Table 3-2
GPA LIQUEFIED PETROLEUM GAS SPECIFICATIONS

PRODUCT CHARACTERISTICS	PRODUCT DESIGNATION		
	COMMERCIAL PROPANE	PROPANE HD-5	TEST METHODS
Composition	Predominantly propane and/or propylene	Not less than 90 liquid volume percent propane; not more than 5 liquid volume percent propylene	ASTM D-2163-77
Vapor pressure at 100 F,* psig, max.	208*	208*	ASTM D-1267-79
Volatile residue:			
temperature at 95% evaporation, deg. F, max.	-37*	-37*	ASTM D-1837-64
or			
butane and heavier, liquid volume percent max.	2.5	2.5	ASTM D-2163-77
pentane and heavier, liquid volume percent max.	—	—	ASTM D-2163-77
Residual matter:			
residue on evaporation of 100 ml, max.	0.05 ml	0.05 ml	ASTM D-2158-65
oil stain observation	pass (1)	pass (1)	ASTM D-2158-65
Corrosion, copper strip, max.	No. 1	No. 1	ASTM D-1838-74
Volatile sulfur, grains per 100 cu ft, max.	15	10	ASTM D-2784-70
Moisture content	pass	pass	GPA Propane Dryness Test (Cobalt Bromide) or D-2713-76
Free water content	—	—	—

(1) An acceptable product shall not yield a persistent oil ring when 0.3 ml of solvent residue mixture is added to a filter paper in 0.1 increments and examined in daylight after 2 minutes as described in ASTM D-2158.

*Metric equivalents: 208 psig = 1434 kPa guage 70 psig = 483 kPa guage -37°F = -38.3°C 36°F = 2.2°C 100°F = 37.8°C

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LPG/air mixtures and natural gas/ air mixtures in their respective flammable ranges are not nearly so far apart. Also, neither LPG or natural gas, once mixed with air will resegregate due to the inherent diffusion characteristics of gases. Aside from specific gravity and diffusion characteristics, convection currents often dominate the actual transport and mixing behavior in fuel release scenarios.

Again referring to Table 3-1, note that the lower limit of flammability of LPG is less than half that of natural gas, but the energy content per cubic foot of LP-gas is over double that of natural gas. Therefore it tends to be easier to form a flammable mixture of LPG in air, and the potential destructive power due to accidental ignition for a given quantity of fuel is greater than with natural gas.

The bottom line is that on a probability basis flammable mixtures of LP-Gas with air are more likely to form in the vicinity of a leak and remain for longer periods of time in low spots than a comparable natural gas leak. This is particularly true if the fugitive gas is not initally well mixed with air by turbulence.

Propane and butane will liquefy under their own vapor pressure in a closed container under normal atmospheric conditions. Methane will not and is distributed solely in the gas phase. The intrinsic thermodynamic properties of LP-Gases add tremendously to their utility as a fuel in decentralized distribution situations, such as suburban or rural environments. These same properties, however, have substantial implications from a safety standpoint. We will examine briefly some of these properties and their implications, using primarily propane as the example. Detailed discussions regarding specific points of interest follow in later text.

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Table 3-3 presents propane vapor pressures as a function of temperature. Propane in a suitable closed container, filled so that both a liquid and gas phase exist, will develop sufficient vapor pressure to feed a residential delivery system using relatively simple, passive regualtion systems - no pumps or motors required. The container also acts as a heat transfer element passively extracting atmospheric heat to vaporize sufficient propane to meet household demands, provided atmospheric temperatures are sufficiently above the atmospheric boiling point (-44 degrees F for propane). At a constant ambient temperature, pressure in the container will tend to remain constant regardless of percentage of fill until the liquid phase disappears. Under withdrawal conditions vaporization cooling will cause a temperature drop in the contents of the container with a resultant minor drop in pressure. Also, minor higher boiling constituents in the commerical product tending to concentrate in the liquid phase can cause some pressure drop on drawdown.

