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Study of Technology for Detecting Pre-Ignition Conditions of Cooking Related Fires Associated with Electric and Gas Ranges: Phase III

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Prepared by the Directorates for Laboratory Sciences
and Engineering Sciences

EXECUTIVE SUMMARY

Range and oven fires are the leading cause of residential fires in the United States. It is estimated that there were an average of 93,800 fires resulting in 250 deaths and 4,700 injuries annually in the years 1990-1994. Property damage amounted to an average of 397 million dollars annually. Seventy-five percent of the fires involved ignition of food, grease or cooking oils and most (65%) were unattended. As a result, the United States Consumer Product Safety Commission (CPSC) initiated a Range Fire Project to determine the possibility of monitoring changes in cooking gases or temperature to identify pre-ignition conditions and lessen. the risk of cooking fires.

The study was accomplished in three phases. The first two phases were performed by the National Institute: of Standards and Technology (NIST) and the third phase by CPSC. The NIST phases of the study identified smoke particulates, hydrocarbon gases, and temperatures as the primary indicators of pre-fire conditions. NIST conducted over 50 tests using electric and gas ranges. Tests included several attended and unattended cooking scenarios. NIST identified the thermocouples and gas sensors as the detection devices that have the greatest potential use in a pre-fire detection system.

The CPSC phase of the study consisted of 94 tests using electric and gas ranges. The tests included both attended and unattended cooking scenarios to examine temperature settings, pan materials and location, air flow and thermal inertia. Finally, the study examined the potential of several detection devices that may be promising for recognizing pre-fire situations. A kitchen mockup similar to that of NIST's was used with the exception that the CPSC kitchen contained a ceiling fan. Detection devices obtained from NIST were used to detect hydrocarbons, alcohols, moisture, and smoke. Thermocouples were used for measuring pan bottom and pan content temperatures.

The study concluded that for the detection devices tested:

- there was comparability between the CPSC and NIS'T tests;
- pan bottom temperatures provided a good indication of pre-ignition condition;
- gas sensors had generally low and variable responses until near ignition;
- smoke detectors did not respond consistently; and
- range hoods and ceiling fans substantially depressed gas sensor and smoke detector responses.

In addition, pan materials, contents, and type of range affected ignition. Signals from gas sensors were affected by the presence of moisture, previous cooking exposure, forced air flow, and pan position. The variable performance of the gas sensors and smoke detectors in this study should not be construed to mean that they could not be modified to function as a part of a control system. Several possible control approaches are presented based on the NIST and CPSC data.

Based on the above conclusions, the following recommendations are proposed:

- meet with manufacturers of gas sensors and smoke detectors to determine if the function of these devices can be sufficiently improved for this application; and

- develop a prototype control system to test for long term reliability in preventing range fires using thermocouples alone or in combination with gas sensors or smoke detectors (if they can be sufficiently improved).

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1.0 OVERVIEW

1.1 INTRODUCTION (SECTION 6.0)

During the years from 1990 through 1994, range and oven fires were the leading cause of residential fires (Monticone, 1997). Annually, ranges and ovens were involved in an average of 93,800 fires resulting in 250 deaths and 4,700 injuries. Property loss amounted to an average of 397 million dollars annually. Seventy-five percent of these fires involved ignition of cooking materials, primarily grease, and sixty-five percent of these involved the absence of the cooks.

As a result of the number of deaths, injuries, and property loss, the Consumer Product Safety Commission (CPSC) initiated a Range Fire Project. The primary objective of the project was to determine if available technology could be used to identify pre-fire conditions and lessen the risk of unattended cooking tires. The specific pre-fire conditions anticipated to have the greatest potential were increases in particles from the thermal degradation of grease or oil, temperatures of the cooking vessel or pan contents and an increase in gaseous organic vapors associated with the thermal degradation of food as it approaches auto-ignition temperatures.

To date the study has progressed through three phases. The first two phases were performed by the staff at the National Institute of Standards and Technology (NIST) (Johnsson 1995 and Johnsson 1997), while the third phase was performed by the CPSC Staff (Phase III). Both the NIST studies and. CPSC studies were conducted in a model kitchen whose dimensions were 8 A (2.4 m) by 12 ft (3.6 m) with a ceiling 8 A (2.4 m) high. The kitchen had entrance doors, a test range, base cabinets, wall cabinets, and a range hood. The model kitchen was equipped with an array of thermocouples, smoke detectors, and gas sensors. The primary difference between the MST and CPSC kitchens was the presence of a ceiling fan in the CPSC kitchen.

This overview provides an expanded summary of the CPSC phase of the range fire study. To place the CPSC phase of the study in perspective, a brief review of the two NIST studies is also presented. Sections listed in parentheses after subsection titles refer to the report section where more detail is provided than in the overview.

1.2 NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, (NIST) STUDIES (SECTION 7.0)

The MST Phase I (Johnsson 1995) study consisted of two parts. In the first part, tests were conducted using various foods on different range types. The second part was a literature and patent search for devices, systems or methods for detection of pre-fire conditions. The types of ranges used in the first part of the study were an open coil electric, a smooth top electric, and a high output gas using foods most often associated with cooking fires such as cooking oils, bacon, and sugar. Common pre-fire indicators were found to be smoke particles, hydrocarbon gases, and the temperatures of the food and cooking vessel. The literature search identified several potential means of detecting these indicators. These included various tin oxide sensors (for alcohols, moisture, and hydrocarbons), light scattering detectors (for smoke particles), miniature infrared detectors (for hydrocarbons), and thermocouples (for temperatures).

The MST Phase II (Johnsson 1997) study expanded the Phase I study by investigating the responses of a variety of detection devices to various cooking scenarios. These devices were located both in the immediate cooking area and at various distances from the range. A total of 21 cooking scenarios and 43 tests were conducted during this phase of the study including extremes of attended cooking such as blackened fish and periods of attended cooking followed by periods of increased heating that led to ignition. Several tests investigated the effects of using a range hood on thermocouple and gas sensor signals and smoke detectors (photoelectric and ionization responses). A review of the MST data indicated that thermocouples and gas sensors at locations not in the immediate vicinity of the range did not produce signals at levels needed for reliable detection of incipient fires. The major findings of the MST Phase II (Johnsson 1997) study were as follows:

1. Individual detection devices produced a stronger signal as the cooking activity approached ignition than in normal cooking.
2. Household photoelectric and ionization smoke detectors used in the study could detect pre-ignition conditions, but generated a significant number of false alarms.
3. All detection devices tested showed some potential for being developed into a system for preventing cooking fires. The number, variety, location, and construction of the detection devices were important aspects of their ability to detect pre-ignition conditions.
4. Some attended cooking procedures may generate signals which are similar to those in pre-ignition conditions. In these cooking procedures, the attending cook could use a bypass switch to override the normal detection/control system response.
5. A combination of three sets of two signals each produced better differentiation between attended and unattended cooking periods than individual detection devices. One cooking-alcohol sensor at the front center of the range hood and a thermocouple contacting the bottom of cooking pan appeared to be the most effective pair.
6. Preliminary data indicated that the detected signals appear independent of range type, hood status, and pan material.
7. Based on the tests conducted, it appears that pre-fire detection systems for range-top cooking are feasible and should be further investigated.

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CPSC conducted 94 tests which were an extension of the two NIST studies and incorporated suggestions from the United States Fire Administration (USFA), NIST, and the Association of Home Appliance Manufacturers (AHAM). The CPSC study consisted of preliminary tests (12) to demonstrate reproducibility of data between NIST and CPSC and 82 tests to evaluate pre-ignition detection devices. The test plan for the Phase III testing had the following objectives: (1.) determine the reproducibility of the CPSC testing results to those of NIST for selected tests in common; (2) complement NIST's pre-fire condition discrimination testing scenarios by looking at additional abnormal and normal cooking scenarios and assessing other key variables such as different temperature settings for cooking, different pan materials and pan locations on the range, room air flow, and thermal inertia; and (3) consider approaches and/or experimental systems that may have potential to prevent range fires.

1.4 TESTING FACILITIES (SECTION 8.1)

The CPSC testing began shortly after completion of the MST Phase II testing. This allowed the kitchen cabinets,, sensors, and ranges used in the MST studies to be transferred and installed in the CPSC testing facility. The sensors installed in the CPSC kitchen were located in the same places as those in the MST kitchen. In both the CPSC and MST kitchens, a range hood was installed over the range. The primary difference was that the CPSC kitchen had a 40 in (1 .01 m) low speed ceiling fan installed roughly in the center of the room. The fan and range hood were only used in tests studying the effect of forced air movement or ventilation on sensor response. The ranges used for the CPSC tests were the same as used in the MST studies. The gas range was a natural gas fired range. The electric ranges were an open electric coil type and a down draft range with open electric coil heating elements.

1.5 RESULTS AND DISCUSSION

1.5.1 Selection of Detection Devices

A qualitative review of the MST and CPSC data showed that many of the same detection devices showed little response from the beginning to ignition during the course of a cooking scenario. These included thermocouples not in the immediate vicinity of the burner on which cooking was taking place and gas sensors that were located outside of the plume of cooking gases. The detection devices that showed significant responses in both studies included gas sensors placed above and along the centerline of the range or cooktop and thermocouples measuring the food, pan bottom, and drip pan temperatures.

1.5.2 Reproducibility of NIST and CPSC Tests (Section 10.1)

To determine the reproducibility between the NIST and CPSC studies, thermocouple readings from the pan bottom and contents were compared for selected tests, as were signals from gas sensors located on the rear wall between the range and range hood, on the front of the range hood, and on the ceiling directly above the range. In the six minute period before ignition, the thermocouple readings were the most consistent for all test comparisons with similar rises in temperature for both laboratories just before ignition. For example, the mean of the pan bottom temperatures in four tests performed with soybean oil (two by NIST and two by CPSC) at ignition averaged 462.1 °C (864°F) with a standard deviation of 35.5 °C (64°F). Similarly, the mean pan content temperatures for the same four tests averaged 394.5 °C (742°F) with a standard deviation of 24.8 °C (44.6°F). These results indicated the reproducibility of data.

Although the signals from the gas detection devices showed less consistency, the general trends were similar, particularly in the six minute period before ignition occurred. The initial sensor voltages were not consistent, however, from run to run for either laboratory nor were the maximum signals recorded just prior to ignition. This may be related to the fact that most of the tests went to ignition and the sensors, particularly those near the range, were repeatedly exposed to high temperatures, smoke, and oil vapor. High initial sensor voltages were typically preceded by an oil cooking scenario.

The following three sections (Tests with 30 ml of oil, thermal inertia, and temperatures at ignition) deal with issues that place the remainder of the test results in perspective. These data define the temperatures used for the remainder of the study.

1.5.3 Tests with 30 ml of Soybean Oil (Section 10.2)

The test plan specified cooking scenarios using as little as 30 ml of soybean oil in some tests. During these tests, the staff observed that the oil tended to form puddles that did not fully cover the bottom of the pan. This prevented the pan content thermocouple from being submerged in the oil. Ignition did not always occur consistently in these tests and when it did occur, the pan content temperatures were inconsistent (range 272°C to 485°C [522°F to 905°F] for metal pans). Pan bottom temperatures for the 30 ml oil tests ranged from 424°C to 452°C (795°F to 846°F) which was consistent with the pan bottom temperature range of 382°C to 494°C (720°F to 92 1 °F) measured for all tests using metal pans.

1.5.4 Thermal Inertia (Section 10.3)

In some tests using oil in different kinds of pans on electric ranges, the oil ignited after the range had been turned off This was due to a thermal inertia effect whereby the residual heat in the burner coils that continued to heat the pan after the range had been turned off. The degree of residual heating (depended on the amount of oil present and the temperature of the oil at shut off The continued temperature rise after the heating coil was turned off was a result of the heat source being at a much higher temperature than the pan and pan contents. The temperature rise of the pan contents, resulting from residual heat in the heating coils was sufficient to result in ignition in some cases even after the heating element had been turned off.

The tests were conducted with empty pans and pans containing either 100 or 500 ml of soybean oil. The tests were allowed to continue to pan content temperatures of 380°C (716°F) for empty pans, and 260°C (500°F), 330°C (626°F), or 360°C (680°F) for tests using oil. These temperatures were chosen to determine the relationship between shut off temperature and pan content temperature increases. In the case of empty pans, the temperature rise of 2°C after shut off of the heating element was the lowest measured. This was probably related to the rapid convective cooling of the pan and the fact that the pan content thermocouple was measuring both pan bottom and air temperature.

Tests with 100 ml and 500 ml of soybean oil showed three features. First, the temperature rise for both the 100 and 500 ml oil tests decreased as the shut off temperature increased from 260°C (500°F) to either 330°C (626°F) (100 ml tests) or 360°C (680°F) (500 ml tests). Second, after shutting off the burner, the 100 ml oil tests resulted in a greater temperature increase than the 500 ml tests. Thus, the pancontent temperature rise after shut off at 260 °C (500°F) was 50°C (90°F) and 34°C (61°F) with 100 ml and 500 ml of oil, respectively. The pan content temperature rise after shut off at 330°C (626°F) (100 ml of oil) or 360°C (680°F) (500 ml of oil) was 32°C (58°F) and 16°C (29°F) respectively. Third, the difference between pan bottom and pan content temperatures, at their maxima, became less as the amount of oil decreased. The differences in pan bottom and pan content temperature for 1.00 ml and 500 ml of oil were 10°C (18°F) and 54°C (97°F), respectively.

1.5.5 Temperatures at Ignition (Section 10.4)

A potentially important parameter in range fires is the temperature of the pan bottom and pan contents at the ignition point. The CPSC testing resulted in 41 tests, using metal pans, that achieved ignition. Of those tests, 37 were conducted with oil alone or oil used in cooking chicken as the pan contents. The remaining two tests used sugar as the pan contents. The tests that used oil or oil and chicken showed a range of pan bottom temperatures from 386°C (727°F) to 494°C (921°F) (average 438°C [820°F] with a standard deviation of 30°C [54°F]), the pan content temperatures at ignition ranged from 346°C (655°F) to 410°C (770°F). The two tests that used sugar as the pan contents had pan bottom temperatures of 334°C (633°F) and 360°C (680°F) and pan content temperatures of 310°C (590°F) and 289°C (552°F). These data indicated no major effect on pan bottom or pan content temperatures at ignition due to the use of range hoods, down draft ranges, or ceiling fans. For these tests, a probability of eliminating 99 percent of the ignitions in metal pans would require that the pan bottom temperature not exceed a temperature of 347°C (657°F). If the effects of thermal inertia for electric ranges are included in establishing a cutoff point to prevent ignition, the pan bottom temperature should not exceed 315°C (603°F) to 330°C (626°F), depending on the volume of oil. These temperatures are consistent with limits for electric frying pans of 300°C (572°F) covered by an Underwriters'

Laboratories Standard 1083, and recommendations by the Food Appliances Section of Good Housekeeping for temperatures required for attended cooking.

1.5.6 Effect of Heat Settings and Pan Materials (Section 10.5.1)

Different pan materials (aluminum, stainless steel, or ceramics) can affect the uniformity of pan or content temperatures or the production of cooking gases. Cooking at lower heat settings also affected the rate of temperature rise and can result in different rates of production of cooking gases. Tests using stainless steel pans, heavy aluminum pans, and ceramic (glass) pans were conducted at high and medium high heat settings, with 500 ml of oil. The only tests that proceeded to ignition were those at the high heat setting. The medium-high heat setting tests were run until the temperatures were essentially constant for a period of 10 minutes. Pan bottom and pan content temperatures, and sensor voltages were compared when the pan content temperature was 288°C (550°F) (pan bottom temperature of 330°C [626°F]).

Voltage outputs increased with increasing cooking gas concentrations, but no effort was made to determine the relationship between voltage and concentration, since the focus of the study was on the ability of the sensors to respond. The data obtained from the gas sensors showed variability both in their initial voltages prior to exposure to cooking fumes and in the differences in voltage between initial voltage and voltage at 288°C (550°F) pan contents temperature. The variation in gas sensor signals for test groups was greatest with ceramic pans. With tests using metal pans, the general hydrocarbon sensors near the range tended to provide greater increases over initial voltages than the other gas sensors on the ceiling in front of the range. The cooking alcohol sensors with metal pans did not show as much site to site variation. Gas sensor responses from aluminum pan tests for medium high (non-ignition) tests were actually greater than sensor responses for high heat tests which did ignite. The medium high tests were performed longer than high heat tests and yet did not terminate in ignition. This effect was only occasionally seen with stainless steel pans, while ceramic pans exhibited mixed behavior. The longer time and constant heat setting (once steady state pan content temperature was reached) caused more cooking vapors to be produced, which allowed the gas sensors to pick up more cooking vapors (hence, produce higher voltages).

1.5.7 Thermocouple Position and Pan Materials (Section 10.5.2)

The low conductivity of the ceramic materials (0.2 to 5 percent of that of metals, [Lange 1956]) highlighted the need to properly place thermocouples to measure the panbottom and pan content temperatures. The pan bottom thermocouple was typically located near the center of the pan, while the pan content thermocouple was typically located closer to the heating coils. For ceramic pans this caused the pan content temperatures to be hotter than the pan bottom temperature. To assess the reasons for the temperature differences observed with ceramic pans, tests were performed with oil or water and pan content thermocouples located in two different positions. Two pan content thermocouples, both in contact with the bottom of the interior of the pan were installed. One was placed over the centrally located pan bottom thermocouple and the second offset about 2.25 in (57 mm) to be closer to the heating coils. The centrally located pan content thermocouple registered a temperature 25°C (45°F) higher than the centrally located pan bottom thermocouple. The offset pan content thermocouple registered a temperature 33 °C (59°F) higher than the centrallylocated pan bottom thermocouple. In contrast, a test with a stainless steel pan showed nearly identical temperatures for the centrally located and offset pan content thermocouples with a pan bottom temperature of about 40°C (72°F) higher than the pan content temperature. 'Accurate measurement of pan bottom temperatures for a variety of cooking vessel materials may require placing at least two thermocouples such that they encompass the various temperature regions associated with the particular heating elements used.

