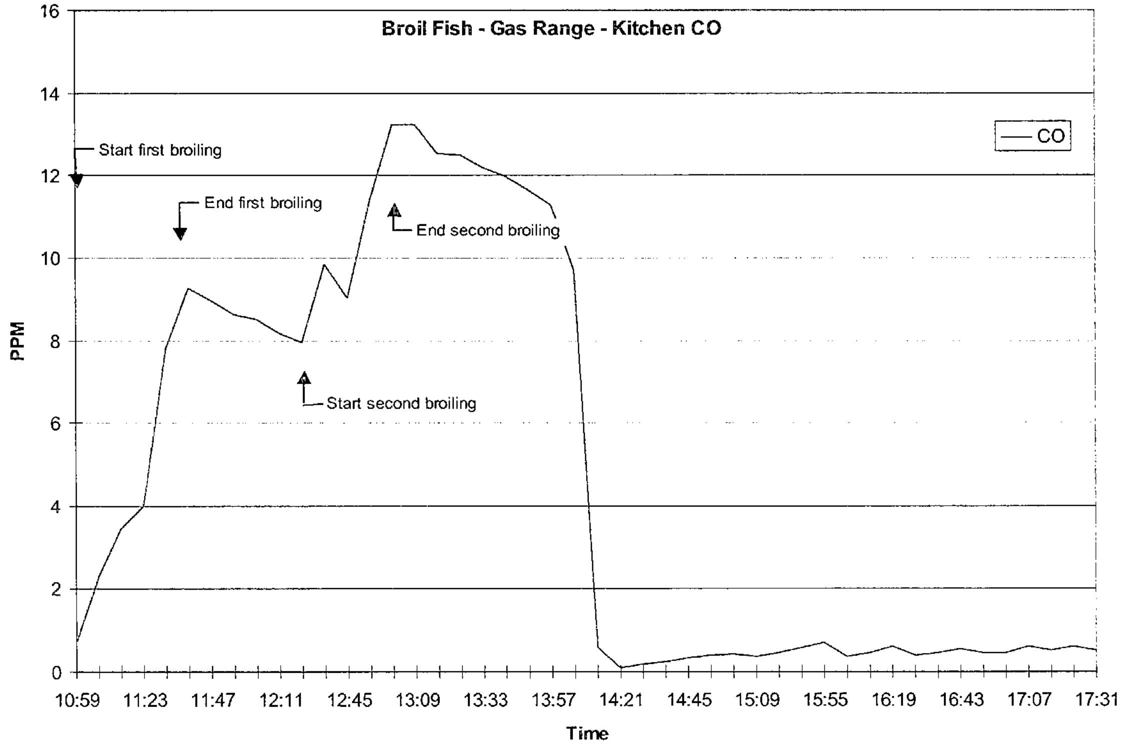
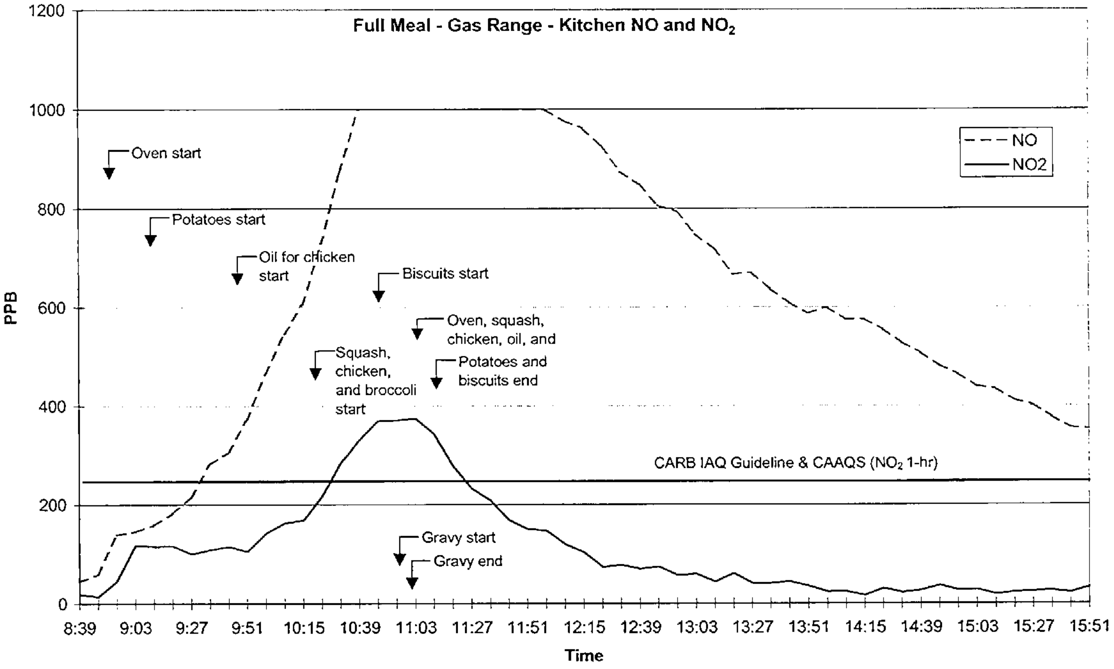
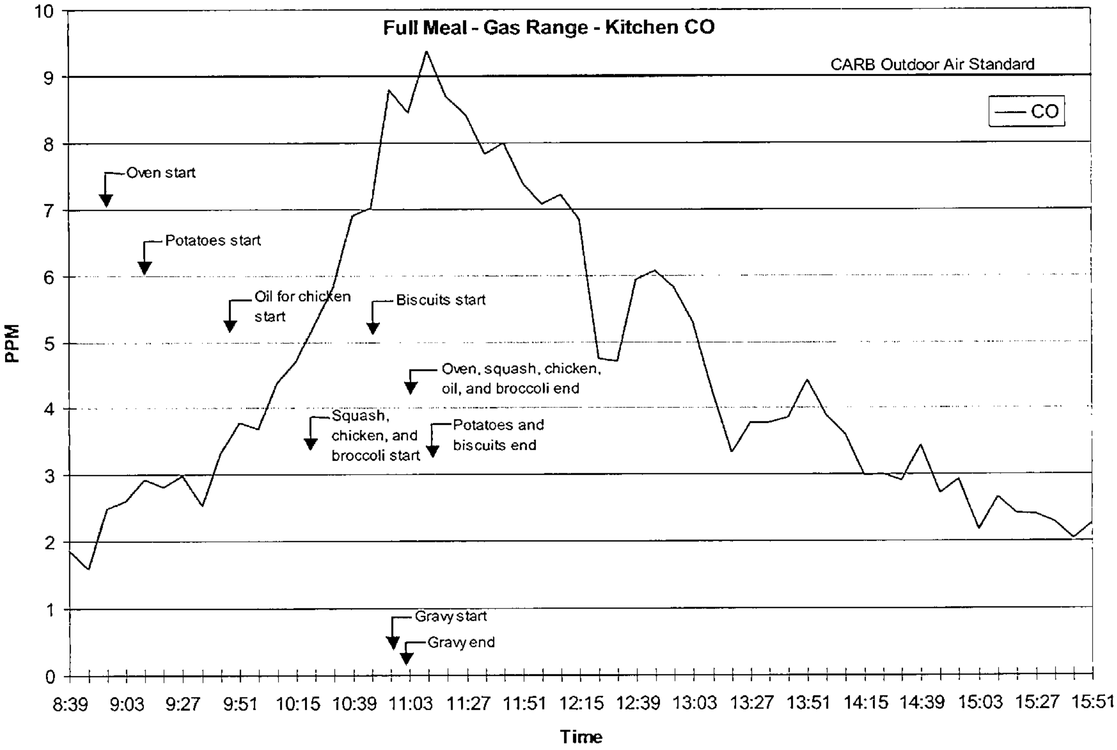


Figure 4-36. NO and NO_2 Concentrations During Full Meal Test



Measurements for NO may be truncated to 1000 ppb due to scale limitations during monitoring.

Figure 4-37. CO Concentrations During Full Meal Test



4.1.5.3 CO, NO, and NO_2 Concentrations During Worst Case Cooking Tests

The impact of the worst case cooking activities on the combustion pollutants was evaluated in tests with the stovetop stir frying, cooking bacon, and broiling fish. All worst case tests were performed with the gas range. The results of the tests are summarized in Table 4-8. During the cooking period, there appeared to be little impact on the average concentrations of CO in the three rooms with measurements.

The NO concentrations in the house were higher during all three worst case tests. There was an impact on NO that was likely related to slightly higher cooking temperatures and longer cooking durations. Average NO concentrations in the kitchen during the cooking period were over two times higher during the stovetop stir fry tests and over seven times higher during bacon frying and fish broiling.

The worst case cooking also resulted in impacted NO_2 concentrations during all three tests. The impact of the worst case cooking method was most dramatic for frying bacon, with average and peak concentrations in the kitchen and living room being nearly twice as high as in the standard test. During the other two worst case tests, there was little impact on the average concentrations, although the peak concentrations were somewhat higher, particularly in the kitchen. This was most likely due to the longer cooking times.

Table 4-7. Average and Peak Concentrations of CO, NO, and NO_2 during Replicate Cooking Tests

Test No.	Type	K		LR		MBR	
		Avg.	Max	Avg.	Max	Avg.	Max
CO							
2	Stovetop Stir Fry	1.2	1.5	1.4	2.2	0.9	1.4
21	Stovetop Stir Fry	1.1	1.8	1.1	1.6	0.6	0.9
%RD		-5	18	-31	-35	-33	-41
5	French Fries	2.5	4.6	2.5	4.7	2.4	4.4
22	French Fries	4.3	7.5	4.1	7.0	3.1	5.9
%RD		53	48	49	40	27	30
7	Bake Lasagna	2.5	3.6	2.6	3.3	2.4	3.4
23	Bake Lasagna	2.0	2.9	1.8	2.9	1.7	2.7
%RD		-20	-21	-36	-13	-35	-23
NO							
2	Stovetop Stir Fry	45.9	82.2	76.1	138.4	32.2	78.1
21	Stovetop Stir Fry	88.8	155.1	86.9	123.2	35.9	50.2
%RD		64	61	13	-12	11	-44
5	French Fries	282.0	514.0	282.6	548.2	282.1	519.2
22	French Fries	354.6	629.3	332.7	621.3	273.5	541.4
%RD		23	20	16	13	-3	4
7	Bake Lasagna	190.8	314.1	199.4	327.2	176.5	294.5
23	Bake Lasagna	301.1	430.4	290.8	447.1	270.6	427.3
%RD		45	31	37	31	42	37
NO2							
2	Stovetop Stir Fry	40.0	41.1	55.8	72.2	30.9	47.0
21	Stovetop Stir Fry	41.6	75.6	37.8	51.9	25.9	35.6
%RD		4	59	-38	-33	-17	-28
5	French Fries	70.4	113.0	68.6	123.4	66.0	119.5
22	French Fries	120.4	167.6	112.6	158.3	84.3	131.3
%RD		52	39	49	25	24	9
7	Bake Lasagna	91.2	113.1	94.4	131.3	84.6	102.9
23	Bake Lasagna	85.4	95.7	84.9	108.9	73.0	106.0
%RD		-7	-17	-11	-19	-15	3

Table 4-8. Impact of Worst Case Cooking Activities on Average Concentrations of CO, NO, and NO_2 and Peak NO_2 during the Cooking Period

Pollutant	Type of Test	Stovetop Stir Fry			Bacon			Fish		
	Room	K	LR	MBR	K	LR	MBR	K	LR	MBR
CO (ppm)	Standard	1.2	1.4	0.9	0.4	0.4	0.5	3.2	4.0	2.6
	Worst Case	1.1	0.8	0.7	1.0	1.3	0.9	3.3	3.8	2.4
NO (ppb)	Standard	46	76	32	9.6	12	8.3	4.9	14	0.9
	Worst Case	120	98	87	76	110	62	34	29	31
NO_2 – Avg. (ppb)	Standard	40	56	31	13	15	15	94	120	78
	Worst Case	47	37	31	40	35	24	93	96	46
NO_2 – peak (ppb)	Standard	41	72	47	17	22	21	125	145	119
	Worst Case	70	60	52	51	46	32	150	167	84

4.1.5.4 Relationship of CO, NO, and NO_2 Concentrations in Cooking Tests to Guidelines and Standards

With the exception of the oven cleaning and fish broiling tests with the gas range, the CO concentrations indoors did not exceed the ARB IAQ Guideline of 9 ppm (8 hour average). The average CO concentration during the five-hour gas oven self-cleaning test was above 14 ppm, which was still below the ARB IAQ Guideline of 20 ppm for one-hour. However, because the oven self-cleaning lasted for four hours, it would be a significant source of exposure in a closed house due to the extended period of elevated CO concentrations following the event. To minimize CO exposure, occupants should be encouraged to leave the home during oven self-cleaning.

The ARB IAQ Guideline for NO_2 is 250 ppb over one hour and was not exceeded during tests with the electric range.

The average NO_2 concentrations were above 400 ppb in all three rooms during the 4-hr hour long self-cleaning gas oven test. This exceeded the ARB IAQ Guideline of 250 ppb over one hour. However, the ARB IAQ 1-hr guideline was not exceeded during the six cooking tests with the gas range.

4.1.6 PAH Concentrations

PAHs and a number of other SVOCs were measured during a selected set of tests. The results were presented in Tables 3-16 and 3-17. Samples were collected concurrently in the kitchen and outdoors. Samples were not collected in other rooms in the house because the pre-test results showed that there was little difference in the concentrations measured in the kitchen and adjacent living room. Of the 13 PAHs targeted for analysis, only pyrene, BeP, BaP, and benzo(b+j+k)phenanthrenes were detected in greater than 60% of the samples. Pyrene was detected in 85% of the samples. The average and maximum concentrations are presented in Table 4-9 and compared to results of measurements during the ARB study of PAHs in northern California (Sheldon et al., 1993) and in PTEAM (Sheldon et al., 1992). Data are presented in the table for the woodstove category in the northern California study because this category had the highest PAH concentrations. The average concentrations indoors were higher than the average outdoor concentrations during the cooking tests. The average indoor concentrations were generally higher than the average concentrations in the northern California study and in the PTEAM samples collected in Riverside, California. For most compounds, the outdoor concentrations in this study were lower than in the northern California study and generally within the range of concentrations measured in PTEAM. However, the measurements in both the ARB northern California study and in PTEAM were the average for 24-hour sampling periods, which would be expected to be lower than the measurements in this study. Measurements during this study were performed over periods of approximately 1.5 to 5 hours.

PAHs were also measured during the worst-case stovetop stir-fry test (Test No. 17) and in Test No. 30 when vegetable oil was used instead of peanut oil for cooking. The peanut oil had higher concentrations of PAHs than the vegetable oil (Table 3-2). Table 4-10 presents data for the worst case and standard tests. Duplicate samples collected during the worst case stir-fry test (Test No. 17) show that precision was poor for the PAH sampling method. Because of the short test, the mass of PAHs in the samples was low, and there was large analytical uncertainty associated with the measurement. As a result, it is not possible to determine if the differences in the PAH concentrations between the tests are significant. There are no clear trends in the PAH concentrations that can be attributed to the worst case cooking method or the use of a different cooking oil. BeP concentrations were 3.5, 9.6, and 0.8 ηg/m^3 in the three samples collected during tests with peanut oil and 4.3 ηg/m^3 in the test with the vegetable oil. These concentrations were higher than one of the outdoor air samples, but lower than the other. BaP concentrations were 2.6, 3.7, non-detectable, and 2.7 ηg/m^3 during cooking tests and 0.4 and 2.1 ηg/m^3 outdoors. For other PAHs, e.g., phenathrene and pyrene, the indoor samples were higher than outdoors.

The data suggest that PAHs may be elevated indoors due to the cooking activities. This is consistent with results of previous studies. Wallace (1998) has shown increased concentrations of total PAHs measured with a continuous PAH monitor during cooking. Dubowsky et al (1999) reported peak total particle-bound PAH concentrations in a range from non-detectable to 670 ηg/m^3 during cooking when measured with a Gossen PAS monitor. Chuang et al. (1991) reported that differences in PAH concentrations could be related to the presence of gas or electric appliances. A number of reports of PAHs in cooking oil fumes have been reported (Wu, et al., 1998; Shuguang et al., 1994; Shields et al., 1995; and Chiang et al, 1997). However, because of the low concentrations and associated high level of analytical uncertainty, it is difficult to draw quantitative conclusions from the data collected in this study. The data indicate that further measurements of this pollutant are warranted to determine the magnitude of cooking as a source. To obtain quantitative measurements that can be related to variables such as the type of cooking oil, different cooking and sampling protocols will be required. Larger volume samples in conjunction with more sensitive analytical methods are necessary to obtain the level of accuracy and precision required to meet this objective.

Due to the health risks associated with PAHs, it is important that data be collected on the contribution of cooking to PAH exposures.

