MEETING LOG
DIRECTORATE FOR ENGINEERING SCIENCES

SUBJECT: Discussion of Possible Technological Solution to the Water Heater Flammable Vapor Ignition Issue

PLACE: International Approval Services Inc., 8501 East Pleasant Valley Road, Cleveland, OH

MEETING DATE: April 1-2, 1998

LOG ENTRY SOURCE: Donald W. Switzer DWS

ENTRY DATE: April 1-2, 1998

COMMISSION ATTENDEES:

Donald W. Switzer ES

NON-COMMISSION ATTENDEES:

See attached attendee list (attachment 1)

MEETING SUMMARY

The Water Heater Industry Joint Product Development Consortium held a public meeting to demonstrate a new technology water heater resistant to flammable vapor ignition and to discuss the latest Gas Appliance Manufacturers Association proposed test method for certifying water heaters' resistance to igniting flammable vapors. American Gas Association Research personnel gave a presentation explaining the method (see attachment 2). The proposed test method (attachment 3) was distributed to the attendees as well as reports on the development of the methodology (attachments 4&5).

In addition to reviewing the test method, the Consortium demonstrated the vapor ignition resistance of a prototype water heater by subjecting the appliance to two gasoline spills identified as summer and winter blend gasoline tests under test condition 1 in the attached proposed test method. In both scenarios, the prototype water heater did not ignite gasoline vapors. When a current technology water heater was exposed to gasoline vapors while installed on an 18 inch stand, vapors were ignited.

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WATER HEATER CONSORTIUM DEMONSTRATION
APRIL 1 AND 2, 1998

LIST OF ATTENDEES

Herb Doty	Minnegasco Consultant
Bill Harrigill	Rheem
Shamel Kassab	Teledyne Laars
Jay Katchka	Robertshaw Controls
P.C. Nanda	Consumers Assn. Canada
Tim Shellenberger	American Water Heater
Drew Smith	State Industries
Paul Beach	White Rodgers
David Lasseter	State Industries
Jake Hall	Rheem
Mark Taylor	Bradford White
Frank Stanonik	GAMA
Don Switzer	CPSC
Terry Logee	DOE
Dale Shropshire	A.O. Smith
Greg Reynolds	A.O. Smith
Sam Bernstein	AGAR/EI
Bob Borgeson	AGAR/EI
George Gruss	IAS
Mike Gable	Gas Consultants, Inc.
Daryl Hosler	So Cal Gas
Clem Erhardt	
Jack Langmead	

AGAResearch
Turning Concepts Into Reality

Development of a Proposed ANSI Test to Evaluate the Resistance of Water Heaters to the Ignition of External Flammable Vapors

Bob Borgeson and Roger Sheridan
AGAResearch

April 1-2, 1998

Background

- Gas water heaters are known to occasionally cause fires because flammable vapors outside the water heater were ignited
  - Massive liability actions in progress
- Annual Incidence from 7 to 30 per million water heaters, depending on area of country (Source: NFIRS data, as reported in GAMA Task 1 report)
- Highest incidence in South
  - Lowest in East
- Source: NFIRS data, as reported in GAMA Task 1 report

AGAResearch

II

Location in Home

- Incidents occur in many locations in home including:
  - Garage (20%)
  - Heating equipment room (14%)
  - Laundry room (10%)
- Source: NFIRS data, as reported in GAMA Task 1 report

AGARresearch

18" Rule

- National Fuel Gas Code and some other Codes require installation so that burner is 18" off the floor.
- Fire incident data is inconclusive whether this is effective

AGARresearch

GAMA Research

- GAMA (Consumer Education and Information Committee of Water Heater Division) funded assessment by A D Little (ADL)
- Task 1 report documents available statistics and describes a series of typical fire incident scenarios such as
  - person using gasoline in the utility room
  - children playing in garage or basement and tipping over a container of gasoline
- Task 2 report uses analytical model and experiments to determine the characteristics which are important to causing an ignition
  - Experiments performed at AGAR

AGARresearch

Task 2 Findings (partial)

- Motion in the room is an extremely important enhancement of ignition
- Ignition by elevated water heaters may be delayed but may produce significant pressure waves
- Room size, spill size and the ventilation rate are an important combined effect on the vapor profile over time
- Room temperature is not as important as room size, motion and size of the spill

AGARresearch

GRI Funded Research

- ADL led project to develop a test method and facility
- Experiments at AGAR defined different vapor profiles - concentration vs. time curves
  - movement or not
  - summer or winter gasoline
- ADL developed their butane/air chamber
  - Delivers specified butane concentration vs. time profile

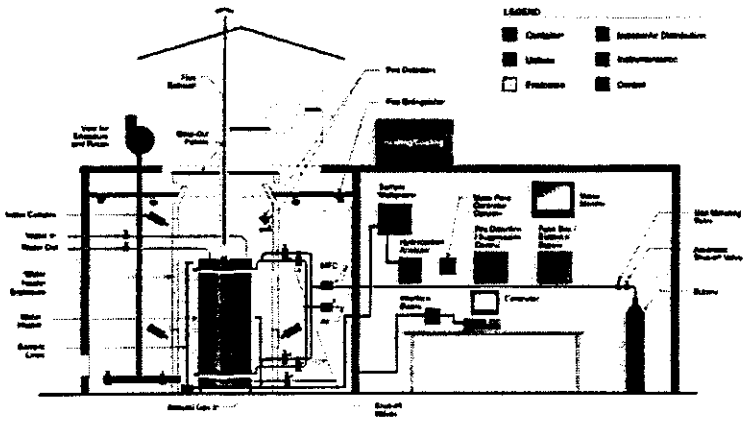
AGARresearch

Gasoline Blends

- "Gasoline" is mixture of many volatile organic hydrocarbons
- Most volatile component is butane
  - Butane will evaporate fastest, immediately after spill
  - Butane flammable from 1.8% to 8.4%
- "Winter Blend" gasoline has added butane

AGARresearch

ADL Test Chamber



AGARresearch

ADL Test Chamber Design

- Water heater test enclosure
- Pressure containment chamber of heavy gauge steel , cylindrical in shape, about twice the diameter and height of a typical 40 gallon heater
- Flue gas vent and blowout panels in the case of vapor ignition
- Vapor delivery system, using a butane-air mixture to simulate gasoline, that can accurately simulate the vapor profiles measured in the AGAR test room, both from a quantitative and qualitative basis
- Computer control to monitor conditions of the test and deliver the pre-determined amounts of vapors.

AGARresearch

ADL Test Chamber Results

- A useful facility was developed for the development of water heater concepts
- The butane-air mixture is cleaner and quicker to clean up after a test
- The test chamber can deliver a quantitative reproduction of a pre-determined vapor profile, presuming that a proper vapor profile scenario is known.

AGAResearch

ADL Test Chamber Limitations

- Different gas water heaters designs will cycle their burner and draw in combustion air at different times because of thermocouple placement, level of insulation
- Different gas water heater designs will draw in different amounts of combustion air depending on their input rate and the draft produced
- If unintended flammable vapors are burning in the combustion chamber, the burning rate and amount of combustion air used is hard to predict
- Gas water heaters with different dimensions will alter the motion of air in the room.

AGAResearch

AGAR Temporary Test Room

- First built for GAMA Task 2 work
- Used to develop vapor profiles for GRI
- Manufacturers began using to test concepts for improving water heaters
- Continuously improved under Water Heater Consortium funding

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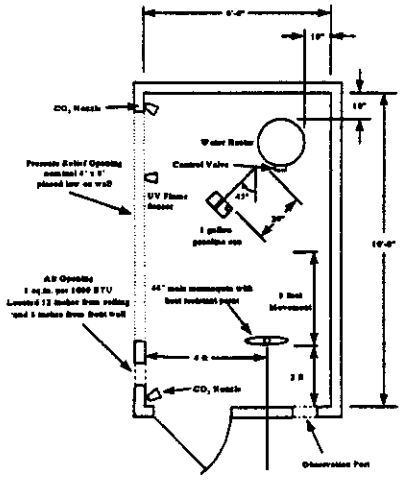
AGAR Test Room Layout



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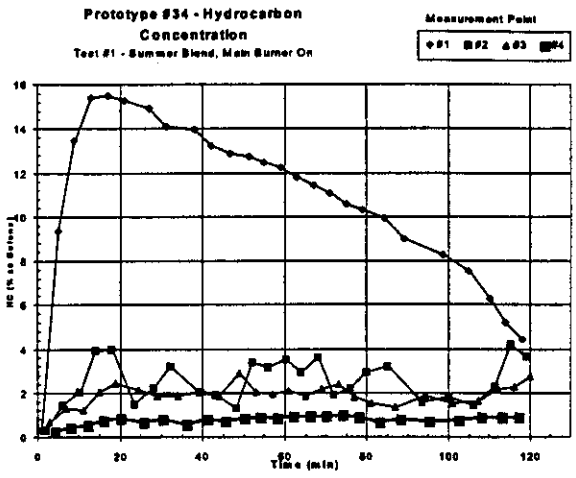
Summer Blend Example 1



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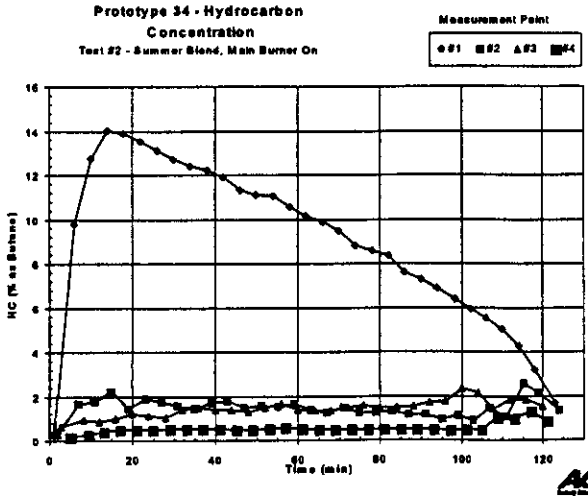
Summer Blend Example 2



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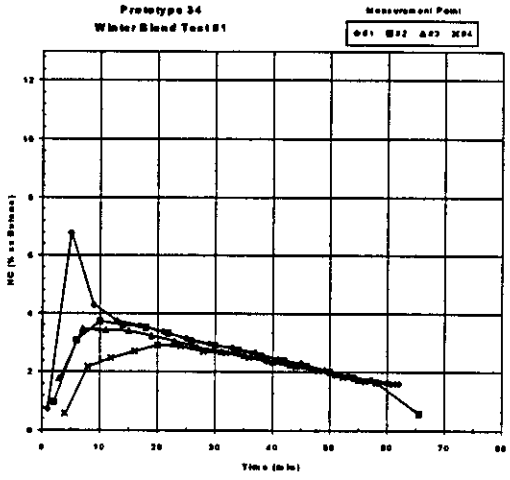
Winter Blend Example 1



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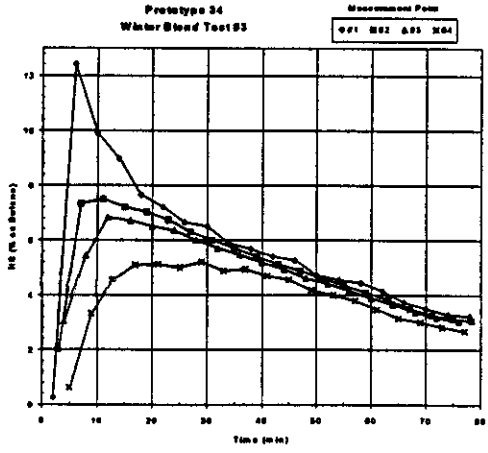
Winter Blend Example 2