1.5.8 Effects of Air Flow (Section 10.6)

One factor that could affect the ability of sensors to react to a particular rate of production of smoke, gases, or hydrocarbons is ventilation or air circulation in the vicinity of the cooking activity. Ventilation from the use of range hoods or down draft ranges, or air circulation from the use of ceiling fans caused the hydrocarbons and smoke to be diluted. Since smoke detectors and gas sensors are dependent on particulate or gas concentration, the dilution effect of ventilation or air circulation could result in their failure to respond to a pre-fire condition. All ventilation tests were conducted at the highest heat setting.

A series of tests investigated the effects of ventilation and air circulation on the signals produced by the gas sensors. Tests were performed on both the front and rear burners using gas sensors located on the centerline of the range at different heights ranging from immediately above the range to the ceiling. Data obtained at a 288°C (550°F) pan content temperature were compared for tests with and without forced ventilation or air circulation.

The tests showed reductions of sensor signals when a range hood, a ceiling fan, or both were operated. On the: front burner, the signal in tests with ventilation ranged from 0 to 15 percent of the non-ventilated test results depending on sensor location. Ceiling mounted sensors showed the least change in strength for the front burner tests with values that were 33 to 43 percent of the non-ventilated tests. On the rear burner, the average of signals from all tests with ventilation ranged from 0 to 60 percent of the non-ventilated tests depending on sensor location. The wall mounted sensors showed the least reduction in strength for rear burner tests with values ranging from 40 to 60 percent of the baseline tests. While the concentration of cooking vapors is relatively low under these conditions, similar effects were noted at higher concentrations closer to ignition.

These data do not quantitatively agree with limited tests done by MST (Johnsson, 1997) where smaller reductions in gas sensor signals were observed with the use of a range hood. Although the difference in data between NIST and CPSC is unexplained at this time, the presence of forced air movement is consistent with dilution of the cooking gases and thus a reduction in gas sensor output.

Tests were also conducted with the down draft range which had an additional set of sensors placed in the down draft opening to evaluate whether sensors would record a change from baseline tests. Tests were performed only on the rear burner. Overall, operating the down draft feature was somewhat less effective in removing/diluting the gases than either the range hood or ceiling fan. The: ceiling mounted sensor signals ranged from 12 to 40 percent of the non-ventilated tests. The gas sensors, even though placed in the exhaust stream, showed some decrease in signal strength when the down draft feature was operating compared to signals from detectors mounted above the range. Thermocouple readings were not affected appreciably by air flow or ventilation.

1.5.9 Effect of Water Vapor and Aging on Gas Sensors (Section 10.7)

The gas sensors tested were general hydrocarbons, total cooking, general alcohols, cooking alcohols, and water vapor sensors. During cooking, water vapors produced by boiling or steaming can be present at the same time that hydrocarbon vapors are being produced from frying procedures. Since gas sensors did not always return to the same pre-fire signal level, the absolute magnitude of the sensor output was not used for evaluation of these data. Rather, the difference between the final voltage and the initial voltage was used as the detector response. Gas detection devices, exposed to water vapor only, showed an increase ranging from 0.25 to 0.7 volts over the initial voltage. When oil was heated in the presence of water vapor, responses were reduced to 40 to 80% of the signal obtained with oil alone.

To evaluate the effects of aging on sensor voltage, the ratio of the resistance of the device with no exposure to gases to the resistance as the amount of gas increased during the cooking scenario was determined,. The resistance ratio was used to normalize the data for the comparisons.

Two total hydrocarbon gas sensors were placed next to each other over the range. One device was new while t:he second had been used by NIST and CPSC for a number of tests. Analysis of the data at both high and medium high heat settings, for cooking scenarios using soybean oil showed that while the two sensors tracked each other, the resistance ratio of the new sensor was slightly lower than that of the old sensor (i.e., the new sensor responded more readily).

1.5.10 Additional Pre-fire Discrimination (Section 10.8)

AHAM suggested four additional test scenarios to better explore the function of gas sensors and thermocouples in detecting pre-fire situations. These consisted of caramelizing sugar on a high heat setting until the sugar boiled over and ignited, deep frying chicken in soybean oil (2 L) using both gas and electric ranges, and preparing a flambe dessert.

In the case of the caramelized sugar test, ignition occurred at a pan bottom temperature of about 330°C (626°F). In comparison 31 tests involving soybean oil ignited at an average pan bottom temperature of 442°C (828°F), ranging nom 382°C (720°F) to 494°C(921°F). The cooking alcohol sensor signal increased as the cooking temperature increased.

Tests involving chicken cooked in 2 L of soybean oil were performed on both gas and electric ranges. Two tests were performed on each range type. In the second of two tests on the electric range, the cooking alcohol sensor at the center front of the range hood had a high initial voltage reading. The final voltage at ignition was about 13 volts for both tests. The high initial voltage for the sensor was probably due to residual contamination of the gas sensor from previous tests. For the two tests on the gas range, the cooking alcohol sensor at the center front hood location exhibited roughly similar responses throughout the test with a maximum voltage at ignition of about 14 volts. With either a gas or an electric range, the center front hood location cooking alcohol sensor produced a signal change of 4 to 11 volts. Gas sensors for total cooking gases at the center front hood location and ceiling above the range hood location also showed increases of 6 to 8 volts.

Two tests were performed to prepare a flambe dessert. The flambe test consisted of pouring warm brandy over heated bananas (pan bottom temperature about 200°C [392°F]). The mixture continued to be heated on a burner and the brandy was ignited. Voltage from the cooking alcohol sensor at the center front hood location rose when the bananas were placed in the pan, fluctuated inconsistently when the brandy was added, and finally increased sharply about a minute after the brandy was ignited. The data showed that the most noticeable changes occurred after ignition of the brandy. Pan bottom temperatures remained low and the bananas did not ignite. Both the caramelized sugar and flambe tests showed that ignition can occur at temperatures lower than seen with oils. Neither test scenario is likely to be unattended.

1.5.11 Smoke Detector Performance (Section 10.9)

Both photoelectric and ionization type smoke detectors were installed at various locations in the test kitchen, to assess their usefulness in detecting pre-fire conditions. The photoelectric detectors were located at the range splash panel, the center front hood, ceiling above hood, and in the entry door. The ionization detectors had been modified, according to instructions provided by the manufacturer's representative, to allow signals to be monitored as the accumulation of smoke built up and alarm occurred. In practice, the modifications did not perform as expected. Further, the staff noted that battery life was shorter than expected and all but one of the ionization detectors failed to produce usable data. Thus, data for the single ionization detector that worked was limited to those tests where the batteries were propqly functioning.

In cases where ignition occurred, all detector alarms activated. Depending on location, 0 to 15 percent alarmed after ignition. The percentage of detectors alarming within 2 minutes of ignition ranged from 18 to 45 percent, while within 4 minutes of ignition, 47 to 64 percent of detectors responded. Thirty-seven to forty-six percent of the alarms occurred at times more than 4 minutes prior to ignition. In some tests, where attended cooking was followed by unattended cooking proceeding to ignition, the alarms occurred during the normal cooking period. In cases where ignition did not occur, the range of "false alarms" (i.e., alarms during attended cooking) was 81 to 100 percent.

The use of a range hood or ceiling fan adversely affected the smoke detector responses. The location of the smoke detector and in the case of the range hood operating, the location of the pan on the range also had an effect. When a range hood, ceiling fan, or down draft range was used, photoelectric detectors located outside the range hood failed to alarm until after ignition in 10 of 14 tests. Ten of eleven tests with cooking on the rear burner while using the range hood resulted in failure of the photoelectric detectors to alarm.

Currently manufactured smoke detectors, as used in these tests, appear to alarm early and during normal cooking to an extent that suggested that different sensitivity settings or exposure/sampling configurations would be required for them to provide a reliable pre-ignition indicator.

1.5.12 Possible Control Svstem Approaches (Section 11)

The CPSC staff modeled three approaches for control systems. The models were based on data obtained from CPSC tests that resulted in ignition. The intention was to define the point at which some action needed to occur. The action could be either setting of an alarm, shutting off the range, or causing the range burner(s) to cycle.

Each of the three modeling approaches was based on a pan bottom temperature of 340°C (644°F) and one of the combined temperature and gas sensor data. The approaches were as follows:

(1) Use of a simple thermostat that, after reaching a preset pan bottom temperature, either shuts off the range or cycles the heating to prevent any further increase in temperature.

(2) Monitoring the rate of increase in pan bottom temperature relative to the pan bottom temperature to provide greater flexibility in allowable pan ‘bottom temperatures. The rationale for this approach was that coupling the rate of change in pan bottom temperature with the actual pan bottom temperature allowed discrimination of the initial heating of the cold pan contents (which could be rapid) from the later phase when the pan contents are approaching the set point temperature. In the later phase, the system could cycle to prevent the pan bottom temperature from increasing to a point that ignition might occur.

(3) Use of a combination of pan bottom temperature and a gas sensor for determining if control action was necessary. This approach was taken to address preliminary work done by NIST that suggested a combination of gas sensors and temperatures might provide better discrimination of pre-fire conditions than either temperatures or gas sensors alone.

The modeling indicated that a simple thermostat that either shuts the range off or cycles the range on and off once a critical pan bottom temperature is reached, would prevent many fires. The critical temperature needs to be chosen carefully to avoid nuisance actions (shut off or alarm) when a pre-fire condition does not exist. Cycling clearly makes such events less likely and lessens the nuisance factor. However, some ignitions of pan contents (such as sugar) may still occur.

Monitoring the rate of change of pan bottom temperature would allow for more rapid initial heating but would then act as the simple thermostat described above. Again the critical level of the pan bottom temperature must be carefully chosen to avoid nuisance alarms and some pan contents such as sugar may still ignite.

The combination of gas sensors and temperature for controlling the range operation permits the possibility of higher temperatures for cooking while potentially offering some additional protection from certain ignition scenarios such as caramelizing sugar. A factor that must be considered is that use of range hoods or ceiling fans causes large decreases in the signals generated by the gas sensors. There also needs to be a way to deal with sensors becoming dirty and to limit nuisance shut offs. The pan contents may still ignite.

1.6 CONCLUSIONS AND RECOMMENDATIONS (SECTION 12.0)

1.6.1 Conclusions .

The major conclusions of this report are based on the measurements and observations obtained with the detection devices, ranges, pans, pan contents, ventilation, and the model kitchen used in this study. Extrapolations to other conditions should be made with caution. Further, while some sensors might not have responded adequately or consistently in this study, they may be able to be modified to work adequately if designed specifically for cooking applications. The major conclusions are as follows:

- Tests performed at the NIST and CPSC showed similar pan bottom and pan content temperatures and signals from gas sensors during the 6 minutes before ignition.

- Thermal inertia caused a temperature increase in the pan contents of 16°C to 50°C (29 to 90°F) after shutting off the electric burner. The variability is related to oil volume and shut off temperature.

- Pan bottom thermocouples provided a reliable indication of pre-fire conditions. Based on the conditions of the tests performed at the CPSC Engineering Laboratory, it is estimated that 99% of the ignitions with metal pans could be detected prior to ignition if detection criteria were that the pan bottom temperature should not exceed 340°C (644°F) and the pan content temperature should not exceed 300°C (572°F).

- Ceramic pans did not conduct heat as well as metal pans and required careful thermocouple positioning to obtain an accurate temperature reading for the pan bottom.

- Gas sensor signals were generally low and variable until the pan contents approached ignition. Their signals were partially depressed by the presence of water vapors. Sensor signals fiom non-ignition cooking tests were as high as those for ignition tests.

- Smoke detectors tended to alarm during normal cooking and in some instances failed to alaxm before a pan bottom temperature of 360°C (680°F).

- Whether the gas sensors and smoke detectors could be modified to more accurately detect a pre-fire condition, with fewer nuisance alarms is uncertain.

- Air flow in the vicinity of the gas detection devices caused by ceiling fans or range hoods can reduce the signals produced to 5 to 10 percent of the signal obtained without forced movement. Use of a range hood or ceiling fan caused most smoke detectors to alaxm after ignition.

1.6.2 Recommendations

Based on the above conclusions, the following recommendations are proposed:

- meet with manufacturers of gas sensors and smoke detectors to determine if the function of these devices can be sufficiently improved for this application; and

- develop a prototype control system to test for long term reliability in preventing range fires using thermocouples alone or in combination with gas sensors or smoke detectors (if they can be sufficiently improved).

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3.0 LIST OF AUTHORS

The following CPSC staff members collaborated in building the mockup kitchen, conducting and analyzing the experiments, and/or preparing this report: Aaron Banerjee, Christopher Brown, Thomas Hardison, Chance Hollewerth (CPSC student intern), Edward Krawiec, Han Lim, Larry Mulligan, Mai Ngo, Diane Porter, Warren Porter, Andrew Trotta, and Andrew Ulsamer.

4.0 LIST OF FIGURES AND TABLES

Page Number

5.0 LIST OF TABLES

6.0 INTRODUCTION

During the five years from 1990 through 1994, range and oven fires were a leading cause of residential fires (Monticone, 1996). The estimated annual number of fires involving ranges and ovens averaged 93,800 resulting in 250 deaths and 4,700 injuries. Property loss amounted to 320 million dollars. Seventy five percent of these fires involved food, oils, or grease and sixty-five percent involved the absence of the cooks.

As a result of the number of deaths, injuries, and property loss, the Consumer Product Safety Commission (CPSC) initiated the Range Fire Project in 1994. The goal of the Range Fire Project was to reduce the number of cooking-related fires in homes. To achieve this objective, the staff initiated a study of the characteristics of residential cooking fires to see how they could be prevented. The major objective of this study was to determine if available technology could be used to identify the pre-fire signatures and lessen the risk of unattended cooking fires.

The specific parameters anticipated to be of value were an increase in smoke particles from vaporized grease or oil, temperatures of the cooking vessel or food contained in the vessel, and an increase in gaseous vapors associated with the evaporation or decomposition of food as it approaches ignition temperatures.

To date the study has progressed through three phases. The first two phases of the study were conducted by the National Institute of Standards and Technology (NIST) (Johnsson 1995 and Johnsson 1997) while the third phase was conducted by the CPSC Staff at the Commission's Engineering Laboratory.

The sections that follow provide a summary of the results of the NIST Phase I and II testing (Section 7), a description of the CPSC test plan and methodology, test facility setup, and instrumentation (Section 8), a summary of the CPSC safety procedures (Section 9), a presentation of the CPSC test results with discussion (Section 10), an assessment of possible control system approaches that could be used to prevent fires (Section 1 1), and the conclusions (Section 12).

7.0 REVIEW OF NIST TESTING

This section provides a summaryof the results and conclusions of the first two phases of the Range Fire project testing conducted for CPSC by MST.

7.1 MST Phase I

This phase of the range fire project (Johnsson 1995) consisted of two parts. The first part was an engineering study in which a total of twenty-two experiments were conducted on two electric ranges, an open coil, and a smooth top, and on a gas stove with high-output burners. Half of these tests were performed with an active range hood. The effect of the hood was insignificant at the center of the cooking plume (approximately 6" above the burner surface), where thermocouples, a laser, an IR device, and a velocity probe were placed. Stainless steel cooking pans were found to produce shorter ignition times than aluminum pans. Among the different food groups, soybean oil, bacon, and table sugar were chosen for their prevalence in cooking fires based upon data evaluated by CPSC. Data on temperature, laser attenuation, plume velocity, and time to ignition were recorded as were infra-red images and Fourier transform infra-red spectroscopic (FTIR) data. This phase of the study indicated that with specific combinations of the above foods and ranges, temperatures, smoke particulates, and hydrocarbon gases were the best parameters for defining pre-ignition.

The second part of the Phase I effort was a literature and patent search of existing or potential devices, systems, or methods capable of detecting preignition conditions. The most promising detection technologies identified were tin oxide (SnO_2) and narrow-band infrared absorption (non-dispersive: infrared NDIR) sensors for hydrocarbons, miniaturized NDIR technology for CO detectors, scattering or attenuation types of photoelectric devices for smoke particles, and thermocouples for contact thermometry. Results from the search also indicated that in related applications such as fire detection, or hazardous gas detection, combining multiple sensor outputs has proven successful in reducing false alarms. Control technology to shut-off and restart an electric or gas range was found to be available.

7.2 NIST Phase II

The objectives of this phase of the MST study were to determine if there was a possibility of differentiating between normal and hazardous pre-ignition cooking conditions. This effort included an evaluation of the potential of individual or combined pre-ignition indicators to sense that window. A wider selection of cooking scenarios was examined based on comments from range manufacturers, Underwriters Laboratories (UL), CPSC staff, and others. Tests included extreme cases of normal cooking procedures, as well as additional detection device locations to acquire data. A total of twenty-one scenarios and forty-three tests were conducted on four different range types. Some of the scenarios generated unusually high levels of one or several pre-ignition indicators such as smoke, steam, hydrocarbon gases, or high temperatures. Several tests consisted of periods of attended cooking followed by periods of unattended cooking leading to ignition by increasing the temperature setting. Numerous selected locations were added to sample distributions of gas concentrations, temperatures, or smoke. Based on the specific ranges, foods, pans, and ventilation, in the Phase II MST tests, the following observations were made by MST:

* Individual detection devices can detect a stronger signal when approaching ignition in hazardous cooking than in normal cooking.
* Household photoelectric and ionization smoke detectors tested can detect preignition conditions fairly well, but generate a significant number of false alarms.
* The detection devices tested all showed some potential for being developed into a system for preventing cooking fires. Some will require more development than others. Also, the quantity, variety, location, and construction of the detection devices were an important aspect of their ability to detect pre-ignition conditions.
* Some attended cooking procedures may generate signals which are similar to those in pre-ignition conditions. Since in these procedures, an attending cook is a prerequisite, a bypass button can override the normal system response.
* A combination of three sets of two signals each produced better differentiation between attended and unattended cooking periods than individual detection devices. One cooking-alcohol sensor at the front center of the range hood and a thermocouple contacting the bottom of the cooking pan appeared to be the most effective pair.
* Preliminary results on the data indicated that the detected signals appeared to be independent of range type, hood status, and pan material.
* Based on. the tests conducted, it appears that pre-fire detection systems for range-top cooking are possible and should be further investigated.