Table 4-9. PAH Concentrations (ηg/m^3) Measured in This Study Compared to the ARB Northern California Study and PTEAM/CARB Study

	Indoor		Outdoor		ARB – Northern CA[a]		PTEAM Range	
	Average	Maximum	Average	Maximum	Average Indoor	Average Outdoor	Indoor	Outdoor
Acenaphthylene	0.0[b]	0.0[b]	0.0[b]	0.0[b]	14	19	NQ[c] - 16	NQ - 16
Phenanthrene	26	53	6.2	6.2	20	27	8.1 – 32	3.0 - 22
Anthracene	0.0[b]	0.0[b]	0.0[b]	0.0[b]	1.2	3.2	NQ – 1.2	NQ – 1.6
Fluoranthene	7.4	20	2.7	2.7	2.3	7.0	NQ – 3.1	NQ – 4.8
Pyrene	12	19	3.7	4.9	2.5	6.5	0.8 - 3.6	0.68 – 4.1
Benz(a)anthracene	18	18	0.7	0.7	0.55	1.4	NQ – 2.3	NQ – 0.56
Chrysene	7.1	12	0.6	0.9	0.61	1.9	NQ – 2.9	NQ – 1.0
BeP	5.4	9.6	2.1	3.5	0.55	0.89	NQ – 0.60	NQ – 0.85
BaP	6.2	21	2.1	3.7	1.2	1.4	NQ – 0.77	NQ – 1.4
Indeno[123-cd]pyrene	0.0[b]	0.0[b]	0.0[b]	0.0[b]	1.9	2.0	NQ – 1.7	NQ – 1.6
Benzo(ghi)perylene	9.2	9.2	0.1	0.1	1.5	1.6	NQ – 3.5	NQ – 3.1
Coronene	6.2	6.2	1.4	2.8	1.2	0.89	0.3 –2.3	NQ – 2.9

[a] Arithmetic mean reported for the Wood stove category

[b] Correction with background data resulted in zero or negative value.

[c] Below quantifiable limit

4.1.7 Aldehyde Concentrations

Samples were collected for determination of aldehydes in six tests. The objective of the sampling was to obtain data that could be used to evaluate the magnitude of the emissions of aldehydes. The tests facilitated comparison of indoor concentrations with gas and electric ranges and of different cooking activities. Samples were collected indoors and outdoors during tests of oven cleaning, broiling fish, and cooking of a pork roast in the oven.

The aldehyde results, presented in Table 3-18, are depicted in Figure 4-38. As was the case for the other air contaminants measured in the study, the highest concentrations were measured during oven cleaning, both with the gas and electric range. All seven aldehydes targeted for quantitation, of which six are depicted in the figure, were measurable during the oven cleaning tests. Benzaldehdye was also detected, but at low concentrations in all tests. The average formaldehyde concentrations during the 5-hr long oven-cleaning events were 417 and 224 μg/m^3 for the gas and electric ranges, respectively. These levels substantially exceed the 1-hour 0.076 ppm (94 μg/m^3) level that is considered to be the "Acute Reference Exposure Level" by the OEHHA.

The concentrations of formaldehyde were also elevated in the kitchen during broiling of fish in the oven, both with the gas and electric ovens. The concentrations in the kitchen with both gas and electric ovens (129 μg/m^3) were over the CARB action level. The other type of cooking event during which aldehydes were measured was cooking of a pork roast in the oven. The concentrations of the aldehydes in the kitchen were substantially lower during this type of cooking. Formaldehyde concentrations were 49 and 36 μg/m^3 during the two tests, with the lower concentration measured during the test with operation of the exhaust fan. Although these concentrations were below the CARB 1-hour Acute REL of 0.076 μg/m^3, they were over half the CARB residential long-term guideline value of 62 μg/m^3.

Figure 4-38. Concentrations of Aldehydes During Selected Cooking Tests

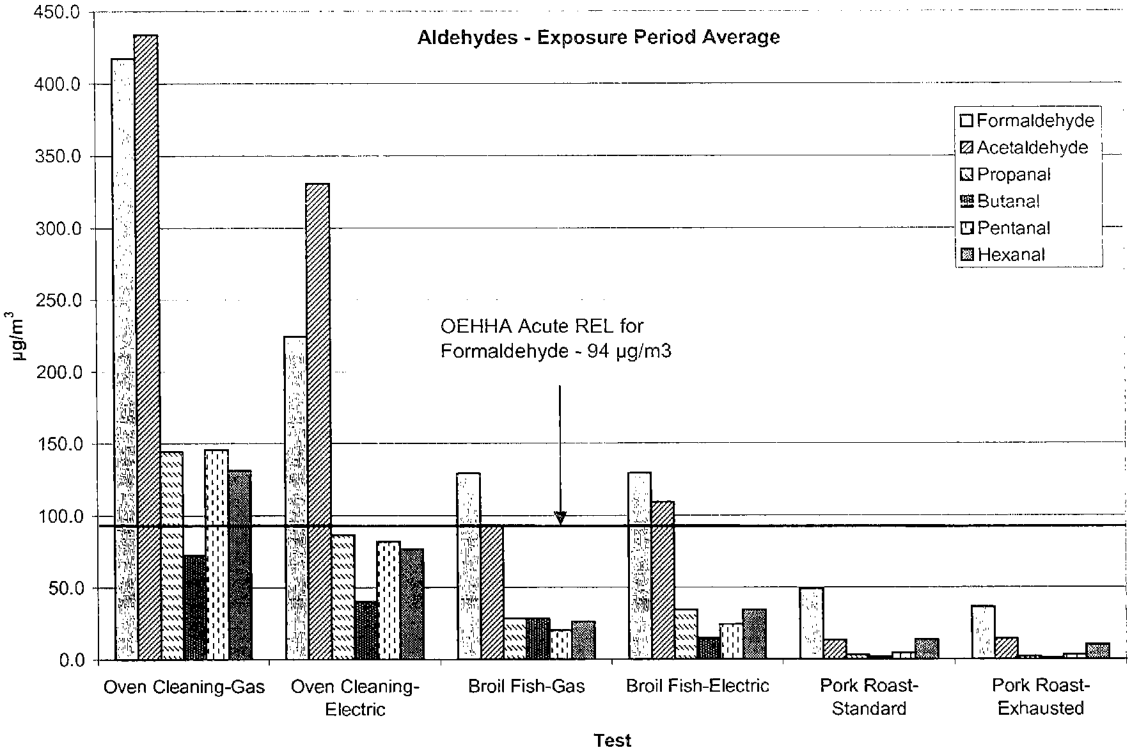


Table 4-10. PAH Concentrations (ηg/m^3) Measured during Cooking Tests

Test No.	21	18,19,21	17	17- Dup	30	17,30
Cooking Method	Stir Fry		Stir Fry	Stir Fry	Stir Fry	
Range	Gas		Gas	Gas	Gas	
Test Type	Standard		Worst Case	Worst Case	Standard	
Cooking Oil	Peanut Oil		Peanut Oil	Peanut Oil	Veg. Oil	
Sampling Location	K	Outdoor	K	K	K	Outdoor
acenaphthylene	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]
acenaphthene	0.0[a]	0.0[a]	0.0[a]	9.0	0.0[a]	0.0[a]
phenanthrene	53.3	6.2	21.6	0.0[a]	33.6	0.0[a]
anthracene	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]
fluoranthene	19.8	0.0[a]	0.0[a]	0.0[a]	*0.7*[b]	0.0[a]
pyrene	16.3	0.0[a]	19.1	9.0	17.4	0.0[a]
benz(a)anthracene	0.0[a]	*0.7*	0.0[a]	0.0[a]	*17.6*	0.0[a]
chrysene	0.0[a]	*0.2*	0.0[a]	*5.7*	0.0[a]	0.0[a]
benzo(b+j+k)phenanthrene	*6.6*	*2.5*	ND	*7.4*	ND	4.8
BeP	*3.5*	*0.2*	*9.6*	*0.8*	*4.3*	3.5
BaP	*2.6*	*0.4*	*3.7*	0.0[a]	*2.7*	2.1
indeno[123-cd]pyrene	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]
benzo(ghi)perylene	0.0[a]	*0.1*	0.0[a]	0.0[a]	*0.5*	0.0[a]
coronene	0.0[a]	*0.7*	*6.2*	*1.2*	0.0[a]	0.0[a]
naphthalene	600.6	0.0[a]	631.4	0.0[a]	646.1	0.0[a]

[a] Correction with background data resulted in zero or negative value.

[b] Concentrations in italics are below the uncertainty level, as defined in Section 2.0

Acetaldehyde, also identified as a Toxic Air Contaminant by the ARB, was measurable in all six tests. The concentrations were 330 $\mu g/m^3$ during oven cleaning and 92 $\mu g/m^3$ during broiling of fish. The acetaldehyde concentrations were below 50 $\mu g/m^3$ in the pork tests. There are no residential guidelines for acetaldehyde, although the California Office of Environmental Health Hazard Assessment has adopted a chronic reference exposure level (REL) of 9 $\mu g/m^3$.

Propanal, butanal, pentanal, and hexanal were also measured in all six tests, but the concentrations were substantially lower than formaldehyde or acetaldehyde. The highest concentrations were measured during oven cleaning.

The elevated concentrations of aldehydes in the house due to cooking are consistent with other published reports. Felton (1995) reported that the main volatile compounds generated during frying were aldehydes, alcohols, ketones, alkanes, phenols, and acids. Schauer et al. (1998) also reported emissions of aldehydes from stir frying of vegetables and deep frying potatoes.

4.2 Impact of Appliance Type, Cooking Method, and Type of Food on Pollutant Concentrations

Tests were performed with a gas range, electric range, and microwave oven in order to evaluate the impact of the cooking appliance on indoor concentrations of the contaminants. As discussed in Section 4.1, seven cooking tests were performed with the gas range and the electric range using the same protocol. In addition, three tests were performed with the microwave oven. The microwave tests involved (1) baking the same type of frozen lasagna as used in the gas oven and electric oven tests, (2) preparing of bacon in the microwave for comparison to frying the bacon in a pan on the range top burner, and (3) microwaving popcorn. During tests with the microwave, PM mass was not collected on filters because of the short duration of the cooking period and low PM concentrations. For microwave tests, PM mass was estimated based on measurements with the ELPI.

A number of comparisons of the gas and electric range were presented in the previous section. The data are described further in this section. Data for $PM_{2.5}$ gravimetric measurements are depicted in Figure 4-39. As shown in the figure, the $PM_{2.5}$ mass concentrations in the kitchen were higher in four of the seven standard tests with the gas range. But, as discussed previously, due to the high variability in the PM measurements in replicate tests, the significance of these differences cannot be determined.

Estimated $PM_{2.5}$ mass concentrations from the ELPI measurements are depicted in Figure 4-40 to compare the gas and electric oven to the microwave oven. As discussed in Section 3, the estimated mass concentrations based on ELPI measurements were frequently, although not always, higher than the gravimetric measurements. However, the magnitude of the difference between ELPI and gravimetric measurements was not consistent; a correction factor for the ELPI mass measurements could not be derived for this data set. The ELPI data are most useful for identifying short-term changes in the PM concentrations. The mass measurements should not be compared to the gravimetric results. This is evident in Figures 4-39 and 4-40, which show that the gravimetric and ELPI mass measurements were in poor agreement during the gas oven self-cleaning, but in reasonably good agreement for the electric oven self-cleaning test.

Figure 4-39. $PM_{2.5}$ Mass in the Kitchen During Gas and Electric Tests

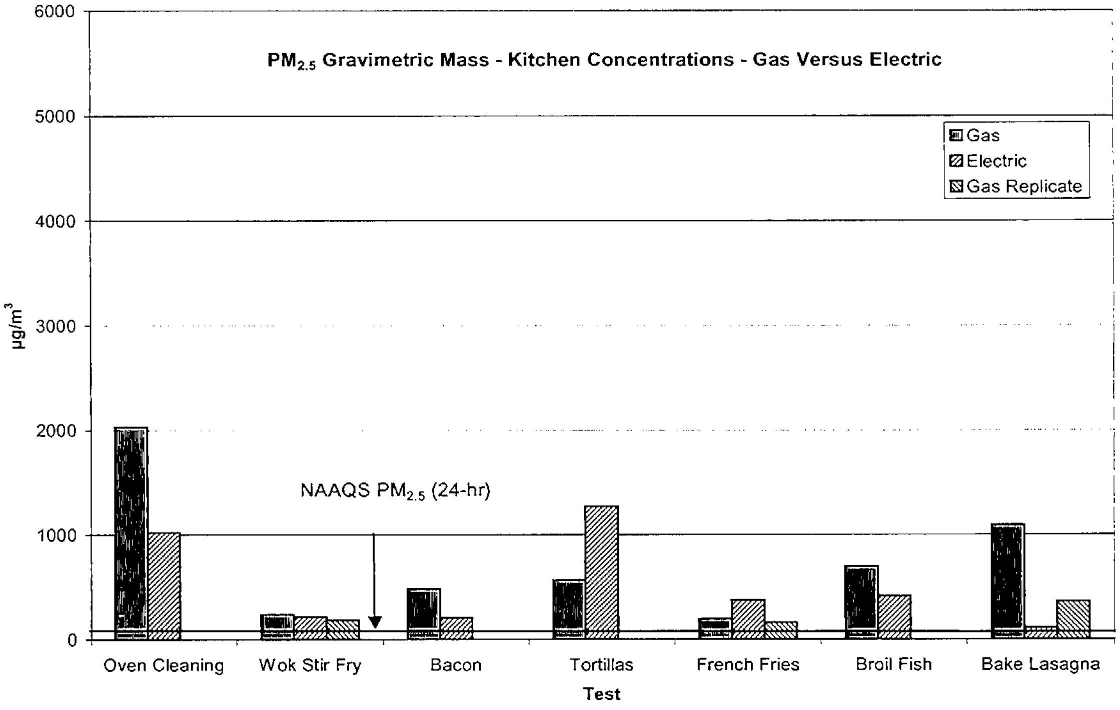
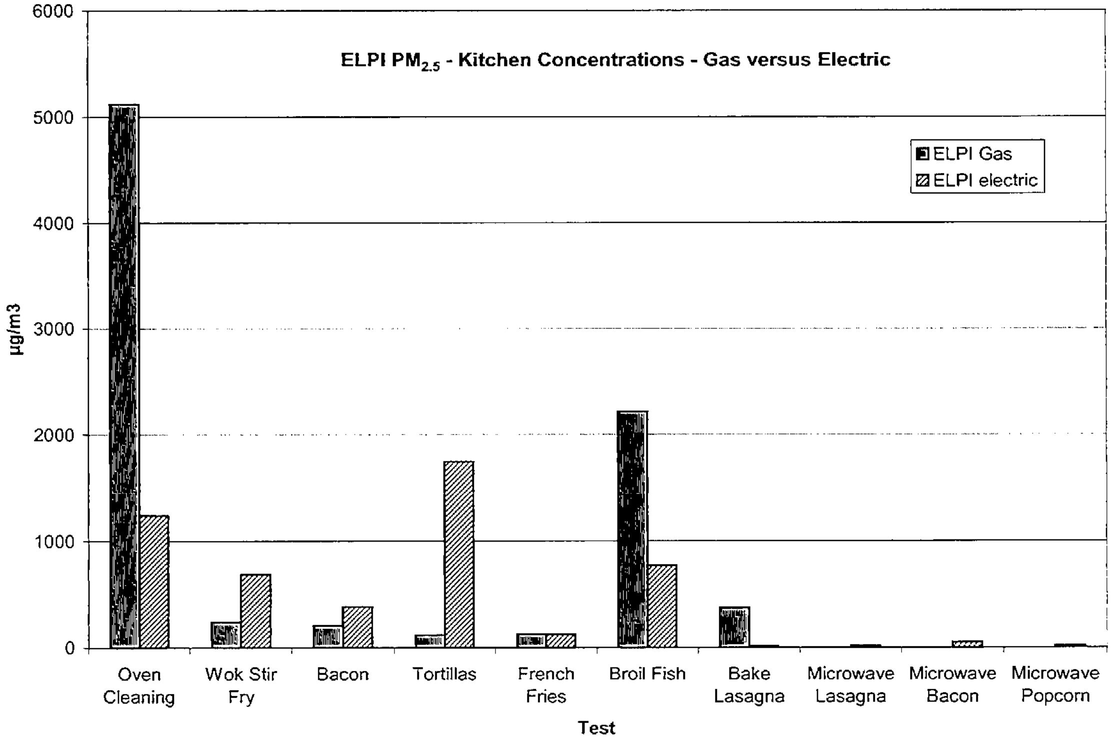


Figure 4-40. ELPI $PM_{2.5}$ Measurements in the Kitchen During Gas and Electric Tests



The data in Figure 4-40 clearly demonstrate the impact of use of the microwave on indoor air quality. During the three microwave tests, the $PM_{2.5}$ concentrations estimated by the ELPI were 17.4, 52.1, and 23.3 $\mu g/m^3$, for lasagna, bacon, and popcorn respectively. These concentrations were substantially lower than in the comparable tests with the gas and electric ranges.

Differences in PM_{10} mass concentrations during the gas and electric range tests were discussed in Section 4.1. The PM_{10} concentrations were higher with the gas range only for oven cleaning and cooking French fries. Due to the high variability in the replicate tests, it is difficult to assess significance of the differences between the gas and electric range tests.