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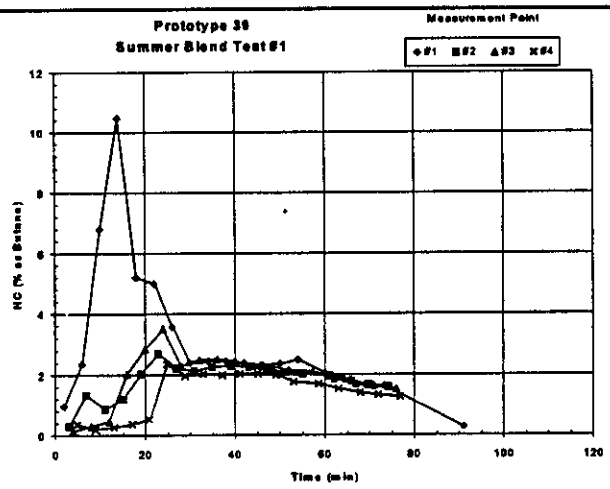
Summer Blend Example 3



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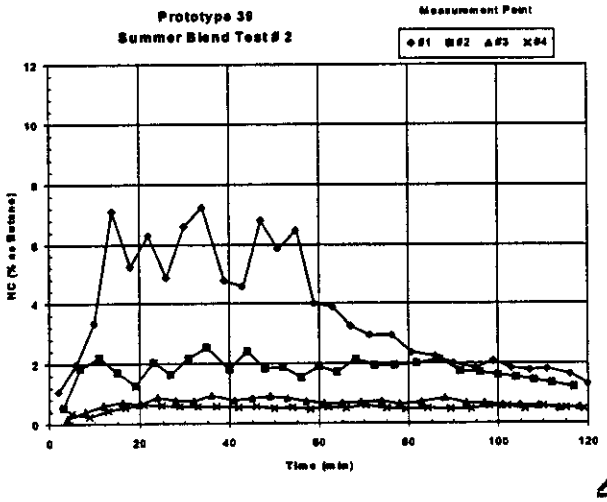
Summer Blend Example 4



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Conclusions

- Flammable vapor test must allow water heater to influence the vapor profile
- Vapor profile not known beforehand
- Defined set of profiles cannot be extrapolated to more than 750 water heater models

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Conclusions

- Excellent example of cooperation between GRI and manufacturers
- ADL Test Chamber is valuable for stressing design concepts under known conditions
- AGAR Test Room more appropriate for final certification

AGARresearch

Next Steps

- ANSI approval
- Design needed test facilities
  - Environmental
  - Safety
- Implement redesign and certification

AGA Research

PROPOSED REVISION TO AMERICAN NATIONAL STANDARD
FOR GAS WATER HEATER, VOLUME 1, STORAGE WATER HEATERS
WITH INPUT RATING OF 75,000 BTU PER HOUR OR LESS

2.38 (ADDED) FLAMMABLE VAPORS IGNITION RESISTANCE

The design of a water heater shall be such that it shall not ignite flammable vapors outside of the water heater created by the spilling of both winter and summer blends of gasoline on to the floor of the test room described in the following method of test.

METHOD OF TEST

These tests shall be conducted at normal inlet test pressure and input rating . The tests shall be conducted under the following three conditions with summer blend gasoline with a Reid Vapor Pressure of no more than 8 PSI and winter blend gasoline with a Reid Vapor Pressure not less than 13 PSI.

TEST CONDITION 1

The water heater shall be installed in a 6 ft. X 10 ft. X 8 ft. high room equipped with a suitable access door. The walls, ceiling and door of the room shall be constructed of fire resistant materials and the floor shall be made of metal and leveled to prevent the gasoline from forming puddles. A diagram of the test room is shown in **FIGURE 1.** The test room shall have:

a. Means to control the temperature of the floor to 70 degrees F plus or minus 10 degrees F.

b. A combustion and ventilation air opening of 1 square inch per 1,000 BTUH of input located 12 inches from the ceiling in the area of the wall shown in **FIGURE** 1.

c. Means to spill a measured amount of gasoline onto a specified area of the floor, using the one gallon gasoline can shown in **FIGURE 2.**

d. Provisions to provide pressure relief of the test room as shown is **FIGURE 1.**

e. A mannequin resembling a young boy and measuring approximately 48 inches in height. The mannequin shall be standing with its' legs spread a distance of approximately 14 inches with hands on hips. The depth of the mannequin shall be approximately 9 inches. The mannequin shall be equipped with a means to move it back and forth over a 3 foot long track at a rate of 3 feet per second.

III

f. Instruments to continuously measure the average floor temperature, ambient air temperature, water heater flue gas temperature, and the hydrocarbon concentration (measured as Butane) at the 4 points in the room, shown in **FIGURE 3**.

g. Means to observe the water heater under test from outside the room.

h. A suitable fire extinguishing system.

i. Means to verify the Reid vapor pressure of the gasoline prior to testing.

The water heater shall be located in the test room in the location shown in **FIGURE -1**. The water heater shall be tested with the venting arrangements described in 2.25.5, as shown in **FIGURE 3,** except as follows. When a manufacturer's supplied terminal(s) for either the air intake, vent exhaust, or both is designed for installation so that all combustion air is derived from the outside atmosphere, or all flue gases discharge to the outside atmosphere, or both, then the terminal(s) shall be installed in accordance with the manufacturer's installation instructions and terminate on the outside of the test chamber. The water heater shall be tested with all access doors in their normal position. If the lighting instructions call for the opening or removal of any door (s) to light the pilot, and if the main burner(s) will operate with those door(s) removed or opened, the tests shall be repeated with removable door(s) removed, and sliding or hinged door(s) left in a fully open position unless self-closing. The water heater shall be supplied with water at a temperature of 70 degrees F plus or minus 10 degrees F.

A quick acting valve shall be located outside of the test room and shall be adjusted or constructed so as to maintain a flow rate of 5 gallons per minute. The quick acting valve shall be arranged so that it will open automatically when the appliance thermostat reduces the gas supply to the burner(s) to a minimum and will close when the appliance thermostat functions.

The water heater thermostat shall be set at the 120 F mark and the water heater operated until the gas supply to the main burner(s) is reduced to a minimum. Initiate water draw off and allow the thermostat to function and ignite the main burner(s). Wait one (1) minute before spilling winter blend gasoline from a full one gallon container with the opening near the floor, as shown in **FIGURE 2**, in the direction of the water heater. The gasoline container shall be at a distance of 20 inches from the water heater as shown in **FIGURE 1**, before being tipped over. Immediately, begin to record the hydrocarbon concentration in the room. At one (1) minute after the spill, move the mannequin three (3) times back and forth over a three (3) foot path at a speed of 3 feet per second. Repeat the mannequin movement after one (1) minute elapses and at one (1) minute intervals until the end of the test . Allow the test to continue until, either a)

the water heater main burner(s) and pilot (if equipped) are inoperative, and flammable vapors no longer burn within the water heater, or b) the hydrocarbon concentrations at all four sensors shown in Figure 4 are below 50 per cent of the lower flammability limit (LFL) of 1.5 percent butane.

Following this test, it shall be determined that either the water heater is not capable of being returned to normal operation or, if the water heater is capable of normal operation, there is no damage other than that of a superficial nature to the water heater wiring and controls, and no safety control (function) has been rendered inoperative. If the water heater is capable of normal operation it shall be used for the remaining tests described in this section. Components intended by the manufacturer to be field serviceable may be replaced between tests. If the water heater is not capable of being returned to normal operation, a new test sample shall be used for the remaining tests.

The previous test shall then be repeated using the summer blend gasoline. The test procedure is the same as that described above for the winter blend gasoline except for the following:

a. Summer blend gasoline replaces the winter blend

b. There shall be no movement of the mannequin, and

c. The direction of the gasoline spill shall be away from the water heater with the opening near the floor..

If the water heater is capable of being returned to normal operation at the completion of the winter blend and summer blend tests, it shall be tested and shall comply with section 2.4 Combustion.

TEST CONDITION 2

The appliance shall be installed as described under **TEST CONDITION 1**. The water heater the thermostat shall be set at the 120F mark and the appliance permitted to operate until the thermostat acts to reduce the gas supply to the main burner(s) to a minimum. The quick acting water valve located in the outlet of the water heater shall be rendered inoperative. Winter blend gasoline shall then be spilled on to the floor of the test room in the manner described under **TEST CONDITION 1**. Immediately after spilling the gasoline the quick acting water valve is returned to service and a draw equal to 5 gallons per minute is placed on the heater. At one (1) minute after the spill, move the mannequin three (3) times back and forth over a three (3) foot path at a speed of 3 feet per second. Repeat the mannequin movement after one (1) minute elapses and at one (1) minute intervals until the end of the test. Allow the test to continue until, either a) the water heater main burner(s) and pilot (if equipped) are inoperative, and flammable vapors no longer burn within the water heater, or b) the hydrocarbon concentrations at all four sensors

shown in Figure 4 are below 50 per cent of the lower flammability limit (LFL) of 1.5 percent butane.. Following this test, it shall be determined that either the water heater is not be capable of being returned to normal operation or, if the water heater is capable of normal operation, there is no damage other than that of a superficial nature to the water heater wiring and controls, and no safety control (function) has been rendered inoperative. If the water heater is capable of normal operation it shall be used for the remaining tests described in this section. Components intended by the manufacturer to be field serviceable may be replaced between tests. If the water heater is not capable of being returned to normal operation, a new test sample shall be used for the remaining tests.

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a. Summer blend gasoline replaces the winter blend
b. There shall be no movement of the mannequin, and
c. .The direction of the gasoline spill shall be away from the water heater with the opening near the floor.

If the water heater is capable of being returned to normal operation at the completion of the winter blend and summer blend tests, it shall be tested and shall comply with section 2.4 Combustion.

TEST CONDITION 3

The appliance is installed as described under **TEST CONDITION 1** and operated until the thermostat acts to reduce the gas supply to the main burner(s) to a minimum. The Main burner is then prevented from operating by placing the gas control in the PILOT position or through similar means. . Winter blend gasoline shall then be spilled on to the floor of the test room in the manner described under TEST **CONDITION 1** . One (1) minute after the gasoline is spilled, move the mannequin three (3) times back and forth over a three (3) foot path at a speed of 3 feet per second. Repeat the mannequin movement after one (1) minute elapses and at one (1) minute intervals until the end of the test. Allow the test to continue until, either a) the pilot (or other ignition means if so equipped) is inoperative, and flammable vapors no longer burn within the water heater, or b) 2 (two) hours have elapsed since the spilling of the gasoline and no ignition of flammable vapors has occurred. Following this test, it shall be determined that either the water heater is not be capable of being returned to normal operation or, if the water heater is capable of

normal operation, there is no damage other than that of a superficial nature to the water heater wiring and controls, and no safety control (function) has been rendered inoperative. If the water heater is capable of normal operation it shall be used for the remaining tests described in this section. Components intended by the manufacturer to be field serviceable may be replaced between tests. If the water heater is not capable of being returned to normal operation, a new test sample shall be used for the remaining tests.