8.0 PHASE III: CPSC TESTING METHODOLOGY

Phase III of the range fire prevention project was conducted at the CPSC Engineering Laboratory as an extension to the MST study. The test plan for the phase III testing had the following objectives: (1) compare CPSC testing results to MST results by repeating some baseline tests performed at NIST to provide for a correlation between the two facilities; (2) complement MST's pre-fire discrimination testing scenarios by looking at additional cooking scenarios and assessing other key variables such as different temperature settings for cooking, different pan materials and locations on the range, room air flow, and thermal inertia effects; and (3) examine the possibility of approaches and/or experimental systems that may be promising to shut off, or warn of, a pending ignition condition. This series of tests included numerous suggestions from the USFA, MST, and the Association of Home Appliance Manufacturers.

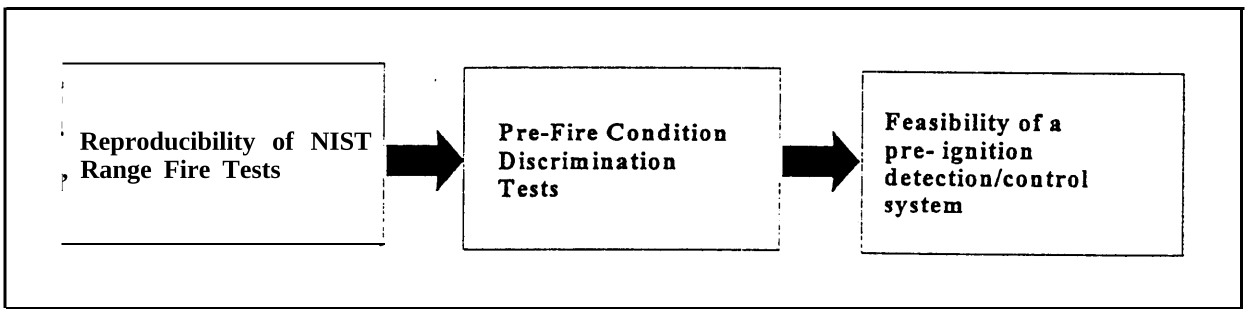

Figure 8.0A: Overall approach to CPSC Testing

The overall approach to the testing performed by CPSC is shown in Figure 8.0A. Test plan Tables 3 through 7 from the phase III CPSC experimental plan describe the tests conducted.

Test Plan Table 3 : Reproduction of Several NIST Tests -- Test Facility Correlation.

Cooking scenario numbering is kept the same as in the NIST Phase II Experimental Test Plan for quick reference.

Cooking Scenarios	Ranges	Descriptions	General Procedures	Number of Tests
1. Soybean oil (A) (ignition) NIST 960 I, 9624	Electric	500 ml oil in a 26 cm (10 in) diameter stainless steel frying pan.	Heat on high until ignition.	Two tests
3. Bacon (ignition) MST 9602.96 17	Electric	227 g (8 oz) bacon in a 26 cm (10 in) diameter stainless steel frying pan.	Thaw bacon. Heat on high until ignition.	Two tests
9. Soybean oil and water (attended to ignition)	Gas (NIST 9635, 9637)& Electric (NIST 9612, 9632)	500 ml oil in a 26 cm (10 in) diameter stainless steel fiying pan. Three 2.5 L water in 3.8 L (4 qt) stainless steel sauce pans.	First heat oven to 204°C (400°F). Then heat water on high on three burners. After 9 min, heat oil on high on the large front burner for 5 min. Decrease heat under oil to medium-low. After 18 min, increase heat under oil to high until ignition.	Two tests on each range Four tests
11. Chicken in soybean oil (attended to ignition) NIST 9608, 9625	Electric	Approximately 750 g (1.65 lb of chicken (3 whole legs) in 500 ml soybean oil in a 26 cm (10 in) diameter stainless steel frying pan.	Heat oil to 190°C 4°F) on high. Introduce chicken to oil. Reduce heat to medium and turn chicken every 4 min for 20 min. Increase heat to high until ignition.	tests
Total of 10 tests.				

Test Plan Table 4: Additional Pre-fire Condition Discrimination Tests

Cooking Scenarios	Ranges	Descriptions	General Procedures	Numb of Tut
1. Caramel Sugar (boil-over to ignition)	Electric	227 g table sugar in a .95 L (1 qt) sauce pan, stainless steel.	Place the measured sugar in a sauce pan on the large front burner. Heat on high until ignition.	Two test
2. Chicken in soybean oil (attended to ignition)	Gas & Electric	Deep Frying. Approximately 750 g (1.65 lb) of chicken (3 whole legs) in 2 L (8 cups) soybean oil in a 6 qt Dutch oven (10" [254 mm] x4½ "[114 mm]) stainless steel pan.	Heat oil to 190°C (374°F) on high at the large front burner. Introduce chicken to oil. Reduce heat to medium. Cook chicken until well-brown on all sides, turning frequently with tongs, up to 15 minutes. When chicken is fork-tender, increase heat to high until ignition.	Two test on each stove Four tes
3. Fruit Flambe	Electric	Flambe 6 split bananas in 3 tablespoons of butter, 3 tablespoons of brown sugar, and ½ cup of Brandy or liqueur.	In a small saucepan, melt the butter first and brown sugar, stirring until dissolved. Cook over low heat for 4 to 5 minutes. Add fruit. Simmer until tender, basting occasionally. Heat ½ cup brandy to lukewarm in a another small saucepan. Sprinkle the fruit lightly with sugar and then pour the warm liqueur over the warm fruit. Re-cover the pan for a moment before touching a lighted match to brandy. location of flambe to be on the front small burner that has been turned off prior to the introduction of the lighted match	Two test
Total of 8 tests.				

Test Plan Table 5: Effect of Heat Settings and Pan Materials

Cooking Scenarios	Types of Pan	Ranges	Descriptions	Genera! Procedures	Number of Tests
1. soybean oil (ignition)	Stainless S teel, Heavy Aluminum, Ceramic (Glass)	Electric	30 ml oil in a frying pan	Place frying pan on large front burner. Heat on high until ignition or steady state.	Two tests on each pan 6 tests
2. Soybean oil (ignition)	Stainless Steel*, Heavy Aluminum, Ceramic (Glass)	Electric	500 ml oil in a frying pan *	Place frying pan on large front burner. Heat on high until ignition or steady state.	Two tests on each pan
3. Soybean oil (ignition)	Stainless steel, Heavy Aluminum, Ceramic (Glass)	Electric	30 ml oil in a frying pan	Place frying pan on large front burner. Heat on medium-high**.	One test with each pan
4. Soybean oil (ignition)	Stainless Steel, Heavy Aluminum, Ceramic (Glass)	Electric	500 ml oil in a frying pan	Place frying pan on large front burner. Heat on medium-high**.	One test with each pan

Total of 17 to 26 tests.
*Stainless steel was not be tested again since this was be done in scenario #1, Table 3
• * If tests done at medium-high, after 15 minutes at a steady state temperature, and no ignition occurred, then these ests are completed at this point Tests on medium heating level were not conducted.
The aluminum and stainless steel pans were manufactured by Revereware™ and the ceramic pans were manufacture by Vision Coming !.

Test Plan Table 6A: Effect of Pan Position

Cooking Scenarios	Ranges	Descriptions	General Procedures	Number of Tests
1. Soybean oil (ignition)	**Electric**	**500 ml oil in a 26 cm (10 in) diameter** stainless steel frying pan	**Place frying** pan on **the** large rear burner. Heat on High until ignition.	Two tests
2. Soybean oil and water (attended to ignition)	**Electric**	1 batch: 500 ml oil in a 26 cm (IO in) diameter stainless steel **frying** pan. 3 batches: 2.5 L water in a 3.8 L (4 qt) stainless steel sauce pan.	First heat oven to 204°C **(400°F). Then** heat water on high on three burners. After **9 min, heat oil on high on the large rear** burner for 5 min. Decrease heat under oil to medium-low. After 18 min, increase heat under oil **to** high until ignition.	Two **tests**
Total of 4 tests				

Test Plan Table 6B: Effect of Air Flow

Cooking Scenarios	Ranges	Descriptions	General Procedures	Number of Tests
1. Soybean oil (ignition)	Electric	**500** ml oil in **a 26** cm **(10** in) diameter stainless steel **frying pan**	Turn ceiling fan on highest speed. **Turn** range hood **on** highest setting. Place **frying** pan on the large front burner. Heat on high until ignition.	Two tests
2. Soybean oil (ignition)	Electric	**500** ml oil in a 26 cm (IO in) diameter stainless steel **frying** Pan	Turn ceiling fan on highest speed. Turn range hood **on** highest setting. Place frying pan on **the** large rear burner. Heat on high until ignition.	Two tests
3. Soybean oil (ignition)	Electric	**500** ml oil in a 26 cm (IO in) diameter stainless **steel frying pan**	Turn ceiling fan on highest setting. Place frying pan on the large **front** burner. Heat on high until ignition	Two tests
4. Soybean oil (ignition)	Electric	**500** ml oil in a 26 cm (10 in) diameter stainless steel **frying pan**	Turn ceiling fan on highest setting. Place frying pan on **the** large rear burner. Heat on high until ignition	Two tests
5. Soybean oil (ignition)	**Electric**	**500 ml oil in a 26 cm (10** in) diameter stainless steel **frying pan**	Turn range hood on highest setting. Place **frying** pan on **the** large rear burner. Heat on high until ignition	. Two tests
6. Soybean oil (ignition)	Electric	**500** ml oil in a 26 cm **(10** in) diameter stainless steel **frying pan**	Turn range hood on highest setting. Place frying pan on **the** large fiont burner. Heat on high until ignition.	Two tests
7. Soybean oil (ignition)	**Electric (down draft vent)**	**500 ml oi! in a 26 cm (IO in) diameter stainless steel frying pan**	**Turn the down draft blower on the highest setting. Place frying** pan on **the** large **front** burner. Heat **on high until ignition.**	**Two tests**
Total of 14 **tests.** The **extreme** conditions were tested **first.** When this resulted in minima! effect, subsequent tests **were** canceled. **The** air flow direction of **the** ceiling fan were the **same for a!! related tests.**				

Test Plan Table 7: Thermal Inertial Effect on Electric Burners

Cooking Scenarios	Ranges	Descriptions	General Procedures	Number of Tests
1. Empty pan	Electric	An empty .95 L (1 qt) sauce pan, stainless steel.	Place the empty pan on the large front burner. Heat on high until the pan temperature is the temperature at which food ignited. Turn off the burner. Record the temperature rise and time until the pan begins to coo!.	Two tests
2. Soybean oil	Electric	30 ml oil in a frying pan, stainless steel.	Place the pan containing oil on the large front burner. Heat on high to a T_1= 260 °C (500°F). Turn off the burner. Record the time and maximum temperature. Note the increase in oil temperature (AT,)*	Two tests
3. Soybean oil	Electric	30 ml oil in a frying pan, stainless steel.	Place the pan containing oil on the large front burner. Heat on high to a T_2= 360°C (680°F). Turn off the burner. Record the time and maximum temperature. Note the increase in oil temperature (ΔT_2).*	Two tests
4. Soybean oil	Electric	500 ml oil in a frying pan, stainless steel.	Place the pan containing oil on the large front burner. Heat on high to a T_1= 260 °C (500°F). Turn off the burner. Record the time and maximum temperature. Note the increase in oil temperature (AT,).+	Two tests
5. Soybean oil	Electric	500 ml oil in a frying pan, stainless steel.	Place the pan containing oil on the large front burner. Heat on high to a T_2= 360°C (680°F). Turn off the burner. Record the time and maximum temperature. Note the increase in oil temperature (ΔT_2).*	Two tests
6. Soybean oil	Electric (halogen elements)	500 ml oil in a frying pan, stainless steel.	Place the pan containing oil on the large front burner. Heat on high to a T_1= 260 °C (500°F). Turn off the burner. Record the time and maximum temperature. Note the increase in oil temperature (AT,).'	Two tests
7. Soybean oil	Electric (halogen elements)	500 ml oil in a frying pan. stainless steel.	Place the pan containing oil on the large front burner. Heat on high to a T_2= 360 °C (680°F). Turn off the burner. Record the time and maximum temperature. Note the increase in oil temperature (ΔT_2).*	Two tests

Table 8.0A shows the test number used throughout the report for each test, and a brief description of the test. This table describes all tests from the scenarios in Tables 3 through 7 and the supplemental tests.

Table 8.0A: Test Identification for CPSC Range Fire Testing Program

Range Fire Report Test Number	CPSC Test Plan: Table and Scenario	Description
1	T3E_S9A	Electric range, 500 ml of oil, stainless steel pan, oven at 204°C, 3 pots boiling water, 5 minutes high, I8 min medium low. high to ignition.
2	T3E S9B	Replicate of test 1
3	T3G S9B	Gas Range, conditions as specified for test I
4	T3G S9C	Replicate of test 3
5	T3_S11A	Electric range, heat 500 ml oil to 190°C on high, reduce heat to med-hi, cook 750 g chicken with turning for 20 min. temp on high to ignition.
6	T3 S11B	Replicate of test 5
7	T3 SIC	Electric range, 500 ml of oil in stainless steel pan, high heat to ignition
8	T3 S1D	Replicate of test 7
9	T3 S3B	Electric range, cook bacon on high heat to ignition
10	T3 S3C	Replicate of test 9
11	T4E_S2A	Electric range, 2000 ml oil to 190°C on high, reduce heat to med-hi. cook 750 g chicken with turning for 15 min. temp on high to ignition.
12	T4E S2B	Replicate of test 11
13	T4G S2A	Gas range, cook chicken in 2000 ml oil as described in test 11
14	T4G S2B	Replicate of test 13
15	T4 S1A	Electric range, heat ½ pound of sugar on high heat to ignition
16	T4 S1B	Replicate of test 15
17	T4_S3B	Electric range, Flambe, 6 spilt bananas, 3 tbsp. butter, low heat 5 minutes, add 3 tbspbrown sugar, simmer, add warm brandy, turn off burner ignite
18	T4 S3C	Replicate of test 17
19	T5 GL1A	Electric, 30 ml oil. ceramic pan, high heat to ignition or steady state
20	T5 GLIB	Replicate of test 19
21	T5 GL2A	Electric, 500 ml oil. ceramic pan. high heat to ignition or steady state
22	T5 GL2B	Replicate of test 21
23	T5 GL3A	Electric range, 30 ml of oil, ceramic pan, medium high heat to ignition or steady state
24	T5 GWB	Replicate of test 24
25	T5 GL4A	Electric range, 500 ml oil. ceramic pan. medium high heat to ignition or steadv state

Table 8 .0A, Continued

Range Fire Report Test Number	CPSC Test Plan: Table and Scenario	Description
26	T5_GL4B	Replicate of test 25
27	T5_HA1A	Electric, 30 ml oil. heavy aluminum pan, high heat to ignition or steady state
28	T5_HA1C	Replicate of test 27
29	T5_HA1D	Replicate of test 27
30	T5_HA1E	Replicate of test 27
31	T5 HA2A	Electric, 500 ml oil. heavy aluminum pan, high heat to ienition or steady state
32	T5 HA2B	Replicate of test 31
33	T5 HA3A	Electric, 30 ml oil. heavy aluminum pan, medium-high heat to ignition or steady state
34	T5 HA3B	Replicate of test 34
35	T5 HA4A	Electric, 500 ml of oil. heavy aluminum pan, med-high heat to ignition or steady state
36	T5 HA4B	Replicate of test 35
37	T5 HW1A	Electric, 30 ml oil. heavy aluminum with wooden handle, high heat to ignition or steady state
38	T5 HW1B	Replicate of test 37
39	T5 SS1A	Electric, 30 ml oil. stainless steel pan, high heat to ignition or steady state
40	T5 SS1B	Replicate of test 39
41	T5 SS3A	Electric, 30 ml oil. stainless steel pan, med-high heat to ignition or steady state
42	T5 SS3B	Replicate of test 41
43	T5 SS4A	Electric, 500 ml oil. stainless steel pan, med-high heat to ignition or steady state
44	T5 SS4B	Replicate of test 43
45	T6A S1A	Electric, 500 ml oil. stainless steel pan, high heat to ignition
46	T6A S1B	Replicate of test 45
47	T6A_S2A	Electric, 500 ml oil, 3 pots boiling water, oven at 204°C. 5 minutes high, 18 min medium low, high to ignition.
48	T6A S2B	Replicate of test 47
49	T6B S1A	Electric, 500 ml oil. stainless steel, ceiling fan and hood on high, large front burner high heat to
50	T6B S1B	Replicate of test 49
51	T6B S2A	Electric, 500 ml oil. stainless steel, ceiling fan and hood on high, large rear burner high heat to
52	T6B S2B	Replicate of test 50
53	T6B S3A	Electric, 500 ml oil. stainless steel, ceiling fan on high, large front burner high heat to ignition

