This "conclusion" in the report was discussed at the December meeting. The experimenter's explanation was that this statement was probably the result of poor proofreading of the report. The test data presented in the report clearly indicates that no ignition will occurs for a one gallon spill with no motion of the dummy when the heater is elevated 18 inches. The data also indicates that the probability of ignition is definitely decreased in the other cases when the heater is elevated 18 inches. From discussions at the meeting in December, it appears that the conclusion A.D. Little wanted to make was that raising the water heater 18 inches, as a mitigation method, would not prevent ignition in all cases.

Analytical Modeling

The report stated the objective of the Analytical Modeling Task was to provide insight into the selection of key parameters for experimental testing. This effort was to include identification and verification of incident scenario patterns and an assessment of parameter sensitivity for experimental testing. From the December meetings, it was evident that the experiential task took precedence over the analytical and that only very cursory analytical modeling was undertaken for this task.

The "SuperChems™" Program.

"SuperChems™", "Super Charged Hazard Evaluation MethodS for Integrated Design Safety™", is a multifarious implementation of mathematical consequence modeling. This type modeling is used for risk quantification, emergency response planning, loss prevention, safe design, and environmental planning. One definition of this modeling is "*the use of solutions of mathematical representations of conservation and physical laws to analyze and quantify potential damaging effects of hazardous events.*"[2]

The modeling in the SuperChems™ program, follows this definition. It begins by determining source terms and then, dependent on the problem to be addressed, can quantify dispersion, fire and explosion hazards. There is no claim that this program "accurately predicts" all these hazards for all cases. The program has been validated for certain type "spills" against large scale tests and showed good agreement.

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[2] Melhem, G.A. & P.A. Croce, "Advanced Consequence Modeling: Emission, Dispersion, Fires and Explosions" Second Draft, July 1993, A.D. Little, Inc.

CPSC has a "Beta test" version of the SuperChems™ program, Version 1.21. The program, although complete in some aspects, is still in development. One of the extensions that A.D. Little appears to be looking at is the application of this tool to areas of more interest to CPSC. These extensions include the potential hazards associated with "small scale" problems, e.g., small gasoline spills ignited by gas water heaters. One possible difficulty in these extensions is that many parameters, used in the current modeling, are based on experimentation and empirical data from large scale spills. The applicability of the approximations, the theory and the program to small spills still has to be shown. As an example for some large spills an accuracy of 100 feet may be more than adequate, where for the small gasoline spills accuracies less than one inch (1") might be needed.

Conclusions:

A.D. Little reached the following conclusions in the report:

> As a result of these tests, we [A.D. Little] have several general conclusions:
>
> - A gasoline spill near a floor mounted water heater is likely to result in ignition of flammable vapor.
> - Rags soaked in gasoline in small rooms can present ignition sources.
> - Repeated tests are required to validate conclusions due to the variability and uncertainty associated with tests of this nature.
> - An 18-inch stand will delay but not eliminate ignition of flammable vapor, particularly in realistic situations where movement is present. The delayed ignition can produce significant pressure waves."

Based on the critical engineering review of the test, analysis and report, and the meetings with A.D. Little, the ES staff conclusions are:

- Raising a water heater 18 inches appears to significantly reduce the likelihood of ignition in the case of a gasoline spill.
- The A.D. Little analysis and test for Task 2 had a much narrower purpose than the overall project purpose stated in the report. That is, rather than "to develop a comprehensive understanding of the extent of the hazards and the effectiveness of current mitigating measures.", the purpose of the Task 2 effort was to show that gasoline spills in the vicinity of gas fired water heater represented a fire and explosion hazard potential.
- The SuperChems™ computer program may have applicability not only to the gasoline vapor / water heater analysis but to many other interests of the Commission, e.g., IAQ. However, the program may need to be verified by experiments depending upon the application.

Recommendations

Since CPSC's efforts in this area are ongoing, it is probably premature to make definitive recommendations as to the direction CPSC should take. However, the efforts, to date, do allow some general comments and recommendations:

- The efforts by CPSC, as well as the tests conducted in the GAMMA/A.D. Little study, show that the risk of injury from the ignition of flammable vapors by gas water heaters can be significantly reduced. This effort to determine the "best" method(s) of mitigation/reduction should be continued.

- A.D. Little is pursuing further studies of this problem and, more importantly, of mitigation methods. Based on the discussions at the December meeting, A.D. Little has shown great interest in conducting design reviews for their future efforts. The design review process is dependent on the desires and agreement of their customer. They have expressed an interest in CPSC's participation in this design review.