Differences in the concentrations of the combustion pollutants during the six standard cooking tests (oven cleaning not included) are summarized in Table 4-11. As expected, the concentrations of CO, NO, and NO_2 were substantially higher during cooking with the gas range. The concentrations of the combustion pollutants during cooking with the electric range were generally close to the outdoor concentrations.

Table 4-11. Comparison of Average Concentrations of CO, NO, and NO_2 during the Six Standard Tests with Gas and Electric Ranges

	K		LR		MBR		OA	
CO (ppm)	**Gas**	**Electric**	**Gas**	**Electric**	**Gas**	**Electric**	**Gas**	**Electric**
Average	2.7	0.97	2.7	1.0	2.4	0.97	0.33	0.51
Std. Dev.	3.1	0.69	2.8	0.79	2.7	0.71	0.06	0.10
Median	1.8	0.67	2.0	0.81	1.6	0.76	0.32	0.51
NO (ppb)								
Average	98	7.4	110	10	91	6.4	7.8	7.3
Std. Dev.	98	4.5	97	6.5	98	4.4	5.7	4.8
Median	78	8.0	98	9.6	61	6.3	8.0	8.8
NO_2 (ppb)								
Average	64	27	70	31	54	26	19	26
Std. Dev.	35	6.0	36	6.7	26	6.3	8.8	6.5
Median	62	26	62	31	58	27	20	25

The impact of the type of cooking on concentrations of PM and the combustion pollutants has been described in detail in the previous discussions. In general, differences were seen between the tests with range burners and those with the oven. There were differences between methods involving frying in oil in a pan on the range top burner versus the pan and stovetop stir-frying; but there was not a clear trend in the differences that could be used to explain the differences, particularly due to the high variability in the emissions.

Similarly, the impact of the type of food on the emissions cannot be clearly discerned based on room air concentrations of the PM and combustion pollutants.

4.3 Impact of Cooking Utensil

During a subset of tests, cooking was performed with different pans and pan lids to determine the impact on emissions during cooking. Figure 4-41 depicts $PM_{2.5}$ and PM_{10} mass concentrations in the kitchen during tests to evaluate different pan materials, use of a pan lid, and operation of the range hood exhaust fan. To evaluate these variables, loose ground beef was fried in a pan on the gas range burner. A second set of tests to evaluate pan materials and the impact of the range hood exhaust fan were performed by cooking a pork roast in the gas oven. The results of those tests are depicted in Figure 4-42. For both cooking types, the standard tests were performed on the same gas range during the pre-test prior to the main study; but there was very high variability in the replicate tests, particularly for the $PM_{2.5}$. For both cooking types, the standard tests were performed on the same gas range during the pre-test prior to the main study; but there was very high variability in the replicate tests, particularly for the $PM_{2.5}$. As discussed previously, there was high variability in both the PM measurement with the PEMs and between replicate tests with the same cooking method. As a result of the high variability, there were cases where the reported $PM_{2.5}$ concentrations were higher than the PM_{10} concentrations. Comparison of results from the different tests, therefore, is difficult.

As shown in Figures 4-41 and 4-42, there is no clear indication that the pan material or use of the pan lid has a significant effect on PM concentrations. Although the PM concentrations are depicted only for the kitchen, concentrations in the other rooms were not substantially different due to different pan materials or use of the lid (Tables 3-4 and 3-5).

Element concentrations were measured in the PM_{10} samples collected during the two tests with the cast iron skillet and the test with the Teflon® skillet with the pan lid. The concentrations of metals, including iron, nickel, copper, and chromium were not elevated in the tests with the cast iron pan compared to the Teflon® coated stainless steel skillet. There were some differences in the metals concentrations between the tests, but they were generally no greater than the differences between the replicate tests with the cast iron skillet.

4.4 Exposure Reduction Methods

The impact of simple exposure reduction methods was evaluated during the study. As discussed above, the use of the microwave had a significant impact on reducing exposure to particles and combustion pollutants. An easily implemented exposure reduction method is the use of range hood exhaust fans. For improved capture efficiency, range hoods can be configured with side shields from the range top to the range hood. These shields can be easily configured. The Test House was equipped with a standard inexpensive single speed exhaust hood fan that vented through the roof of the house. The airflow rate through the hood was measured at 218 cubic feet per minute ($6.17 \text{ m}^3/\text{min} = 370 \text{ m}^3/\text{hr}$). The impact of the range exhaust hood on indoor air concentrations of the pollutants emitted during cooking was evaluated during frying of loose ground beef in a pan on the range top burner and cooking a pork roast in the gas oven.

The results are depicted in Figures 4-43 and 4-44. The figures show the results for tests with the range exhaust and the exhaust configured with range hood shields.

Figure 4-41. Impact of Exposure Reduction Methods During Frying of Ground Beef

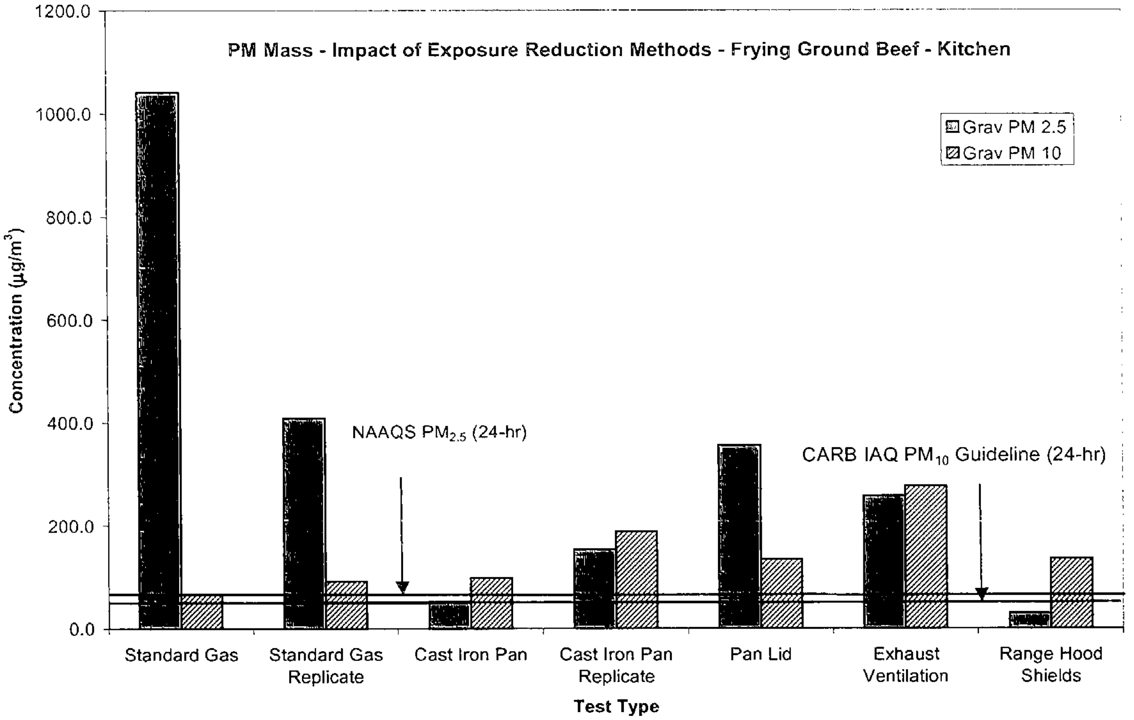


Figure 4-42. Impact of Exposure Reduction Methods During Cooking Pork Roast in Oven

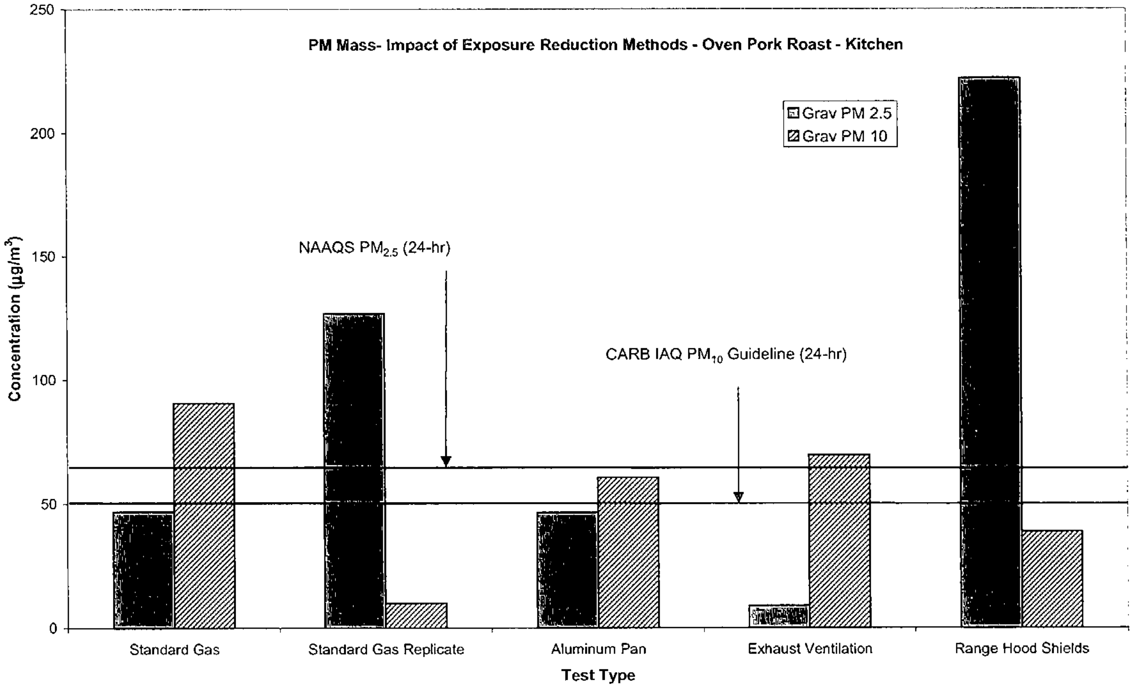


Figure 4-43. Impact of Range Hood Exhaust on $PM_{2.5}$ Concentrations

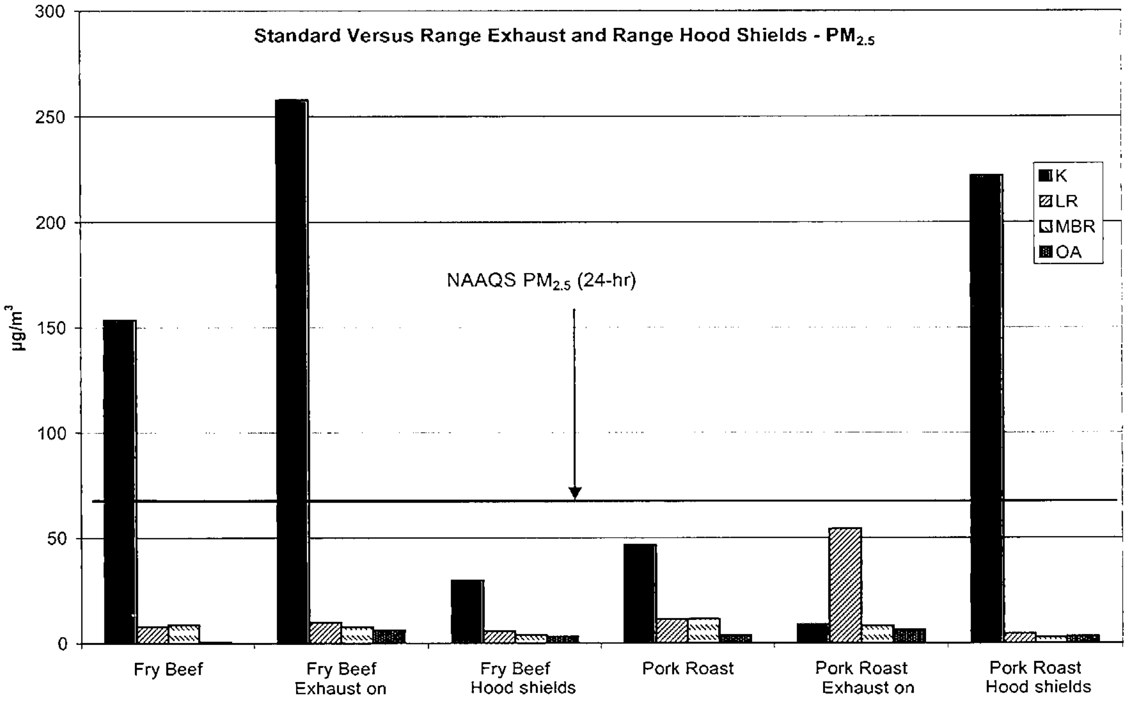
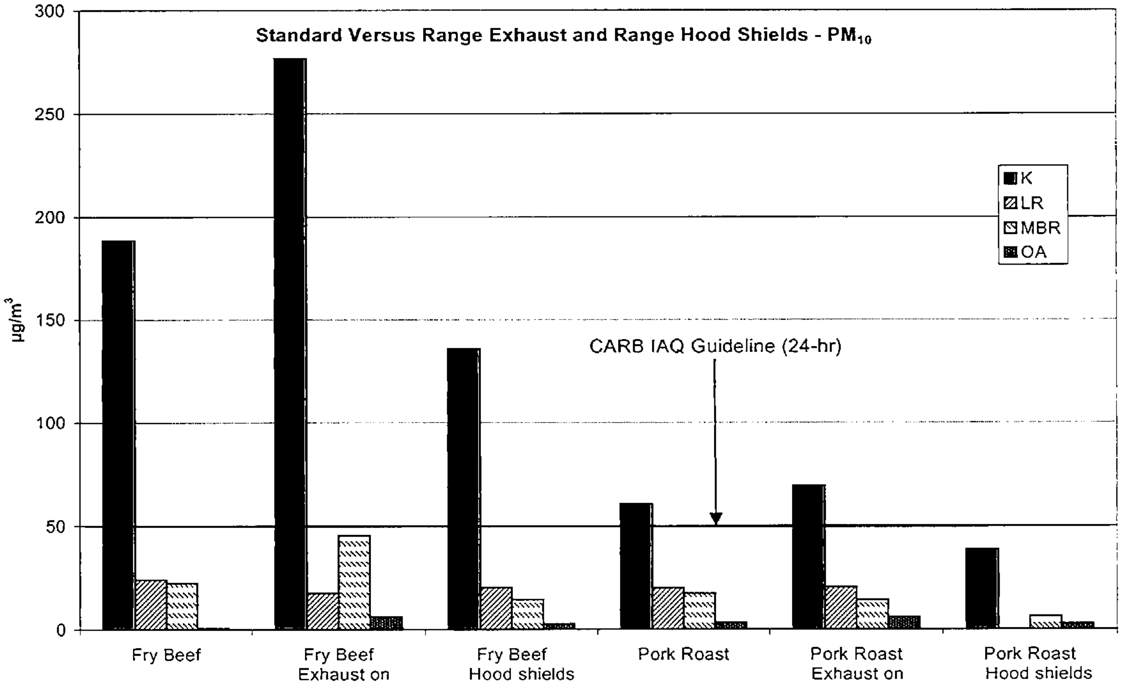


Figure 4-44. Impact of Range Hood Exhaust on PM_{10} Concentrations



Operation of the exhaust hood increased the air exchange rates in the house. Whole house air exchange rates, listed previously in Table 3-25, were in a range from 0.2 to 0.3 hr^{-1} during tests with the house closed and fans off. The following rates were measured during the tests with the exhaust hood operation:

- Test 26 – Ground beef fried on range top and exhaust hood operated = 0.58 hr^{-1}
- Test 28 – Ground beef fried on range top and exhaust hood operated with range hood shields = 0.53 hr^{-1}
- Test 27 – Pork roast in oven and exhaust hood operated = 1.07 hr^{-1}
- Test 29 – Pork roast in oven and exhaust hood operated with range hood shields = 0.78 hr^{-1}
- Test 19 – Fish broiled in oven with no exhaust fan operation, but window in MBR open = 0.98 hr^{-1}

The use of the exhaust fan without range hood shields during frying ground beef on the range top did not appear to impact concentrations of $PM_{2.5}$ in the kitchen, based on the gravimetric measurements (Figure 4-43). The concentration of $PM_{2.5}$ in the LR and MBR were similar, regardless of whether the fan was used or not. However, the fan operated with the range hood shields did have an impact, resulting in lower $PM_{2.5}$ concentrations in all rooms. Measurements with the ELPI during the three tests showed lower concentrations of $PM_{2.5}$ during use of the range fan only and the range fan with range hood side shields. During operation of the range hood fan, the average concentration during the test was 40% of that without fan operation. When the fan was operated with the range hood side shields, the average $PM_{2.5}$ concentration was 34% of that without the fan.

During the tests for frying ground beef on the range top, the PM_{10} concentrations were also lower when the fan was operated with side shields. Operation of the range fan only did not show a reduction in PM_{10} concentration. As discussed previously, the ELPI could not be used to estimate PM_{10} concentrations due to the low number of particles in the large fractions. The impact of the range hood fan and range hood side shields, therefore, could not be verified with ELPI measurements. The apparently poor performance of the exhaust fan only may have been related to the fact that the front burner was used, and due to the presence of the cook at the front of the range. Both factors may reduce capture efficiency. Use of the range hood shields appeared to improve capture efficiency.