Table 8.0A, continued

Range Fire Report Test Number	CPSC Test Plan: Table and Scenario	Description
54	T6B S3B	Replicate of test 53
55	T6B S4A	Electric, 500 ml oil, stainless steel, ceiling fan on high, large rear burner high heat to ignition
56	T6B S4B	Replicate of test 55
57	T6B S5A	Electric, 500 ml oil. stainless steel, range hood on high. large rear burner on high to ignition
58	T6B S5B	Replicate of test 57
59	T6B S6A	Electric, 500 ml oil. stainless steel, range hood on high, large front burner on high to ignition
60	T6B S6B	Replicate of test 58
61	T6B_S7A	Electric down draft, 500 ml oil stainless steel, blower on high, large front burner on high to ignitio
62	T6B S7B	Replicate of test 60
63	T7_SS1A	Electric, empty, stainless steel, high heat to ignition temperature of oil, thermal inertia
64	T7_SS1B	Replicate of test 63
65	T7_SS2A	Electric, 100 ml of oil, stainless steel, high to 260°C, shut off burner, record temperature rise
66	T7_SS2B	Replicate of test 66
67	T7_SS3A	Electric, 100 ml of oil, stainless steel, high to 330°C, shut off burner. record temperature rise
68	T7_SS3C	Replicate of test 67
69	T7_SS4A	Electric, 500 ml of oil, stainless steel, high to 260°C, shut off burner, record temperature rise
70	T7_SS4B	Replicate of test 69
71	T7_SS5A	Electric, 500 ml of oil, stainless steel, high to 360°C, shut off burner, record temperature rise
72	T7_SS5B	Replicate of test 71
73	WATER11	Electric, 500 ml of water, stainless steel high, at steady state shut off burner, record heat rise
74	WATER12	Replicate of test 73
75	OLDGL2A	Electric, 500 ml of oil, transparent ceramic pan without interior coating, medium high
76	CRH201A	Electric, 500 ml of water, white opaque ceramic pan, medium high
77	CRH201B	Replicate of 76
78	CROIL1A	Electric, 500 ml of oil, white opaque ceramic pan, medium high
79	NEWGL1A	Electric, 500 ml of water, transparent ceramic pan with interior coating, medium high
80	NEWGL2A	Electric, 500 ml of oil, transparent ceramic pan with interior coating, medium high
81	NEWGL3A	Electric, 150 ml of oil, transparent ceramic pan with interior coating, medium high
82	OLDGL1A	Electric, 500 ml of water, transparent ceramic pan without interior coating, medium high

Table 8.0A, continued

Range Fire Report Test Number	CPSC Test Plan: Table and Scenario	Description
83	OLDGL2A	Electric, 500 ml of oil, transparent ceramic pan without interior coating, medium high; same as 75
84	OLDGL3A	Electric, 150 ml of oil, transparent ceramic pan without interior coating, medium high
85	OLDGLNT1	Electric, 500 ml of oil, transparent ceramic pan without interior coating, medium high,
86	OLDGLTC3	Electric, 500 ml of used oil. trans.ceramic pan w/o interior coating, med-hi
87	TMP DIF3	Electric, 150 ml of oil, trans.ceramic pan w/o interior coating, med-hi, two pan content temp used
88	TMP DIF7	Electric, 150 ml of oil, stainless steel pan, med-hi, two pan content temp used
89	EMTPY2.PRN	Electric, empty 10" stainless steel pan heated on high until pan content temp=380°C then shut off
90	EMPTY3.PRN	Replicate of 89
91	TH-100A	Electric, 100 ml oil heated on high on stainless steel pan until pan content temp=330°C (626°F)
92	TH-100B	Replicate of 92
93	TH-100D	Electric, 500 ml oil heated on high on a stainless steel pan until pan content temp=360°C (680°F)
94	TH-100E	Replicate of 93
95	OLDGL4A	Electric, 30 ml oil heated on medium high on transparent ceramic pan without interior coating

8.1 FACILITY CONSTRUCTION

The design and construction of the CPSC test facility replicated the physical characteristics of the MST test facility to the extent practicable. Disassembly of the NIST test facility for building renovations allowed the relocation of many components of the NIST facility to the CPSC facility including the ranges, the cabinets, and all of the sensors. There are, however, some differences between the MST and CPSC Range Fire Project test facilities. Those differences resulted from the need to construct the CPSC facility within the confines of a small fire-testing building and from the addition of a paddle-blade type ceiling fan. Figures 8.1A through 8.1 C are dimensional drawings of the CPSC test facility. Except as detailed below, the NIST and CPSC Range Fire Project test facilities were essentially identical.

8.1.1 NIST and CPSC Test Facility Comparison

The MST facility was a free-standing structure built within a very large, high ceiling building. Sufficient clearances from other test equipment and the building structure were provided to allow unobstructed access to all portions of the NIST facility. Double-wide doors were provided in the fi-ont wall of the structure. The doors remained opened during all test work and served as the only port through which air could enter or combustion products leave the structure.

The CPSC test facility was a similar free-standing structure which was modified slightly to accommodate the structural components and the dimensions of the building within which it was fabricated.

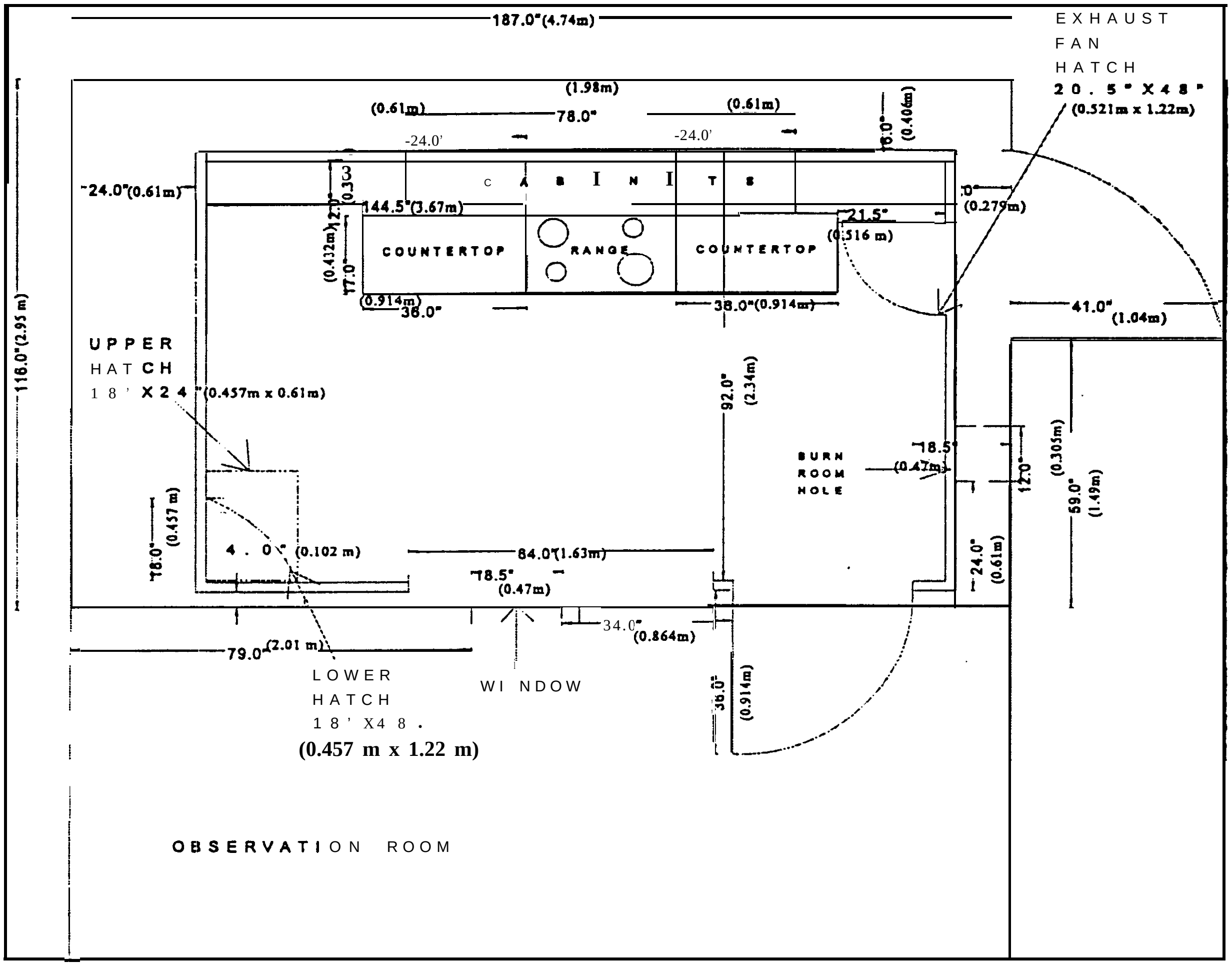

Figure 8.1A: Approximate location of the test range, cabinets, and countertops relative to the location of the bum room and the observation room.

Both structures used conventional gypsum drywall, but the right hand portion of the front wall of the CPSC structure extending from the doorway to the corner of the room was fabricated from plywood and hinged to permit access to the test area through a door to the outside of the building. The plywood portion of the structure wall was held closed by a spring latch during all test work so that, as was the case in the NIST facility, the double-door doorway was the only path for air entering or leaving the test area.

Additional hinged plywood access hatches were provided in the front portion of the left hand side wall and the rear portion of the right hand side wall to permit access to the spaces between .

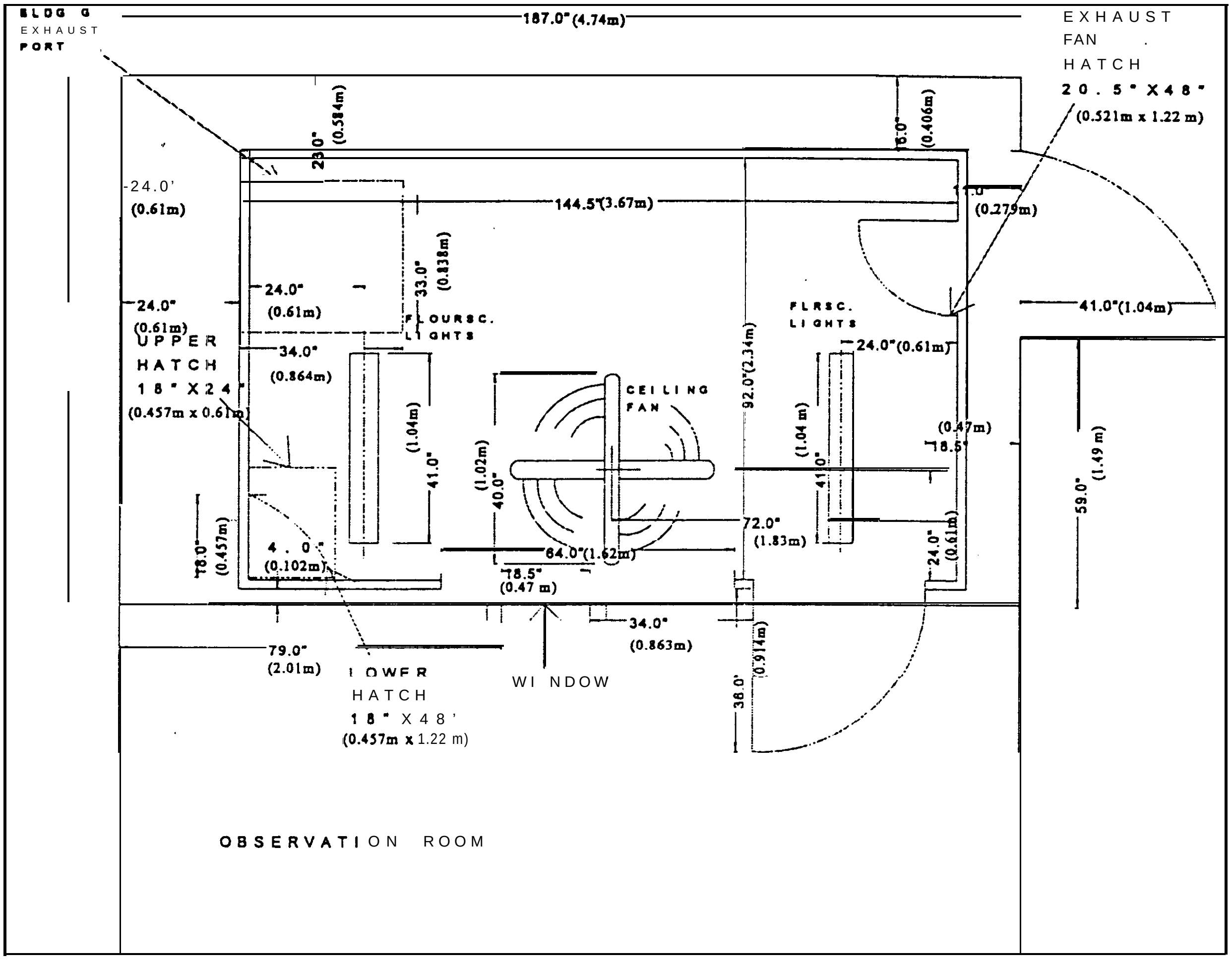

Figure 8.1B: Approximate location of the ceiling fan and fluorescent bulbs in the test area.

the test facility and the building walls. These hatches were 4 ft (1.22 m) tall and wide enough to span the distance between the wall studs at their respective locations while providing sufficient contact with the studs to minimize air flow through the ports. A final hinged plywood hatch was located in the front left hand comer of the ceiling. This hatch provided access to the space above the ceiling of the facility and also allowed smoke to be drawn by an exhaust fan from the test area after a test was completed. This hatch was approximately 18 in (0.45 m) wide and 24 in (0.61 m) long.

The depth of the CPSC facility is approximately 4 in (102 mm) less than that of the MST facility.

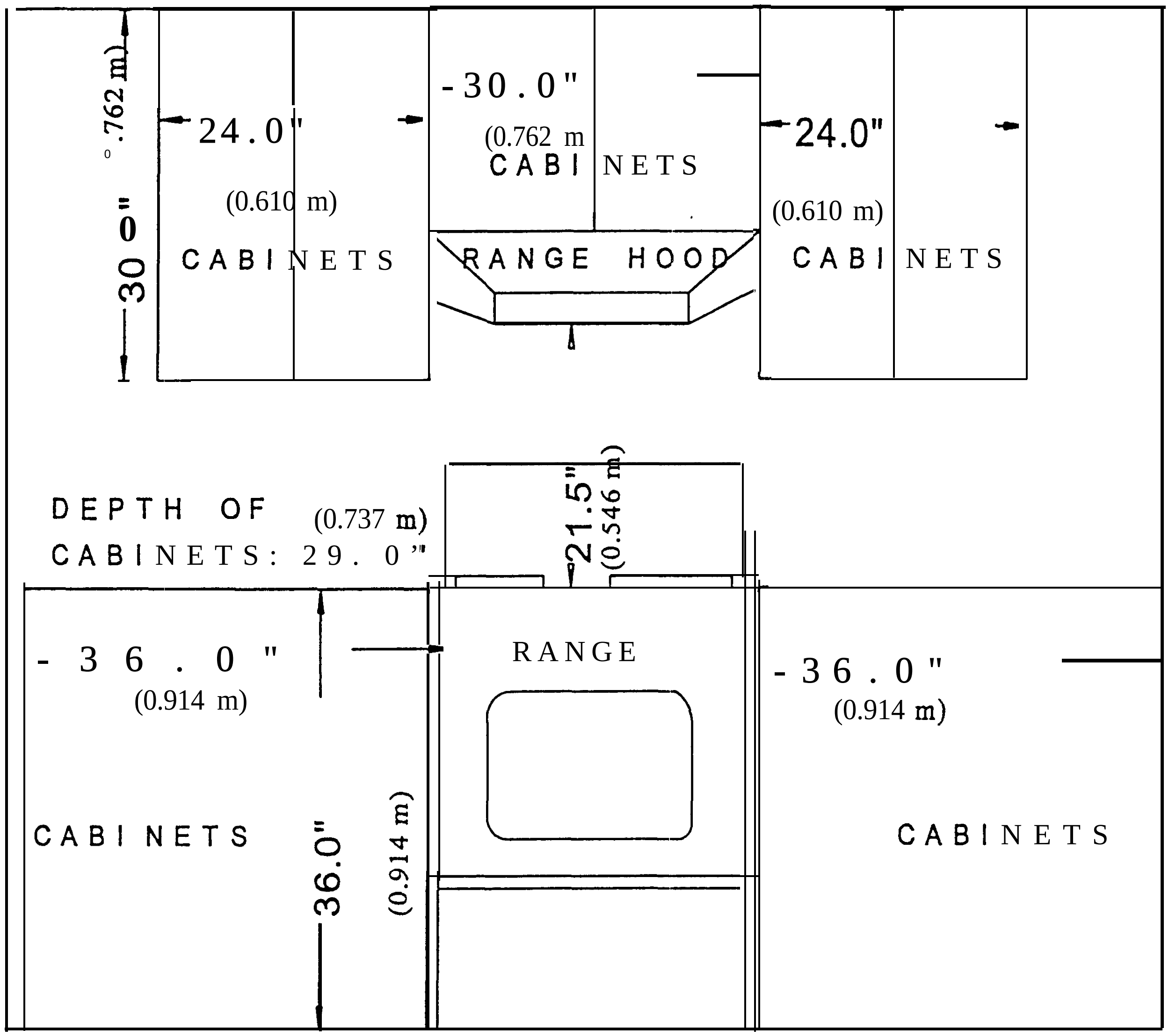

Figure 8.1C: Dimensions of the test kitchen and test range.