- The evaluation of the SuperChems™ program's applicability to this problem should continue, with perhaps testing of the prediction ability based on CPSC tests. In addition the applicability of the program to other CPSC efforts should be investigated.

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United States
CONSUMER PRODUCT SAFETY COMMISSION
Washington, D.C. 20207

MEMORANDUM

DATE: September 22, 1994

TO: Don Switzer, ESEE

Through: William H. King, Division Director ESEE

FROM: Tim Johnson, ESEE T. J.

SUBJECT: Analysis Of Data Contained In Tables 8-10, pages 20-22, Of The A.D. Little Task 2 Flammable Vapor Hazards Ignition Study.

Ref: A.D. Little Flammable Vapor Hazard Ignition Study, Task 2: Modeling and Experimental Testing, Reference 42238, 15 July 1993

Introduction and Purpose:

The purpose of this memo is to present a CPSC analysis of the data supplied in tables 8-10, pages 20-22, of the A.D. Little Task 2 study. These tables list the results of 32 "live-fire" tests performed by A.D. Little (ADL) and are included in Appendix 1 of this memo. Eight parameters were varied throughout the 32 "live-fire" tests outlined in Appendix 1. The effect that these eight parameters had on ignition time of gasoline vapors by a water heater were looked at by staff. Ignition time is defined as the time from when gasoline is spilled to the time the vapors are ignited by the water heater.

The eight parameters consisted of:
1) ELEVATION
2) MOVEMENT - Effect of room movement on ignition time.
3) FLOOR TEMPERATURE.
4) ROOM TEMPERATURE.
5) FLOOR TEMPERATURE GREATER THAN ROOM TEMPERATURE.
6) ROOM SIZE.
7) AMOUNT of gasoline spilled.
8) SPILL DISTANCE of gasoline with respect to the water heater.

Note that staff does NOT claim that the following is a rigorous statistical analysis. There were very few tests run that consisted of similar parameter values. Due to the small number

of tests run in relation to the number of variable parameters (8), it is nearly impossible to do a "high level" statistical analysis on the A.D. Little data such that firm conclusions can be drawn. Instead, staff has grouped together tests in which 7 of the 8 parameters are essentially the same in order to compare results of similar experiments (tests) where measured variables were held constant. As a result, it is possible to "isolate" a particular parameter such that its effects on gasoline vapor ignition time can be more clearly understood.

Analysis Criteria:

In analyzing the eight parameters outlined above staff grouped together two sets of tests for each parameter. The criteria for a test set was that for all tests in the set 7 out of the 8 parameters needed to be essentially the same for all tests in the set. Often this constraint resulted in small sets of 2 or 3 tests. The goal of each test set was to have only 1 parameter changing significantly for each test in the set. The ultimate goal of the analysis is to ascertain the effect that each parameter has on gasoline vapor ignition time by a water heater.

Analysis:

Attached tables 1a,1b,2a,2b,3a,3b,4a,4b,5a,5b,6a,6b,7a,7b,8a,8b, form the basis for staff's analysis and were created by Engineering Science (ES) staff from the ADL data contained in Appendix 1. Each table represents one of the test sets grouped together by staff. Note that the result of many of the tests included in these tables was "NO FIRE". Tests that resulted in NO FIRE were stopped when it was determined that a fire was never going to occur. This is determined by a measuring device in the room that can measure when the gasoline vapor has dispersed to a point below the Lower Explosive Limit (LEL). If the concentration of gasoline vapors is below the LEL it is impossible for the gasoline vapor to ignite.

1) ELEVATION - Effect of elevating a water heater on ignition time of gasoline vapors.

Table 1a (note attached tables) shows that in tests 2 and 29 the ignition hazard is eliminated, i.e. no ignition, when the water heater is elevated 18" and there is no air movement in the room. This is a dramatic change from test 1 in which, under similar circumstances, ignition occurred in 15 sec. Note that tests 2 and 29 were run for about 2 hours before they were stopped. They were stopped when it was determined that the concentration of gasoline vapors was below the Lower Explosive Limit (LEL).

Table 1b shows that in test 8 the ignition hazard is eliminated, i.e. no ignition of gasoline vapors, when gasoline is spilled 8 feet from the water heater and there is movement in the room. This is a dramatic change from tests 7 and 11 in which, under similar circumstances, ignition of gasoline vapors occurred in approximately 1 minute. Note that in tests 7 and 11 there was no movement in the room.

2) MOVEMENT - Effect of movement in the room on ignition time.