During use of the oven for the pork roast, there appeared to be little impact of the use of the exhaust fan only on $PM_{2.5}$ or PM_{10} concentrations in the three rooms, based on the gravimetric measurements of PM. However, use of the range hood shields resulted in lower $PM_{2.5}$ concentrations in the LR and MBR. The high $PM_{2.5}$ concentration measured by the gravimetric method during the test with the range hood shields appears to be an outlier because the concentration was so much higher than the PM_{10} concentration. This was confirmed by the estimated $PM_{2.5}$ based on the ELPI measurements, which showed a large reduction in $PM_{2.5}$ in the kitchens due to operation of the exhaust fan with and without range hood side shields. Based on the ELPI measurements in the size fractions less than 2.5 µm, the average concentration was 33.5 $\mu g/m^3$ during the test without exhaust fan operation (Test No. 25), 3.2 $\mu g/m^3$ during the test with the exhaust fan only (Test No. 27), and 5.8 $\mu g/m^3$ during Test No. 29 when the exhaust fan was operated with range hood side shields. For the PM_{10} size fraction there appeared to be little impact if the range hood exhaust fan was operated without side shields. With range hood side shields, there was a reduction in PM_{10} concentrations in the three rooms.

The impact of the exposure reduction methods on concentrations of combustion pollutants is summarized in Table 4-12. The results, like those for PM, were inconclusive. During the tests involving frying of ground beef on the range-top burner, there was no clear impact on CO because the concentrations were near the detection limit. There was a reduction of NO in the tests with operation of the exhaust fan with and without the range hood side shields, but there was no apparent impact of the range hood exhaust fan on NO_2 when only the exhaust fan was operated. However, the outdoor NO_2 concentration on the day of the test with the range hood exhaust fan was 22.3 ppb compared to 12.5 ppb on the day without exhaust fan operation. Similarly, the apparently large impact of the exhaust fan operated with range hood side shields in place was partially due to the fact that the outdoor concentration averaged 0.9 ppb during the test. For this series of tests, the outdoor concentrations of NO_2 had a major impact on the test results.

During the use of the oven for cooking the pork roast under standard conditions without the exhaust fan (Test No. 25), the data for CO, NO, and NO_2 were lost due to a malfunction of the data acquisition system. If data from the pre-test are used for comparison to the tests in the main study with the exhaust fan, there appears to be a substantial effect of the exhaust fan on the pollutant concentrations when operated either with, or without the range hood side shields. For this series of tests, the outdoor NO_2 concentrations were similar during the three tests.

The study design was too limited in scope to adequately address the impact of the simple exposure reduction methods on indoor air concentrations and exposures to emissions from cooking. A larger number of tests, with more replication, would be required.

Table 4-12. Impact of Exposure Reduction Methods on Average Combustion Pollutant Concentrations in the Kitchen during the Cooking Period

Pollutant	Type of Test	Ground Beef	Pork Roast	Broil Fish
CO (ppm)	Standard	0.9	3.8[a]	3.2 (2.6)[b]
	Exhaust Hood	0.9	1.2	--[c]
	Range Hood Shields	0.4	1.0	--
	MBR Window Open	-[d]	-	3.3 (2.4)
NO (ppb)	Standard	90.5	148[a]	4.9 (0.9)
	Exhaust Hood	49.3	80.1	--
	Range Hood Shields	19.8	68.6	--
	MBR Window Open	-	-	33.5 (31.0)
NO_2 (ppb)	Standard	17.9	107[a]	94.1 (78.4)
	Exhaust Hood	27.2	17.5	--
	Range Hood Shields	1.6	18.3	--
	MBR Window Open	-	-	92.7 (46.0)

[a] Concentrations measured in Pre-Test; data in Test No. 25 lost due to data acquisition system problem
[b] Concentrations in parentheses are in the MBR
[c] Range hood not operated during these tests
[d] Window opening applies only to one broiling fish test

4.5 Emission Rates

The emission rates for PM and the combustion pollutants were calculated for each test and presented in the tables in Section 3. Emission rates were also calculated for PAHs and elements, although the number of samples with measurable concentrations was low, and samples were collected at only one location in the house (kitchen). Calculations were made using room air concentrations, the outdoor concentrations, and the air exchange rates measured during the tests. The following discussion summarizes the calculated emission rates.

4.5.1 PM Mass Emissions

The emission rates for PM mass were calculated using a dynamic mass balance model, as described in Section 2.0. The house volume of 187.2 m^3 was used for the mass measurements made in the kitchen. A penetration factor of 1.0 was used for both $PM_{2.5}$ and PM_{10}. The deposition velocity was estimated for $PM_{2.5}$ using the SF_6 decay rate during air exchange rate measurements and the concentration data from ELPI measurements during the one-hour post exposure period. The deposition velocity calculated for 14 standard tests was $0.31 \pm 0.12\ hr^{-1}$. The deposition velocity of 0.31 hr^{-1} for $PM_{2.5}$ was in reasonable agreement with the value of 0.39 hr^{-1} reported for the PTEAM study (Wallace, 1996). It should be recognized that this deposition may be low because it was estimated based on measurements with the ELPI, which was located in the kitchen with the source. The deposition velocity may have been higher had the measurements with the ELPI been performed further away from the source. This may be especially true for the emissions from cooking, which are primarily grease droplets. The deposition velocity for PM_{10} could not be estimated with the ELPI data. There were too few particles in the three largest size fractions for reliable measurements with the ELPI. Therefore, the deposition velocity of 1.01 hr^{-1} reported for PTEAM (Wallace, 1996) was used for PM_{10}.

The emission rates for $PM_{2.5}$ and PM_{10} were presented in Tables 3-31 and 3-32. Summary statistics are presented in Tables 4-13 and 4-14 to compare emission rates for the six standard tests with gas versus the same six tests with the electric range. The oven cleaning tests are not included in this analysis. The emission rates for $PM_{2.5}$ ranged from 65.9 to 318.2 mg/hr for the six standard gas range cooking tests and 25.5 to 617.8 mg/hr for the electric tests. Both the average and median emission rates were similar during the electric tests than in the gas tests. The source strengths (μg $PM_{2.5}$ per g of food, which is equivalent to mg/kg) were more similar than the emission rates, with average source strength of 172.1 μg/g for the six gas tests and 100.6 μg/g for the electric tests. Source strengths for the six standard cooking tests are depicted in Figure 4-45. The source strengths for $PM_{2.5}$ in these six tests differed the most between the gas and electric range for the tests with frying of tortillas and baking the lasagna in the oven. When normalized to energy use during the cooking tests, the average emission factors for the six tests were higher for the tests with the electric range.

The emission rates for PM_{10} during the six standard tests also differed substantially for the gas and electric tests (Table 4-10). The emission rates ranged from 135.6 to 1362 mg/hr with the electric range compared to 70.7 to 318 for the gas range during the six tests, the average and median rates being higher for the electric tests. As depicted in Figure 4-46, the PM_{10} source

Figure 4-45. $PM_{2.5}$ Source Strengths (mg/kg food)

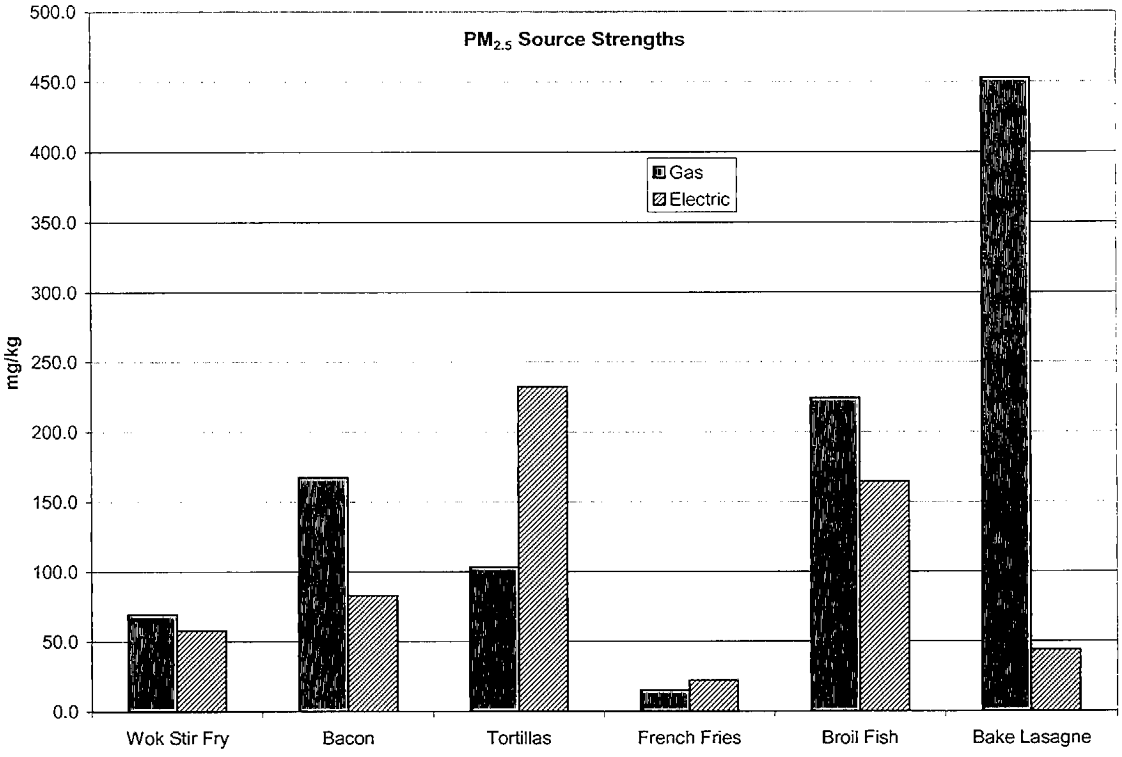
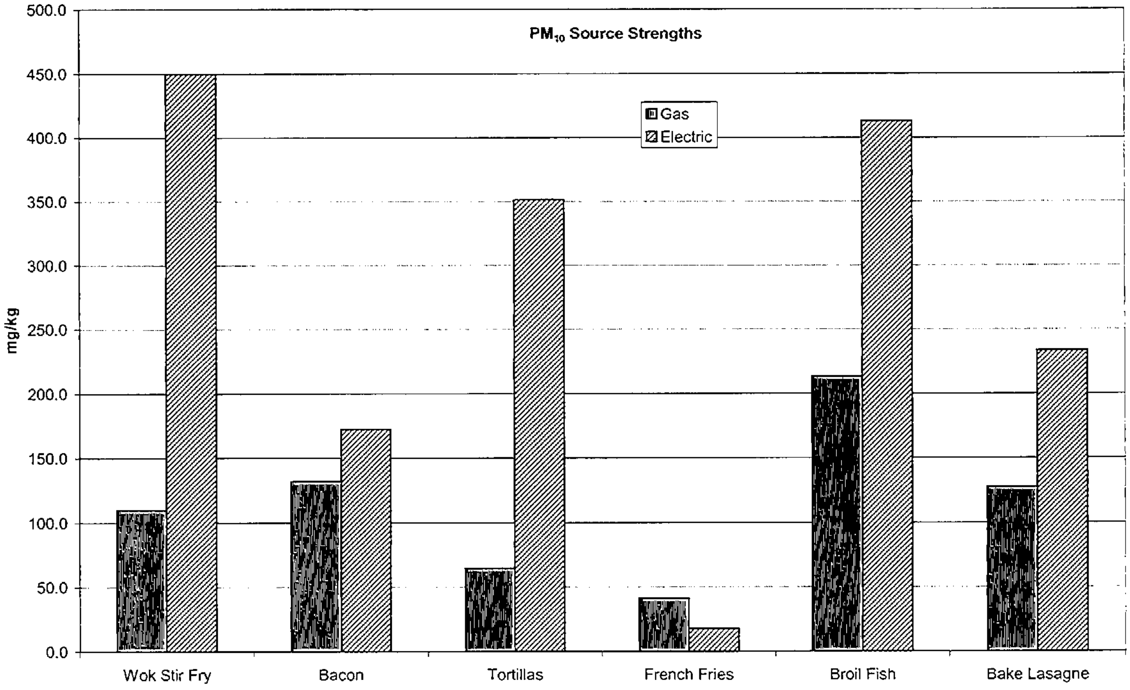


Figure 4-46. PM_{10} Source Strengths (mg/kg food)



strengths were higher in five tests with the electric range, similar for French fries, and higher for the gas oven tests.

For both $PM_{2.5}$ and PM_{10}, the source strengths were higher for the gas range in the two tests that involved cooking with the oven.

Emission rates during replicate tests were discussed previously in Section 4.1.1.2 and summarized in Table 4-1. For the best case, the replicate test with French fries, the relative difference in the source strength was 15% for $PM_{2.5}$ and 44% for PM_{10}. For the worst case replicate test, baking lasagna in the gas oven, the relative differences between the replicate tests were 66% for $PM_{2.5}$ and 47% for PM_{10}. The differences were similar when emission rates were normalized to the energy use (µg/BTU) with relative differences of 29% and 53% for $PM_{2.5}$ and PM_{10}, respectively. The emission rate measurements, like the room air concentration measurements discussed in Section 4.1, showed that there was high variability in the emissions during cooking, even with replicate tests using the same food item and cooking method.

There are few published data available for comparison of emission rates and source strengths. Rogge et al. (1997) reported source strengths measured during tests in an environmental test chamber ranging from approximately 50 to 1500 mg/kg for cooking tests with gas and electric ranges. Although the paper did not list the values, the figure included in the paper showed emissions of approximately 100 mg/kg, over an order of magnitude higher than the emissions measured in this study for the French fries test. His results for pan-frying meats averaged approximately 300 mg/kg, again an order of magnitude higher than the rates calculated for frying bacon in this study. Error bars on his chart showed that the emissions varied substantially. In the case of pan-frying meats, the results were approximately 300 ± 100 mg/kg.

The emissions reported by Rogge et al. (1997) for PM_{10} ranged from approximately 100 mg/kg for French fries to nearly 2,500 mg/kg for pan-frying fish. The emissions measured in this study were substantially less. The maximum PM_{10} emissions during cooking in this study were 108.3 mg/kg for the worst case broiling fish test.

Table 4-13. Calculated Emission Rates for $PM_{2.5}$ Mass (Gravimetric Samples)

	Emission Rate	Source Strength	Food-specific Emission Factor	Power-specific Emission Factor
	mg/hr	μg/g food	μg/g/hr	μg/BTU
Gas Tests (2- 7)				
Minimum	65.9	15.3	13.5	8.5
Maximum	318.2	452.8	305.9	51.8
Average	220.5	172.1	185.0	33.0
Std. Dev.	84.8	155.8	100.3	14.9
Median	242.1	135.2	207.1	36.1
Electric Tests (9 – 14)				
Minimum	25.5	22.4	21.8	7.8
Maximum	617.8	232.4	324.3	80.7
Average	232.6	100.6	156.0	35.3
Std. Dev.	208.2	81.1	121.8	26.7
Median	201.8	70.3	131.3	24.8

Table 4-14. Calculated Emission Rates for PM_{10} Mass (Gravimetric Samples)

	Emission Rate	Source Strength	Food-specific Emission Factor	Power-specific Emission Factor
	mg/hr	μg/g food	μg/g/hr	μg/BTU
Gas Tests (2- 7)				
Minimum	70.7	41.2	36.3	14.6
Maximum	318.3	213.2	313.6	39.8
Average	201.8	114.7	162.7	27.5
Std. Dev.	93.4	60.1	120.0	8.6
Median	180.4	118.6	137.5	28.0
Electric Tests (9 – 14)				
Minimum	135.6	17.6	42.4	19.6
Maximum	1361.8	449.7	1284.7	161.3
Average	565.4	272.9	470.6	86.1
Std. Dev.	496.4	163.6	467.2	53.9
Median	390.4	292.6	346.4	86.4

Emission rates during cooking with commercial institutional scale deep fryers have been reported by Schauer et al. (1998) for an ARB project. In that project, professional chefs prepared vegetables by stir frying in soybean or canola oil and deep fat fried potatoes in oil. Fine particle emission rates were 21.5 ± 1.2, 29.5 ± 1.3, and 13.1 ± 1.2 mg/kg for vegetables cooked in the two oils and deep fat frying of potatoes, respectively. These emission rates are within the range of rates measured in this study. However, emissions during food preparation by a professional chef using large commercial cookers may differ substantially from emissions in a residence.

Gerstler et al. (1998) also measured emissions from commercial cooking appliances. They measure PM emissions from institutional size griddles, fryers, broilers, ovens, and ranges. As an example of their results, they reported $PM_{2.5}$ and PM_{10} source strengths of less than 0.5 g/kg during tests with the gas oven. The emissions during cooking with the gas range top burners were even lower.

At the present time, there is little data on cooking emission rates for comparison to the results of this study. Although the emission rates measured in this study appear to be much lower than those measured by Rogge et al. (1997) in chamber tests, the comparison is made based only on data presented in a single technical paper. The complete database is not available. There may be many reasons to explain the lower emissions measured during this study compared to the data published by Rogge et al. The foods and cooking methods undoubtedly differed. Because the final report for the work by Rogge et al. was not available at the time this report was prepared, we do not know how the cooking protocols and test methods differed. We also do not have details on the foods cooked in those tests.