Given a pure gas there by definition could be no difference in a concentrations of the gas between liquid and gas phase. With the "real" LP product, which consists of a mixture of components, there will be a concentration difference between liquid and vapor phases for the various constituents, including added odorant. The concentration difference will vary with temperature and extent of vapor drawoff that has occurred as the fuel is used. These variations can have safety implications and are discussed in section 4.2.3 and 5.4.4. The liquid phase is highly efficient in packing a lot of energy in a small volume. Considering the dangers as well as the utility, however, it may be observed that upon release, the liquid will inherently be dispersed under pressure and vaporize rapidly to a much greater volume which is readily ignitable. A small container may release an enormous quantity of gas, an expansion ratio of approximately 273 to 1. Proper operation

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Table 3-3
PROPANE VAPOR PRESSURES AT VARIOUS TEMPERATURES

°F	psig	°F	psig
-20	10.7	55	84.6
-15	13.6	60	92.5
-10	16.7	65	100.7
-5	20.0	70	109.3
0	23.5	75	118.5
5	27.2	80	128.1
10	31.3	85	138.4
15	35.9	90	149.3
20	40.8	95	160.3
25	46.2	100	172.3
30	51.6	105	185.3
35	57.3	110	197.3
40	63.3	115	211.3
45	69.9	120	225.3
50	77.1	125	239.3

NOTE: All pressures based on typical propane with a specific gravity of 1.53.

Source: NTA&S, Inc.

depends on maintaining a gas phase in the container and insuring that control devices downstream do not "see" a liquid phase. This will be discussed further in Sections 4.2 and 5.2, but it is obvious the human element has now been introduced into the equation to insure a gas phase exists (no overfill). No equivalent concern is present with natural gas (exclusive of cryogenic operations).

3.2 Distribution Practices Related to Safety

One may characterize the LP gas distribution chain as comprising three principal variations. Some hazard elements exist in common, but may be emphasized in one scheme, and some hazard elements are nearly unique.

The domestic LPG distribution industry was essentially founded on the cylinder exchange distribution system. This system still survives today. The most common embodiment of this system is that the cylinders or tanks are generally the property of the primary supplier or dealer, filled at the distributorship, and transported full to the customer in exchange for empty containers. A variation of this system involves the conversion of the cylinders for volumetric fill and filling on the user premises. Classically, 100 lb. (LP capacity) DOT (ICC before 1967) cylinders have been the mainstay of this business, although other sizes are used. A key to consumer risk are dealer practices with regard to out-of-gas procedures, inspection practices, pilot relight and adherence to a host of other good practice procedures. The second element of risk is inherent to the type of system used, i.e. single or dual cylinder, manual or automatic changeover, single or dual regulation, and protection of the regulator from the elements, for example. Each out-of-gas shutdown, service restoration and relight sequence is an opportunity for something to go wrong and can put the user right in the center of the classic "fire triangle'i.e. with fuel, air and a source-of-ignition. Historical accident

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patterns consistently reveal problems in this operational sequence.

The second major variation in distribution practice is the filling on the consumer premises of tanks, typically 250 gallons or larger from a dealer "bobtail" truck. Since the tanks are fixed, filling is done on a volumetric basis rather than by weight. Either ASME or DOT specification containers may be used, however ASME tanks predominate. ASME stationary service tanks may be moved, however, only if their contained LP volume has been reduced to no more than 5% of their capacity. Tanks are usually, but not always dealer owned and leased to the user. Since tanks are located further from the home, underground piping is frequently employed, with resulting potential for corrosion and damage by digging activities. Dual stage regulation is the recommended practice, but is not universally employed. Unlike DOT containers, ASME tanks on residential premises do not have to be recertified or requalified - ever, except in special circumstances or if required by a state or local code. Such code requirements exist, but are the exception rather than the rule.

The third variation in distribution is potentially very troublesome, the filling of customer owned portable containers. This is epitomized by the ubiquitous 20 pound LP capacity cylinders seen on recreational vehicles and gas-fired grills all over the country. This market has been growing at an enormous rate and has given rise to the proliferation of numerous "filling" stations which are not primarily LP dealers and whose personnel training may be indifferent. The ultimate for non-professional filling is the "self-serve" dispensing outlet, a development in its infancy at the retail level. Severe, and growing troubles are seen with the loss of control in professional training for filling, handling, storage and maintenance of customer owned gear.