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c. The direction of the gasoline spill shall be away from the water heater with the opening near the floor.

If the water heater is capable of being returned to normal operation at the completion of the winter blend and summer blend tests, it shall be tested and shall comply with section 2.4 Combustion.

RATIONALE:. *The following provides further information on the details of the test. The size of the test room reflects the fact that a room of this size was shown to represent the majority of cases where an incident occurred between flammable vapors and a gas-fired water heater according to a study sponsored by Gas Appliance Manufacturers Association (GAMA), "Flammable Vapors Hazards Ignition Study, Task 1 Report", GAMA, Arlington, VA. June 16, 1993. This test room is representative of real situations and is appropriate for this test. The GAMA Task 1 study also showed that the majority of incidents between flammable vapors and gas-fired water heaters occurred in the warm months, or in warm climates. Therefore, a floor temperature of 70 degrees F is specified. Further, the floor temperature is important to the rate of evaporation of a flammable liquid that is spilled onto the floor; therefore a +/- 10 degrees F control of the floor temperature is specified. The test specifies one combustion air supply opening in the room located 12 inches from the ceiling and sized at 1 sq. in. per*

1000 Btu's of input to the water heater. This is based on the indoor combustion and ventilation air supply requirements for confined spaces specified in the National Fuel Gas Code. Those requirements specify 2 openings, one at 12 inches from the ceiling and one at 12 inches from the floor sized at 1 sq. .in. per 1000 Btu's input. Only one high opening is specified, rather than the 2 specified by the NFGC, to prevent flammable vapors from spilling out of the test room through the low opening.

The GAMA Task I Report shows that gasoline vapors were the major cause of incidents between flammable vapors and gas-fired water heaters. Gasoline vapor profile studies conducted for the Gas Research Institute (GRI), by A. D. Little Inc., "Flammable Vapor Test Methodology Development for Gas-Fired Water Heaters", GRI Report 96-0102, April 1996, showed that the type of gasoline significantly influences the profiles. Summer blend gasoline generally has a Reid Vapor Pressure of 7-9 psi, while winter blend gasoline has a Reid Vapor Pressure of 13-15 psi. The study identified that the vapor profiles reached the lower explosive limit of gasoline vapors at different times at different heights and that they exhibited both mixed and stratified profiles, (see test scenarios #2 and #7 in the GRI April 1996 report). Also, as outlined in that report, a can containing one gallon of either winter or summer blend gasoline, is spilled either toward or away from the water heater. Therefore, 2 test conditions are specified: a Winter Blend Test and a Summer Blend Test to represent the extremes of vapor profiles exposed to the gas-fired water heater. Further, to insure different gasolines are used in the tests, an upper limit of 8 psi Reid Vapor Pressure is specified for the summer blend gasoline; and a lower limit of 13 psi is specified for the winter blend gasoline. The construction material of the room, the specification for a pressure relief means a fire extinguishing systems are to provide for operator safety. The use of a child sized mannequin is based on the fact that the GRI April 1996 report showed no statistical difference in the gasoline profile between the use of a child-sized and adult-sized mannequin. Further the GAMA June 16, 1993 report showed most of the incidents between flammable vapors and gas-fired

water heaters involved children. Therefore, the test specifies using a child-sized mannequin moving at walking speed, 3 ft./sec. to mix the gasoline vapors for the Winter Blend Test, as shown in FIGURE 3. All tests are to be conducted using the spillage test stack installed on the water heater, except that special venting systems should be installed in accordance with the manufacturers installation instructions. Since any unit must comply with all provisions of this standard, there is no need to conduct these tests on other than normal test pressure and input rating. Since access doors which must be opened or removed during the normal lighting process may not be closed or replaced and therefore, these tests should be conducted with those doors opened or removed.

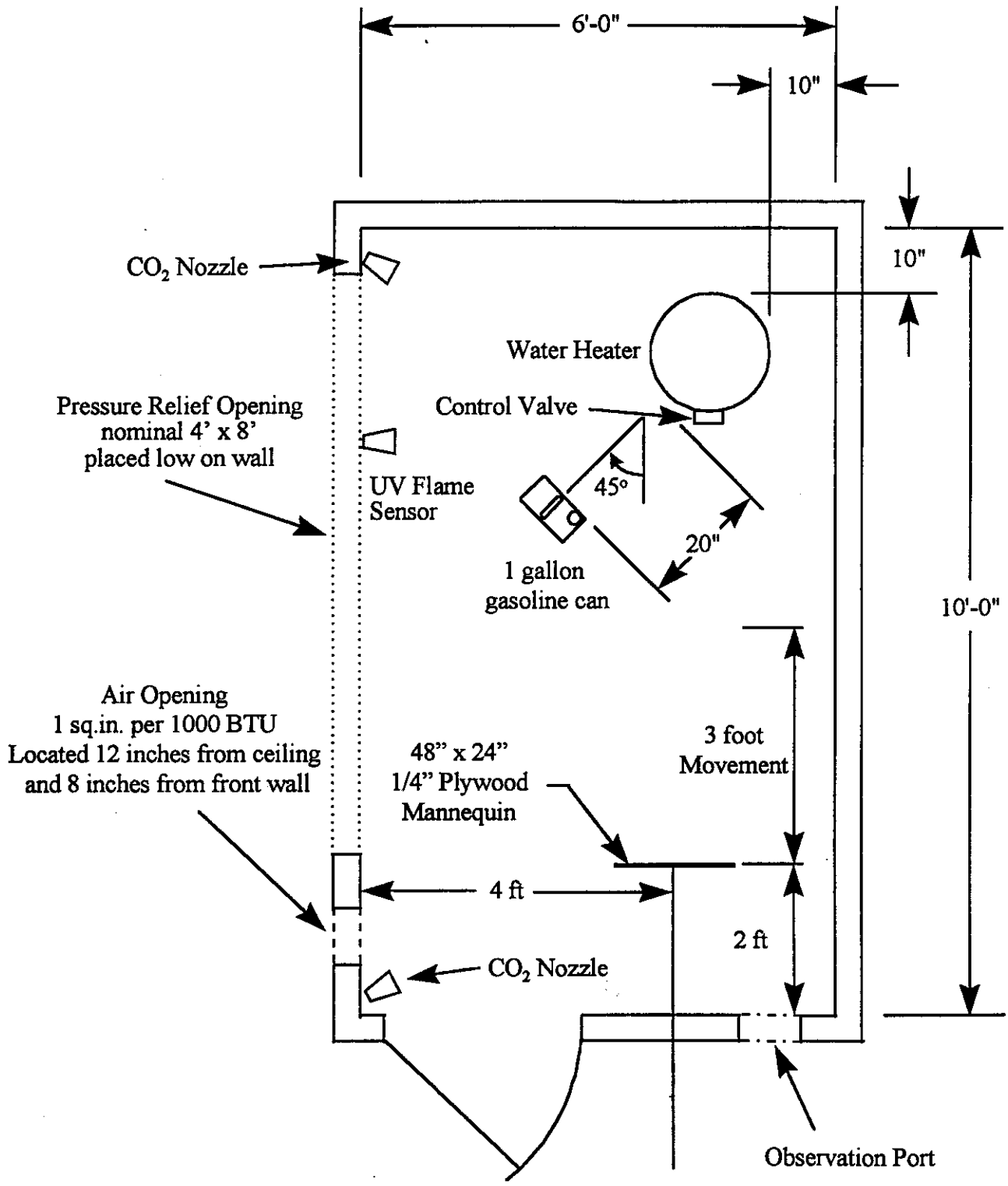
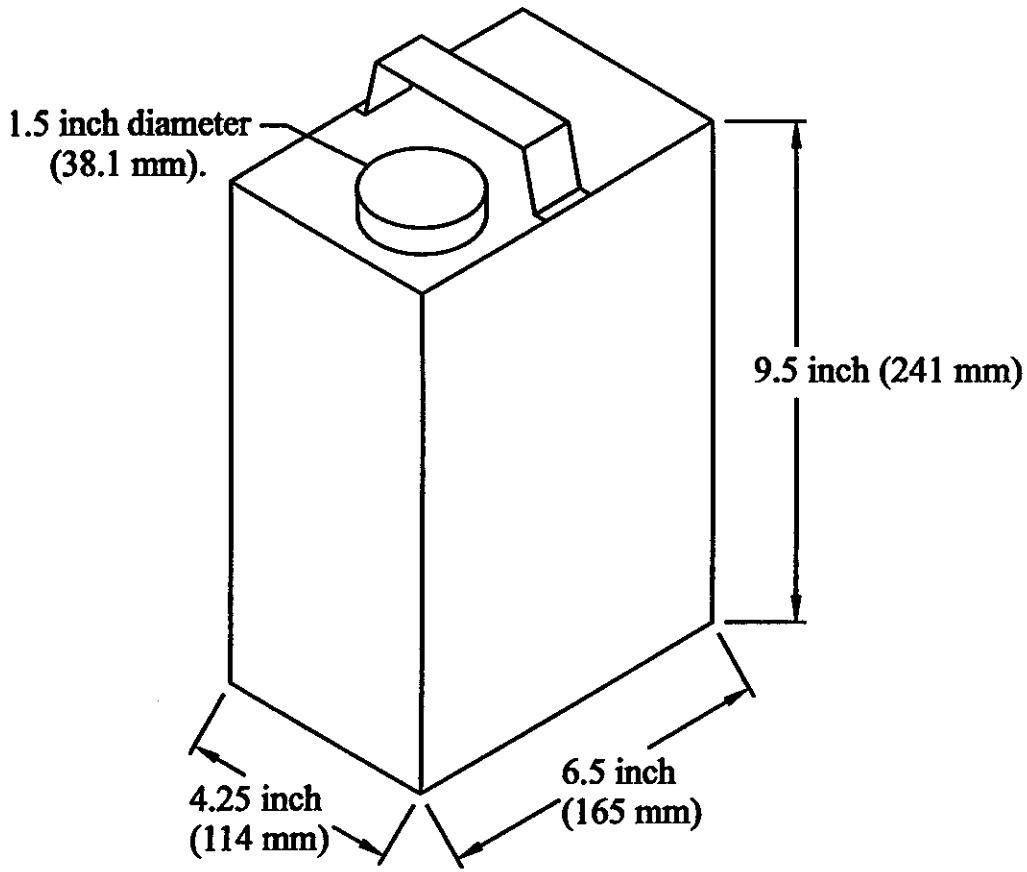