4.5.2 Gaseous Combustion Pollutant Emission Rates (CO, NO, NO_2)

Emission rates were calculated for CO, NO, and NO_2 using data collected with the real-time monitor that cycled through the K, LR, MBR, and outdoor sampling locations. CO, NO, and NO_2 emission rates were calculated with the mass balance model described in Section 2. A penetration factor of 1.0 and decay rate of 0.0 hr^{-1} were used for CO and NO calculations. A penetration factor of 1.0 and decay rate of 0.8 hr^{-1} were used for the NO_2 calculations. The decay rate was the same as recommended in the model developed by ARB for assessing indoor exposure to air pollutants (Koontz et al. 1998). The value is consistent with the value of 0.77 hr^{-1} that Traynor (1999) found in the review of data from six studies.

The CO emission rates, presented in Table 3-28, can be summarized as follows:

- Emission rates ranged from 25.7 mg/hr during frying of bacon on the electric range top burner to 10405 mg/hr during the test broiling fish in the gas oven
- The average emission rate for the gas range tests was 1293 ± 1930 mg/hr, with the oven self-cleaning test excluded
- The average source strength, normalized to the mass of food cooked, ranged from 34.5 to 20205 µg/g/hr, with an average of 398 ± 718 µg/g/hr
- Normalized to the energy used for cooking, the emissions averaged 159.6 ± 187.3 µg/BTU

- The CO emission rate averaged 78.3 µg/BTU during operation of the oven without cooking of food
- The CO emission rate averaged 153.3 µg/BTU during operation of the range top burner with only a pan of water
- The CO emission rate averaged 143.1 µg/BTU during cleaning the gas oven and averaged 137.8 µg/BTU for the electric oven

The emission rates for CO, based on the weight of food cooked, are depicted in Figure 4-47. As expected, the source strengths were related to the use of the gas range, with the emissions higher in five of the six standard cooking tests with the gas range. CO emissions with the electric range were highest when the oven was used to broil fish, but the emissions were still substantially less than when fish were broiled in the gas oven. Rogge et al. (1997) reported CO emissions as high as approximately 3500 mg/kg of food during broiling meats. Their emissions were nearly an order of magnitude higher than measured in this study. The CO measurements during oven cleaning reflect the cooking of food residues deposited on the oven lining. The level during the gas oven cleaning was over three times the background measurements taken for an empty, clean oven, and the electric oven measurements reflect only residue burning due to the absence of a flame.

NO emission rates, presented in Table 3-29, ranged from 8.2 to 132.6 mg/hr during gas range tests with an average for 31 test periods of 89.4 ± 59.5 mg/hr. The emissions ranged from 3.1 to 152.9 mg/kg of food and averaged 47.1 ± 37.1 mg/kg. Normalized to gas use, the emissions averaged 13.7 ± 8.2 µg/BTU. For the six standard tests, the highest emissions of NO were measured during French fries on the gas range. As expected the emissions during cooking with the electric range were insignificant compared to the gas range. The emissions measured in this study were lower than those reported by Rogge et al. (1997). They reported NO emissions of up to approximately 150 mg/kg during cooking French fries.

The NO_2 emission rates, presented in Table 3-30, can be summarized as follows:

- Emissions ranged from 6.2 to 167.8 mg/hr and averaged 54.6 ± 41.7 mg/hr in 31 test periods during which the gas range was used for cooking, excluding oven cleaning.
- During oven cleaning, the NO_2 emission rate was 137.4 mg/hr.
- Emissions averaged 7.6 ± 3.6 µg/BTU during the 31 cooking periods with the gas range.
- The highest emissions rate occurred during oven cleaning, broiling fish in the oven, stovetop-stir fry, and baking the lasagna in the oven. This was consistent with the higher emissions rate measured during background tests with the oven.
- Baseline emission rates without food cooking were 5.8 µg/Btu from the range top burner and 7.8 µg/BTU from the oven.

Rogge et al. reported NO_2 emissions of up to approximately 180 mg/kg for broiling meats. During this study, the highest emission of NO_2 was 166.3 mg/kg during the worst case broiling fish test. But the NO_2 emission rates, as depicted in Figure 4-48, appear to be closer to the values reported by Rogge et al. than either NO or CO. Differences between the Rogge et al. results and results in this study may be due to the cooking protocols, differences in the gas ranges, or other factors.

Figure 4-47. CO Source Strengths (mg/kg food)

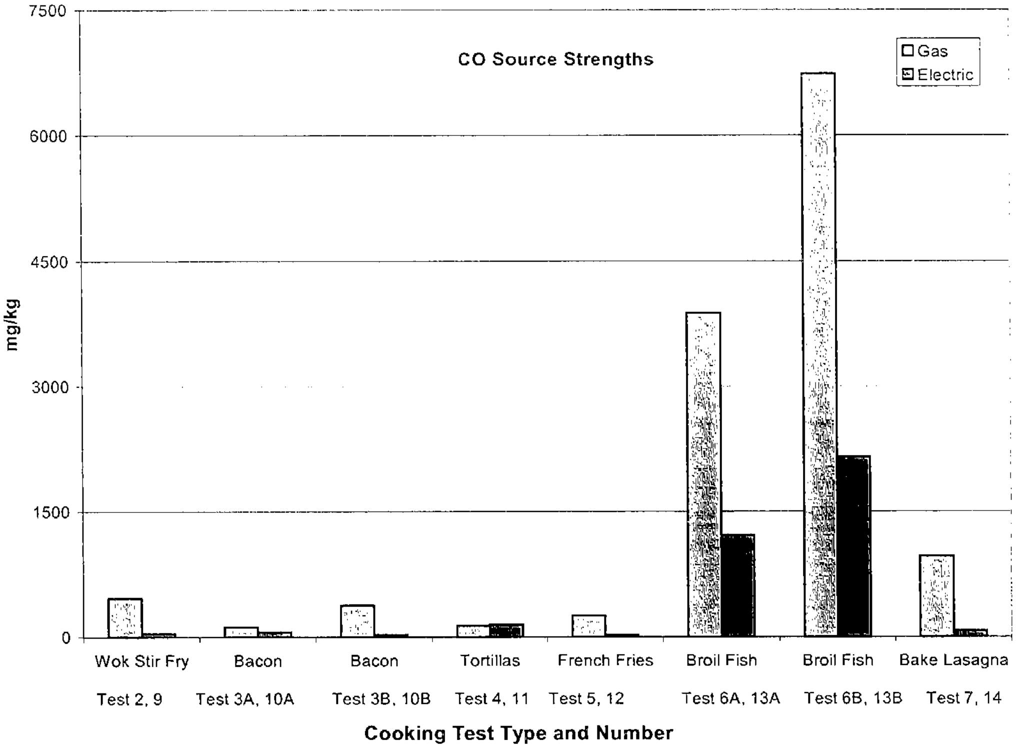
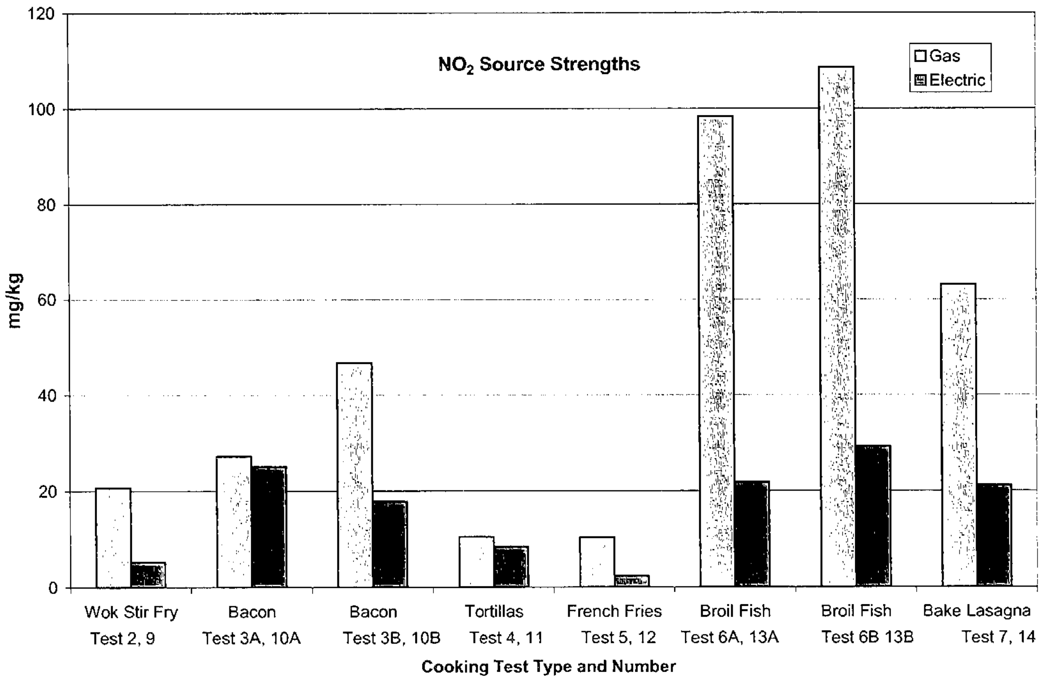


Figure 4-48. NO_2 Source Strengths (mg/kg food)



4.5.3 PM Emission Rates Measured with the ELPI

Emission rates were calculated for particle concentrations and particle mass based on the ELPI measurements for different size fractions. The results were presented in Tables 3-33 and 3-34. The emission rates for particles ranged from less than one million/hr to 650 million particles/hr. The highest emission rate was measured during the worst case test with broiling fish, consistent with the emission rate calculated based on gravimetric $PM_{2.5}$ measurements. The average emission rate was 124 ± 137 million/hr. The results showed that most of the particles were in the less than 0.5 µm size fraction for practically all tests. Although these data are not discussed in detail in this report, they may be useful for comparing emission rates of the different size fractions for the different cooking methods.

Mass emission rates were also calculated using the ELPI measurement data. The results, presented in Table 3-34 should be considered qualitative because the relationship between the mass estimates with the ELPI and the actual concentrations could not be determined from the gravimetric measurements. As shown in the table, the estimated concentrations for PM_{10} are often unrealistic when compared to the gravimetric PM mass data. The ELPI generally over predicts the PM_{10} mass concentrations. There were few particles in the large size fractions during these tests, which would result in poor counting statistics and inaccurate mass estimates. For the smaller size fractions, the average estimated PM mass concentrations were 1.7, 28.1, 49.1, and 59.5 $\mu g/m^3$ for the 0.1, 0.5, 1.0, and 2.5 µm size fractions, respectively. The ELPI data suggest that most of the mass is in the less than 1.0 µm size fraction.

4.5.4 Aldehyde Emission Rates

Aldehydes were measured during six tests to obtain preliminary data on the impact of cooking on aldehyde exposures in the home. The samples were collected only in the kitchen. The emission rates, therefore, were calculated using the single measurement to represent the concentration in all rooms of the house. Due to the lack of data, the penetration rate was assumed to be 1.0 hr^{-1}, and a deposition rate of 0.0 hr^{-1} was used in the mass balance model. The estimated emission rates were presented in Table 3-35.

Formaldehyde and acetaldehyde emission rates are highlighted in Table 4-15. The highest emissions occurred during fish broiling. The self-cleaning oven rates with the gas range were about twice those for the self-cleaning of the electric oven. During the tests of broiling fish, the emissions were not substantially different for the tests with the gas and electric range. The estimated emission rates for the other test with the oven, cooking a pork roast, were similar to the emissions during the other cooking tests. During Test 25, the acetaldehyde concentration in the outdoor air sample was higher than indoors, resulting in the negative rate calculated with the mass balance model. These data are entered as flagged zeros.

Emission rates have not been reported previously for cooking in residences. In a previous ARB project to measure emissions during commercial cooking operations, Schauer et al. (1998) reported emissions of 20,100 µg of formaldehyde per g of food during stir frying of vegetables in an institutional size cooker. They reported emissions of 12,400 µg/g of formaldehyde and 20,900 µg/g of acetaldehyde during deep fat frying of potatoes. These rate over three orders of magnitude higher than measured in this study. But the commercial cooking method and the residential method emissions may be substantially different. The number of tests and number of samples collected in this study for aldehydes was too limited to draw conclusions about the emission rates. The data, however, show that impact of cooking on exposure to aldehydes should be addressed in future exposure studies.

Table 4-15. Formaldehyde and Acetaldehyde Emission Rates

Test No.	Type	Range	Conditions	Emission Rate	Source Strength (per gram of food)	Food-specific Emission Factor	Power-specific Emission Factor
				mg/hr	μg/g	μg/g/hr	μg/BTU
1	Oven Cleaning	Gas	Formaldehyde	49.8	N/A	N/A	9.4
			Acetaldehyde	52.1	N/A	N/A	9.9
8	Oven Cleaning	Electric	Formaldehyde	26.6	N/A	N/A	3.7
			Acetaldehyde	39.3	N/A	N/A	5.5
6	Broil Fish	Gas	Formaldehyde	48.0	33.9	46.2	4.9
			Acetaldehyde	34.7	24.5	33.4	3.5
13	Broil Fish	Electric	Formaldehyde	59.5	42.7	71.2	6.4
			Acetaldehyde	50.0	35.9	59.9	5.4
25	Pork Roast	Gas	Formaldehyde	6.9	10.8	3.6	2.0
			Acetaldehyde	0.0[a]	N/A	N/A	N/A
27	Pork Roast	Gas	Formaldehyde	10.5	16.1	5.3	2.9
			Acetaldehyde	3.9	6.0	2.0	1.1

[a]- Correction with background data resulted in zero or negative value.

4.5.5 Element Emission Rates

Emission rates were estimated for the elements measured in PM_{10} samples collected in a subset of tests. The rates are based on the concentration measured in the kitchen, which had to be used to represent the concentration within the whole house volume. A penetration rate of 1.0 hr^{-1} was assumed. The deposition rate used for PM_{10} of 1.01 hr^{-1} was used in the mass balance model. Results were presented in Table 3-37. Because of the low number of samples with measurable concentrations, there is a high level of uncertainty associated with the emissions estimates. Consistent with the indoor air concentration data, the emission rates were highest during the oven cleaning tests. Emission rates were highest for silicon, phosphorous, chlorine, bromine, and potassium. The emissions were generally low for the heavy metals. Copper emissions were elevated, but they were an artifact because the source was most likely the sampling pumps and motors in the house.

4.5.6 PAH Emission Rates

The emission rates estimated for the PAHs were presented in Table 3-36. With the exception of naphthalene, elements measured in PM_{10} samples were collected in a subset of tests. The rates are based on the concentration measured in the kitchen, which had to be used to represent the concentration within the whole house volume. A penetration rate of 1.0 hr^{-1} was assumed. The deposition rate used for PM_{10} of 1.01 hr^{-1} was used in the mass balance model.

Emission rates listed as zero in the table mean that the compound was not detected in the sample. PAH emission rates were less than 19.9 µg/hr for all compounds except naphthalene. In most cases, the emission rate was zero or negative. Naphthalene source strengths ranged from zero during the French fries test to 302.1 ηg/g during the broiling fish test.

Although the emission rates estimated from the samples collected in this study were low, the presence of PAHs in the cooking oils and the concentrations measured indoors during the tests suggest that additional measurements are warranted to more fully evaluate the impact of cooking on exposure to PAHs.

5.0 SUMMARY AND CONCLUSIONS

This study was performed to collect data to gain a better understanding of the impact of cooking on indoor air concentrations and personal exposures to air contaminants generated by cooking in residences. The objectives of the study were to:

- Characterize indoor air concentrations and emission rates and resultant indoor air concentrations and personal exposures for particulate matter (PM), carbon monoxide (CO), nitric oxide (NO), and nitrogen dioxide (NO_2) produced by residential cooking under typical and realistic worst-case conditions.
- Characterize indoor air concentrations and emission rates and resultant indoor air concentrations for other cooking pollutants such as PAHs, elements, and other potential marker compounds.
- Measure the effectiveness of selected exposure reduction practices.

The study reported here represents the first large-scale study of cooking emissions and the resultant exposures in a residential setting under semi-controlled conditions. The study included thirty-two cooking tests with a variety of cooking methods and foods. It addressed various factors that may impact emissions from cooking and evaluated simple exposure reduction methods.

To meet the study objectives, a test house was rented in Rohnert Park, California. The house was a small single-story ranch style home constructed in the 1970s. The small size of the house (less than 1000 ft^2) and the layout of the rooms, consisting of a kitchen, adjacent living room, and three bedrooms, resulted in good mixing in the house even though the house air handler was not operated during testing. The house had an attached garage where a laboratory was set up. The test house was instrumented with temperature and relative humidity sensors in the rooms and outdoors. Temperature sensors, a power transducer, and a dry gas meter were installed to collect data during cooking tests. Teflon® sampling lines were routed to the kitchen (K), living room (LR), master bedroom (MBR), and outdoors (OA) for collection of air contaminants. A second set of sampling lines was routed to the same rooms for collection of SF_6, the tracer gas measured to calculate air exchange rates. A laboratory was set up in the garage with pollutant monitoring instrumentation, a data acquisition system, and support hardware for instrument calibrations.