3.3 User activities and Environmental Factors Related to Safety

3.3.1 Introduction

The LP-Gas user population is neither homogeneous by geographical location or by principal use for which they employ LP-Gas in a given area. It was useful, and in fact, imperative to separate the analysis into two major groupings, as well. The first of these groupings considered permanent or semi-permanent installations, and the second dealt with portable/ recreational uses. Outdoor portable cooking equipment received particular emphasis. First we will address specifically the recreational use situation.

3.3.2 Portable/Recreational Use

With sales running approximately three (3) million units per year[1], portable grills have in half a decade surpassed the unit population of all the major LP appliances combined. Along with other recreational activities this has caused the number of individual containers (without regard to aggregate capacity) that are customer owned to skyrocket past the number of dealer owned or controlled containers. In addition, portable/recreational use represents a wider, more evenly distributed user base of persons (many with apparently limited knowledge of LP gas behavior) than is experienced with permanent installations.

The estimated number of LP Gas fired portable grills in use, exclusive of table top units using small DOT Style 39 cylinders is approximately eleven (11) million units, with almost seven (7) million of those going in service within the last three years. The number of residential customer owned containers in service, of which nearly 95% are of 20 lb. nominal propane capacity, is estimated to be on the order of eighteen (18) million units. Over a third of these

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were produced in the last three years. These estimates were derived by FTA from sales and or estimated populations reported by NLPGA, GAMA, Recreational Vehicle Institute (RVI) and the Barbecue Grill Association.

The implications of this staggering growth include the fact that even if the accident rate, expressed as the number of annual accidents divided by the product of the appliance population times number of annual uses, remains at historical values, the total number of accidents will jump dramatically. Moreover, the chance for an individual user to be injured increases with the aggregated number of uses over the product lifetime even if it is assumed that the probability of injury for any given use remains unchanged. Thus we would expect an induction or "lag" time whereby the increase in accidents will be displaced from the time of appliance population increases, but will eventually follow a similar path.

This delay phenomenon has been observed with products in the past, frequently catching the unwary with a serious problem they did not realize was pending. Given the recent nature of the growth in the portable grill market and concomitant growth in customer owned containers, we would not anticipate present accident statistics to reflect the recent rapid growth. Considering, then, that significant problems already exist in this area we have serious cause for concern.

Section 4.2 and 5.2 of this report deal with filling practices and related issues. Section 5.6 develops additional detail with regard to special considerations regarding Outdoor Portable Cooking Equipment. It is nevertheless useful at this point to highlight some representative accident scenarios regarding overfilling of small customer owned cylinders and to capsulize our overall concerns regarding portable/recreational equipment and outdoor portable cooking equipment specifically.

Small containers equipped with dip tubes and bleeder valves may be filled volumetrically. Otherwise weight fill must be used. In either case check weighing is supposed to be performed - a requirement that on the basis of personal observation is often ignored. Either type cylinder is susceptible to overfill problems. DOT specifications are predicated on uninsulated containers not being liquid full at 130 degrees F. Hence, inital "outage" would be variable depending on filling temperature. Normal capacities and dip tube lengths are intended to provide some safety cushion for unusual variations between filling temperature and temperatures reached in transport or storage. The cushion is small, however.

A classic accident scenario can be the overfilling of a 20 lb. portable container, placing it in the trunk of a car in a non-upright position. With warm-up the tank goes liquid full, the safety relief valve opens at 375 psig, spraying vaporizing propane ripe for ignition. On its side the relief will pass more total propane per unit time (liquid vs. vapor flow) and with less cooldown since the vaporization is external to the tank than when the tank is upright. A variation of this theme is the custom built camper with its carefully constructed (but non-code) inside hamper for the propane bottle. The bottle is filled in cold weather, placed in the warm camper (propane fired furnace) with its propane refrigerator and oven. The liquid volume increases when heated and the safety valve vents when the bottle becomes full. Escaping propane is then ignited by one of the appliances and an inferno results. The accident record is replete with accidents where overfilling was a certain or by far the most probable cause of injury, property damage or both.