Tables 2a and 2b show that movement in the room can greatly reduce the ignition time of gasoline vapors by a water heater. Note that in test 13, of table 2b, an unbaffled vent was used on a windy day, suggesting that there was movement of the air (air turbulence) in the room. This could explain why ignition occurred in this test as opposed to tests 14 and 19.

3) FLOOR TEMPERATURE - Effect of floor temperature on ignition time.

Tables 3a and 3b show that increasing the floor temperature decreased the ignition time of gasoline vapors by a water heater. However, the extent to which ignition time can be controlled by increasing or decreasing the floor temperature is unclear. It appears from the limited data sets shown in tables 3a and 3b that floor temperature is not a primary factor in determining ignition time.

4) ROOM TEMPERATURE - Effect of room temperature on ignition time.

Tables 4a and 4b show that increasing the room temperature decreased the ignition time of gasoline vapors by a water heater. However, the extent to which ignition time can be controlled by increasing or decreasing the room temperature is unclear. It appears from the limited data sets shown in tables 4a and 4b that room temperature is not a primary factor in determining ignition time.

5) FLOOR TEMPERATURE GREATER THAN ROOM TEMPERATURE - Effect of having the floor temperature greater (higher) than the room temperature on ignition time of gasoline vapors.

Tables 5a and 5b show that when the floor temperature is higher than the room temperature ignition time is decreased. However, the extent to which ignition time can be controlled by having the floor temperature greater than the room temperature is unclear. It appears from the limited data sets shown in tables 5a and 5b that having the floor temperature greater than the room temperature does not significantly decrease the time to ignition and thus is not a primary factor in determining ignition time.

6) ROOM SIZE - Effect of room size on ignition time of gasoline vapors by a water heater.

Tables 6a and 6b show that increasing the room size increased the ignition time of gasoline vapors by a water heater. Note in table 6b, tests 12,15 and 27 no ignition occurred (test duration of approximately 1 hour) when these tests were run in the larger room as opposed to fairly quick ignition times of about 4 minutes for tests 33,28,and 35, run in the smaller room. In table 6a, a less dramatic change occurs between test 35 (small room test) and test 26 (larger room test) as far as ignition time is concerned. Thus, as we would expect, a larger room will increase the time to ignition, however, the extent to which it will be increased

cannot be ascertained from the A.D. Little data.

7) AMOUNT OF SPILL - Effect of the amount of gasoline spilled on ignition time of gasoline vapors by a water heater.

Table 7a shows that increasing the amount of gasoline spilled from 1 to 2 gallons slightly decreased gasoline vapor ignition time. Table 7b shows that increasing the amount of gasoline spilled from 0.5 to 1 gallon did not significantly change the ignition time.

8) SPILL DISTANCE - Effect of gasoline spill distance on ignition time of gasoline vapors by a water heater.

Tables 8a and 8b show that increasing the spill distance increased the ignition time for gasoline vapors by a water heater.

Conclusion:

Using data obtained from the A.D. Little Task 2 Study, staff analyzed the effect of eight variable parameters on gasoline vapor ignition time. The eight parameters were: water heater elevation, movement, floor temperature, room temperature, effect of having floor temp greater than room temp, room size, amount of gasoline spilled, and gasoline spill distance. Of these eight parameters, three had a significant effect on the ignition time of gasoline vapors - elevation, movement, and room size.

ELEVATION of a water heater can, in some situations, significantly reduce and/or eliminate the gasoline vapor ignition hazard. Note, however, that the only test results included in the ADL study for which direct comparisons can be made between elevated and non-elevated tests were those in which there was either no movement present or the spill distance was 8 feet. Most tests run by A.D. Little, where the water heater was elevated 18", used a spill distance of 2.5 feet. As other tests in the A.D. Little study showed, ignition can occur in as little as 3-7 minutes if a combination of 2 or more of the following conditions is present: a) the room size is small (500 cubic feet), b) there is a significant amount of movement in the room, c) a large amount of gasoline is spilled (1.5 - 2 gallons), and d) the spill distance is relatively small (2.5 feet).

MOVEMENT in the room is another key factor in determining when ignition will occur. Movement can greatly reduce the ignition time of gasoline vapors by a water heater. Movement in a room causes air turbulence which usually causes gasoline vapors, emanating from a spill, to reach the burner portion of the water heater much faster. Obviously, this will decrease the time to ignition.

ROOM SIZE is yet another key factor. As expected, it will take longer for a water heater to ignite gasoline fumes when installed in a large room. In some of the ADL tests conducted in a "large" room (1600 cubic ft) no ignition occurred.

The other five parameters appeared to play a somewhat less significant role in determining if and when gasoline vapor ignition occurred. Their effects on ignition time were:

- FLOOR TEMPERATURE. Increasing floor temperature will decrease the ignition time of gasoline vapors by a water heater.