The double-door entry of the NIST facility opened into a large open area which served as a travel way for personnel and motorized equipment. A low velocity fume hood connected to the building vent system was constructed on the outside of the NIST facility immediately over the top of the double-door entry. The hood served to capture the combustion products from the test area before they could contaminate the rest of the building.

The CPSC facility required a different approach to simulate the NIST air flow patterns. The distance between the front wall of the CPSC facility and the building wall separating the test from the observation area was 4 in (102 mm). The double-door width of the CPSC facility opened onto a solid portion of the building wall equipped with a fixed glass observation window. The test area of the building was equipped with a vent system which extracted room air through a square duct (approximately 33 in [0.84 m] wide per side) located approximately 24 in (0.61 m) from either wall in the rear left comer of the ceiling of the building. The building was also equipped with a 12 in (0.30 m) diameter port through the lower right exterior wall of the building approximately 26 in (0.66 m) from the right front comer of the CPSC test facility and approximately 18 in (0.46 m) above the floor. This was left open during testing which allowed fresh air to be drawn past the kitchen double door opening and exhausted by the vent system. The CPSC test kitchen could be ventilated in a similar manner to the NIST kitchen during testing. At the end of each test, the lower right and upper hatches were opened and the exhaust fan was turned on which allowed the smoke to be cleared.

The NIST facility was equipped with three double-tube surface mounted fluorescent lighting fixtures on its interior ceiling each 4 ft (1.22 m) long. The fixtures were mounted with their long dimension parallel to the side walls of the structure with one fixture located along the structure's centerline and one fixture each located approximately four feet on either side of the centerline. The front edges of the fixtures were located approximately 12 in (0.3 1 m) inward from the interior side of the front wall of the facility. In order to accommodate the paddle-blade ceiling fan in the CPSC test facility, the fluorescent fixture along the centerline of the room was eliminated. The ceiling fan had a 40 in (1.02 m) blade and was located along the centerline of the structure approximately 24 in (0.61 m) inward from the interior side of the front wall.

Since the depth of the CPSC facility was approximately 4 in (0.102 m) less than the NIST facility, maintaining the front wall mounting distance resulted in some smoke detectors located 4 in (0.102 m) closer to the range and the ceiling mounted smoke detectors. All other sensors were located in identical positions as the NIST test setup.

8.1.2 Energy Supplies

The CPSC facility was equipped with both natural gas and electrical power as provided by local utility companies.

The electrical power consisted of two phases of a 1201208 voltage AC (VAC) Y system with grounded (neutral) and grounding conductors brought to a 4-wire receptacle on the building wall. Electrical power to the test ranges was controlled by manual actuation of a circuit breaker mounted in a distribution panel board located in the observation area of the building. Two 30 ampere manually adjustable auto-transformers were connected across the 208 VAC supply in order to provide the 120/240 VAC power required for the electric ranges. The voltage delivered by the auto-transformers was checked and adjusted (as necessary) under load before a test was started. The voltage was monitored during the tests but required only the initial adjustment. The maximum voltage variation was ± 5 VAC from the initial 240 VAC setting during testing. This arrangement was used for tests involving multiple burners only. The 30 ampere limitation of the auto-transformers required their replacement with a 25 kva dry-type transformer in order to conduct tests simultaneously using all four surface burners and the oven of the test ranges. The transformer was fabricated with a 208 volt primary winding and two 120 volt secondary windings equipped with two sets of 2.5% manually selected under-voltage taps. This transformer provided approximately 250 VAC to the test ranges.

The natural gas supply pressure was measured at the supply port for the test range prior to installation of the range. The initial pressure was approximately 0.32 psig (2.21 kPa) (approx. 8.8 in [0.22 m] of water) at the supply port. All piping was 3/4 in (19 mm) threaded black iron pipe up to the solenoid valve. A conventional flexible connector was used to connect the test range to the gas outlet port. The normally closed solenoid valve was controlled by a switch located in the observation area of the building. It was installed as a safety device since the only readily accessible manual gas shut-off valve was located outside of the building at some distance from the test facility. Neither the gas pressure nor the gas flow were monitored during the tests.

8.1.3 Test Ranges

Both gas and electric ranges were used during this test program. These were obtained from NIST following use in their testing program. A single make/model gas range having sealed surface burners was used. Two out of three donated models of electric ranges were used. Most of the tests were conducted on a conventional range with open-coil surface burners. Tests were also conducted on a down-draft range with open-coil surface burners. The third electric range was a "smooth-top" range having both halogen and radiant type surface burners. Table 8.1.3A provides the nominal energy ratings for the test ranges and their individual burners.

8.1.4 Range Hood

The range hood used in the CPSC facility was the same make and model as the hood used in the second phase test program conducted at NIST. It had a variable speed fan with a maximum air flow rating of 350 cfm (10 m^3/min). It was approximately 30 in (0.76 m) wide and 18 in (0.46m) inches deep overall. The front portion tapered outward from 25 in (0.63 m) wide at the front edge to approximately 30 in (0.76 m) wide at a distance greater than 9 in (0.23 m) rearward from the front edge. The hood was off (power disconnected to the unit) for most tests but was energized at its maximum air flow rating when used.

8.1.5 Ceiling Fan

The paddle-blade: type ceiling fan was a 3 speed, reversible, surface mounted unit rated 0.5 amps at 120 VAC (60 watts). It was equipped with four paddle-blades measuring approximately 40 inches from blade tip to blade tip. The ceiling fan was off (power disconnected from the unit) for most tests but was energized in the high speed, downward air flow mode when used.

Table 8.1.3A: Nominal Energy Ratings for the Test Ranges and Their Individual Burners

RANGE TYPE	OVERALL RATING'	SURFACE BURNER RATINGS' ...				OVEN RATINGS'	
		LEFT FRONT	RIGHT FRONT	LEFT REAR	RIGHT REAR	BAKE	BROIL
GAS	N/A	2930 watts (10,000 BTU/hr)	1758 watts (6,000 BTU/hr)	1758 watts (6,000 BTU/hr)	2930 watts (10,000 BTU/hr)	4395 watts (15,000 BTU/hr)	2637 watts (9,000 BTU/hr)
OPEN ELECTRIC COIL	10,200 -watts (34,884 BTU/hr)	1325 watts (452 1 BTU/hr)	2350 watts (8037 BTU/hr)	2350 watts (8037 BTU/hr)	1325 watts (452 1 BTU/hr)	2585 watts (8840 BTU/hr)	3410 watts (11,662 BTU/hr)
DOW-DRAFT OPEN ELECTRIC COIL	Maximum: 14,100 watts (48,222 BTU/hr)	NONE'	1500 watts (5130 BTU/hr)	NONE'	2100 watts (7182 BTU/hr)	2500 watts (6075 BTU/hr)	2800 watts (9576 BTU/hr)
SMOOTH TOP ELECTRIC	11,400 watts (38,988 BTU/hr)	Halogen 1500 watts (5130 BTU/hr)	Radiant 2500 watts (8550 BTU/hr)	Halogen 2200 watts (7524 BTU/hr)	Radiant 500 watts (1710 BTU/hr)	2585 watts (8840 BTU/hr)	3410 watts (11,662 BTU/hr)

Note 1 **all electrical ratings are at a supply voltage of 240 VAC; all gas ratings are with natural gas**

Note 2 the "down-draft" range has provisions for user interchangeable surface cooking units. A front-to-rear broiler (in place o the Left Front and Left Rear surface Burners) was installed in the test range but not used in any test

8.2 INSTRUMENTATION

Table 8.2A lists and describes the gas sensor and smoke detector locations for the NIST and CPSC test facilities as well as the designations used by each agency in their reports. Table 8.2B lists and describes the thermocouple locations for the NIST and CPSC test facilities. Figure 8.2.1 shows the approximate site locations (sites 1 through I 1) for the various detection devices.

Table 8.2A: List of Laser, Gas and Smoke Particulate Sensors for Both Facilities

Sensor Description	NO.	Design:ations		Site	General Location of Sensor
		NTST	CPSC		
Laser scattering (5 dcg position)	1	LScatl	Laser		
Laser transmissivity	2	LTran			
Laser scattering (10 deg position)	3	LScat2		-	
Carbon monoxide	4	c o		-	
Carbon dioxide	5	co2	-		
Total cooking gases	6	1C	TotCk 1	1	Base of splash panel, left
Total cooking gases	7	2c	Totck 2	2	Base of splash panel, center
Total cooking gases	a	3c	TotCk 3	3	Base of splash panel, right
Total cooking gases	9	4c	TotCk 4	4	Top of splash panel, left
Total cooking gases	10	5C	TotCk 5	5	Top of splash panel, center
Photoelectric smoke detector analog signal	11	5Xsig	PhoSi 5		
Photoelectric smoke detector alarm voltage	12	5Xalm	PhoAl 5		
Total cooking gases	13	6C	TotCk 6	6	Top of splash panel, right
General hydrocarbon gases	14	7Ahc	GenHy 7	7	On rear wall just below range hood, center
General alcohols	15	7Aalc	GenA17		
Total cooking gases	16	7Btot	TotCk 7		
Cooking alcohols	17	7Balc	CkAl 7		
Water vapor	18	7Bwat	CkWt 7		
Total cooking gases	19	ac	TotCk 8	a	Front of range hood. left
General hydrocarbon gases	20	9Ahhc	GenHy 9	9	Front of range hood, center
General alcohols	21	9Ahalc	GenAl 9		
Total cooking gases	22	9Btot	TotCk 9		
Cooking alcohols	23	9Balc	CkAl 9		
Water vapor	24	9Bwat	CkWt 9		
Carbon monoxide	25	9D	co9		
Photoelectric smoke detector analog signal	26	9Xsig	PhoSi 9		
Photoelectric smoke detector alarm voltage	27	9Xalm	PhoAl 9		
Hydrocarbon analyzer	28	HC			
Total cooking gases	29	10C	TotCk 10	10	Front of range hood, right
General hydrocarbon gases	30	11Ahc	GenHy 11	11	On the ceiling over front, center (above site 9)
General alcohols	31	11Aalc	GenAl 11		
Total cooking gases	32	11 Btot	TotCk 11		
Cooking alcohols	33	11Balc	CkAl 11		
Water vapor	34	11 Bwat	CkWt 11		
Carbon monoxide	35	11D	CO!!		
Photoelectric smoke detector analog signal	36	11Xsig	PhoSi 11		
Photoelectric smoke detector alarm voltage	37	11Xalm	PhoAl 11		
Photoelectric smoke detector analog signal	38	13Xsig	PhoSi 13	13	Ceiling, centered front to back, 106 cm from right wall
Photoelectric smoke detector alarm voltage	39	13Xalm	PhoAl 13		

Sensor Description	No.	Designations NIST	CPSC	Site	General Location of Sensor
Photoelectric smoke detector analog signal	40	14Xsig	PhoSi 14	14	Ceiling, centered left to right,
Photoelectric smoke detector alarm voltage	41	14Xalm	PhoAl 14		15 cm from front wall
Ionization smoke detector analog signal	42	14Zsig	IoSig 14		
Ionization smoke detector alarm voltage	43	14Zalm	IoAl 14		
Photoelectric smoke detector analog signal	44	15Xsig	PhoSi 15	15	Ceiling, 30 cm from right wall and
Photoelectric smoke detector alarm voltage	45	15Xalm	PhoAl 15		30 cm from front wall
Ionization smoke detector analog signal	46	15Zsig	IoSig 15		
Ionization smoke detector alarm voltage	47	15Zalm	IoAl 15	15	
Photoelectric smoke detector analog signal	48	16Xsig	PhoSi 16	16	Ceiling, centered front to back,
Photoelectric smoke detector alarm voltage	49	16Xalm	PhoAl 16		30 cm from right wall
Ionization smoke detector analog signal	50	16Zsig	IoSig 16		
Ionization smoke detector alarm voltaee	51	16Zalm	IoAl16		
Photoelectric smoke detector analog signal	52	17Xsig	PhoSi 17	17	Ceiling, 30 cm from right wall and
Photoelectric smoke detector alarm voltage	53	17Xalm	PhoAl 17		30 cm from rear wall
Ionization smoke detector analog signal	54	17Zsig	IoSig 17		
Ionization smoke detector alarm voltage	55	17Zalm	IoAl 17		
Bidirectional Velocitv Probe	56	Vlctv			
Total Cookine Gases	-		102(x3)n		
Total Cooking Gases	-		103(x3)o	9A	

Table 8.2B: List of Thermocouples for Both Facilities

Sensor No.	Designations NIST	CPSC	General Thermocouple Location
57	Tl	Tl	Base of splash panel at left edge of range
58	T2	T2	Base of splash panel at center of range
59	T3	T3	Base of splash panel at right edge of range
60	T4	T4	Top of splash panel at left edge of range
61	T5	T5	Top of splash panel at center of range
62	T6	T6	Top of splash panel at right edge of range
63	T7	T7	On rear wall just below range hood at center of range
64	T8	T8	Front of range hood at left edge of range
65	T9	T9	Front of range hood at center of range
66	T10	T10	Front of range hood at right edge of range
67	Tll	-	On the ceiling over front, center (above site 9)
68	T13		Ceiling, centered front to back, 106 cm from right wall
69	T14	-	Ceiling, centered left to right, 15 cm from front wall
76	T15		Ceiling, 30 cm from right wall and 30 cm from front wall
71	T16		Ceiling, centered front to back, 30 cm from right wall
‘75	T17	-	Ceiling, 30 cm from right wall and 30 cm from rear wall
76	T18	T18	Range top, left edge, centered front to back
77	T19	T19	Range top center
78	T20	T20	Range top, right edge, centered front to back
79	T21	T21	Range top, left front comer
80	T22	T22	Range top, front center
81	T23	T23	Range top, right front comer
82	T24	T24	Left rear burner
83	T25	T25	Right rear burner
84	T26	T26	Right front burner, normally pan bottom on focus burner
85	T27	T27	Left front burner
86	T28	T28	Focus burner at edge of drip pan hole
a7	T29	T29	Beneath range top surface, left front burner
88	T30	T30	Beneath center of range top surface
a9	T31	T31	Inside oven, at top, center left to right, near front
90	T32	T32	Inside front edge of range hood, left
91	T33	T33	Inside Front edge of range hood, right
92	T34	T34	Under range hood filter, left
93	T35	T35	Under range hood filter, right
94	T36	T36	Mid-height splash panel, left
95	T37	T37	Mid-height splash panel, center
96	T38	T38	Mid-height splash panel, right
97	T39	T39	Submerged in food, near pan surface at center
98	T40	-	At gas sampling probe tip
99	T41	-	Gas sampling probe surface (one-third way)
100	T42	-	Gas sampling probe surface (two-thirds way)
101	T43		Near duct velocity probe

8.2.1 Thermocouples

Omega type K (Chrome-Alumel), 30 gauge, 0.25 mm (0.010") diameter thermocouples were used for all of the tests. The thermocouples varied in length depending on the location of each thermocouple. Initially, a large number of thermocouples were used to measure temperatures in several areas around the range and hood areas. All of the thermocouple locations are shown in Figure 8.2.1A.

The thermocouples placed underneath each burner or heating element or in the pan contents were encased in ceramic rods. All others were mounted with high temperature tape. The pan content thermocouple's ceramic rod allowed the rod's weight to push the thermocouple's welded bead to contact the floor of the pan. The thermocouples placed under each heating element for the open coil type electric range were mounted with a spring loaded mechanism. As the weight of the pan and contents push down on the thermocouple bead, the spring compresses, forcing the thermocouple to make contact with the pan bottom. Figure 8.2.1B illustrates this mechanism.

For the gas range, a lever mechanism for each of the four burner thermocouples was attached to a mounting bracket to hold the thermocouples under each burner. An aluminum weight was mounted on the ceramic rod opposite side the thermocouple bead. The weight was heavy enough to pivot the rod so that the bead pressed against the pan bottom. Once a pan and/or its contents are placed onto the burner frame, the thermocouple bead makes contact as it swings down with the pan. The aluminum weight pivots about the pivot point, allowing the thermocouple bead to make contact with the pan bottom surface. Figure 8.2.1C illustrates the mechanism used for the gas range. The oven thermocouple did not have a ceramic rod casing.