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Thus far our discussion has dealt with filling activities incidental to actual use of a grill for example. There is a general pattern of mishandling, including improper storage of customer owned containers such as in the garage or basement. Part of the problem undoubtedly stems from ignorance of the hazards involved. A significant portion of the difficulty however, is the near impossibility of following to the letter all of the currently supplied cautionary statements and still be able to use the appliance. This occurs in a host of residential settings, especially condominium and apartment complexes where use or storage space is at a premium, or non-existant. Transport, use, and storage are all problems.

Another common problem involves the accidental partial opening of a cylinder valve on a disconnected container, with subsequent ignition of escaping gas. The use of "POL plugs", a blind termination for closing off the valve outlet, is far from universal.

Principal accident patterns specific to grill use dealing with gas release away from the burner were a potpourri of initial releases from either a regulator vent relief, container safety-relief valve or leaking connections. Some of these incidents were probably caused by the effect of radiant heating of the LPG cylinder and its contents by an operating grill, coupled with an initial overfill condition. If the liquid fuel volume expansion induced by heating outpaces the fuel volume reduction caused by burner operation, relief operation may be expected in some circumstances. As noted in Section 2.0 there was an overabundance of occurrences with new cylinders having just received their first propane fill, and older cylinders which had gotten the first fill of the season.(In the latter cases it was not usually stated that the container was completely empty before filling, but probably was). This is strongly suggestive of poor purge techniques. Section 4.0 following provides underlying technical relationships of fuel

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composition and temperature important to understanding these observations and conclusions.

Injury accidents involving gas releases at the burner(s) or console controls primarily took place during an initial ignition sequence, as might be expected. Burner or control displacement, fouling of the air supply and incorrect lighting procedures were most frequently involved.

There were other significant accident patterns, as well. These are dealt with in Section 5.6 discussions.

The grill market creates such a strong demand for the 20 lb. DOT cylinder that it is the overwhelmingly dominant container in terms of number in use. Nearly all are customer owned. The specifications as originally developed for DOT cylinders and appurtenances such as cylinder valves and safety relief valves contemplated temperature ranges in the transportation environment, limited consumer interaction for filling, storage and handling, plus restrictions on immediate source of ignition for any released gases. Similarly, specifications for hoses, connectors and regulators were developed considering different environments than those associated with portable grill use.

Without diminishing the role and importance of labeling, we fear that design options with regard to outdoor portable cooking equipment providing more intrinsic safety, irrespective of the competence of the user, are not receiving appropriate levels of attention. Numerous proposals originating within the industry, recognizing and dealing with the unique nature of this market, have been made through standards bodies. There has been movement, but the momentum appears to have been lost, perhaps in part from disappointment or fear of so-called "teething" or "learning-curve" problems often associated with new equipment items.

The analysis of accident patterns to date associated with grill use indicate a renewed emphasis on existing, but languishing proposals dealing with such items as connectors, high-temperature shut-offs, regulator, vent relief requirements and cylinder construction is necessary. The recommendations formulated in this study take a somewhat different form in some cases than those of the original Standards Subcommittee proposals. The recommendations appear in Sections 2.0 and 5.6 of the text.

3.3.3 Permanent/Semi-Permanent Installations

Residences in rural localities are the primary users of LP-Gas. Among users of gaseous fuels, those living in manufactured housing (mobile homes) utilize LP-Gas in numbers disproportionately higher than their counterparts living in homes of conventional construction. There are also significiant regional differences in the extent LP-Gas is used and what utilization activity constitutes the highest numerical (not necessarily volume) use. We may visualize these differences by looking at Figures 3-1 through 3-5, supported by tabular presentations in Tables 3-4 through 3-6. A more detailed breakdown of the demographics associated with the residential use of LP-Gas may be found in Appendix B .

The above use characteristics are important in understanding and analyzing both the potential hazards and possible improvements. For example, this report will frequently compare the accident picture with LP-Gas to natural gas for similar circumstances and equipment. It is important to realize, however, that one fuel is not an alternative to the other in many circumstances given the differences in urban/rural availability.