- ROOM TEMPERATURE. Increasing room temperature will decrease the ignition time of gasoline vapors by a water heater.

- FLOOR TEMPERATURE GREATER THAN ROOM TEMPERATURE. Having a situation in which the floor temperature is greater than the room temperature appears to decrease the ignition time of gasoline vapors by a water heater.

- AMOUNT OF SPILL. Increasing the amount of gasoline spilled from 1 to 2 gallons slightly decreased gasoline vapor ignition time. Increasing the amount of gasoline spilled from 0.5 to 1 gallon did not significantly change the ignition time.

- SPILL DISTANCE. Increasing the spill distance generally increased the ignition time for gasoline vapors by a water heater.

Finally, staff emphasizes that, in the A.D. Little Flammable Vapor Ignition Study - Task 2, there were not enough tests run, in relation to the large number (8) of variable parameters, to perform an in-depth, high level type of statistical analysis. Thus, no firm conclusions can be drawn from the above analysis. However, by grouping "like" tests and using a common sense approach, it is possible to gain a better understanding of the effects of certain key variables on ignition time of gasoline vapors.

1) ELEVATION - Effect of elevating a water heater on ignition time.

Table 1a

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
1	approx 500 ft^3	0	No	1	88	57	2 ft 5 in	15 sec	Fire	Vented Room
2	approx 500 ft^3	18	No	1	85	69	2 ft 4 in	2 hr 36 min	No Fire	Cold Floor
29	approx 500 ft^3	18	No	1	84	59	2 ft 6 in	2 hr	No Fire	Warm Floor, Room

* Tests were run in either an 8'x8'x8' room or a 6'x10'x8' room = approx 500 ft^3 (cubic feet)

Table 1b

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
7	10'x20'x8' (1600 ft^3)	0	No	1	91	68	8 ft	51 sec	Fire	Pilot Only
11	10'x20'x8' (1600 ft^3)	0	No	1	85	69	8 ft	68 sec	Fire	Ventilation - approx. 2 Air Changes
8	10'x20'x8' (1600 ft^3)	18	Yes	1	84	59	8 ft	1 hr 57 min	No Fire	Continuous Movement, 30 sec. intervals

Conclusion - In some situations the gasoline vapor ignition hazard was eliminated by elevating a water heater.

2) MOVEMENT - Effect of movement within a room on ignition time.

Table 2a

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
2	approx 500^3 ft	18	No	1	71	52	2 ft 4 in	2 hr 36 min	No Fire	Cold Floor
4	approx 500^3 ft	18	Yes	1	79	45	2 ft 4 in	15 min	Fire	Movement every 5 min

* Tests were run in either an 8'x8'x8' room or a 6'x10'x8' room = approx 500 ft^3 (cubic feet)

Table 2b

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
13	10'x20'x8' (1600 ft^3)	18	No	2	92	114	2 ft 6 in	1 hr 13 min	Fire	Windy Day, Unbaffled Vent
14	10'x20'x8' (1600 ft^3)	18	No	2	80	94	2 ft 6 in	2 hr 11 min	No Fire	
19	10'x20'x8' (1600 ft^3)	18	No	2	96	83	2 ft 6 in	1 hr 28 min	No Fire	
21	10'x20'x8' (1600 ft^3)	18	Yes	2	84	77	2 ft 6 in	7 min	Fire	Continuous Movement 30 sec intervals

Conclusion - room movement greatly reduces the ignition time of gasoline vapors by a water heater.

3) FLOOR TEMPERATURE - Effect of floor temperature on ignition time.

Table 3a

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
4	approx 500^3 ft	18	Yes	1	79	45	2 ft 4 in	15 min	Fire	Movement every 5 min
35	approx 500^3 ft	18	Yes	1	84	86	2 ft 6 in	4 min 15 sec	Fire	Continuous Movement, 30 sec intervals

* Tests were run in either an 8'x8'x8' room or an 6'x10'x8' room = approx 500 ft^3 (cubic feet)

Table 3b

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
23	10'x20'x8' (1600 ft^3)	18	No	2	87	78	2 ft 6 in	1 hr 49 min	Fire	FID showed output fluctuation
13	10'x20'x8' (1600 ft^3)	18	No	2	92	114	2 ft 6 in	1 hr 13 min	Fire	Windy Day, Unbaffled Vent

Conclusion - increasing the floor temperature decreased the ignition time of gasoline vapors by a water heater.

4) ROOM TEMPERATURE - Effect of room temperature on ignition time.