Figure 1 -Flammable Vapors Test Room



Tipped Position with Opening at Floor

Figure 2 - Standard One Gallon Gas Can

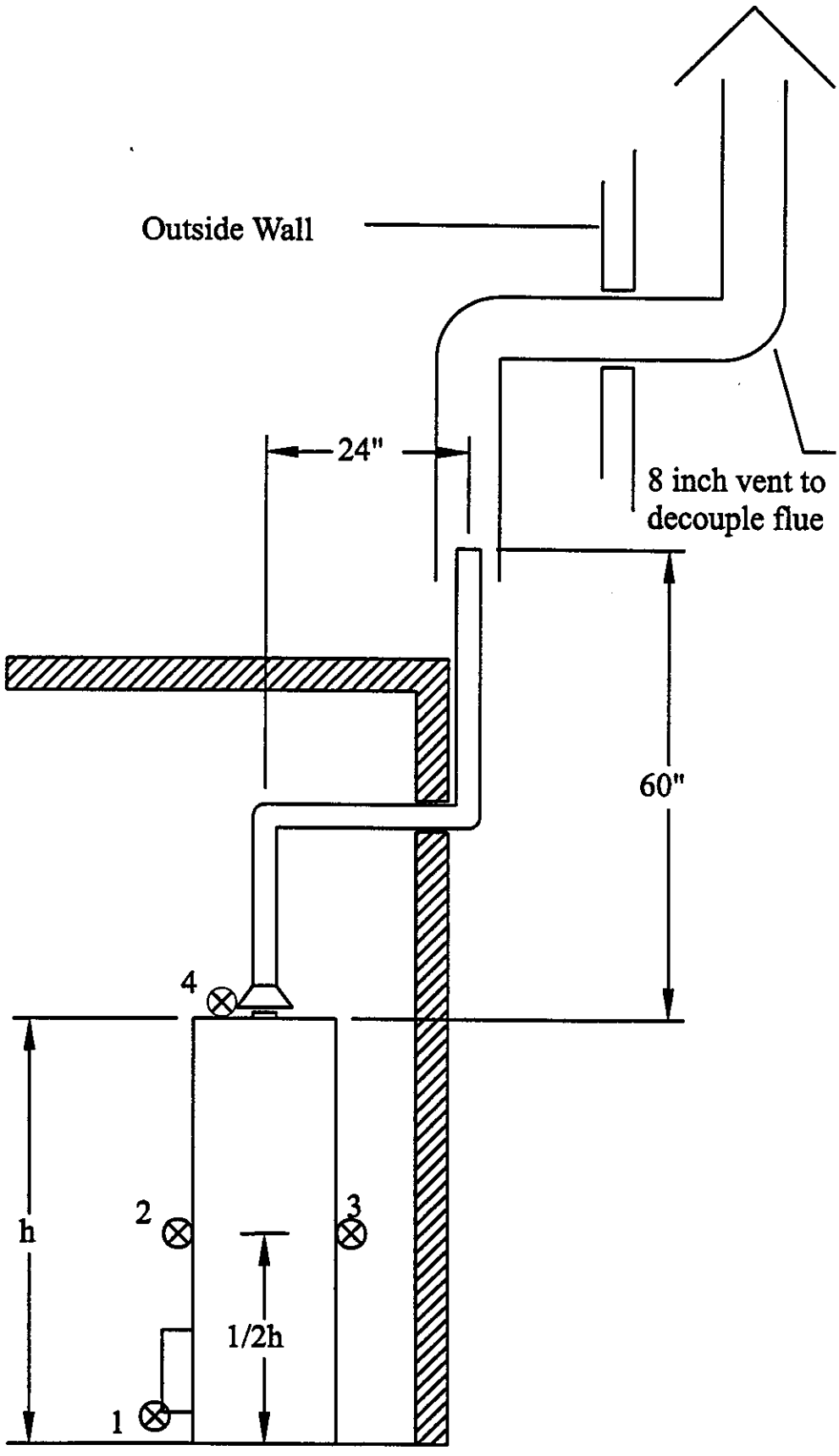


Figure 3 - Setup for Vent and Location of Hydrocarbon Sampling Points

WATER HEATER INDUSTRY
JOINT RESEARCH AND DEVELOPMENT CONSORTIUM
Coordinator: J. P. Langmead
2513 Fauquier Lane
Reston, VA. 20191
Telephone: 703:860-2754
Fax: 703:860-3313

MARCH 31, 1998

FLAMMABLE VAPOR TEST METHODOLOGY

Objective

Provide a design-insensitive test method that will verify a given water heater will not likely ignite flammable vapors external to the appliance.

Background

On June 16, 1993, Arthur D. Little, Inc., (ADL) published Flammable Vapor Hazards Ignition Study - Task 1 Report, identifying gasoline as the flammable substance involved in the vast majority of incidents involving ignition of flammable vapors. This report, as part of a comprehensive program sponsored by the Gas Appliance Manufacturers Association (GAMA), provided the basis for development of a test to determine the resistance of a water heater to ignite flammable vapors external to the heater.

In October, 1994, the Gas Research Institute (GRI) formed a Flammable Vapor Technical Advisory Group (TAG) and contracted with ADL to develop a suitable test methodology and procedure. GAMA and the major water heater manufacturers actively participated in this work.

The Water Heater Industry Joint Research and Development Consortium (Consortium) was formed and held an initial technical meeting in April, 1995. In addition to the pooling of resources to expedite development of flammable vapor ignition resistant designs, development of a consensus test method was also identified as a critical activity. As members of the Consortium, water heater manufacturers continued to gainfully support the work by ADL.

ADL's initial work equated to an extension of the prior noted GAMA sponsored program. In light of ADL's view that the actual spilling of gasoline during a test was undesirable, they identified and selected butane as a surrogate fuel.

IV

Vapor Profile Generation

ADL conducted a series of experiments in the American Gas Association Research (AGAR) gasoline spill test facility to determine the resultant vapor profile using simulated water heaters.[1] A means was provided to simulate the normal flow of combustion products through the appliance.

With this data, ADL proceeded to attempt to replicate these vapor profiles with computer controlled flow of butane and air into an isolated environment, hence the "Chamber Method" or "ADL Chamber".

The Consortium recognizes ADL appears able to replicate a given vapor profile, but that profile must be determined in the first instance by the actual spilling of gasoline.

Interactions

Although the approach proposed by ADL has merit, it does not recognize that different technologies can influence a vapor profile and thus the test. For example, during the course of developing, refining and testing Consortium concepts, prototypes were observed to consume/exhaust the gasoline spill test room of all flammable vapors in as little as twenty (20) minutes. Other prototypes required over one (1) hour to consume/ exhaust the same amount of flammable vapors.

Test Set-Up

In the gasoline spill test, a water heater is installed per the manufacturer's instructions in a 8 ft high - 6 ft wide by 10 ft long fireproof structure. The unit is then subjected to six (6) tests using spills of winter and summer blend gasoline while the unit is in standby, recovery, and primary ignition modes. In essence, every water heater is subjected to the same conditions and allowed to "operate on its own" with no interactions required by the test operator.

Over the course of development, ADL has proposed several vapor delivery schedules. To date, none of the vapor delivery schedules are adjusted to match the affect of the water heater's consumption of those vapors or otherwise recognizes that the water heater can be a significant driver during the test. The dynamics associated with a water heater burning flammable vapors within its combustion chamber is significantly different from a water heater simply burning its intended fuel supply.

---

[1]One 35,000 BTU per hour, 40 gallon, 3 inch, center flued, underfired water heater and one 75,000 BTU per hour, 75 gallon, 4 inch, center flued, underfired water heater were connected to a spillage stack equipped with an inducer to simulate the same flow through the water heater and vent as would occur under a main burner operating condition.

Summary

ADL's latest proposed vapor delivery schedule considers the use of both winter and summer blend gasoline and simulates common vapor delivery profiles for each water heater regardless of the water heater's size, type or firing rate. The test does not consider the rate at which a given water heater may consume the vapor. In this light, the possibility exists for the test chamber not to stress the appliance in the same manner or to the same degree as that associated with an actual gasoline spill.

The Consortium does recognize the ADL Chamber as a viable development tool. However, until correlation between the ADL Chamber method and spill test method are developed and proved, the Consortium supports the actual spilling of gasoline, in a controlled environment, as the method of choice for incorporation in ANSI Z21.10.1 Standard.

Flammable Vapor Test Protocol for Water Heaters Using a Gasoline Spill

A Report for

The Water Heater Consortium

By

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1. Objective

The objective of this report is to present the background, development and rationale for a test using gasoline to determine the resistance of gas-fired water heaters to ignite flammable vapors which are outside the appliance. This has been done by reviewing studies sponsored by the Gas Appliance Manufacturers Association (GAMA) and Gas Research Institute (GRI) that were aimed at identifying issues related to flammable vapors incidents. The report also compares and contrasts two test methods that are both currently being considered.

2. Background

The proposed gasoline-based tests to determine the resistance of a water heater to ignite flammable vapors both grew out two related projects which were funded by the GRI and GAMA. The original test room at AGAResearch (AGAR) was built to support Task 2 of a GAMA project[1] conducted by A. D. Little (ADL). It was later used in support of a GRI project that was intended to develop a test method that uses butane as a surrogate for a flammable liquid spill[2]. The AGAR test method and test room has been improved continuously since then under funding from the Water Heater Consortium (WHC). The development of these test methods is a model of cooperative funding between GRI and the water heater industry.

The Gas Appliance Manufacturers Association (GAMA) began this overall research effort due to documented field problems involving property damage and injury to consumers. GAMA members then undertook a proactive program to improve consumer's awareness of the hazards associated with the misuse of gasoline with the consent of the US Consumer Products Safety Commission (CPSC). CPSC continues to monitor the development of a test to verify the resistance of water heaters to ignite flammable vapors outside the appliance, as well as the development of new water heater conceptual designs that are expected to pass it.

The first organized review of flammable vapors incidents involving gas-fired water heaters was sponsored by GAMA and conducted by ADL[3]. The overall goal of this effort was to develop a comprehensive document detailing the extent of the hazard and the effectiveness of mitigating measures. In performing this task, the following data resources were reviewed:

- 142 detailed incident reports from several sources (CPSC, NFPA & NEISS),
- National and state fire incident databases,
- 26 interviews with persons knowledgeable about incidents and
- Published reports on the subject.

2.1 Typical Scenaris Identified

As a result of analyzing the incidents in a population of 53 million water heaters using the data bases shown above, there appear to be 7 typical scenarios where flammable vapors incidents with water heaters occur:

- 1 bathroom scenario,
- 2 utility room scenarios,
- 3 garage and basement scenarios and
- 1 garage scenario.

These scenarios occur in rooms ranging in size from small bathrooms up to larger rooms such as a garage. The casualty rate in small bathrooms was more than twice the average for all other gas-fired water heater flammable vapor ignition incidents.

The utility room scenarios are the second smallest room in which incidents were reported. The 2 utility room scenarios were characterized by:

- A 10 ft x 10 ft x 8 ft room,
- 1 gallon of gasoline for Scenario 1, spill outside room,
- 1-5 gallons of gasoline for Scenario 2, spill inside room,
- Movement was involved in Scenario 2 and
- Gas-fired water heater located in corner

In the detailed description of one actual Scenario 1 incident, a person was using gasoline to remove stains from trousers performed the cleaning operation outdoors near an open door to the utility room. The day was windy and the person thought that would disperse the vapors. As the person lifted the trousers from the soak pot, a flame from the gas-fired water heater located behind a closed door ignited the gasoline flammable vapors. This incident highlights how much room air motion can amplify the danger from the flammable vapors.

Three garage and basement scenarios were characterized by:

- A 20 ft x 10 ft x 8 ft room,
- 1 quart - 5 gallons of gasoline,

mixture is too lean. The Higher Flammability Limit (HFL) is the maximum concentration of vapor that can support a flame, above which level the mixture is too rich.