Following a pre-test and refinement of the study design and test protocols, a main study was performed that consisted of 32 cooking tests at the test house. The tests involved cooking with an electric range, gas range, and microwave oven. The microwave was used in three tests to compare emissions with the gas and electric ranges. The electric range was used for seven cooking tests. These same seven cooking activities were performed with the gas range for comparison. All other tests were performed with the gas range. Parameters measured during all tests included the following:

- CO, NO, and NO_2 with continuous pollutant monitors
- PM concentrations and size distributions (12 size fractions from 0.04 to 8.4 μm, aerodynamic mean diameter) with an electrical low pressure impactor (ELPI) that recorded data continuously

- $PM_{2.5}$ and PM_{10} mass, collected on Teflon® filters with size selective inlets
- Air exchange rates
- Temperature and relative humidity (RH) indoors and outdoors
- Range top burner and oven temperatures
- Gas or electric use during cooking

During selected tests, additional samples were collected for other air contaminants. These included samples for PAHs, elements, and aldehydes.

The 32 tests were designed to collect information on the following factors:

- Appliance type (gas, electric, and microwave)
- Cooking method (frying, baking, broiling, range-top burner, oven)
- Food type (variety of foods cooked)
- Cooking vessel (pan material, lids)
- Exposure reduction methods (exhaust fan, hood shields)

Realistic cooking activities were performed during the study. They involved cooking activities such as stovetop stir-frying on the range top burner, frying tortillas in oil, broiling fish in the oven, and baking a pre-packaged frozen lasagna in the oven. The amount of food cooked was larger than would be typical in a residential setting, and the duration of cooking was generally longer than typical in order to obtain sufficient pollutant mass for analysis.

$PM_{2.5}$ and PM_{10} were collected on Teflon® filters with size selective inlets both indoors and outdoors during all tests. The outdoor $PM_{2.5}$ concentrations in Rohnert Park during February 2000 when the main study was performed were low, ranging from 0.6 to 13.6 $\mu g/m^3$. PM_{10} concentrations outdoors ranged from below the detection limit to 19.3 $\mu g/m^3$. Cooking resulted in substantially increased indoor concentrations of $PM_{2.5}$. During the 32 cooking tests, $PM_{2.5}$ concentrations ranged from below the detection limit to 3880 $\mu g/m^3$, with the highest concentrations occurring during the self-cleaning of the gas oven. During that five-hour event, the average concentrations were above 2000 $\mu g/m^3$ in the kitchen, living room, and bedroom, constituting a significant source of PM exposure in the house. The PM_{10} concentrations were over 3500 $\mu g/m^3$ in the kitchen during the gas oven self-cleaning test. Oven cleaning was also a significant source of PM for the electric oven, but the PM concentrations were less than half that measured during the gas oven self-cleaning test.

During six standard cooking tests that included stovetop stir-frying, frying bacon, frying tortillas, cooking French fries, broiling fish in the oven, and baking a pre-packaged lasagna in the oven, $PM_{2.5}$ concentrations ranged from 195 to 1090 $\mu g/m^3$ in the kitchen for the gas range tests and from 112 to 1270 $\mu g/m^3$ with the electric range. The median concentrations were 524 and 294 $\mu g/m^3$ in the kitchen for the comparable gas and electric tests. Although the $PM_{2.5}$ concentrations were lower in the living room and master bedroom, they were very high relative to outdoors. Median concentrations during the six standard cooking tests with the gas range were 142 and 134 $\mu g/m^3$ in the living room and bedroom, respectively. They were even higher during the tests with the electric range. The median $PM_{2.5}$ concentrations were 391 and 300 $\mu g/m^3$ in the living room and bedroom, respectively.

PM_{10} concentrations in the house were also substantially elevated due to cooking. Median concentrations in the kitchen, living room, and master bedroom during the six standard tests were 265, 216, and 274 for the tests with the gas range and 538, 407, and 402 $\mu g/m^3$, respectively for the tests with the electric range.

The $PM_{2.5}$ and PM_{10} concentrations measured by the integrated sampling and gravimetric analysis method during the cooking tests were highly variable. Some of the variability was associated with poor precision of the sampling method. The relative standard deviation was greater than 25% for all duplicate samples of $PM_{2.5}$. The precision of the PM_{10} gravimetric samples was better, with six of the eight pairs of samples having a relative standard deviation of less than the data indicator goal of ± 25%. The poor precision for the PEMs may have been related to poor stability of the pump flow rates over the duration of the sampling period. The impactors used in the study have not been validated for collection of cooking aerosols. The type of particulate matter, being predominantly oil droplets, may have adversely affected sampler performance.

The PM concentrations measured in replicate cooking tests using the same cooking method and type of food varied substantially. In three sets of duplicate cooking tests, the indoor concentrations of $PM_{2.5}$ had a relative difference ranging from 2% (frying beef, bedroom sample) to 103% (baking lasagna, living room sample). The relative difference for the PM_{10} concentrations ranged from 2% (frying beef, living room sample) to 155% (baking lasagna, bedroom sample). Although some of the variability may have been related to the poor precision of the PM measurements, analysis of the CO, NO, and NO_2 concentrations during the replicate tests showed that much of the variability was in the replication of the tests. Average CO concentrations during three replicate cooking tests differed by between 5 and 53%. NO concentrations differed by 3 to 64% during replicate tests. Similarly, average NO_2 concentrations differed by 4 to 52%, and peak concentrations differed by up to 59%.

The median and average concentrations of $PM_{2.5}$ during these standard cooking events, which ranged from approximately 1.5 to 5 hours in duration, exceeded the NAAQS of 65 $\mu g/m^3$ (24 hour average). The PM_{10} concentrations exceeded the California 24 hour standard of 50 $\mu g/m^3$ and the NAAQS of 150 $\mu g/m^3$. The data indicate that cooking can be a significant source of exposure to PM.

Measurements with the ELPI, a real-time PM monitor, showed that the particles emitted during cooking were primarily less than 1 μm aerodynamic diameter. The instrument has the capability to measure particles down to 0.04 μm diameter, but peak particle sizes from natural gas flames are typically in the 0.01 μm range. Therefore, the ELPI did not detect the peak particle size except in tests during which bacon was cooked in a pan and tortillas were fried in oil in a pan on the electric range burner. In those tests, the peak particle sizes were at 0.21 and 0.13 μm. The small particle size has significant implications with respect to human exposure to these emissions.

As expected, the concentrations of combustion pollutants, CO, NO, and NO_2, increased substantially in the house during cooking tests with the gas range. The highest concentrations of CO occurred during the self-cleaning test with the gas oven, averaging approximately 14 ppm in the kitchen, living room, and bedroom during the five-hour test. The self-cleaning test with the electric oven resulted in CO concentrations of approximately 8 ppm in the three rooms. During the six standard cooking tests, the CO concentrations in the house averaged less than 4 ppm except in the test during which fish was broiled in the gas oven. NO concentrations were high during oven cleaning tests with both the gas and electric ovens, with average concentrations of approximately 400 ppb for the gas range and 140 ppb for the electric range. During oven cleaning with the gas range, the California 1-hour standard for NO_2 of 250 ppb was exceeded. During the six standard cooking tests, the concentrations of NO and NO_2 were elevated in the house only for the tests with the gas range. The NO_2 concentrations in the house during four of the six standard cooking tests with the gas range exceeded the NAAQS annual mean standard of 53 ppb.

PAHs were measured during a subset of tests. Because of the short test durations, it was difficult to collect sufficient mass for analysis. The number of compounds detected in the samples was low. The low amount of mass collected resulted in a high level of analytical uncertainty in the measurement results. However, the emission rates were low, less than 11.1 ηg/g of food, for all compounds except naphthalene. Although PAHs were measurable in cooking oils used for the study, there was not a clear relationship between the presence of PAHs in the oils and in emissions during cooking. The data are not adequate for estimating exposure to PAHs due to cooking, nor to evaluate the impact on emissions of variables such as the type of cooking oil. However, despite the low concentrations and analytical uncertainty, the data suggest that cooking may impact indoor concentrations and exposures. The data suggest that additional testing and analysis are warranted to more fully evaluate the impact of cooking as a source of PAH exposure in residences. Alternative technical approaches will be required in future studies to ensure that sufficient mass can be collected during cooking tests in order to reduce the analytical uncertainty.

Element concentrations were measured in PM_{10} mass collected during a subset of tests. Indoor concentrations during the cooking tests exceeded outdoor concentrations for most elements. Of particular significance were elevated concentrations of chromium, titanium, nickel, and zinc during the oven self-cleaning tests. The element measurements suffered the same limitation as the PAH measurements, having a high level of analytical uncertainty due to the small amount of mass that could be collected during the short cooking tests.

Aldehydes were measured in a subset of six tests to obtain preliminary data to evaluate the impact of cooking on aldehyde exposures in the home. Formaldehyde and acetaldehyde, Toxic Air Contaminants identified by the ARB, were measured in oven cleaning, broiling fish, and baking pork roast tests. During the 5-hr oven cleaning tests, the formaldehyde concentrations of 417 and 224 $\mu g/m^3$ with the gas and electric ranges, respectively, substantially exceeded the 0.1 ppm (124 $\mu g/m^3$) action level identified by the ARB. During the broiling fish test, the formaldehyde concentration of 129 $\mu g/m^3$ also exceeded the action level.

Acetaldehyde concentrations were also elevated during the tests, with concentrations of 434 and 92 $\mu g/m^3$ measured during oven cleaning and fish broiling tests with the gas range.

Although the aldehyde measurements were limited in scope, they indicated that cooking may have a significant impact on aldehyde exposures.

A number of tests were performed to evaluate the impact of various factors on emissions of air pollutants during cooking. Emissions were compared for gas and electric ranges. PM concentrations in the house were always higher during use of the gas oven than during use of the electric oven. This included both self-cleaning oven tests and the cooking tests. When cooking was performed on the range top burners, the PM emissions were higher during tests with the electric range that involved deep fat frying of French fries and tortillas.

Of the six standard cooking tests performed with both the gas and electric range, the highest emissions of $PM_{2.5}$ occurred during frying of tortillas in oil on the electric range and baking a frozen lasagna in the gas oven. Broiling fish also produced high PM emissions.

In worst-case tests that involved realistic activities such heating cooking oils too hot or slightly burning food, indoor air concentrations and emission rates were generally higher than in the standard tests. With the exception of the oven-cleaning tests, the highest PM concentrations were measured during the worst-case stovetop stir-frying test.

In general, the impact of variables such as type of cooking method, type of food, or pan material could not be determined precisely from the limited number of samples in this study. The concentrations of the air pollutants measured in the rooms and the emission rates calculated with the mass balance model were too variable to determine the significance of differences between different cooking activities.

Tests with the microwave demonstrated that emissions of PM and combustion pollutants were low with this cooking method. It was the most effective exposure reduction method evaluated in the study. Tests with the range hood exhaust and range hood side shields resulted in lower concentrations of some of the air contaminants, but there was not a dramatic reduction in indoor air pollutant concentrations. However, only four tests were performed with a single range hood exhaust system. Additional tests in a large number of homes with range hood exhaust systems of different age and design should be performed to determine the magnitude of the impact of range hoods on indoor pollutant concentrations under realistic conditions of use.

The study was successful in that the results provide data necessary to obtain a better understanding of the impact of cooking on indoor air pollutant concentrations and exposure. The data indicate that cooking is a significant, although highly variable, source of PM indoors. Exposure to PM due to cooking may be substantial for many individuals, depending on the amount of cooking that is done and the duration of time spent in the home following cooking. With a gas range, exposure to CO and NO_2 is increased substantially. The results of the study cannot be used to precisely assess the impact of different types of cooking methods, different foods, or other parameters related to cooking methods and utensils due to the high variability in the emissions. To evaluate the impact of these parameters, a much larger number of tests would need to be performed. These tests could be performed under highly controlled conditions in environment test chambers or in field studies under realistic cooking conditions.

6.0 RECOMMENDATIONS

This study has provided important information on the impact of cooking on indoor air concentrations and exposure. The data provide a better understanding of the magnitude and variability of emissions from cooking. Additional work in this area is recommended to obtain more precise data that can be used to estimate the impact of cooking on exposure to air contaminants. The following work would more fully address the ARB objectives with respect to cooking as a source of exposure to air contaminants in the home:

- Personal monitoring and area monitoring should be performed in field studies to obtain more comprehensive data on exposures to PM, PAHs, and combustion pollutants under realistic conditions in residences. If there is an opportunity to perform additional data collection in on-going or planned studies, survey questionnaires should address cooking as a source. Diaries that document cooking activities should also be considered. For new studies, data could be collected either in randomly sampled populations or in studies utilizing scripted protocol methods. In the latter studies, participants would be recruited into the study to meet a defined set of selection criteria developed to obtain a study sample that is reasonably representative of the California population with regard to home and cooking characteristics. Home occupants would perform normal cooking activities, but according to a protocol that would ensure that two or three meals were cooked during a 24-hour monitoring period. Diaries and cooking records should be maintained during the monitoring period. Monitoring and sample collection should be performed over 12 or 24-hour periods to obtain exposure estimates. Tests should be performed to measure the collection efficiency of PM samplers for aerosols representative of emissions during cooking. The impact of flow rate and sampler design on collection efficiency should be evaluated. The impact of high water vapor concentrations during sample collection should also be determined. Testing should be performed to determine the losses of VOCs and SVOCs during collection of cooking aerosols by gravimetric sampling methods. In future studies of cooking emissions, researchers should consider use of methods that incorporate collection of PM and SVOCS with sampling systems configured with denuders, filter packs, and sorbents. Such systems are currently being used to measure SVOCs and PM in source studies, and they can be configured to measure SVOCs lost from the particles during the sampling period.
- Prior to performing additional work to measure personal exposure to PM due to cooking, methods development and validation testing should be performed to document the performance of available PM samplers. The inlets used for personal sampling are currently validated for solid particles. Emissions from cooking result in a much different type of aerosol, consisting of grease droplets, often in the presence of high water vapor concentrations. Tests should be performed to measure the collection efficiency of PM samplers for aerosols representative of emissions during cooking. The impact of flow rate and sampler design on collection efficiency should be evaluated. The impact of high water vapor concentrations during sample collection should also be determined. Testing should be performed to determine the losses of VOCs and SVOCs during collection of cooking aerosols by both sampling artifacts and gravimetric sampling methods currently in use. In future studies of cooking emissions, researchers should consider use of methods that incorporate collection of PM and SVOCS with sampling systems

configured with denuders, filter packs, and sorbents. Such systems are currently being used to measure SVOCs and PM, and they can also be configured to measure SVOCs lost from the particles during the sampling period.

- Additional work should be performed to characterize the emissions from cooking. Emission rates are needed to predict exposure to PM and gas phase contaminants generated during cooking. This data can most easily and accurately be obtained by performing tests in controlled environment chambers. This work should include tests to determine the sink effect and deposition velocities specific to the aerosols generated during cooking.
- The impact of cooking in residences on exposures to aldehydes and PAHs should be further evaluated. Results of this study suggest that cooking may greatly impact exposures to these Toxic Air Contaminants.

7.0 REFERENCES

Air Resources Board (ARB), "Supplement to Indoor Air Quality Guideline No. 2, Combustion Pollutants in Your Home," Research Division, May 1994.

Air Resources Board (ARB), "Formaldahyde in the Home," Indoor Air Quality Guideline No. 1. Research Division, September 1991. http://www.arb.ca.gov/research/indoor/formald.htm

Annis, J. C., and P. J. Annis, "Size Distributions and Mass Concentrations of Naturally Generated Cooking Aerosols," ASHRAE Transactions 95(1): CH 89-9-1, 1989.

Ashbaugh, Lowell L., Robert. A Eldred, and Susanne Hering, "Loss of Particle Nitrate from Teflon Sampling Filters: Effects on Measured Gravimetric Mass," California Air Resources Board, Final Report No. 96-305, Sacramento, CA, September 1998.

ASTM (1999). *ASTM E 741*, "Standard practice for measuring air leakage rates by the tracer dilution method," American Society for Testing and Materials, Philadelphia, PA, 1999.

Brauer, Michael, Andrea 't Mannetje, Barbara Lang, "Continuous assessment of indoor fine particles with a portable nephelometer," Proceedings of the 2nd Colloquium on Particulate Air Pollution and Healt, Park City, UT, May 1-3, 1996.

Brauer, Michael, Robert Hirtle, Barbara Lang, and Wayne Ott, "Assessment of indoor fine aerosol contributions from environmental tobacco smoke and cooking with a portable nephelometer," *Journal of Exposure Analysis and Environmental Epidemiology*, Vol. 10, 2000, pp. 136-144.

California Office of Environmental Health Hazard Assessment (OEHHA). Toxicity Criteria Database. Acute Reference Exposure Levels. (machine readable data file http://www.oehha.org/risk/chemicalDB/index.asp), 1999.

Chiang, Tai-An, Pei-Fen Wu, Li-Fang Wang, Huei Lee, Chien-Hung Lee, and Ying-Chin Ko, "Mutagenicity and polycyclic aromatic hydrocarbon content of fumes from heated cooking oils produced in Taiwan," *Mutation Research*, 381, July, 3, 1997, pp. 157-161.