Table 4a

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
37	approx 500 ft^3	18	Yes	0.5	76	68	2 ft 6 in	4 min 40 sec	Fire	Continuous movement, 30 sec intervals
30	approx 500 ft^3	18	Yes	0.5	99	87	2 ft 6 in	3 min	Fire	Continuous movement, 30 sec intervals

* Tests were run in either an 8'x8'x8' ft room or a 6'x10'x8' room = approx 500 ft^3 (cubic feet)

Table 4b

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
11	10'x20'x8' (1600 ft^3)	0	No	1	85	69	8	68 sec	Fire	Ventilation - approx. 2 air exchanges
10	10'x20'x8' (1600 ft^3)	0	No	1	105	72	8	40 sec	Fire	Ventilation - approx. 2 air exchanges

Conclusion - increasing the room temperature decreased the ignition time of gasoline vapors by a water heater.

5) FLOOR TEMPERATURE GREATER THAN ROOM TEMPERATURE.

Effect of having floor temperature greater than room temperature on ignition time of gasoline vapors by a water heater.

Table 5a

Test No.	Room* Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
28	approx 500 ft^3	18	Yes	1	88	77	2 ft 6 in	4 min	Fire	Continuous Movement, 30 sec intervals
33	approx 500 ft^3	18	Yes	1	78	84	2 ft 6 in	3 min	Fire	Continuous Movement, 30 sec intervals

* Tests were run in either an 8'x8'x8' room or a 6'x10'x8' room = approx 500 ft^3 (cubic feet)

Table 5b

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
23	10'x20'x8' (1600 ft^3)	18	No	2	87	78	2 ft 6 in	1 hr 49 min	Fire	FID showed output fluctuation
13	10'x20'x8' (1600 ft^3)	18	No	2	92	114	2 ft 6 in	1 hr 13 min	Fire	Windy Day, Unbaffled Vent

Conclusion - Having floor temperature greater than room temperature decreased the ignition time of gasoline vapors by a water heater.

6) ROOM SIZE - Effect of room size on ignition time.

Table 6a

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
35	approx 500^3 ft	18	Yes	1	84	86	2 ft 6 in	4 min 15 sec	Fire	Continuous Movement, 30 sec intervals
26	10'x20'x8' (1600^3 ft)	18	Yes	1	87	89	2 ft 6 in	15 min	Fire	Continuous Movement, 30 sec intervals

Table 6b

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
33	approx 500^3 ft	18	Yes	1	78	84	2 ft 6 in	3 min	Fire	Continuous Movement, 30 sec intervals
28	approx 500^3 ft	18	Yes	1	88	77	2 ft 6 in	4 min	Fire	Continuous Movement, 30 sec intervals
35	approx 500^3 ft	18	Yes	1	84	86	2 ft 6 in	4 min 15 sec	Fire	Continuous Movement, 30 sec intervals
12	10'x20'x8' (1600^3 ft)	18	Yes	1	99	99	2 ft 6 in	45 min	No Fire	Continuous Movement, 30 sec intervals
15	10'x20'x8' (1600^3 ft)	18	Yes	1	84	94	2 ft 6 in	1 hr 17 min	No Fire	Continuous Movement, 30 sec intervals
26	10'x20'x8' (1600^3 ft)	18	Yes	1	87	89	2 ft 6 in	15 min	Fire	Continuous Movement, 30 sec intervals
27	10'x20'x8' (1600^3 ft)	18	Yes	1	87	88	2 ft 6 in	1 hr 35 min	No Fire	Continuous Movement, 30 sec intervals

Conclusion - Increasing the room size increased the ignition time of gasoline vapors by a water heater.

7) AMOUNT OF SPILL - Effect of amount of gasoline spilled on ignition time.

Table 7a

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
26	10x20'x8' (1600 ft^3)	18	Yes	1	87	89	2 ft 6 in	15 min	Fire	Continuous Movement, 30 sec intervals
21	10x20'x8' (1600 ft^3)	18	Yes	2	84	77	2 ft 6 in	7 min	Fire	Continuous Movement, 30 sec intervals

Table 7b

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
30	approx 500^3 ft	18	Yes	0.5	99	87	2 ft 6 in	3 min	Fire	Continuous Movement, 30 sec intervals
34	approx 500^3 ft	18	Yes	0.5	80	77	2 ft 6 in	3 min	Fire	Continuous Movement, 30 sec intervals
37	approx 500^3 ft	18	Yes	0.5	76	68	2 ft 6 in	4 min 40 sec	Fire	Continuous Movement, 30 sec intervals
33	approx 500^3 ft	18	Yes	1	78	84	2 ft 6 in	3 min	Fire	Continuous Movement, 30 sec intervals
28	approx 500^3 ft	18	Yes	1	88	77	2 ft 6 in	4 min	Fire	Continuous Movement, 30 sec intervals
35	approx 500^3 ft	18	Yes	1	84	86	2 ft 6 in	4 min 15 sec	Fire	Continuous Movement, 30 sec intervals