Gasoline is a mixture of hydrocarbon and other compounds. The component with the highest vapor pressure is butane. Therefore, it is likely that the initial vapor cloud over a gasoline spill will be rich in butane. The LFL of butane is about 1.8% and the HFL about 8.4%. From a description of incidents, it seems that the LFL is the point at which most incidents occur. This is the level that is first achieved following a spill. However, it is also possible that ignition could be avoided somehow immediately after the spill. In this case, the concentration could possibly rise above the HFL. Should this occur, there is also a possibility of ignition as the concentration drops and becomes flammable again. It is also conceivable that the vapor concentration could remain within the flammable region for some period of time. In this case, ignition could occur at any time, until the concentration leaves the flammable region.

The time it takes to reach LFL after a spill is partially determined by the gasoline's volatility. Other factors include the size of the spill and room, temperature, air change rate and room air motion. Volatility refers to how quickly the liquid will evaporate, creating the flammable vapors*. One measure of the volatility is the Reid Vapor Pressure (RVP). A higher value for the RVP indicates that evaporation will occur faster. The composition of gasoline varies by brand, time and location but there are two generic gasolines that represent the extremes of volatility:

- "Summer blend" gasoline with a Reid Vapor Pressure of about 9 psi and
- "Winter blend" gasoline with a Reid Vapor Pressure of about 12-15 psi.

The winter blend gasoline is essentially, summer blend gas that has had butane added to it to increase the volatility. This presents practical problems for developing a test method using a consistent blend of gasoline. It is well understood that the volatility of the winter blend makes it very difficult to store while preserving it's RVP† since the butane is likely to be lost over time.

3.2 Large and Small Room Tests

Under the auspices of GAMA, 37 gasoline spill tests were conducted in the AGAR test facility, in the presence of operating gas-fired water heaters:

- 21 tests in a 10' x 20' x 8' room,

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* The reader is reminded that ***liquid*** gasoline does not burn. It must be in the form of a gas to mix with oxygen and be flammable.

† Recently, a gasoline refinery was located that will provide consistent gasoline blends on a custom basis throughout the year.

- 10 tests in a 6' x 10' x 8' room and
- 6 tests in an 8' x 8' x 8' room.

Results of these tests are presented in the GAMA Task 2 Report.

3.3 Conclusions

Task 2 of the GAMA study helped to understand the relative importance of the following factors that influence the potential ignition of flammable vapors by gas-fired water heaters:

- Spill surface,
- Floor and room temperature,
- Room size,
- Flammable vapor liquid composition and
- Ventilation rate.

The room experiments resulted in several conclusions including:

- A gasoline spill near a gas-fired water heater is likely to result in an ignition of the flammable vapors;
- Installation of a water heater on an 18" stand may delay but cannot guarantee to eliminate the ignition of flammable vapors and
- Rags soaked in gasoline can present ignition sources in small rooms.

In addition there were several general observations that provide an insight to these experiments.

- Air motion is an important accelerator of ignition. Without forced convection in the room, the vapors will diffuse slowly away from the spill and be diluted by the room's ventilation. Therefore, without an induced air movement, a false sense of security can result.

- While elevation of the water heater delayed ignition of the vapors, the ignition may release more force than for floor mounted water heaters. This due to the larger volume of flammable vapors which are then present at the time of ignition.

- Room size, spill size and the ventilation rate are an important combined effect on the vapor profile over time

- Room temperature is not as important as room size, motion and size of the spill.

4. The ADL Butane-Air Test Chamber Development

GRI funded a program to develop a test methodology to assess the ability of a gas-fired water heater to resist ignition of flammable vapors[4,5]. The work was carried in the following phases:

4.1 Measurement of Vapor Profiles Resulting From Gasoline Spills

This series of fractional factorial tests was conducted at AGAR in the small room used as the basis for the development of the test chamber. These tests established that the important factors in a vapor composition profile in a room are:

- The time to reach the LFL at the water heater burner level,
- The peak concentration achieved,
- The total time the vapors are within the flammable region and
- The difference between the unique profiles created by summer and winter blend gasoline.

4.2 Design a Test Chamber

The facility designed, fabricated and tested at ADL consisted of the following components:

- Water heater test enclosure,
- Pressure containment chamber of heavy gauge steel , cylindrical in shape, about twice the diameter and height of a typical 40 gallon heater,
- Flue gas vent and blowout panels in the case of vapor ignition,
- Vapor delivery system, using a butane-air mixture to simulate gasoline, that can accurately simulate the vapor profiles measured in the AGAR test room, both from a quantitative and qualitative basis and
- Computer control to monitor conditions of the test and deliver the pre-determined amounts of vapors.

See Figure 1 for a schematic of the entire system.

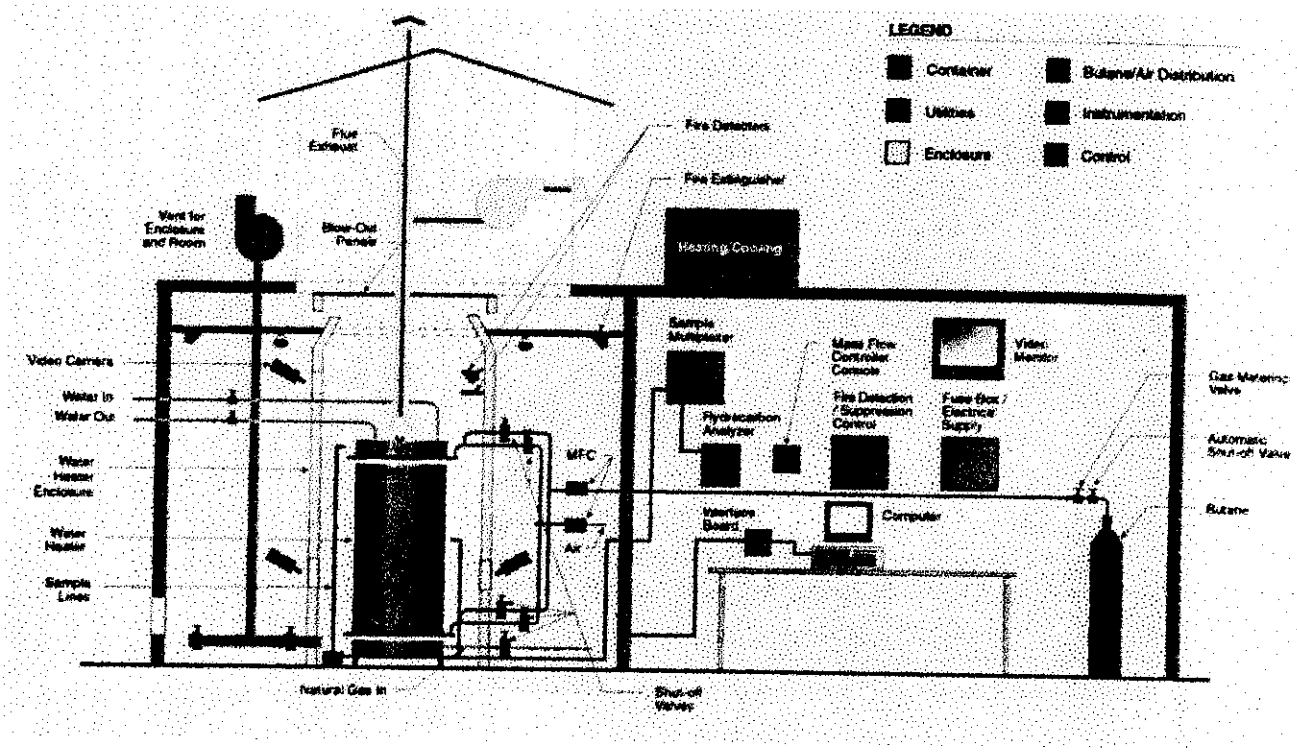

Figure 1 – Butane-air test chamber developed by ADL

4.3 Verification of the ADL Test Chamber

Six vapor profiles were selected to verify that the ADL test chamber's vapor delivery system could reproduce those obtained in the AGAR test room. The results of these tests showed that the chamber effectively reproduced the actual spill profiles. Further, as shown in Table 1, tests when ignitions occurred showed that the simulation closely duplicated the ignition times measured with actual gasoline spills in the AGAR test room (Spill scenario 2 is the winter gasoline protocol and scenario 7 the summer gasoline blend protocol).

Comparison of Times to Ignition for Water Heaters in the AGAR Test Room and the ADL Butane-Air Test Chamber				
	Water Heater on Floor		Water Heater on 18" Stand	
	Gasoline Spill	Butane-Air	Gasoline Spill	Butane-Air
Scenario 2	3-5 seconds	7 seconds	4-5 minutes	5 minutes
Scenario 7	15 seconds	15 seconds	31-51 minutes	30 minutes

Table 1 – Comparison of Gasoline Spill and Butane-Air Results

4.4 Define the Test Conditions Needed to Stress Potential Designs Aimed at Resisting the Ignition of Gasoline Vapors

The report shows that the test chamber can be used to test a wide range of water heater designs. In addition it will work with potential designs aimed at preventing the ignition of flammable vapors, such as:

- Fully premixed combustion systems,
- Remote air intake designs,
- Flame arresters and
- Flammable vapors sensors.

ADL went on to detail the types of conditions which are most critical for different types of hardware for preventing ignition. For example, a flame arrester will be stressed more when the flammable mixture is near the stoichiometric concentration. Using these concepts and the vapor profiles observed in the AGAR facility, ADL designed vapor profiles for different test purposes.

4.5 Conclusions

ADL's development of their test chamber was successful in that:

- A useful facility was developed for the development of water heater concepts;
- The butane-air mixture is cleaner and quicker to clean up after a test and
- The test chamber can deliver a quantitative reproduction of a pre-determined vapor profile, presuming that a proper vapor profile scenario is known.

However, the test chamber is limited in applicability by several practical considerations:

- Different gas water heaters designs will cycle their burner and draw in combustion air at different times because of thermocouple placement, level of insulation, etc.;
- Different gas water heater designs will draw in different amounts of combustion air depending on their input rate and the draft produced;
- If unintended flammable vapors are burning in the combustion chamber, the burning rate and amount of combustion air used is hard to predict and

- Gas water heaters with different dimensions will alter the motion of air in the room.

These considerations mean that it is likely that each water heater will create its own individual vapor profile. It is unlikely that a set of predefined vapor profiles can be extrapolated to a population of gas water heaters in the market that exceeds 750 models. In Section 5.3, results from tests in the AGAR test room will illustrate the wide range of vapor profiles that are possible under different conditions.

5. AGAR Gasoline Test Room Construction

5.1 History

The current flammable vapor test room at AGAR evolved over several years. The room was originally constructed to support the GAMA Task 2 work of ADL as described above. The structure had two rooms that could be used to perform tests in different volumes. The structure was wood frame with drywall construction and was housed under a plastic film structure. The larger part of the facility was abandoned and sealed off as the smaller room was settled on as the preferred test condition.

During the summer of 1997, construction began on a new, improved and automated structure reflecting the experience gained in the old room. This new room is sheltered under an improved plastic film structure and has proven to be much more reliable. It should be pointed out that the new room is still a temporary structure. It is anticipated that permanent test rooms will be built once the ANSI subcommittee approves the test method.