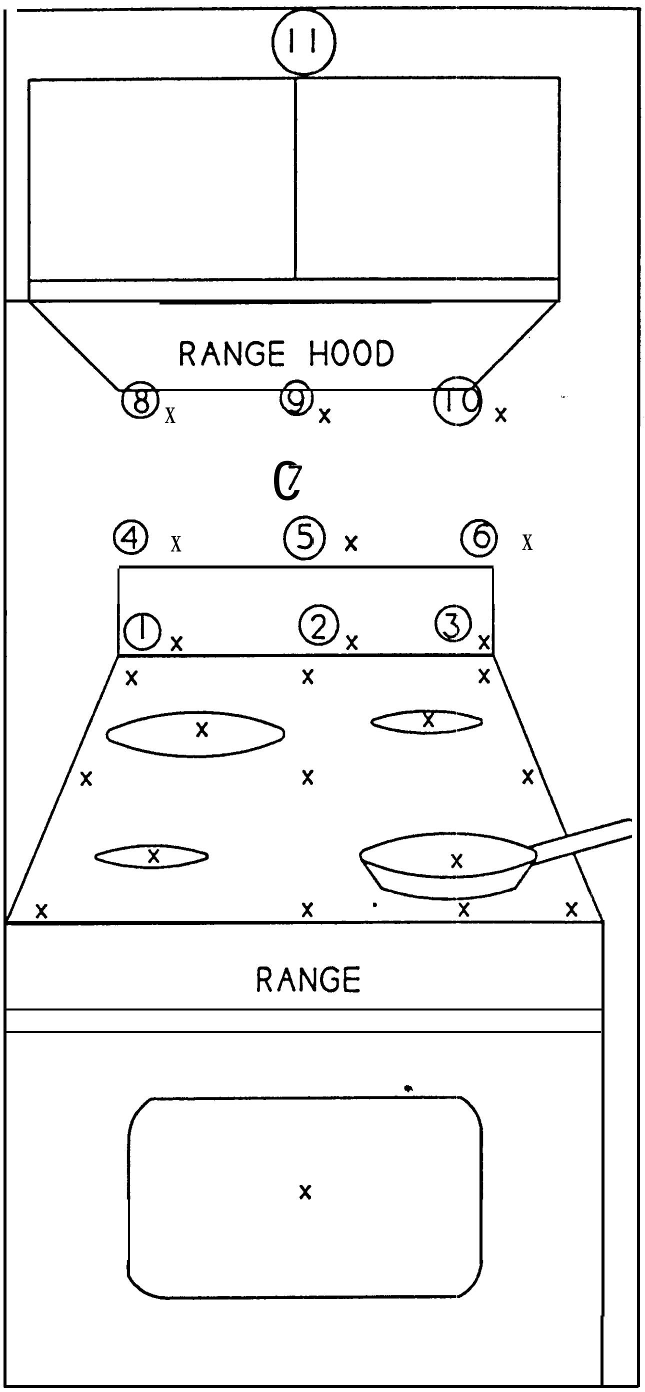

Figure 8.2.1A: X's indicate thermocouple locations; circled numbers indicate gas sensor/smoke detector site location numbers

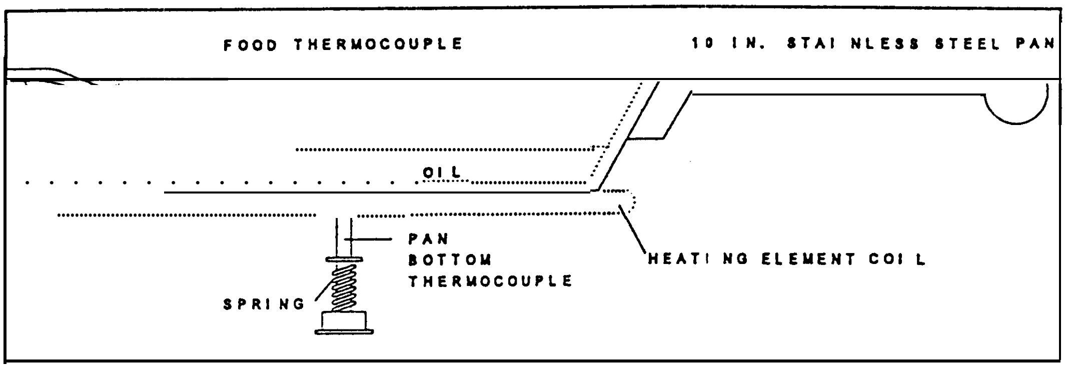

Figure 8.2.1B: Pan content and pan bottom thermocouple locations for the electric range

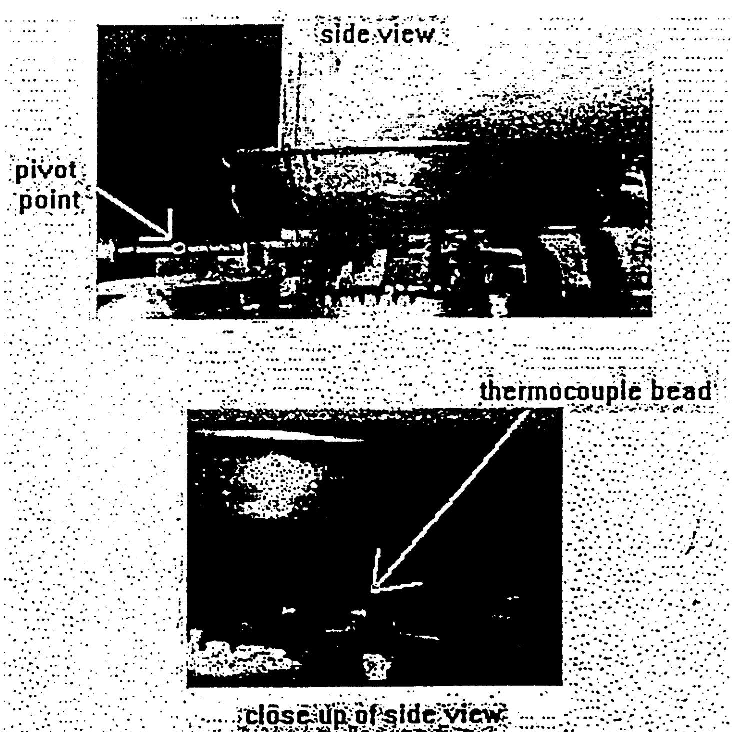

Figure 8.2.1 C: Pan bottom thermocouple mechanism for the gas range

8.2.2 Laser Attenuation Apparatus

The laser attenuation apparatus was incorporated into the data acquisition system to examine the vapor density generated from the various'test scenarios. The responses from the laser attenuation system indicate density of gases/particulates generated before ignition. The laser attenuation system consisted of a helium neon laser with a 1mW power output, a silicon photo diode, and a power supply for the photo diode. The helium neon laser projects a beam onto a silicon element, which sends an electrical signal to the data acquisition system. Stands with vertical and horizontal adjustment were used to position the laser and photo diode. Figure 8.2.2A shows the laser and photo diode arrangement. The laser attenuation system was placed so that the laser beam would project over the test area (e.g., pan with oil and/or food contents).

The laser attenuation apparatus acquired from NIST was used in CPSC's range fire testing. The laser attenuation system consisted of a Melles Griot model 05-LLR-811 helium neon laser, a Hamamatsu model S 1337-1010 BQ silicon photo diode, and a Power One brand 15 V DC power supply. The laser and photo diode were used in NIST's phase II testing for the range fire project. Although CPSC and MST shared the sarne laser and photo diode, CPSC's data acquisition system and power supply differed from NIST's. CPSC used Keithley-Metrabyte™ EXP-16 boards which supports up to 10 V DC per data channel (see section 8.3). The power supply for the photo diode: exceeded the 10 V DC limitation from the DAS 16 boards. Therefore, a voltage divider was used to scale down the reading from the output port of the photo diode. A 10 MΩ and 20 MΩ resistors in series were connected to the output leads of the photo diode. The signal read by data acquisitions board was across the 20 MΩ resistor to obtain a maximum of 10 V DC. Figure 8.2.2B shows an overall schematic for the photo diode signal adjustment. The voltage read from the 20 MΩ was then multiplied by a 1.5 factor by the data acquisition program (section 8.3.1) to achieve a maximum of 15 V (for comparability to MST's output voltages). The gas sensor output voltages were obtained in the same manner as the photo diode voltages.

The laser and photo diode were positioned 23 cm (9 in) above the upper edge of the pan for all of the tests. The laser and photo diode units were positioned to have the beam run across the near center of the pan.

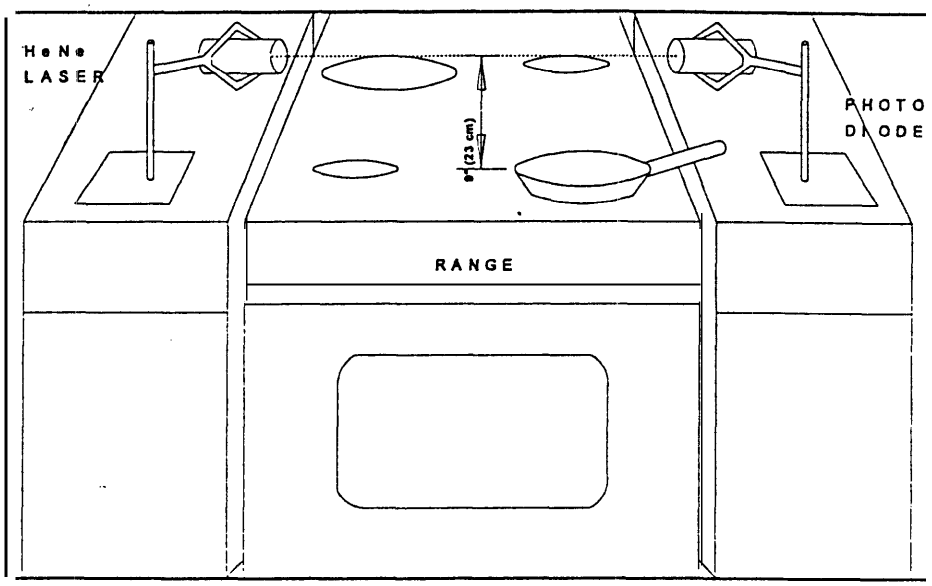

Figure 8.2.2A: Placement of laser attenuation apparatus.

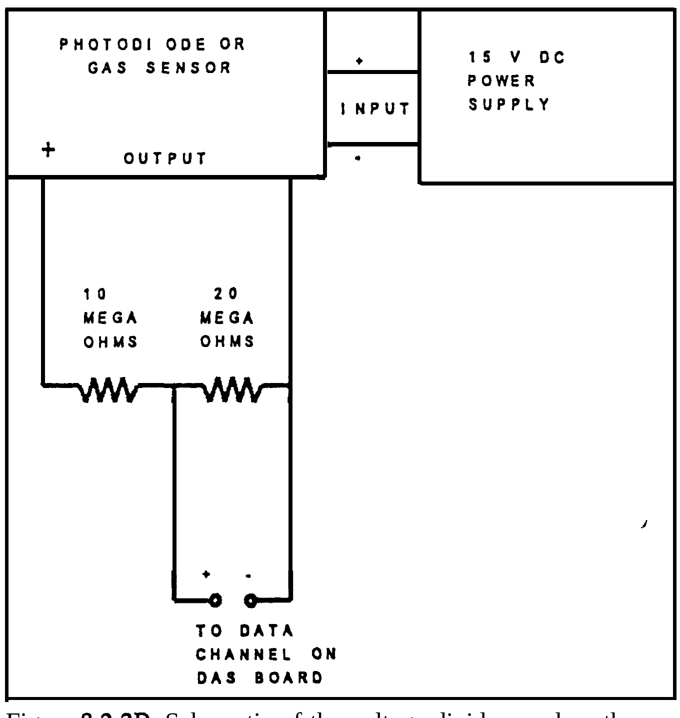

Figure 8.2.2B: Schematic of the voltage divider used on the photo diode and gas sensors

8.2.3 Videotape Recording: Equipment

The videotape recordings allowed the test personnel to examine a number of characteristics, such as smoke density just before ignition, laser beam obscuration, oil splatter, and location of flame at ignition. The video camera was placed in front of the bum room window to capture the range and its immediate vicinity. A Panasonic AG-190 model VHS recorder was used for filming all of the tests except for the thermal inertia scenarios. The AG-190 produces 30 standard frames per second.

During each test, the video recorder and data acquisition system (DAS) were started simultaneously. With the exception of a few tests, the electric range or gas range was turned on two minutes after the DAS and video recorder had started. For each filming, the video recorder recorded the test events with the date and time displayed. For each filming, the tests were recorded in SP mode for best picture quality.

8.2.4. Gas Sensors

The gas sensors. used in this study were those used by NIST. The types of gas sensors used in this range fire study were total cooking, cooking alcohol, carbon monoxide, general hydrocarbon, and general alcohol sensors.

All gas sensors were of the thin film type (manufactured by Figaro Engineering™), except the carbon monoxide sensors which are of the thick- film type). The thin film sensors used a tin oxide (SnO_2) semiconductor with low conductivity in ambient air. The model numbers for the thin film gas sensors are as follows: TGS 8 13 (General Hydrocarbon), TGS 822 (General Alcohol), TGS 880 (Total Cooking), and TGS 882 (Cooking Alcohol). The sensor's resistance decreased in the presence of a detectable gas depending on the gas concentration picked up in the sensor chamber. An electrical circuit is used to convert the change in conductivity to an output voltage. The sensors were connected to circuits and 15 V DC power to provide output signals. Each power supply powered three to six sensors. These sensors respond to various gases including methane, ethanol, propane, isobutane, water vapor, and hydrogen.

The carbon monoxide thick film sensors (manufacturea by Dee Electronics™, model 203) are almost 100% specific for carbon monoxide with the filter option. Without the filter option there are interferences with ammonia, hydrogen sulfide, higher hydrocarbons and solvents. Each carbon monoxide sensor had its own printed circuit board with a 5 V DC power supply to regulate the heating to maintain a constant temperature. The sensor's resistance varies depending on the gas concentration. A simple voltage divider circuit was constructed to provide an output signal.

8.2.5 Smoke Detectors

The photoelectric and ionization type smoke detectors were removed from the MST test facility and re-installed in the CPSC facility in the same positions at MST as shown in Figures 8.2.5A (ceiling mounted) and 8.2.1A (grouped with gas sensors and thermocouples). Late in the test schedule (approximately two-thirds to completion), an additional photoelectric smoke detector was installed in the space above the ceiling of the CPSC test facility ("plenum smoke detector") in order to evaluate the response of such a detector when located outside of the simulated kitchen area.

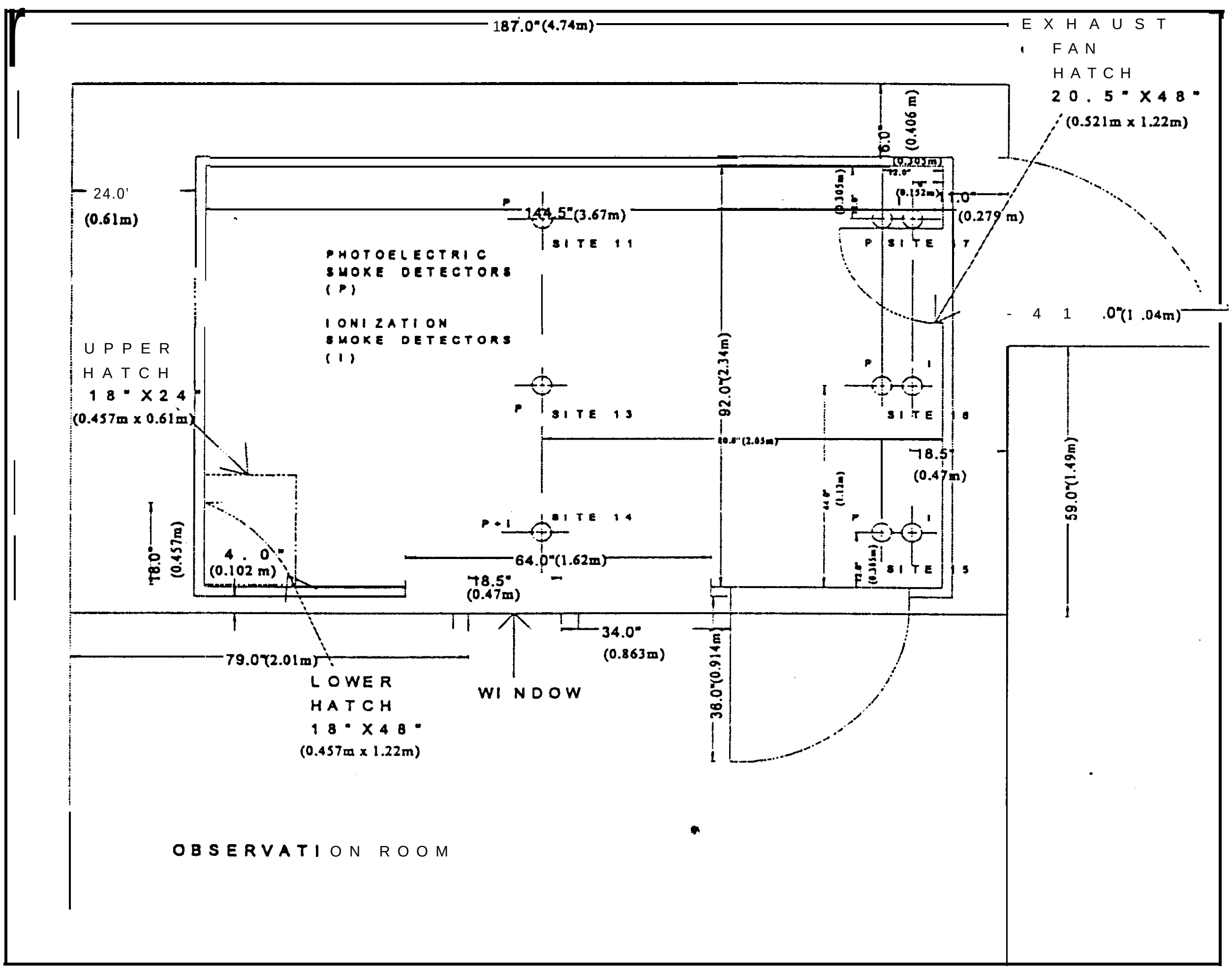

Figure 8.2.5A: Ceiling mounted smoke detector locations in the test room

Two types of photoelectric smoke detectors and one type of ionization detector were installed. One type of photoelectric detector was designed for use with a "control panel" while the other photoelectric detector ("plenum smoke detector") and the ionization detectors were the self-contained or "single station" type. All of the smoke detectors were listed by Underwriters Laboratories Inc. as complying with the applicable voluntary standards at the time of their manufacture.

The "control panel" type of smoke detector was connected to a remote panel which provided operating power and processed alarm signals from the detector. It was powered from a remotely located, well-regulated DC power supply and its alarm contacts provided a definite indication of alarm or no-alarm status which could be directly monitored by a data-acquisition system.