* Tests were run in either an 8'x8'x8' room or a 6'x10'x8' room = approx. 500^ft

Conclusion - Increasing the amount of gasoline spilled from 1 to 2 gallons slightly decreased gasoline vapor ignition time by a water heater.
Increasing the amount of gasoline spilled from 0.5 to 1 gallon did not significantly change the ignition time of gasoline vapors by a water heater.

8) SPILL DISTANCE - Effect of gasoline spill distance on ignition time.

Table 8a

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Distance	Test Duration	Result	Comments
11	10x20'x8' (1600 ft^3)	0	No	1	85	69	8 ft	1 min 8 sec	Fire	Ventilation - approx 2 air exchanges
16	10x20'x8' (1600 ft^3)	0	No	1	83	68	13 ft	2 min 3 sec	Fire	Spill Towards Back Wall

Table 8b

Test No.	Room Size	Elevation (in)	Movement	Amount (gal)	Room Temp (F)	Floor Temp (F)	Spill Dist	Test Duration	Result	Comments
21	10'x20'x8'	18	Yes	2	84	77	2 ft 6 in	7 min	Fire	Continuous Movement, 30 sec intervals
9	10'x20'x8'	18	Yes	2	87	63	approx 7 ft	19 min	Fire	Continuous Movement, 1 min intervals

Conclusion - increased spill distance increased the ignition time for gasoline vapors by a water heater.

APPENDIX 1

Tables 8-10, from A.D. Little Flammable Vapor Hazard Ignition Study, Task 2: Modeling and Experimental Testing, Reference 42238, 15 July 1993.

** Note **

Tables 8-10 have been updated by A. D. Little to correct errors in the tables originally published in the A.D. Little report of 15 July 1993. A.D. Little supplied the corrected tables in a letter dated 11/24/93 to GAMA (forwarded to CPSC).

Table 8: Matrix of Tests Completed - Spills With Water Heater Located on Floor

Test No.	Room Size	Amount	Room Temp °F	Floor Temp °F	Spill Dist	Movement	Time (sec)	Result	Comments
1	8x8x8	1 gal	88	57	29"	No	15	Fire	Vented Room
7	10x20x8	1 gal	91	68	8'	No	51	Fire	Pilot Only
10	10x20x8	1 gal	105	72	8'	No	40	Fire	Ventilation ~ 2 Air Changes
11	10x20x8	1 gal	85	69	8'	No	68	Fire	Ventilation ~ 2 Air Changes
16	10x20x8	1 gal	83	68	13'	No	123	Fire	Spill Towards Back Wall

Table 9: Matrix of Tests Completed - Spills With Water the Heater Installed on an 18" Stand, 10'x20'x8' Room

Test No.	Movement	Amount	Room Temp °F	Floor Temp °F	Spill Dist	Time	Result	Comments
13	No	2 gal	92	114	30"	1 hr 13 min	Fire	Windy Day, Unbaffled Vent
14	No	2 gal	80	94	30"	2 hr 11 min	No Fire	
19	No	2 gal	96	83	30"	1 hr 28 min	No Fire	
23	No	2 gal	87	78	30"	1 hr 49 min	Fire	FID Output Showed Fluctuation
24	No	2 gal	87	97	30"	4 hr 15 min	No Fire	
9	Yes	2 gal	87	63	6', 8'	19 min	Fire	Continuous Movement, 1 min int
21	Yes	2 gal	84	77	30"	7 min	Fire	Continuous Movement, 30s int
20	Yes	1.5 gal	93	89	30"	53 min	No Fire	Continuous Movement, 30s int
22	Yes	1.5 gal	84	81	30"	5 min	Fire	Continuous Movement, 30s int
25	Yes	1.5 gal	96	79	30"	7 min	Fire	Continuous Movement, 30s int
8	Yes	1 gal	84	59	8'	1 hr 57 min	No Fire	Continuous Movement, 30s int
12	Yes	1 gal	99	99	30"	45 min	No Fire	Continuous Movement, 30s int
15	Yes	1 gal	84	94	30"	1 hr 17 min	No Fire	Continuous Movement, 30s int
26	Yes	1 gal	87	89	30"	15 min	Fire	Continuous Movement, 30s int
27	Yes	1 gal	87	88	30"	1 hr 35 min	No Fire	Continuous Movement, 30s int