5.2 Description of Room

Figure 2 shows the floor plan for the test room. The room is:

- Constructed with metal studs covered with sheet metal,
- Foundation is a concrete pad embedded with hydronic heating coils,
- Floor is a single piece stainless steel,
- Pressure relief opening is covered with plastic or foil with perforations to minimize pressure buildup within the chamber,

- Water heater is vented through the back wall. The vent pipe is terminated within the outer plastic structure underneath an 8 inch diameter duct connected to the outside of the greenhouse. This duct acts to isolate the water heater vent from variable outdoor conditions such as temperature, rain, or wind and
- Mannequin is attached to a pneumatic cylinder with a three foot stroke length. Cylinder movement is manually controlled from the control room.

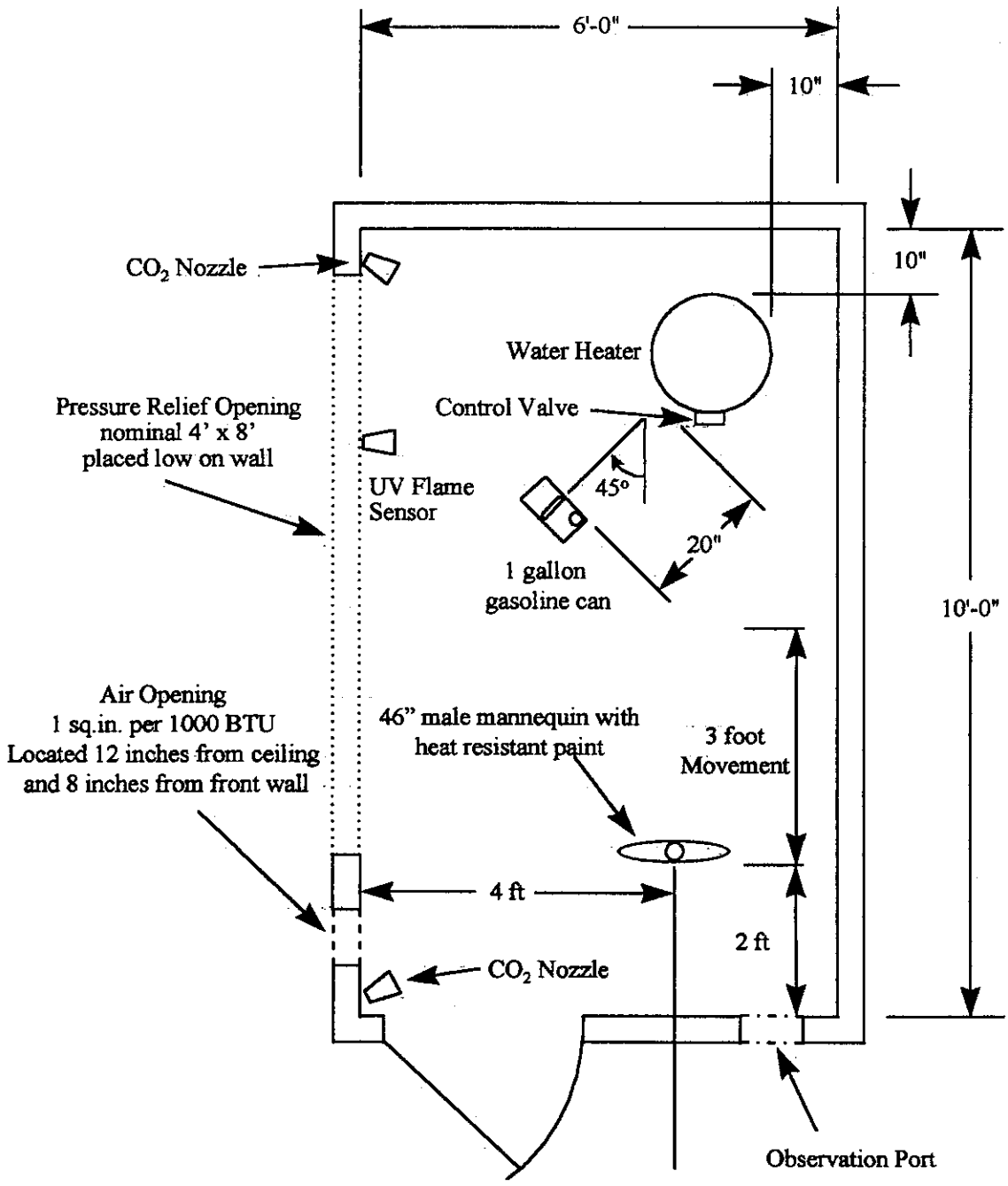

Figure 2 – Diagram of the Current AGAR Test Room

The following data is taken during a test:

- Temperature:
  1. Test chamber ambient,
  2. Water heater flue before the draft hood,
  3. Water within the heater at a level equal to the location of the T-P Valve
  4. Test chamber floor,
  5. Green house ambient at the combustion air inlet to the test chamber.

- Pressure:
  1. Differential between the test chamber and the exterior structure,
  2. Differential between the water heater vent and the exterior structure.

- Hydrocarbon Concentration (measured as butane) Sample Points:
  1. At the combustion air opening,
  2. At half the height of the water heater on the front,
  3. At half the height of the water heater on the back,
  4. On the top of the water heater near the draft hood.

- Miscellaneous:
  1. Relative humidity in the exterior structure at the combustion air inlet to the test chamber,
  2. Pilot millivoltage

5.3 Test Results

The new test facility provides a stable platform for performing a variety of tests with gasoline. The results obtained thus far are dependent on the specific water heater - as it should be. Unfortunately, the test can damage the water heater being tested. In particular, very different vapor profiles have been observed as different gas water heaters react to the spill.

Tests of WHC prototypes in the new room, as it was being developed, show that the facility has been improved. Similar water heaters produce similar results. The tests are also instructive in showing how much the water heater's size or operation can change the resulting vapor profile. The following discussion highlights results obtained in the new room from December 1997 through January 1998. In the interest of protecting the confidentiality of the manufacturers, the specific design differences in each test will not be discussed. But, they are all different and the reader should not expect the results to be exactly the same.

Figure 3 shows the vapor profile results for one test of Prototype 34. The test presented is for summer blend gasoline, without movement. The burner was on at the start of the test.

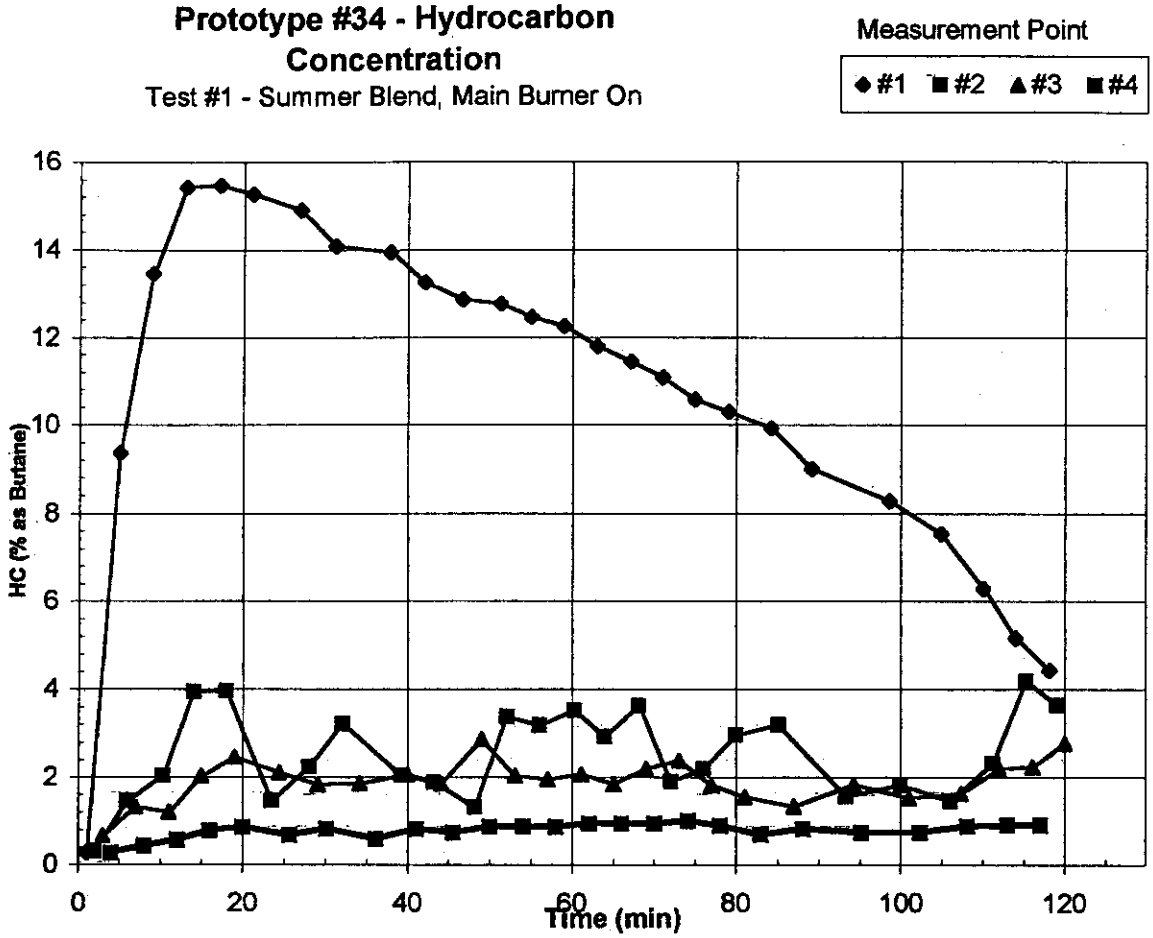

Figure 3

In Figure 3, the four traces are hydrocarbon concentrations at different elevations in the room. The hydrocarbon concentrations are measured as a butane equivalent. The sampling system can only read each measurement point once every 3 to 5 minutes[‡]. The long sampling runs also introduce a lag time between what is happening in the test room and when the measurement is recorded. The most important measurement point is #1, which is 3 inches above the floor and is closest to where the vapors are being pulled into the heater.

[‡] As this is being written, new hydrocarbon analyzers which allow simultaneous measurements are being installed.

Measurement points 2 to 4 are progressively higher in the room, as described in Section 5.2. Note that, a large difference in concentration exists for an extended period between point 1 and the rest of the room. This is characteristic of a test with no movement. The floor concentration rises immediately and then gradually decreases as the heater consumes the vapors.

Figure 4 presents the same data from a repeated test of the same heater. It was "the same" except that some components needed to be replaced after the first test. Comparing Figures 3 and 4, we see a good correspondence between the vapor profiles. And, in the end, the water heater passed the test both times.