The particular "control panel" type of photoelectric detector installed in the MST and CPSC facilities also provided a "test port" for connection of a voltmeter during in-site tests of the detector's operating condition. The voltage available at this port was monitored during all of the tests conducted by MST and CPSC. However, the relationship between the test port voltage and the density of the smoke in the vicinity of the detector is unknown so the data were not analyzed. Seven such "control panel" type photoelectric detectors were installed.

The "single station" type of smoke detector used in these studies were battery powered and incorporated all of the circuitry and components necessary to detect smoke and provide an audible alarm. One photoelectric and four ionization type "single station" smoke detectors were installed.

The "single station" ionization detectors installed in the MST and CPSC test facilities were modified by soldering lead wires to certain connections on the detectors' printed-wiring boards suggested by a representative of the manufacturer. They provided signals to the data acquisition system so that the time each detector alarmed could be automatically recorded. These connections also defeated the internal horns and lights which are activated when the detectors alarm but had no effect on the ability of the detectors to respond to smoke.

Two analog signals were obtained from each ionization detector. One signal was intended to provide data which would allow verification of the calibration of the ionization detector under the varying conditions of the tests. In practice, this signal did not provide the anticipated data and was not included in this analysis. The other signal provided the time at which the ionization smoke detector entered alarm mode. The "time to alarm" is the elapsed test time at which the magnitude of the voltage of the monitored signal increased by 1 volt compared to the value at the beginning of the test when no smoke was present in the test facility.

The "single station" photoelectric detector installed in the space above the ceiling of the CPSC test facility was not connected to the data acquisition system. Personnel conducting the tests relied upon the audible signal generated by that detector to determine the time at which it alarmed. The elapsed test time to alarm was then manually noted in the test log.

The sensitivities (percent change in light transmission per foot of light beam, also called "obscuration") marked on the labels of the smoke detectors were as follows:

Type of Smoke Detector	Marked Sensitivity	Tolerance
"'Control Panel" Photoelectric	3.0 % / A. (9.84% / m)	+/- 0.9 % / ft. (2.95% / m)
"Single Station" Photoelectric	1.75 % / ft. (5.74% / m)	+/- 0.6 % / ft. (1.97% / m)
"Single Station" Ionization	1.05 % / ft. (3.44% / m)	+/- 0.4 % / ft. (1.31% / m)

8.3 DATA ACQUISITION. DATA REDUCTION / PLOTTING

8.3.1 Data acquisition

CPSC's data acquisition system @AS) used for the range fire project consisted of Keithley-Metrabyte™ data acquisition hardware, gas sensors, smoke detectors (photoelectric and ionization types), thermocouples, a 486 PC, a series of 15 V DC power supplies and Labtech™ notebook software. A signal flow diagram is shown in Figure 8.3.1A. Note that in the signal flow diagram, the Keithley-Metrabyte™ DAS-8 interface card is inserted into the 486 motherboard in the computer. This interface card provided the link between the external hardware and software.

The gas sensors, "'control panel" photoelectric smoke detectors, and laser attenuation system required external input power. A 15 V DC power supply was used to power three gas sensor groupings and three photoelectric detector groupings. The laser was equipped with its own AC power supply. However, the photo diode required a 15 V DC power supply. The ionization smoke detectors were powered by 9 V batteries. Two signals (alarm and smoke sensing) from each smoke detector were entered into the Keithley-Metrabyte™ EXP-16 expansion boards.

The thermocouples were signal conditioned by the Keithley-Metrabyte™ EXP-16 boards; no separate power supplies were needed. The Keithley-Metrabyte™ boards have a cold junction temperature compensation feature designed into the data acquisition system. Once all the thermocouples were connected to their respective data channels, the temperature readings were acquired when the Labtech™ program was activated. The Labtech™ program automatically converted a raw voltage output into a temperature reading via a multi-ordered polynomial for a specific type of thermocouple.

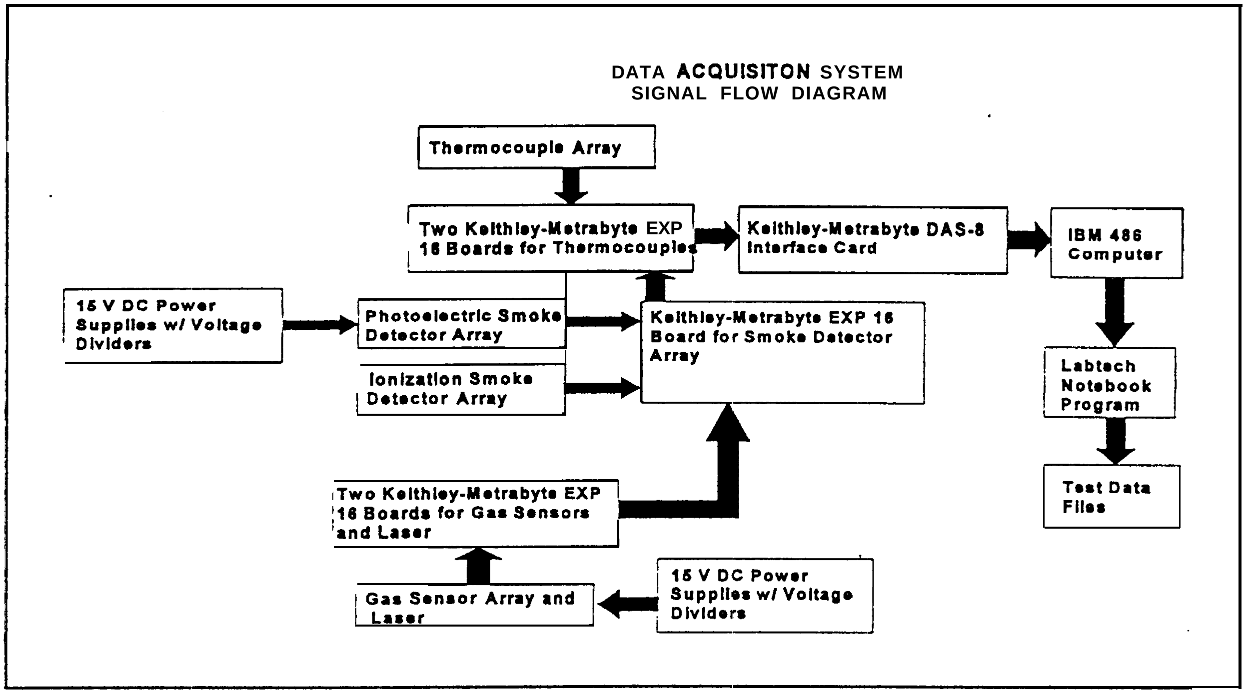

Figure 8.3.1A: Signal Flow Diagram for the data acquisition system

The Labtech™ program resembled the signal flow diagram in Figure 8.3.1A. Once the Keithley-Metrabyte™ EXP-16 boards picked up signals, the Labtech™ program recorded the data into data files which could be accessed for post processing. The Labtech™ program produced a data file that consisted of a header, the data column headings, and the data columns. The header indicated date and time the test was performed, the filename of the test run, a brief description of the test, and other comments that explained events and identified any anomalies with the test procedure or test setup. The data columns designated the sensor number, site number, and sensor type. During a test, these data columns were not displayed beyond the current reading. All data files were written in text file format which allowed post processing with spreadsheet software such as Quattro Pro™.

Data were sampled every 10 seconds for the first few tests and then every 5 seconds for the remainder of the testing to gain additional detail.

<u>8.3.2 Data Reduction / Plotting</u>

A macro program written in Quattro Pro™ allowed viewing and printing of each data channel from each test run. Once the first graph was generated by the user, the macro would copy the first graph's attributes, but change the data columns and graph titles as appropriate. The macro program would repeat this sequence until all of the 84 data channels were plotted. Each graph was labeled with features such as the test run name, the sensor number, the sensor type, etc. Macros were written to compare CPSC and NIST test runs, NIST test runs with repeat NIST test runs, and CPSC test runs with repeat CPSC test runs. All data were plotted without any curve smoothing, except for Figures 10.7.2A (p. 92), 10.7.3A (p. 94), and 10.7.3B (p. 95), where a 3 point moving average was used.

9.0 SAFETY PRACTICES

Full face breathing masks attached to a large stationary cylinder of breathing air were used by personnel when entering the kitchen after ignition. Nomex III flame resistant lab coats and leather welding gloves provided additional fire protection.

The flaming pan was capped with a pan top connected to an extension pole. Then a nozzle was used to apply CO_2 from a 50 lb (22.7 kg) cylinder to the pan. A backup CO_2 nozzle to suppress the fire stood in the room and was directed at the pan of interest. It was designed to be turned on from outside of the room.

10.0 RESULTS AND DISCUSSION

10.1 REPRODUCIBILITY BETWEEN CPSC AND NIST TEST RESULTS

10.1.1 Introduction

To determine whether the results from the CPSC phase of the range fire project were comparable to the NIST Phase II work, five NIST cooking scenarios were repeated by CPSC in duplicate. The test kitchen constructed in the CPSC Engineering Laboratory bum room was approximately the same size as that used by NIST (8 ft [2.43 m] by 12 ft [3.66 m]). The objective of this comparison was to relate the data for the two test laboratories so that results and conclusions developed by NIST could be used along with the CPSC test results to evaluate the possibility of a pre-ignition detection/control system. The five test scenarios that were used for the data comparison are described in Table 10. 1 . 1 A.

Table 10.1.1A Description of Test Conditions to Verify Reproducibility

Cooking Ingredients/Description	General Procedures	Test Run Numbers	
		NIST	CPSC
Sovbean oil 500 ml of soybean oil in a 26 cm diameter stainless steel frying pan	On an electric range: Heat on high until ignition.	9601 9624	7 8
Bacon 227 g bacon in a 26 cm diameter stainless steel Frying pan	On an electric range: Heat on high until ignition.	9602 9617	9 10
Soybean oil and water 500 ml soybean oil in a 26 cm diameter stainless steel frying pan; 2.5 L water in each of three 3.8 L stainless steel sauce pans	On both an electric and gas range: First heat oven to 204°C(399°F). Then heat water on high on three burners. Heat oil on high on one burner for 5 min. Decrease heat under oil to medium-low. After oil reaches a steady temperature, maintain for 15 min, and then increase heat to highuntil ignition.	Electric 9612 9632 Gas 9635 9637	 1 2 3 4
Chicken in sovbean oil Approximately 750 g of chicken (3 whole legs) in 500 ml soybean oil in a 26 cm diameter stainless steel frying pan	On an electric range: Heat oil to 187°C (369°F) on high. Introduce chicken to oil. Reduce heat to medium and turn chicken every 4 min for 20 min. Increase heat to high until ignition.	9608 9625	5 6

10.1.2 Defining: A Subset of Sensors to Simplify the Reproducibility Comparison

A comparison of selected sensors was performed due to the voluminous amount of data generated from the tests (e.g., over 80 signals for twenty tests - five scenarios performed twice at each lab). The approach was to identify a subset of sensors that adequately characterized the data.

Selection of the detection device subset for the comparison was based upon the ability of the detection device to produce repeatable and responsive pre-ignition signals. Similarly, a detection device failing to meet these criteria also provided. an indication of comparability.

Applying the above comparability criteria to the thermocouples, the four that were contiguous to the focus burner (pan bottom, edge of drip pan, beneath the range top surface, and submerged in the food) were the most indicative of the temperatures of the ignition source prior to ignition The remaining thermocouples exhibited only minimal responses prior to ignition (temperature increases were gradual and many did not change more than 20°C (36°F); which is similar to the NIST finding). Figure 10.1.2A is a plot of thermocouple T19 (located on the top of the range in the center) which showed a significant rise in temperature even though it is in relatively close proximity to the focus burner. The two thermocouples with the most direct relationship to ignition were o:n the pan bottom and submerged in the food and will therefore be the only temperatures discussed in detail for this reproducibility comparison.

Problems with the ionization smoke detectors during CPSC tests precluded them from the reproducibility comparisons. In this series of tests for test facility reproducibility, the photoelectric smoke particulate sensors produced alarms before ignition (section 10.9), but these alarms were usually several minutes prior to ignition. The alarm times for the short time-to-ignition scenarios (bacon and 500 ml oil) for all four tests of a given scenario were grouped closely, usually occurring within a minute of each other. However, during the high

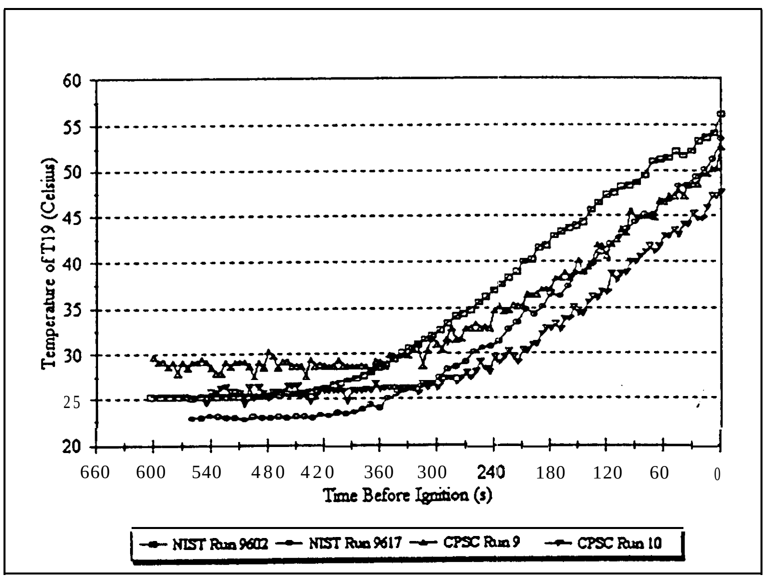

Figure 10.1.2A: Temperature in the center of the range top for the bacon cooking scenario

smoke and lower heat-rise rate conditions, the alarms were usually several minutes before ignition, as shown in Figure 10.1.2B, which is a plot of the Site 9 photoelectric smoke detector alarm voltage during the oil and water (electric stove) cooking scenario. Ignition occurred at time 0. Both NIST and CPSC found that the photoelectric smoke particulate sensors did not discriminate enough to minimize false fire indications and thus were excluded from the reproducibility comparison.

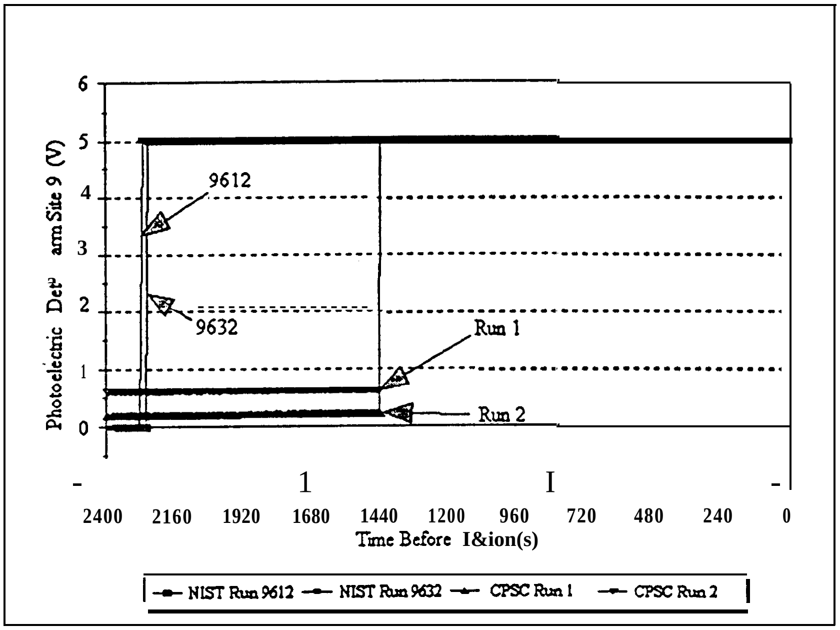

Figure 10.1.2B: Site 14 photoelectric smoke detector alarm voltage for oil and water (on electric range) cooking scenario

Although it provided a reliable indication of when ignition occurred, the laser transmissivity signal did not exhibit any pre-ignition characteristics. Also, the laser and photo diode receptor were intended more as a laboratory aide than as a potential candidate for household implementation as a pre-ignition detector. Therefore, the laser signal was not used in the reproducibility comparison.

The water vapor tin-oxide sensors did not provide a useful indication of pre-ignition conditions at either NIST or CPSC. During the 500 ml oil cooking scenario, the water vapor sensors were largely unresponsive (as would be expected since the fuel source was only oil); see Figure 10.1.2C. For other scenarios (chicken and bacon), the water vapor sensors exhibited moderate responses to indicate impending ignition (i.e., an increase in output voltage). However, the most significant change in magnitude was usually less than 100 seconds before ignition occurred. As a result, the water vapor sensors were not included in the reproducibility comparison.