Chuang, Jane C., Gregory A. Mack, Michael R. Kuhlman, and Nancy K. Wilson, "Polycyclic Aromatic Hydrocarbons and Their Derivatives in Indoor and Outdoor Air in an Eight-Home Study," *Atmospheric Environment*, Vol. 25B, No. 3, 1991, pp. 369-380.

Clayton, C. Andrew, Rebecca L. Perritt, Edo D. Pellizzari, Kent W. Thomas, Roy W. Whitmore, Lance A.Wallace, Haluk Ozkaynak, and John D. Spengler, "Particle Total Exposure Assessment Methodology (PTEAM) Study: Distributions of Aerosol and Elemental Concentrations in Personal, Indoor, and Outdoor Air Samples in a Southern California Community," *Journal of Exposure Analysis and Environmental Epidemiology*, Vol. 3, No. 2, 1993, pp. 227-250.

Consumers Reports, "What's Cookin' in Electric Ranges," Vol. 65, No. 1, January 2000, pp. 20-23.

"Conventional Home Weatherization Installation Standards," California Department of Economic Opportunity. January 1995.

Cui, Wenxuan., Delbert J. Eatough, and Norman L. Eatough, "Fine Particle Organic Material in the Los Angeles Basin – I: Assessment of the High Volume Brigham Young University Organic Sampling System, BIG BOSS," *Journal of the Air and Waste Management Association*, Volume 48, 1998, pp. 1024-1037.

Dubowsky, Sara D., Lance A. Wallace, and Timothy J. Buckley, "The contribution of traffic to indoor concentrations of polycyclic aromatic hydrocarbons," *Journal of Exposure Analysis and Environmental Epidemiology*, Vol. 1, 1999, pp. 312-321.

Felton, J., "Food Mutagens: The Cooking Makes a Difference," *Science & Technology Review*, July 1995, pp. 18-25.

Fortmann, R. C., N. L. Nagda, and I. H. Billick, "Indoor Air Quality Monitoring in Test Residences," Proceedings of the International Gas Research Conference, 1986.

Fortmann, R., C. Gentry, K.K. Foarde, D.W. VanOsdell, and R.N. Kulp , "Results of a pilot field study to evaluate the effectiveness of cleaning residential heating and air conditioning systems and the impact on indoor air quality and system-performance," Contract No. 68-D4-0005, Work Assignment 2-30, U.S. Environmental Protection Agency Office of Research and Development, Washington, DC, 2000.

Gerstler, William D., Thomas H. Kuehn, David Y. H. Pui, James W. Ramsey, Michael J. Rosen, Richard R. Carlson, and Sean D. Peterson, "Identification and Characterization of Effluents from Various Cooking Appliances and Processes as Related to Optimum Design of Kitchen Ventilation Systems," Final Report, ASHRAE 745-RP Phase II, Minneapolis, MN, July 21, 1998.

Guo, Zhishi, Ronald Mosely, Jenia McBrian, and Roy Fortmann, "Fine Particulate Matter Emissions from Candles," Proceedings from The Symposium on Engineering Solutions to Indoor Air Quality Problems, Raleigh, NC, July 2000.

Kamens, R., C.T. Lee, R. Weiner, and D. Leith, "A study to characterize indoor particles in three non-smoking homes," *Atmos. Environ*, Vol. 25, 1991, pp.939-948.

Kelly, Thomas, Personal Communication, Battelle, Columbus, OH, August 2000.

Kim, Bong M., Julia Lester, Laki Tisopulos, and Melvin D. Zeldin, "Nitrate Artifcats during $PM_{2.5}$ Sampling in the South Coast Air Basin of California," *Journal of the Air and Waste Management Association*, Volume 49, 1999, pp. PM-142–153.

Koontz, M.D., W.C. Evans and C.R. Wilkes, "Development of a Model for Assessing Indoor Exposure to Air Pollutants," California Air Resources Board, Final Report No. A 933-157, Sacramento, CA, 1998.

Kootnz, Michael D., and Niren L. Nagda, "Experimental Design and Protocols for Research at GEOMET's Test Houses: A Case Study," *Design and Protocol for Monitoring Indoor Air Quality, ASTM STP 1002*, N. L. Nagda and J. P. Harper, Eds., American Society for Testing and Materials, Philadelphia, 1989, pp. 148-165.

Li, Chih-Shan, Wen-Hai Lin, and Fu-Tien Jenq, "Size Distributions of Submicrometer Aerosols from Cooking," *Environment International*, Vol. 19, 1993, pp. 147-154.

Lin, Duanmu, Ao Yong'an, and Feng Guohui, "The Control of Air Quality in Chinese Kitchen," *Proceedings of Indoor Air*, Vol. 1, 1999, pp. 24-29.

Mitchell, Peter, Personal communication to Tom Philips from Peter Mitchell, Cooperative Extension, University of California at Berkeley, Berkeley, CA, 1998.

Nelson, Gary, Robert Nevitt, Neil Moyer, and John Tooley, "Measured Duct Leakage, Mechanical System Induced Pressures and Infiltration in Eight Randomly Selected New Minnesota Houses," Proceedings of the 1993 Energy Efficient Building Association (EEBA) Annual Conference, Boston, MA, March 1993.

Ozkaynak, H., J. Xue, J. Spengler, L. Wallace, E. Pellizzari, and P. Jenkins, "Personal Exposure to Airborne Particles and Metals: Results from the Particle TEAM Study in Riverside, California," *Journal of Exposure Analysis and Environmental Epidemiology*, Vol. 6, No. 1, 1996, pp. 57-78.

Patterson, Emily and Delbert J. Eatough, "Indoor/Outdoor Relationships for Ambient $PM_{2.5}$ and Associated Pollutants: Epidemiological Implications in Lindon, Utah," *Journal of the Air and Waste Management Association*, Volume 50, 2000, pp. 103-110.

Pope, C.A., III, D.W. Dockery, and J. Schwartz, "A review of epidemiological evidence of health effects of particulate air pollution," *Inhalation Toxicology*, Vol. 7, 1995, pp. 1-18.

Rodes, C., L. Sheldon, D. Whitaker, A. Clayton, K. Fitzgerald, J. Flanagan, F. DiGenova, S. Hering, C. Frazier, "Measuring Concentrations of Selected Air Pollutants inside California Vehicles," Final Report, California Air Resources Board, Research Division, Contract No. 95-339, Sacramento, CA, December 1998.

Rogge, Wolfgang F., Lynn M. Hildemann, Monica A. Mazurek, Glen R. Cass, and Bernd R. T. Slmonelt, "Sources of Fine Organic Aerosol. 5. Natural Gas Home Appliances," *Environmental Science Technology*, Vol. 27, No. 13, 1993, pp. 2736-2744.

Rogge, Wolfgang F., Lynn M. Hildemann, Monica A. Mazurek, Glen R. Cass, and Bernd R. T. Slmonelt, "Sources of Fine Organic Aerosol. 1. Charbroilers and Meat Cooking Operations," *Environmental Science Technology*, Vol. 25, No. 6, 1991, pp. 1112-1125.

Rogge, Wolfgang F., Lynn M. Hildemann, Monica A. Mazurek, Glen R. Cass, and Bernd R. T. Simoneit, "Sources of Fine Organic Aerosol. 5. Natural Gas Home Appliances," *Environmental Science Technology*, Vol. 27, 1993, pp. 2736-2744.

Rogge, Wolfgang F., Wenxuan Cui, Zhihua Zhang, Yujun Yan, and Sampson Sit, "Gaseous and Particulate Emission Rates for Residential Food Cooking," Proceedings of the Symposium on Engineering Solutions to Indoor Air Quality Problems, Research Triangle Park, NC, July 1997, pp. 36-44.

Rogge, Wolfgang F., Wenxuan Cui, Zhihua Zhang, Yujun Yan, and Sampson Sit, "Characterizations of Gaseous and Particulate Emissions from Natural Gas Cooking Flames on a Molecular Level," Proceedings of the Symposium on Engineering Solutions to Indoor Air Quality Problems, Research Triangle Park, NC, July 1997, pp.128-136.

Ross, D.I., S.L. Upton, D.J. Hall, and I.P. Bennett, "Preliminary Measurement of Ultrafine Aerosol Emissions from Gas Cooking," *Proceedings of Indoor Air*, Vol.4, 1999, pp. 1043-1048.

Schauer, James J., Mike J. Kleeman, Glen R. Cass, and Bernd R. T. Simoneit, "Characterization and Control of Organic Compounds Emitted from Air Pollution Sources," Final Report, California Air Resources Board, Contract No. 93-329, Sacramento, CA, April 1998.

Schauer, James J., Wolfgang F. Rogge, Lynn M. Hildemann, Monica A. Mazurek, Glen R. Cass, and Bernd R. T. Simoneit, "Source Apportionment of Airborne Particulate Matter Using Organic Compounds as Tracers," *Atmospheric Environment*, Vol. 30, No. 22, 1996, pp. 3837-3855.

Sheldon, L., A. Clayton, J. Keever, R. Perritt, and D. Whitaker, "PTEAM: Monitoring of Phthalates and PAHs in Indoor and Outdoor Air Samples in Riverside, California: Final Report, Volume II," California Air Resources Board, Research Division, Contract No. A933-144, Sacramento, CA, December 1992.

Sheldon, L., A. Clayton, J. Keever, R. Perritt, and D. Whitaker, "Indoor Concentrations of Polycyclic Aromatic Hydrocarbons in California Residences," Final Report, California Air Resources Board, Contract No. A033-132, Sacramento, CA, August 1993.

Sheldon, Linda, Andrew Clayton, Rebecca Perritt, Donald A. Whitaker and Jeffrey Keever, "Indoor Concentrations of Polycyclic Aromatic Hydrocarbons in California Residences and Their Relationship to Combustion Source Use," *Proceedings of Indoor Air,* Vol. 3, 1993, pp. 29-34.

Sheldon, Linda, Donald Whitaker, Jeffrey Keever, Andrew Clayton, and Rebecca Perritt, "Phthalates and PAHS in Indoor and Outdoor Air in a Southern California Community," *Proceedings of Indoor Air,* Vol. 3, 1993, pp. 109-114.

Shields, P. G., G. X. Xu, W. J. Blot, J. F. Fraumeni, Jr., G. E. Trivers, E. D. Pellizzari, Y. H. Qu, Y. T. Gao, and C. C. Harris, "Mutagens from Heated Chinese and U. S. Cooking Oils," *Journal of the National Cancer Institute*, Vol. 87, No. 11, June 7, 1995, pp. 836-841.

Shuguang, Li, Pan Dinhua, and Wang Guoxiong, "Analysis of Polycyclic Aromatic Hydrocarbons in Cooking Oil Fumes," *Archives of Environmental Health*, Vol. 49, No. 2, March/April 1994, pp. 119-122.

Thiebaud, H. P., M. G. Knize, P. A. Kuzmicky, et al., "Mutagenicity and Chemical Analysis of Fumes from Cooking Meat," *J. Agric Food Chem*, 1994, 42, 1502-1510.

Thomas, Kent W., Edo D. Pellizzari, C. Andrew Clayton, Donald A. Whitaker, Richard C. Shores, Jack Spengler, Haluk Ozkaynak, Susan E. Froehlich, and Lance A. Wallace, "Particle Exposure Assessment Methodology (PTEAM) 1990 Study: Method Performance and Data Quality for Personal, Indoor, and Outdoor Monitoring," *Journal of Exposure Analysis and Environmental Epidemiology*, Vol. 3, No. 2, 1993, pp. 203-226.

Traynor, Gregory W., "Evaluation of Technical Literature,Indoor Air Pollution Modeling, Options for California Standards, and Recommended Standards," Final Report, California Department of Health Services, Contract No. 97-11429, Berkeley, CA, September 1999.

Tsongas, George, "Field Measurement of Elevated Carbon Monoxide Levels form Gas Ovens," presented at *Energy Northwest 94*, Portland State University School of Engineering and Applied Science, Portland, OR, April 1994.

Turner, William A., Bernard A. Olson, and George A. Allen, "Calibration of Sharp Cut Impactors for Indoor and Outdoor Particle Sampling," *Journal of the Air & Waste Management Association*, Volume 50, April 2000, pp. 484-487.

U.S. Department of Agriculture, 2000. "Continuing Survey of Food Intakes by Individuals (CSFII) 1994-96, 1998," U.S. Department of Agriculture, Beltsville, MD. Available from the National Technical Information Service, NTIS Order Number PB2000-500027.

U.S. Environmental Protection Agency, "Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air – Second Edition," EPA/625/R-96/010b, EPA Center for Environmental Research Information, January 1999.

U.S. Environmental Protection Agency, "EPA Large Buildings Studies Integrateed Protocol," Indoor Air Division, Office of Radiation and Indoor Air, Washington, DC, and Atmospheric Research and Exposure Assessment Laboratory Office of Modeling, Monitoring Systems, and Quality Assurance, Research Triangle Park, NC, June 1, 1993.

Underwriter's Laboratory, "Standard of Safety for Household Electric Ranges," Section 98.3, UL 858, 14th Edition, Research Triangle Park, NC.

Wallace, L., "Cooking as a source of fine particles: experiments in a townhouse," Proceedings of the 1996 EPA-AWMA International Symposium on the Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC, May 1996.

Wallace, Lance, "Continuous Monitoring of Fine, Coarse, and Ultrafine Particles and Black Carbon in a Home," Proceedings of the ISEA Annual Conference, Boston, MA, August 15-18, 1998.

Wallace, Lance, "Indoor Particles: A Review," *Journal of the Air and Waste Management Association*, Vol. 46, 1996, pp. 98-126.

Wallace, Lance, "Real-Time Monitoring of Particles, PAH, and CO in an Occupied Townhouse," Proceedings of the ACGIH Applied Workshop on Occupational and Environmental Exposure Assessment, Chapel Hill, NC, February 23-25, 1998.

Wu, Pei-Fen, Tai-An Chiang, Li-Fang Wang, Chia-Shiung Chang, Ying-Chin Ko, "Nitro-polycyclic aromatic hydrocarbon contents of fumes from heated cooking oils and prevention of mutagenicity by catechin," Mutation Research 403, 1998, pp. 29-34.

Zhong, Lijie, Mark S. Goldberg, Yu-Tang Gao, and Fan Jin, "Lung Cancer and Indoor Air Pollution Arising from Chinese-Style Cooking among Nonsmoking Women Living in Shanghai, China," *Epidemiology*, Vol. 10, No. 5, September 1999.

Zielinska, Barbara, Eric Fujita, John Sagebiel, Greg Harshfield, Ewa Uberna, Terry Hayes, and Frank Keene, "Arizona Hazardous Air Pollutants Monitoring Program," *Journal of the Air & Waste Management Association*, Volume 48, November 1998, pp. 1038-1050.

APPENDIX A

Literature Review Bibliography

Literature Review Bibliography

Annis, J. C., and P. J. Annis, "Size Distributions and Mass Concentrations of Naturally Generated Cooking Aerosols," *ASHRAE Transactions CH-89-8-1*, 1989.

Annis, P. J., and J. C. Annis, "Comparison of the Effectiveness of Three Types of Kitchen Range Exhaust Systems," Proceedings of the 41st Annual International Appliance Technical Conference, Ohio State University, Columbus, OH.

Brauer, M., "Assessment of Indoor Aerosols with an Integrating Nephelometer," *Journal of Exposure Analysis and Environmental Epidemiology,* 1995, 5, 45-56.

Brauer, M., A. Mennetjie, and B. Lang, "Continuous Assessment of Indoor Fine Particles with a Nephelometer," Presented at the Second Colloquium on Particulate Air Pollution and Health, Park City, UT, 1996.

Brauer, Michael, Robert Hirtle, Barbara Lang, and Wayne Ott, "Assessment of indoor fine aerosol contributions from environmental tobacco smoke and cooking with a portable nephelometer," *Journal of Exposure Analysis and Environmental Epidemiology*, Vol. 10, 2000, pp. 136-144.

Chiang, T-A., P-F. Wu, and Y-C. Ko, "Prevention of Exposure to Mutagenic Fumes Produced by Hot Cooking Oil in Taiwanese Kitchens," *Environmental and Molecular Mutagenisis*, 1998, 31, 92-96.

Chiang, T-A., P-F. Wu, L-F. Wang, et al., "Mutagenicity and Polycyclic Aromatic Hydrocarbon Content of Fumes from Heated Cooking Oils Produced in Taiwan," *Mutation Research*, 1997, 381, 157-161.

Gerstler, W. D., T. H. Kuehn, D. Y. H. Pui, et al., "Identification and Characterization of Effluents from Various Cooking Appliances and Processes as Related to Optimum Design of Kitchen Ventilation Systems," *Final report ASHRAE 745-RP Phase II*, University of Minnesota, Minneapolis, MN, 1998.

Hildemann, L. M., D. B. Klinedinst, G. A. Klouda, et al., "Sources of Urban Contemporary Carbon Aerosol," *Environmental Science Technology*, 1994, 28, 1565-1576.

Hildemann, L. M., G. R. Markowski, M. C. Jones, et al., "Submicrometer Aerosol Mass Distributions of Emissions from Boilers, Fireplaces, Automobiles, Diesel Trucks, and Meat-Cooking Operations," *Aerosol Science and Technology*, 1991, 14, 138-152.