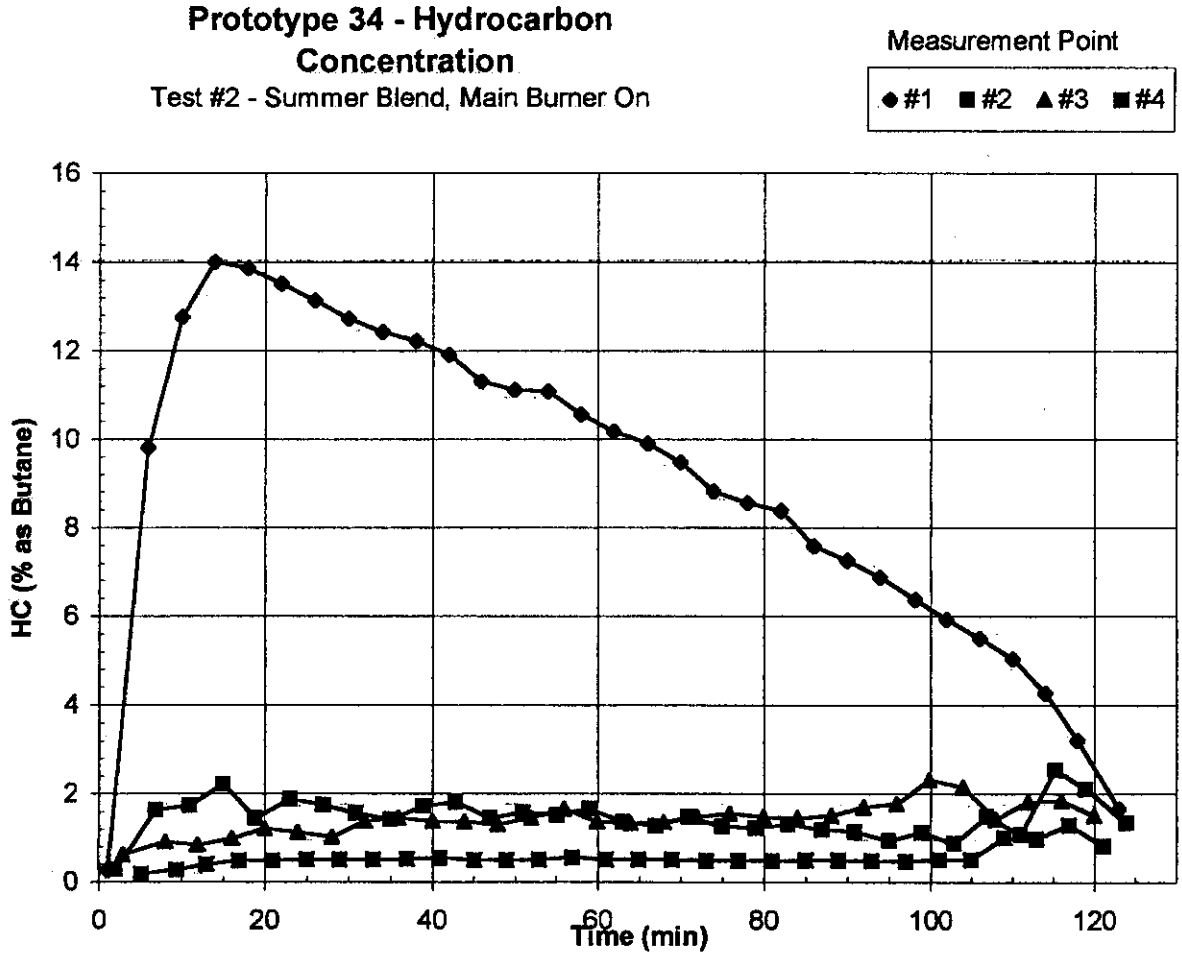

Figure 4

Figures 5 and 6 present continued tests of the same, though repaired, water heater. In this case, the two tests use winter blend gasoline, with room air motion caused by the flat mannequin. Both tests illustrate the different vapor profile caused by room air motion. In these tests, the vapor concentration rises quickly near floor level, represented by point 1. However, the difference between

the concentration near the floor and higher in the room diminishes more quickly compared to a test with no room air motion.

In these two tests, the vapor profiles are qualitatively quite similar. The difference in the absolute concentration is probably the result of the way the gasoline splashes at the start of the test. Despite the differences, the gasoline vapor at the level where the vapors can enter the heater was in the flammable range and the water heater passed the test both times.

It is certainly possible to design a standard way of spilling the gasoline. However, it is believed that spilling the gasoline by tipping over the container increases the realism of the test because of the splashing it creates.

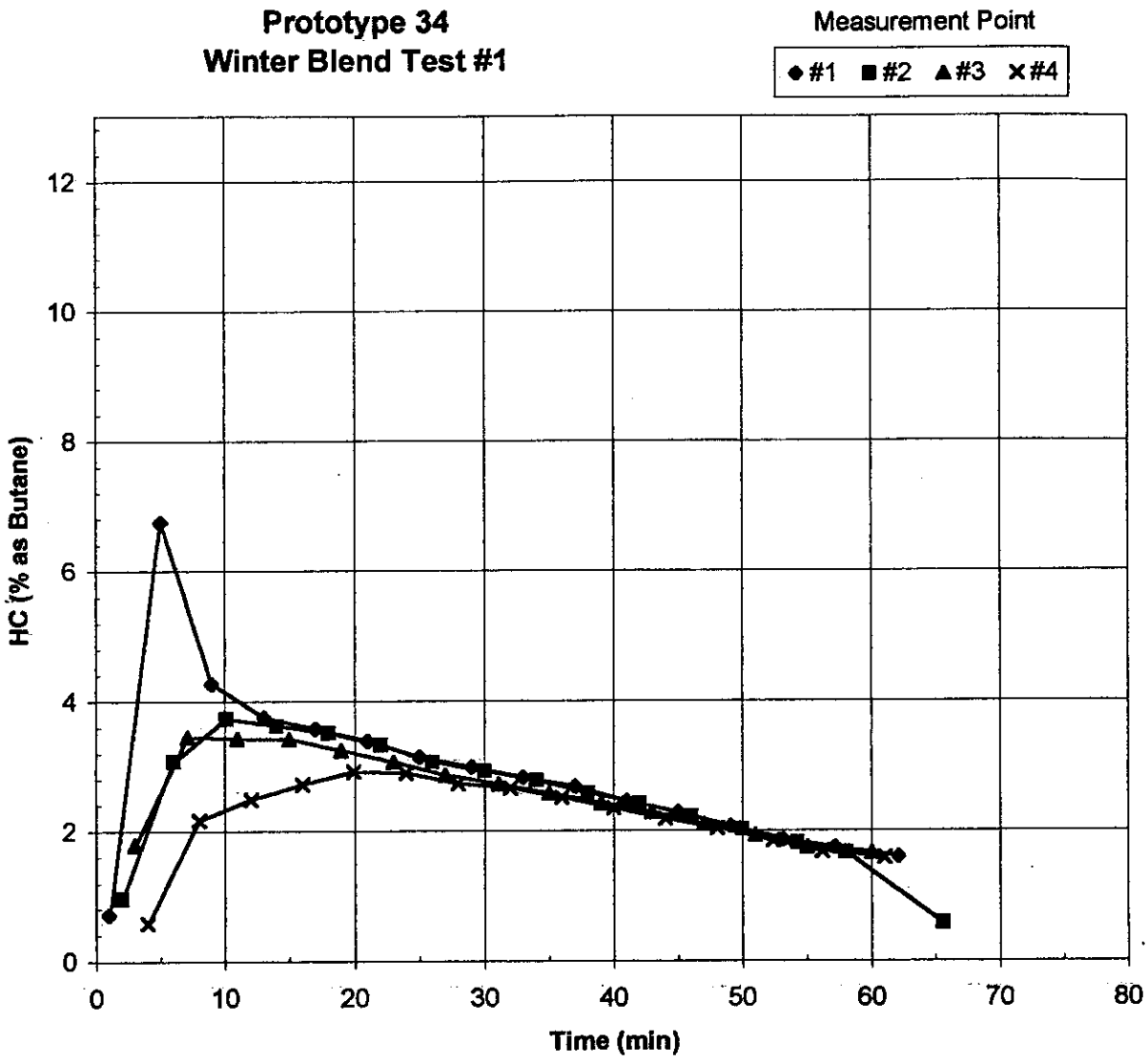
Prototype 34
Winter Blend Test #1
Measurement Point
◆#1 ■#2 ▲#3 ×#4
HC (% as Butane)
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
Time (min)

Figure 5

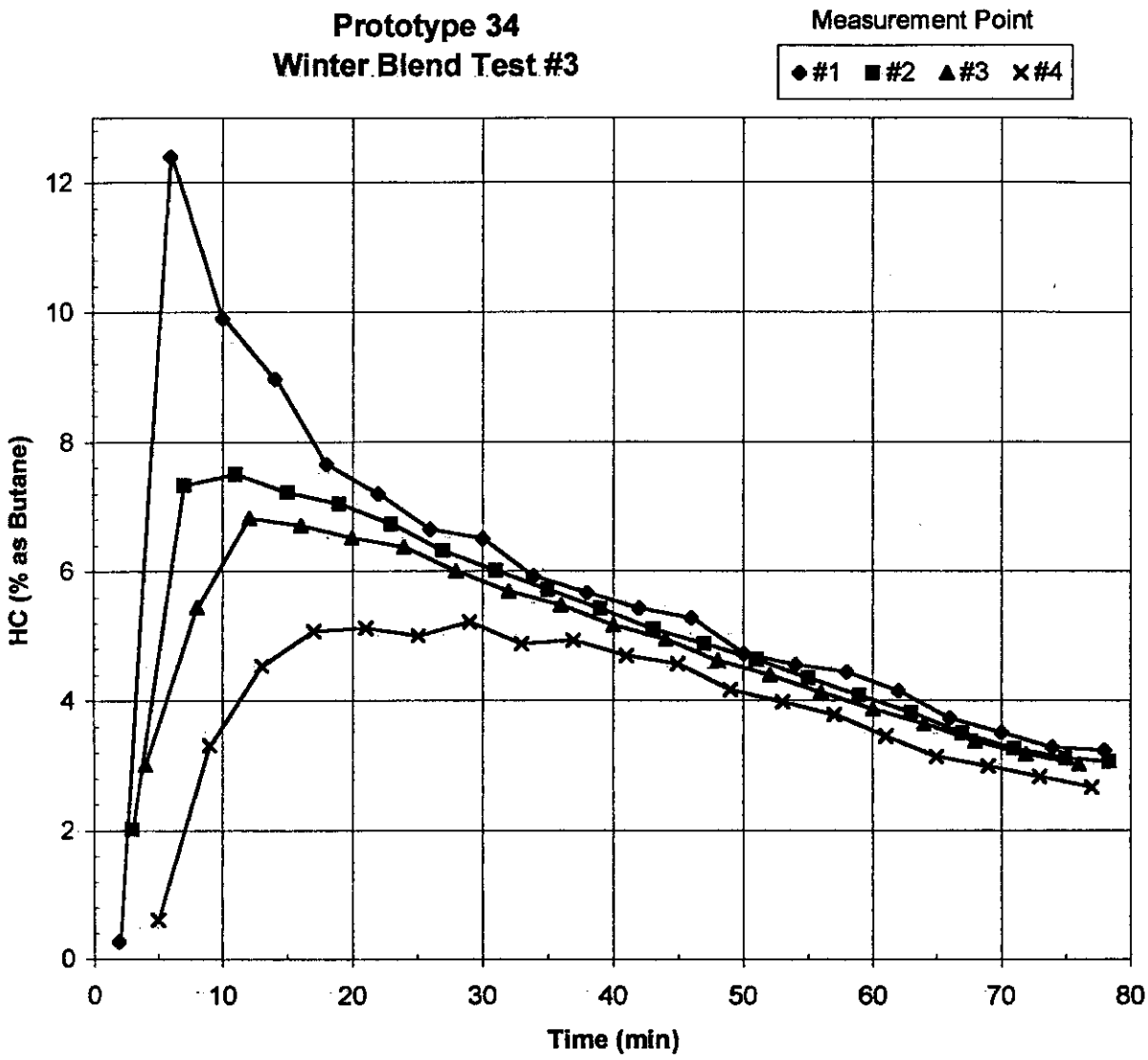

Figure 6

Recent tests also show how much the vapor profiles can be changed by differences in the water heater's operation, even using the same water heater. Figures 7 and 8 present the results of two tests, with room air motion caused by the mannequin on the same heater. The difference between the two tests is simply that the burner in Figure 7 of the heater ceased to operate soon after the spill. In Figure 8, the burner cycled on and off repeatedly, dramatically changing the profile as it consumed the vapors near the floor. In both cases, the heater passed the test, since it continued to consume the vapors without ignition outside the heater, until the vapors were below the LFL.