Table 10: Matrix of Tests Completed - Spills With the Water Heater Installed on an 18" Stand, 8'x8'x8' and 6'x10'x8' Room

Test No.	Movement	Amount	Room Temp °F	Floor Temp °F	Spill Dist	Time	Result	Comments
2	No	1 gal	71	52	28"	2 hr 36 min	No Fire	Cold Floor
29	No	1 gal	92	87	30"	2 hr	No Fire	Warm Floor, Room
3	Yes	1 gal	84	54	28"	46 min	Fire	Began movement at 41 min
4	Yes	1 gal	79	45	28"	15 min	Fire	Moved every 5 min
6	Yes	1 gal	97	60	28"	4 min	Fire	Continuous Movement, 5 s int
33	Yes	1 gal	78	84	30"	3 min	Fire	Continuous Movement, 30 s int
28	Yes	1 gal	88	77	30"	4 min	Fire	Continuous Movement, 30 s int
35	Yes	1 gal	84	86	30"	4 min 15 sec	Fire	Continuous Movement, 30 s int
30	Yes	.5 gal	99	87	30"	3 min	Fire	Continuous Movement, 30 s int
34	Yes	.5 gal	80	77	30"	3 min	Fire	Continuous Movement, 30 s int
36	Yes	.5 gal	72	72	30"	7 min 44 sec	Fire	Start Movement at 4 min
37	Yes	.5 gal	76	68	30"	4 min 40 sec	Fire	Continuous Movement, 30 s int

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United States
CONSUMER PRODUCT SAFETY COMMISSION
Washington, D.C. 20207

MEMORANDUM

DATE: November 8, 1994

TO : Donald W. Switzer
Project Manager for Fire and Gas Voluntary Standards

Through: Fay H. Dworkin Ph.D., Division Director, ECSS

FROM : Robert Franklin, Economist, ECSS (504-0962)

SUBJECT: Some Economic Issues Related to Residential Gas Water Heaters and the Ignition of Flammable Vapors

This memorandum provides some information on the residential gas water heater industry and estimates on the societal costs of the ignition of flammable vapors by gas water heaters. This information is intended to provide some background to the Commission and staff in determining what actions, if any, should be taken to address this hazard.

Number in Use and Annual Sales of Gas Water Heaters

According to the Department of Energy's Residential Energy Consumption Survey of 1990, 40 million to 50 million U.S. households have gas water heaters. All other things being equal, the number of gas water heaters in use will likely increase over the foreseeable future as the number of households in the United States increases. Based upon current sales trends and the replacement rate for gas water heaters, there may be an additional 10 million units in use by the end of this decade.

Annual sales of residential gas water heaters have been increasing. From 1960 through 1965, an average of just under 2.5 million gas water heaters were shipped annually. Since 1987, over 3.5 million units have been shipped annually (American Gas Association). The number of shipments in any particular year is influenced by the volume of new housing starts in particular and overall economic conditions in general. Shipments of water heaters will also be affected by changes in the retail price of natural gas relative to the retail price of electricity and by energy-related regulations that favor the use of natural gas over electricity.

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A new gas water heater with a 50 gallon capacity can be expected to cost at least $175 for the most basic unit. "Top-of-the-line" units, which often include features such as direct or power venting and higher energy efficiency ratings, may cost 3 or 4 times this amount. A consumer may have to pay another $150 to install a new water heater. The price of a gas water heater tends to be somewhat higher than the price of a similar electric model. However, gas water heaters are generally more energy efficient than similar electric models.

Structure of the Industry

We have identified nine manufacturers of residential gas water heaters. The water heater manufacturing industry is highly concentrated; according to *Appliance Magazine*, the five largest water heater manufacturers have a combined market share of 99 percent. The high degree of concentration in the water heater industry should facilitate standards development and enforcement. It is a much less onerous task to coordinate standards development and enforcement in a market dominated by a small number of large manufacturers than it is in a market in which there are many small and medium size manufacturers. This applies to both voluntary and mandatory standards.

Societal Costs of Incidents

The Directorate for Epidemiology has provided estimates of the annual average number of fires, injuries, deaths, and property damages associated with the ignition of flammable vapors by residential gas water heaters over the six year period from 1986 to 1991 (CPSC, 1994). Using these estimates the Directorate for Economic Analysis has estimated the average annual societal costs associated with these incidents.