Hildemann, L. M., M. A. Mazurek, and G. R. Cass, "Quantitative Characterization of Urban Sources of Organic Aerosol High-Resolution Gas Chromatography," *Environmental Science Technology*, 1991, 25, 1311-1325.

Hildemann, L. M., G. R. Markowski, and G. R. Cass, "Chemical Composition of Emissions from Urban Sources of Fine Organic Aerosol," *Environmental Science Technology*, 1991, 25, 744-759.

Koo, L. C., H. Matsushita, J. H-C. Ho, et al., "Carcinogens in the Indoor Air of Hong Kong Homes: Levels, Sources, and Ventilation Effects on 7 Polynuclear Aromatic Hydrocarbons," *Environmental Technology*, 1994, 15, 401-418.

Kuczmarski, M. F., A. Mashfegh, and R. Briefel, "Update on Nutrition Monitoring Activities in the United States," *Journal of the American Dietetic Association*, 1994, 94, 753-760.

Kuehn, T. H., J. Ramsey, H. Han, et al., "A Study of Kitchen Range Exhaust Systems," *ASHRAE Transactions, CH-89-9-2*, 1989 95, 744-752.

Li, C-S., W. H. Lin, and F-T. Jenq, "Size Distributions of Submicrometer Aerosols from Cooking," *Environment International*, 1993, 19, 147-154.

Li, C-S., W. H. Lin, and F-T. Jenq, "Removal Efficiency of Particulate Matter by a Range Exhaust Fan," *Environment International*, 1993, 19, 371-380.

Li, S., D. Pan, and G. Wang, "Analysis of Polycyclic Aromatic Hydrocarbons in Cooking Oil Fumes," *Archives of Environmental Health*, 1994, 49, 119-122.

Lofroth, G., "Airborne Mutagens and Carcinogens from Cooking and Other Food Preparation Processes," *Toxicology Letters*, 1994, 72, 83-86.

Lofroth, G., C. Stensman, and M. Brandhorst-Satzkorn, "Indoor Sources of Mutagenic Aerosol Particulate Matter: Smoking, Cooking and Incense Burning," *Mutation Research*, 1991, 261, 21-28.

Loria, C.M., T.L. Bush, M. D. Carroll, et al., "Macronutrient Intakes among Adult Hispanics: A Comparison of Mexican Americans, Cuban Americans, and Mainland Puerto Ricans," *American Journal of Public Health*, 1995, 85, 684-689.

McDonald, J., B. Zielinska, E. Fujita, J. Chow, J. Watson, and J. Sagebiel, "The Development of Chemical Emission Profiles for Residential Wood Combustion and Meat Cooking for Use in the Apportionment of Atmospheric Carbonaceous Aerosol," In Proceedings of "PM2.5: A Fine Particle Standard", AWMA/EPA Conference, Long Beach, CA, January 28-30, 1998.

Nardini, B., G. Manuela, and E. Clonfero, "Mutagens in Indoor Air Particulate," *Mutation Research*, 1994, 322, 193-202.

Norbeck, J. M., and W. A. Welch, “Further Development of Emission Test Methods and Development of Emission Factors for Various Commercial Cooking Operations,” Final Report for Applied Science and Technology Division, South Coast Air Quality Management District, Report # 97-AP-RT58-002-FR for contract #96027, 1997.

Qu, Y.H., G. X. Xu, J. Z. Zhou, et al., “Genotoxicity of Heated Cooking Oil Vapors,” *Mutation Research*, 1992, 298, 105-111.

Rogge, W. F., W. Cui, Z. Zhang, et al., “Gaseous and Particulate Emission Rates for Residential Food Cooking,” *Engineering Solutions to Indoor Air Quality Problems*, pp. 36-44, Air & Waste Management Association and Environmental Protection Agency: Research Triangle Park, NC, 1997.

Rogge, W. F., L. M. Hildemann, M. A. Mazurek, et al., “Sources of Fine Organic Aerosol. 1. Charbroilers and Meat Cooking,” *Environmental Science Technology*, 1991, 25, 1112-1125.

Rogge, W. F., L. M. Hildemann, M. A. Mazurek, et al., “Sources of Fine Organic Aerosol. 5. Natural Gas Home Appliances,” *Environmental Science Technology*, 1993, 27, 2736-2744.

Rogge, W.F., W. Cui, Y. Yan, et al., “Characterization of Gaseous and Particulate Emissions from Natural Gas Cooking Flames on a Molecular Level,” *Engineering Solutions to Indoor Air Quality Problems*, pp. 128-137, Air & Waste Management Association and Environmental Protection Agency, Research Triangle Park, NC, 1997.

Schauer, J. J., M. J. Kleeman, and G. R. Cass, “Characterization and Control of Organic Compounds Emitted from Air Pollution Sources,” Final Report for California Air Resources Board, Research Division, Sacramento, CA, For contract #93-329, 1998.

Schauer, J. J., W. F. Rogge, L. M. Hildemann, et al., “Source Apportionment of Airborne Particulate Matter Using Organic Compounds as Tracers,” *Atmospheric Environment*, 1996, 30, 3837-3855.

Sexton, K., L. M. Webber, S. B. Hayward, et al., “Characterization of Particle Composition, Organic Vapor Constituents, and Mutagenicity of Indoor Air Pollutant Emissions,” *Environment International*, 1986, 12, 351-362.

Sexton, K., D. K. Wagener, S. G. Selevan, et al., “An Inventory of Human Exposure-Related Data Bases,” *Journal of Exposure Analysis and Environmental Epidemiology*, 1994, 4, 95-109.

Shields, P. G., G. X. Xu, W. J. Blot, et al., “Mutagens from Heated Chinese and U.S. Cooking Oils,” *Journal of the National Cancer Institute*, 1995, 87, 836-840.

Siegmann, K., and K. Sattler, "Aerosol from Hot Cooking Oil, a Possible Health Hazard," *J. Aerosol Sci*, 1996, 27, 5493-5494.

Specht, K., and W. Baltes, "Identification of Volatile Flavor Compounds with High Aroma Values from Shallow-Fried Beef," *J. Agric Food Chem*, 42, 2246-2253.

Thiebaud, H. P., M. G. Knize, P. A. Kuzmicky, et al., "Airborne Mutagens Produced by Frying Beef, Pork and a Soy-based Food," *Fd. Chem. Toxic*, 1995, 33, 821-828.

Thiebaud, H. P., M. G. Knize, P. A. Kuzmicky, et al., "Mutagenicity and Chemical Analysis of Fumes from Cooking Meat," *J. Agric Food Chem*, 1994, 42, 1502-1510.

Vainiotalo, S., and K. Matveinen, "Cooking Fumes as a Hygienic Problem in the Food and Catering Industries," *American Industrial Hygiene Association Journal*, 1993, 54, 376-382.

Wilson, N. D., N. M. Shear, D. J. Paustenbach, and P. S. Price, "The Effect of Cooking Practices on the Concentration of DDT and PCB Compounds in the Edible Tissue of Fish," *Journal of Exposure Analysis and Environmental Epidemiology*, 1998, 8, 423-440.

Wu, P-F., T-A. Chiang, L-F. Wang, et al., "Nitro-Polycyclic Aromatic Hydrocarbon Contents Of Fumes From Heated Cooking Oils And Prevention Of Mutagenicity By Catechin," *Mutation Research*, 1998, 403, 29-34.

Yang, C-C., S. N. Jenq, and H. Lee, "Characterization of the Carcinogen 2-amino-3,8-dimethylimidazo[4,5-f]quinoxaline in Cooking Aerosols under Domestic Conditions," *Carcinogenisis*, 1998, 19, 359-363.

APPENDIX B

Technical Review Group Members

Technical Review Group Members

Mike Brauer
The University of British Columbia
Department of Medicine, Respiratory Division
Occupational Hygiene Program
2206 East Mall, 3rd Floor
Vancouver, BC V6T 1Z3 Canada

Thomas Kuehn
Professor and Director of Undergraduate Studies
Department of Mechanical Engineering
University of Minnesota
111 Church St., S.E.
Minneapolis, MN 55455-0111

Wolfgang Rogge
Department of Civil and Environmental Engineering
University Park, EAS Building
Florida International University
Miami, FL 33199

Tracy Thatcher
659 Davis Hall
Department of Civil and Environmental Engineering
University of California, Berkeley
Berkeley, CA 94720-1710

Lance Wallace
U.S. Environmental Protection Agency
12201 Sunrise Valley Drive
555 National Center
Reston, VA 20192

APPENDIX C

Cooking Protocols

Cooking Protocols

Note: All food items were weighed before and after cooking. The food mass varied slightly among cooking tests for the same food type (see Table 3-1), this includes both multiple batch cooing events and for the total mass cooked.

1. Oven Dirtying

Food Cooked	Mass (g)	Food Description
Cherry Pie Filling	30	Oregon Fruit Products / Pitted Bing Cherries in Heavy Syrup / 16 oz Can
Tomato Puree	30	Contadina Tomato Puree 15 oz Can
Vegetable Oil	30	Crisco Pure Vegetable Oil

Combine first two ingredients and apply to bottom of oven. Apply oil evenly to sides and top of oven with one paper towel. Turn oven on the 350 °F for one hour to bake onto surface.

2. Oven Cleaning

Food Cooked	Mass (g)	Food Description
None		

Turn oven self clean feature on for 4 hours.

3. Wok Stir Fry

Food Cooked	Mass (g)	Food Description
Chicken	580	Foster Farms / Boneless Skinless Chicken Breasts / California Grown Fresh
Vegetables	435	Green Giant / Create a Meal! / Stir Fry Teriyaki / Broccoli, sugar snap peas, water chestnuts, red peppers
Oil	65	Planters Peanut Oil

Cut up chicken breasts into 1-inch pieces. Place wok on burner and set to high for 1 minute. Add approximately ¼ of the oil to the wok and place half of vegetables in the wok. Cook for 3 minutes, stirring constantly. Remove cooked vegetables from wok. Repeat with more oil and rest of vegetables. Add more oil to pan and half of the cut up chicken. Cook for 3 minutes, stirring constantly. Remove cooked chicken from wok. Repeat with more oil and rest of chicken.

4. Bacon

Food Cooked	Mass (g)	Food Description
Bacon	975	Roger Wilco Platter Bacon / Extra Lean

a. Gas / Electric Directions

Place 12-inch skillet on burner and set to medium-high. Place ½ pound of bacon as separated strips in pan and cook for 10 minutes. Turn bacon over and cook for an additional two minutes. Remove cooked bacon from pan and repeat with ½ pound of bacon, leaving oil from 1st batch in the pan.

b. Microwave Directions

Line a 9-in x 13-in Pyrex baking dish with paper towels. Place 6 slices (approximately ½ pound) of bacon in dish and cover with more paper towels. Microwave on high for 15 minutes; rotate 90° every 3 minutes. Repeat with an additional 6 slices of bacon.

5. Tortillas

Food Cooked	Mass (g)	Food Description
Tortillas	765	La Tortilla Factory / White corn tortillas / Santa Rosa California
Oil	1075	Crisco Pure Vegetable Oil

Place 12-inch skillet on burner and set to medium-high. Add oil to pan and heat for 10 minutes. Add one tortilla at a time to the oil and cook for 2 minutes. Remove from pan and repeat with rest of tortillas.

6. French Fries

Food Cooked	Mass (g)	Food Description
French Fries	1825	Special Value / Steak Cut French Fries 32 oz
Oil	3045	Crisco Pure Vegetable Oil

Place cast iron pot on stove and set burner on high. Add 1 gallon of oil to pot and heat for 40 minutes or until oil temperature reaches 190 °C. Add 2 pounds of French fires to basket and cook for 6 minutes. Allow oil to reheat to 190 °C and repeat with rest of French fries.

7. Broil Fish

Food Cooked	Mass (g)	Food Description
Fish	1010	Atlantic Salmon Steaks / Albertson's
Oil	30	Star Olive Oil / Extra Virgin

Place one salmon steak in center of a 9-in x 13-in Pyrex baking dish. Cover steak with 15 grams of olive oil. Heat broiler for 5 minutes on broil setting and place dish in oven on the highest rack directly beneath the broiler. Close oven door. Cook for 5 minutes, remove from oven and turn steak over. Place in oven broiler for an additional 5 minutes. Remove from oven.

8. Lasagna

Food Cooked	Mass (g)	Food Description
Lasagna	1165	Michael Angelo's / The Art of Italian Cuisine / Lasagna with meat sauce

a. Gas / Electric Directions

Turn oven on to 375 °F and pre-heat the oven for 30 minutes. Remove lasagna from freezer and open one corner of package. Place in oven and cook 1.5 hours.

b. Microwave Directions

Remove lasagna from freezer and open one corner of package. Place in oven cook for 11 minutes on high. Open oven and turn lasagna 90°. Cook for and additional 11 minutes or until hot.

9. Popcorn

Food Cooked	Mass (g)	Food Description
Popcorn	220	Orville Redenbacher's Movie Theatre Butter / 6 - 3.5 oz bags

Remove cellophane from package and place in center of microwave. Microwave on high for 4 minutes.

10. Pork Roast

Food Cooked	Mass (g)	Food Description
Pork Roast	2405	Albertson's Center Cut Pork Loin Rib Roast

Turn oven on to 275 °F and pre-heat the oven for 30 minutes. Place pork roast fat side up in the center of a 9-in x 13-in Pyrex baking dish. Place in center of oven and cook uncovered for 2.5 hours.

11. Ground Beef

Food Cooked	Mass (g)	Food Description
Ground Beef	915	Albertson's / less than 30% fat

Place 12-inch skillet on burner and set to medium-high. Pre-heat the pan for one minute. Crumble 2 pounds of ground beef into pan and stir. Continue to cook ground beef for 20 minutes stirring every 5 minutes.

12. Full Meal

Food Cooked	Mass (g)	Food Description
Potatoes	1475	Russet Bakers / Albertson's
Squash and Onion	2555	Yellow squash with yellow onion / Albertson's
Fried Chicken	2130	Foster Farms / whole chicken cut-up / Dixie Fry Original Recipe / Naturally Seasoned Coating Mix
Oil for Chicken	3390	Crisco Pure Vegetable Oil
Broccoli	2935	Ocean Mist / Albertson's / Code # 4060
Gravy	255	Albertson's Brown Gravy Mix
Biscuits	405	Bridgeford Fast-N-Easy / 6 Ranch Style Buttermilk Biscuits / Frozen Package

Turn oven on to 400 ° F and pre-heat the oven for 30 minutes. Pierce potatoes with knife several times and place in 9-in x13-in Pyrex baking dish. Place potatoes in oven for 1 hour 50 minutes. Heat oil in cast iron pot on high for 35 minutes. Pour breading into a large plastic bag and coat pieces of chicken. Cook ½ of chicken in oil for 20 minutes. Repeat with other ½ chicken. Slice yellow squash and onion and place into 4-quart steamer. Cover with water and bring to boil. Simmer for 50 minutes. Cut broccoli florets from the stem and place in to 4-quart steamer. Cover with water and bring to boil. Simmer for 50 minutes. To prepare gravy mix, put 1 cup of water and gravy mix into 4-quart saucepan and bring to boil, simmer for 1minute. During final 25 minutes of potato cooking, remove biscuits from freezer and remove plastic packaging. Place next to potatoes in oven and cook for 25 minutes. All food cooking should be timed to finish at the same time.

APPENDIX D

Gas Range Adjustment Methods and Data

Measurement of Gas Range and Oven CO

Adjustment Method for Range Top Burner

1 – Turn burner control to highest setting. Allow flame to burn for at least 15 seconds.
2 – Burner grate shall be in place.
3 – Arrange Draeger CO detector over sampling hood approximately 12 in. above flame.
4 – Take readings of CO.
5 – Adjust shutter air valve to minimize CO if adjustment is necessary.

Measurement	Location / Burner Setting	CO ppm	Gas flow rate l/min
As is	Left Front / High	35	NA
Out of tune	Left Front / High	47	NA
Back to tune	Left Front / High	25	NA
In tune - stabilized	Left Front / High	13	NA
In tune	Left Front / Medium	5	NA
In tune	Left Front / Low	4	NA
As is	Right Front / High	47	NA
Out of tune	Right Front / High	59	NA
Back to tune	Right Front / High	40	NA
In tune - stabilized	Right Front / High	20	8.9
In tune	Right Front / Medium	5	2.5
In tune	Right Front / Low	5	0.9

NA = not available

Adjustment Method for Oven Burner

1 – Arrange Draeger CO monitor over oven vent exhaust.
2 - Turn burner oven control to 250 °F.
3 – Take readings of CO.
4 – Adjust shutter air valve to minimize CO if adjustment is necessary.
5 – Allow at least 5 minutes before final reading.

Measurement	Location / Condition	CO ppm	Gas flow rate l/min
As is	Oven / warming up for 2 min.	Over 1000	5.85
As is	Oven / warming up for 6 min.	143	5.85
As is	Oven / 5 min. after warm up	8	0

Reference
Conventional Home Weatherization Installation Standards. California Department of Economic Opportunity. January 1995.