The two tests shown in Figures 7 and 8 point out that there is an element of chance both in the test and in real life. The reason for the different operation between the two tests shown is that the flames in the combustion chamber in the test shown in Figure 7 damaged a small component of the burner assembly. But, the component survived in Figure 8. This probably occurred because the flames in the combustion chamber are not steady. When the flame pattern changed, so did the life of that component. It is interesting to note that a test that directly controls the vapor profile might have missed the two potential outcomes.

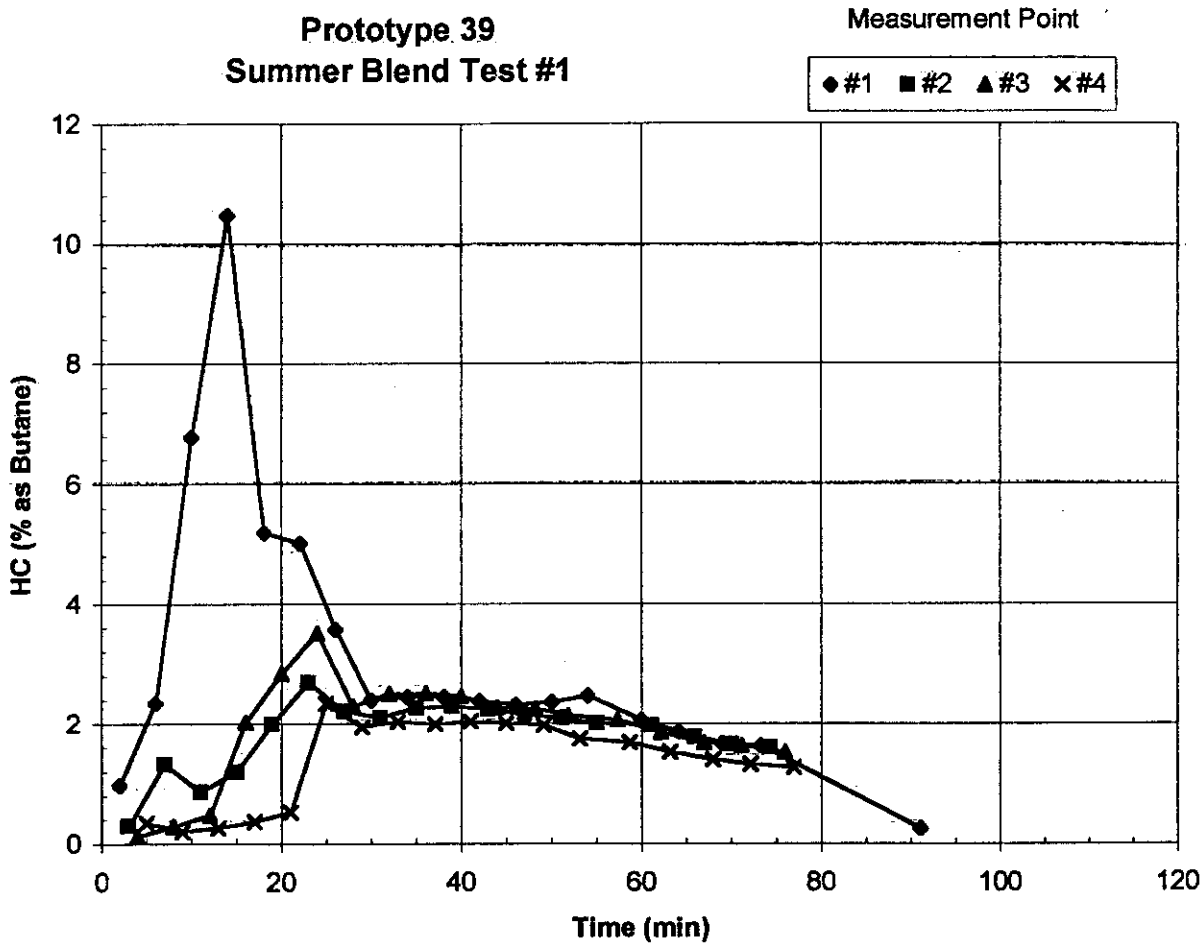

Figure 7

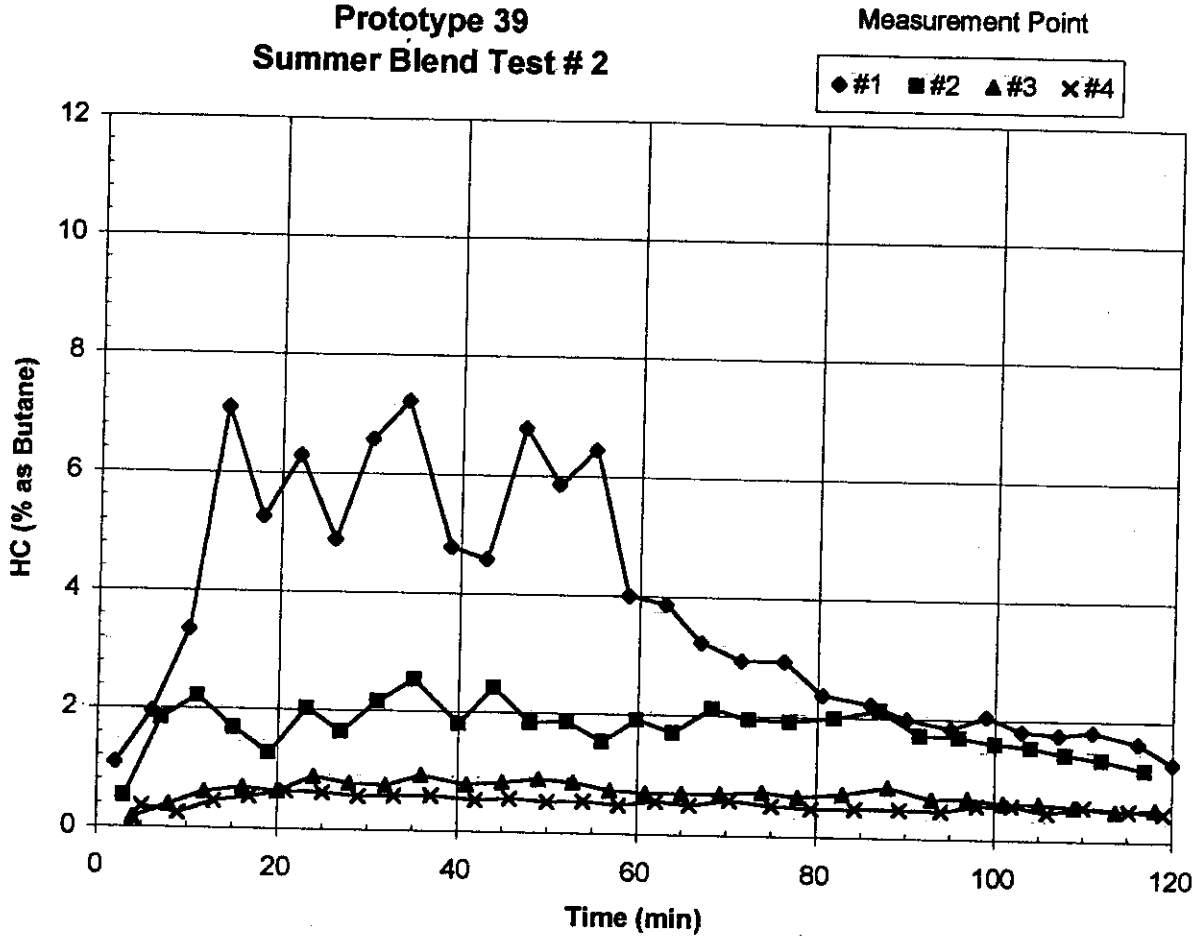

Figure 8

6. *Development of Proposed ANSI Test*

The Water Heater Consortium drafted a proposed ANSI Z21.10.1 Test "2.38 (Added) Flammable Vapors Ignition Resistance". This procedure was reviewed and endorsed by the GAMA Water Heater Technical Committee and forwarded to the ANSI Z21.1 subcommittee during June 1997. This proposal was aimed at the development of a realistic test of water heaters using gasoline spills. Further the test used a small room as the test platform, again to represent a set of realistic conditions that represent the Scenarios where actual incidents have occurred in the past.

The draft was discussed as Item 4 at the Z21/CGA Joint Water Heater Subcommittee Meeting , August 13-14, 1997 and sent to the Flammable Vapors Working Group. On November 13-14, 1997 the Working Group considered:

- The gasoline spill test option submitted by GAMA and
- A test option using Butane-Air mixtures as a surrogate for gasoline in the chamber developed at AD Little, drafted by AD Little (ref.: Item 2, Flammable Vapors Working Group Meeting, November 13-14, 1997).

The Working Group sent both options back to the main subcommittee, without a recommendation. The Subcommittee on Standards for Gas Water Heaters will consider the 2 options at their next meeting.

7. Conclusions

The cooperation between GRI, GAMA and WHC has produced two test methods for the resistance of gas-fired water heaters to ignite flammable vapors outside the appliance. The tests produce similar results, if they are carefully coordinated. Both have their place in the design and development of a water heater.

AGAR believes that ADL has provided the water heater industry with excellent service with their investigation of flammable vapor-related incidents and the development of the ADL Test Chamber. AGAR was proud to support them in this development. The ADL Test Chamber is particularly useful to stress water heater concepts or their components under specifically controlled conditions. The AGAR test room, with a real gasoline spill, is more useful for the practical testing of water heaters in a way that includes the many design specific parameters of the appliance. For this reason, AGAR believes that the gasoline spill test is more appropriate for testing water heaters in the latter stages of development and for certification purposes.

References

[1] Flammable Vapor Hazards Ignition Study, AD Little, July 15, 1993, GAMA Task 2 Report
[2] R.F. Topping and K.R. Benedek, Flammable Vapor Test Methodology Development for Gas-Fired Water Heaters, Arthur D. Little, Inc, Cambridge, Massachusetts, April, 1996, GRI-96/0102.
[3] Flammable Vapors Hazards Ignition Study, AD Little, June 16, 1993, GAMA Task 1 Report.
[4] Flammable Vapor Test Methodology Development for Gas-Fired Water Heaters, AD Little, April 1996, GRI Report 96/0102
[5] Flammable Vapor Test Methodology Development for Gas-Fired Water Heaters (With Data Appendix), AD Little, May 1996, GRI Report 96/0102.1