There were an average of 316 people injured each year between 1986 and 1991 in incidents involving gas water heaters and flammable vapors (CPSC, 1994). Although the nature and severity of all the injuries is not known, it is known that many of the injuries involve second and third degree burns. Severe burns are among the most costly personal injuries that can be suffered in terms of direct medical expense, loss of income, physical pain, emotional trauma, and damage to interpersonal relationships. Elizabeth Leland reported in a 1992 memorandum that in 1988, 22 percent of the jury awards for burn injuries ranged from $100,000 to $299,000 and 35 percent of the awards exceeded one million dollars (CPSC, 1992). A CPSC sponsored study estimated that the average societal cost of a hospitalized cigarette burn was $900,000. (Miller, 1993). If one assumes that all of the injuries involving the ignition of flammable vapors by gas water heaters are comparable to cigarette burns requiring hospitalization, the annual societal costs of the injuries may be as high as $284 million.

An average of 17 people die each year in incidents involving residential gas water heaters and all flammable vapors. Under the assumption that the statististical value of life is $5 million, the cost to society of the deaths is $85 million annually. The property losses from residential gas water heater fires and flammable vapors are estimated to be $26 million annually (CPSC, 1994).

When the societal cost of injuries, deaths, and property damage are added together, the total cost to society of fires involving residential gas water heaters and all flammable vapors may reach $395 million annually. There are an estimated 40 to 50 million residential gas water heaters in use in the United States; the expected cost to society of these incidents per water heater is $7.90 to $9.88 annually. Assuming a discount rate of 5 percent and an average useful life for a water heater of 11 years, we estimate that modifications that prevent virtually all incidents would be cost effective at $68 to $85 per unit.

References

American Gas Association, Gas Facts (1982 and 1991 editions).

Appliance Magazine (September 1993) pp. 50-55.

Appliance Magazine (April 1993) p. 53.

CPSC (1992), "Benefits of Preventing Accidents Associated with Flammable Vapor Ignition by Gas-Fired Water Heaters," memorandum from Elizabeth W. Leland (EC) to Joseph Z. Fandey (ESSE) (January 8, 1992).

CPSC (1994), "Summary of Data on Gas-Fueled Water Heaters and Flammable Vapors," CPSC Memorandum from William L. Rowe (EPHA) to Joseph Z. Fandey (ESEE) (April 18, 1994).

Miller, Ted R., et al., Estimating the Costs to Society of Cigarette Fire Injuries: Final Report, Submitted to Consumer Product Safety Commission, Directorate for Economic Analysis, Contract CPSC-C-93-1118 (July 1993).

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CONSUMER PRODUCT SAFETY COMMISSION

16 CFR Part 1212

Gas Water Heaters

Advance Notice of Proposed Rulemaking; Request for Comments and Information

AGENCY: Consumer Product Safety Commission.

ACTION: Advance notice of proposed rulemaking.

SUMMARY: Based on information currently available to the Commission, there is reason to believe that unreasonable risks of injury and death may be associated with gas water heaters that provide insufficient resistance to igniting vapors from flammable liquids that are spilled in the vicinity of the water heater. Each year, approximately 1,961 fires are associated with gas water heaters igniting flammable vapors, especially gasoline. These fires annually cause approximately 316 burn injuries and 17 deaths. This advance notice of proposed rulemaking ("ANPR") initiates a rulemaking proceeding under the authority of the Consumer Product Safety Act ("CPSA"). One result of the proceeding could be the promulgation of a rule mandating performance standards for gas water heaters.

The Commission solicits written comments from interested persons concerning the risks of injury and death associated with the ignition of flammable vapors by gas water heaters, the regulatory alternatives discussed in this notice, other possible means to address these risks, and the economic impacts of the various regulatory alternatives. The Commission also invites interested persons to submit an existing standard, or a statement of intent to modify or develop a voluntary standard, to address the risks of injury described in this notice.

DATE: Written comments and submissions in response to this notice must be received by the Commission by [insert date that is 60 days after publication].

ADDRESS: Comments should be mailed, preferably in five copies, to the Office of the Secretary, Consumer Product Safety Commission, Washington, D.C. 20207-0001, or delivered to the Office of the Secretary, Consumer Product Safety Commission, Room 502, 4330 East-West Highway, Bethesda, Maryland 20814; telephone (301) 504-0800.

FOR FURTHER INFORMATION CONTACT: Don Switzer, Project Manager, Directorate for Engineering Sciences, Consumer Product Safety Commission, Washington, D.C. 20207; telephone (301) 504-0508, ext. 1303.

SUPPLEMENTARY INFORMATION:

A. Background

For a number of years, the staff of the Consumer Product Safety Commission ("CPSC" or the "Commission") has been aware of