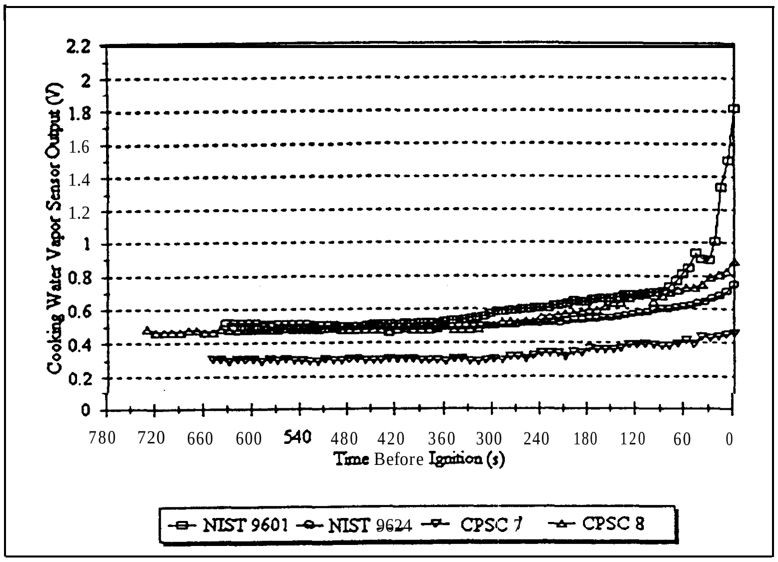

Figure 10.1.2C: Site 9 cooking water vapor output voltage versus time for the 500 ml oil cooking scenario

Unlike the other tin-oxide gas sensors, the carbon monoxide sensors had an inverse relationship to the CO concentration, i.e., the voltage decreased in response to increasing gas concentration. For the reproducibility scenarios, the CO sensors initial output voltage was in the range of 1.5 to 2.0 volts. The voltage change between the initial value and the value at ignition was typically 0.5 volts and often most of the decrease occurred in the final 60 seconds before ignition. This is illustrated in Figure 10.1.2D, which is a plot of the Site 9 carbon monoxide sensor voltage for the bacon cooking scenario at both NIST and CPSC. The CO sensor data was not included in the reproducibility comparison because of the change in voltage was small.

Elimination of the above detection devices resulted in a reduced set of sensors for the reproducibility comparison. These are two thermocouples (pan bottom and pan contents) and four tin-oxide gas sensors (general hydrocarbons, general alcohols, total cooking gases and cooking alcohols).

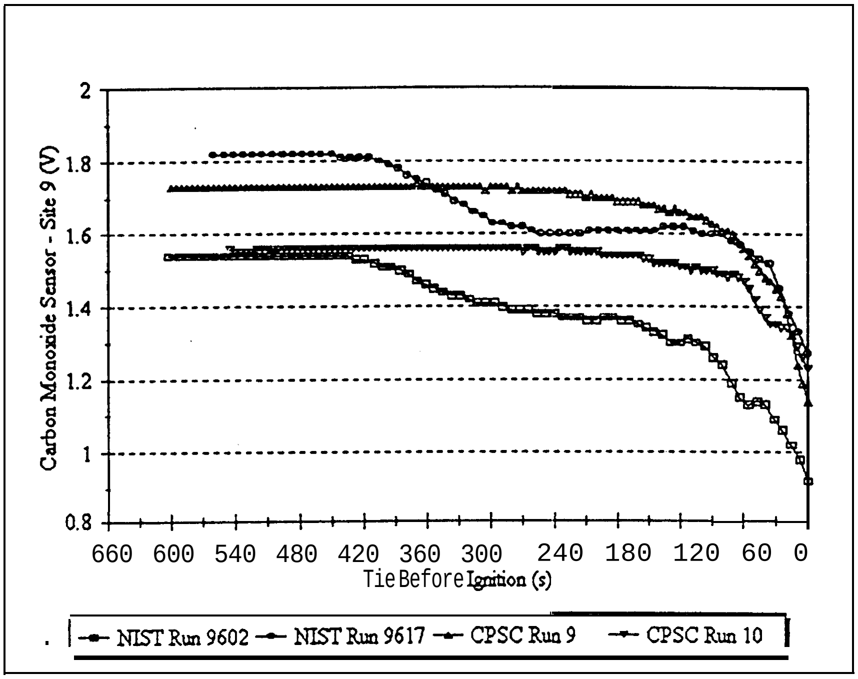

Figure 10.1.2D: Site 9 carbon monoxide sensor voltage for the bacon cooking scenario

Next, a representative gas sensor site was chosen to further simplify the data presentation and discussion while still providing a reasonable indication that results from the two laboratories were comparable. Site 7 (on the rear wall just below the range hood), Site 9 (on the front of the range hood) and Site 11 (on the ceiling) were located on the center line of the range and therefore provided a symmetrical reference point to all the burners. A graphical analysis of the data suggested that, for the purposes of this discussion, the sensors at Site 9 adequately represented those at Sites '7 and 11. This is illustrated by Figure 10.1.2E, which shows the response of the general hydrocarbons sensors at Site 7, 9 and 11 for one of the CPSC 500 ml soybean oil scenarios (CPSC Test 7). Although this plot was selected because it clearly illustrated the point, site 9 sensors generally followed the same trend as those at Sites 7 and 11 for most of the reproducibility test runs.

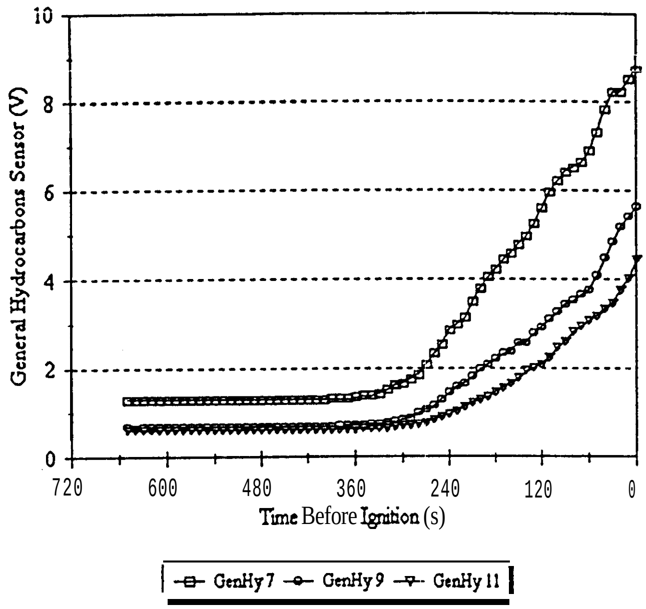

Figure 10.1.2E: Comparison of general hydrocarbons sensors at Sites 7, 9 and 11 for CPSC 500 ml soybean cooking scenario (CPSC Test 7)

10.1.3 Comparison of NIST and CPSC Results

The inter-laboratory reproducibility comparisons were performed in two key performance areas: thermocouples and Site 9 gas sensors. For this comparison, the NIST and CPSC data sets for each scenario were assumed to be from the same population. The mean, standard deviation, and the percent of the standard deviation to the mean for each scenario were then calculated for the instantaneous values of each sensor at the time of ignition and 120 seconds before ignition. In addition, the number of standard deviations from the mean to each value was computed to show how the data was distributed.

IO. 1.3. I Comparison of Pan Bottom and Pan Content thermocouples

The results of the analysis of temperatures measured by pan bottom and pan content thermocouples are shown in Tables 10.1.3.1A and 10.1.3.1B, respectively. For nearly all of the scenarios, the pan bottom temperatures between CPSC and NIST at ignition compare reasonably well. The numbers tracked similarly at 120 seconds prior to ignition and at ignition. Notice that the coefficient of variation is 10% or less with the exception of the soybean oil and water test in Table 10.1.3.1A. Figures 10.1.3.1A and 10.1.3.1B are provided as examples of the closeness of the data at ignition and 120 seconds before ignition.

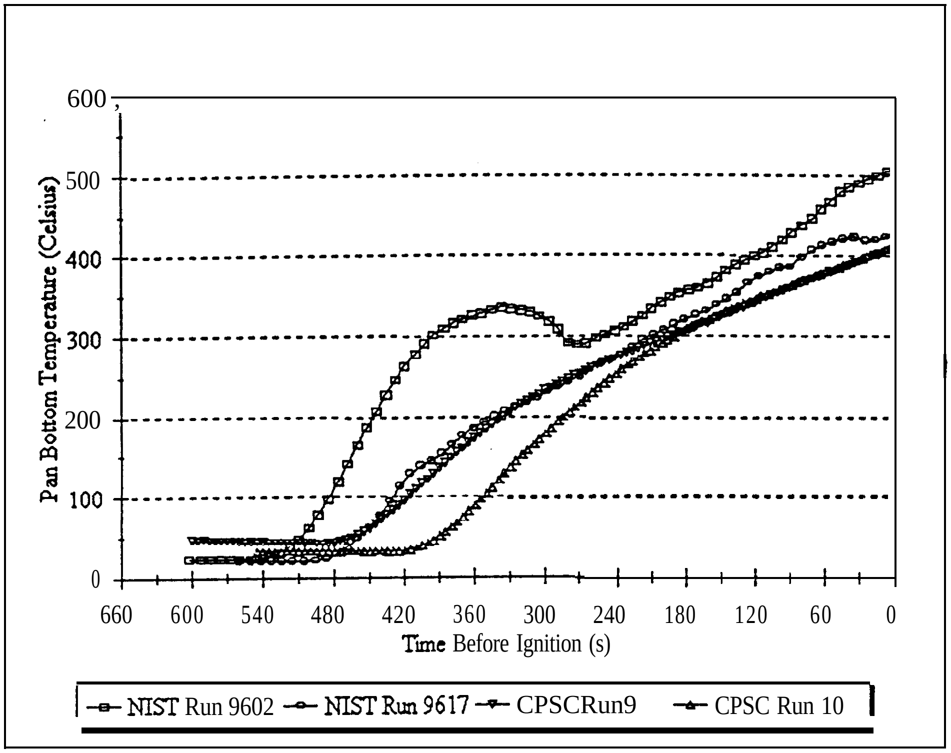

Figure 10.1.3.1A: Pan bottom temperature for bacon cooking scenario

Table 10.1.3.1A: Comparison of Pan Bottom Thermocouple Data (Electric Range)

	Oil		Bacon		Soybean Oil & Water (Electric Stove)		Chicken	
At Time of Ignition	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean
NIST 1	444.6	-0.57	509.4	1.70	463.9	1.12	449.5	-1.19
NIST 2	515.0	1.73	432.6	-0.25	-	-	471.7	1.24
CPSC 1	448.0	-0.46	412.7	-0.76	433.7	0.18	453.6	-0.74
CPSC 2	440.7	-0.70	415.6	-0.69	385.7	-1.31	466.7	0.69
Mean of Four Values	462.1		442.6		427.8		460.4	
Standard Deviation	35.41		45.41		39.12		10.53	
Coefficient of Variation (Std Dev as % Mean)	7.66%		10.26%		9.22%		2.29%	
120 Seconds Before Ignition	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean
NIST 1	419.6	-0.17	399.8	1.47	421.3	1.09	411.9	-1.31
NIST 2	473.0	1.68	374.1	0.37	-	-	423.1	-0.51
CPSC 1	402.3	-0.77	342.9	-0.98	383.3	0.24	436.9	0.48
CPSC 2	403.1	-0.74	345.6	-0.86	312.9	-1.33	448.8	1.34
Mean of Four Values	424.5		365.6		372.5		430.2	
Standard Deviation	33.30		26.83		54.20		16.09	
Coefficient of Variation (Std Dev as % Mean)	7.84%		7.34%		14.75%		3.74%	

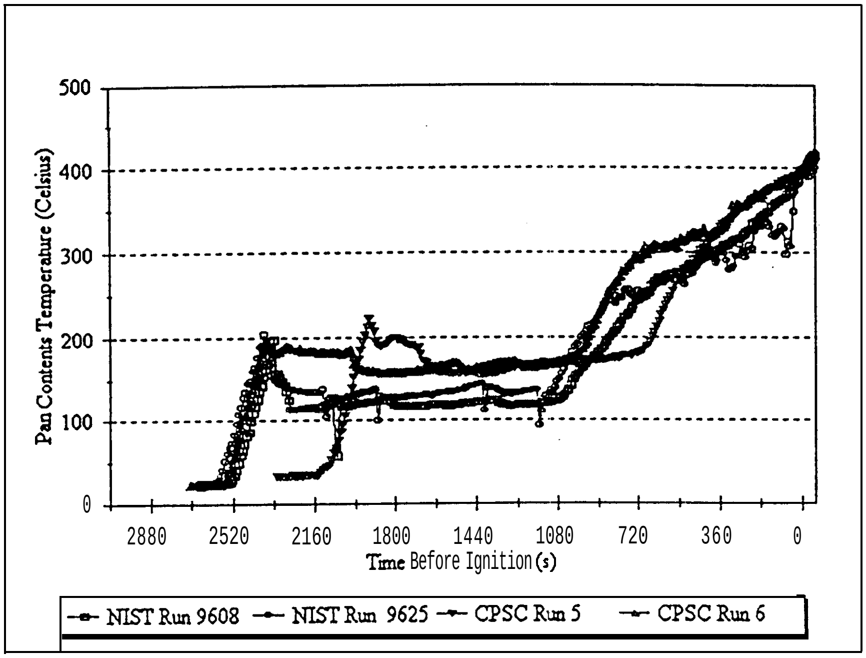

Figure 10.1.3.1B: Pan content temperatures for chicken cooking scenario

Table 10.1.3.1B: Numerical Comparison of Pan Content Temperatures (Electric Range)

	Oil		Bacon		Soybean Oil & Water (Electric Stove)		Chicken	
At Time of Ignition	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean
NIST 1	429.2	0.16	427.1	2.65	416.7	0.98	415.4	-1.06
NIST 2	395.5	-1.01	285.5	-3.45	381.4	0.20	400.7	-2.12
CPSC 1	376.8	-1.65	366.7	0.05	380.5	0.18	406.3	-1.71
CPSC 2	376.5	-1.66	373.7	0.35	367.0	-0.12	419.1	-0.79
Mean	394.5		363.3		386.4		410.4	
Standard Deviation	24.78		58.43		22.93		8.40	
Coefficient of Variation (Std Dev as % Mean)	6.28%		16.09%		5.98%		2.05%	
120 Seconds Before Ignition	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean	Temperature (°C)	No. of Std Dev from Mean
NIST 1	357.0	1.45	290.4	1.06	378.2	0.88	369.5	0.25
NIST 2	343.1	0.36	288.2	0.84	382.8	1.01	298.5	-1.70
CPSC 1	324.0	-1.13	274.9	-0.51	331.3	-0.47	387.2	0.73
CPSC 2	329.7	-0.69	266.3	-1.38	298.1	-1.42	387.0	0.72
Mean of Four Values	338.5		279.9		347.6		360.5	
Standard Deviation	14.72		11.41		43.20		42.19	
Coefficient of Variation (Std Dev as % Mean)	4.35%		4.08%		12.57%		11.70%	

The pan content temperatures from the tests also tracked each other reasonably well, both at *ignition* and at 120 seconds before ignition. The differences may be explained *by* variations in thermocouple placement and the non-homogeneity of the pan contents in some tests.

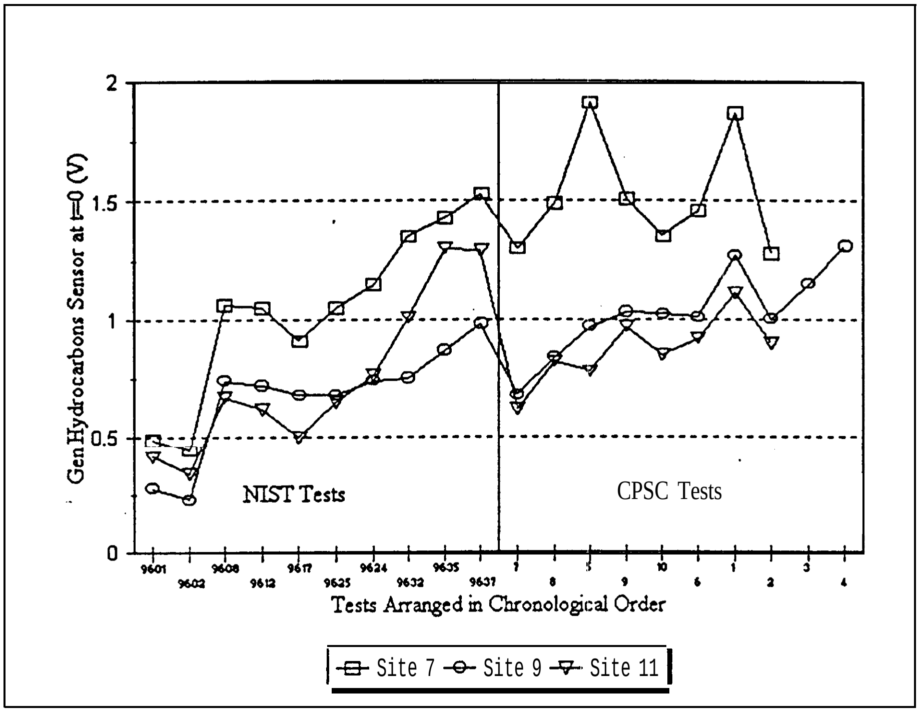

Figure 10.1.3.2A: General hydrocarbon sensor initial voltage offset versus chronological occurrence of tests

<u>*IO.1.3.2 Comparison of Gas Sensors*</u>

The output voltages from the gas sensors were not converted to gas concentrations, but rather were compared directly. Since the gas sensors used at CPSC were the same sensors used at NIST, they had been subjected to a considerable amount of smoke, heat, grease, and fire even before the first CPSC test run. The effects of aging and degradation may explain some-of the differences between the NIST and CPSC data. Also, at the beginning of the test runs, the sensor voltages did not start from zero, and this offset voltage varied from test to test. The gas sensor voltages at sites 7, 9, and 11 at the beginning of the twenty test runs were chronologically sorted and graphed in Figures 10.1.3.2A through 10.1.3.2D for the four selected types of gas sensor (general hydrocarbons, general alcohols, total cooking gases and cooking alcohols, respectively). Additional Phase II tests were conducted at NIST, but the initial voltage for the reproduction scenarios are the only ones shown here. Although the focus here is Site 9, the Site 7 and Site 11 offset voltage data are also presented to illustrate that the offset was not random.