The urban/rural differences in fire protection and medical services must also be taken into account. NFPA and National Bureau of Standards (NBS) studies reported by NFPA[9] show the rural fire loss and death rate to be disproportionately high. Heating equipment fires were a leading category and also accounted for the prinicipal differences in fatality rates between rural and other localities. A comparison by heating fuel involved shows solid fuels, principally wood, are an

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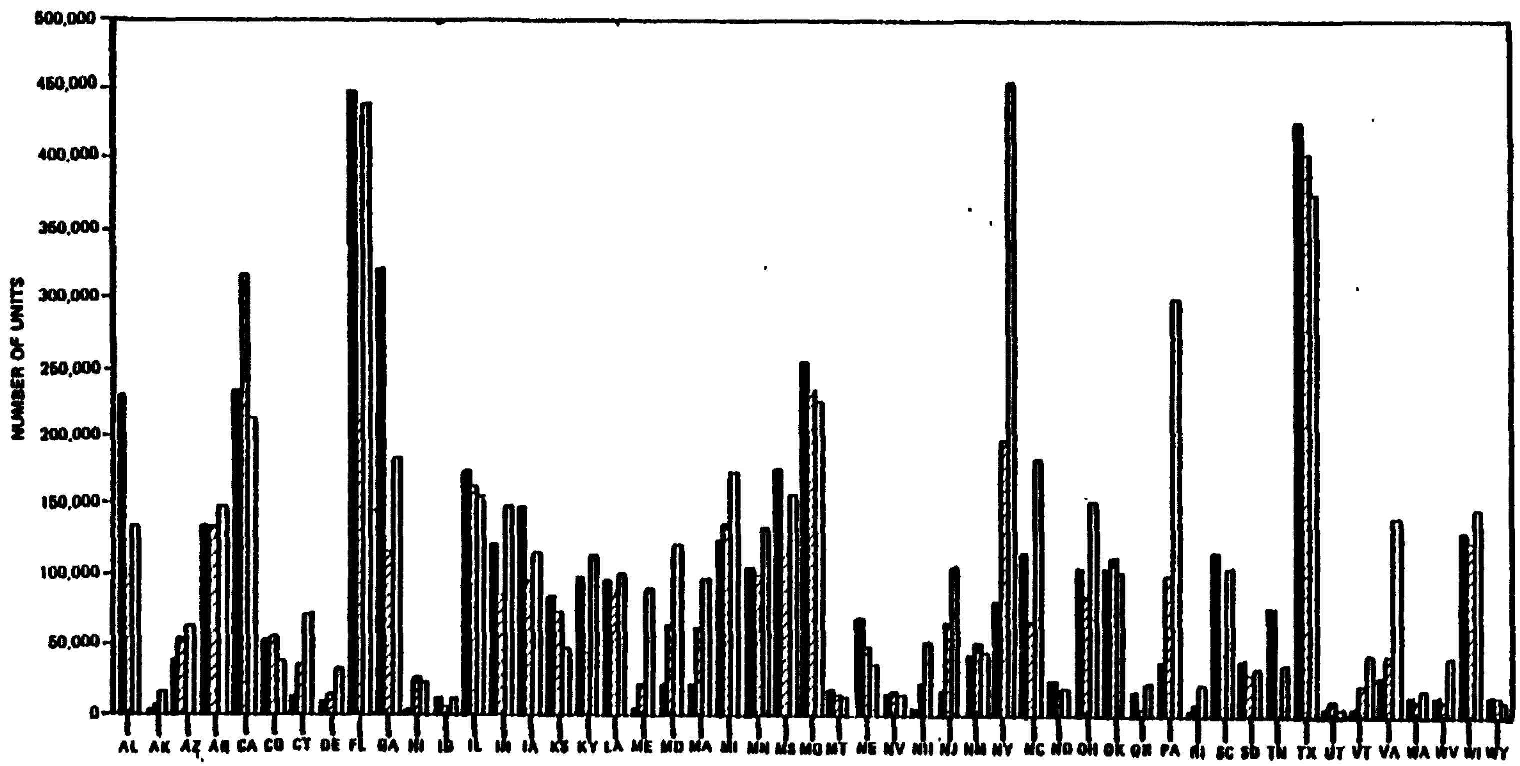

Source: 1980 Census of Housing, Vol. 1
Characteristics of Housing Units, Chapter B
Detailed Housing Characteristics, Part 1
United States Summary HC80-1-B1, Issued December 1983

Figure 3-1 LP FUEL USERS BY STATE

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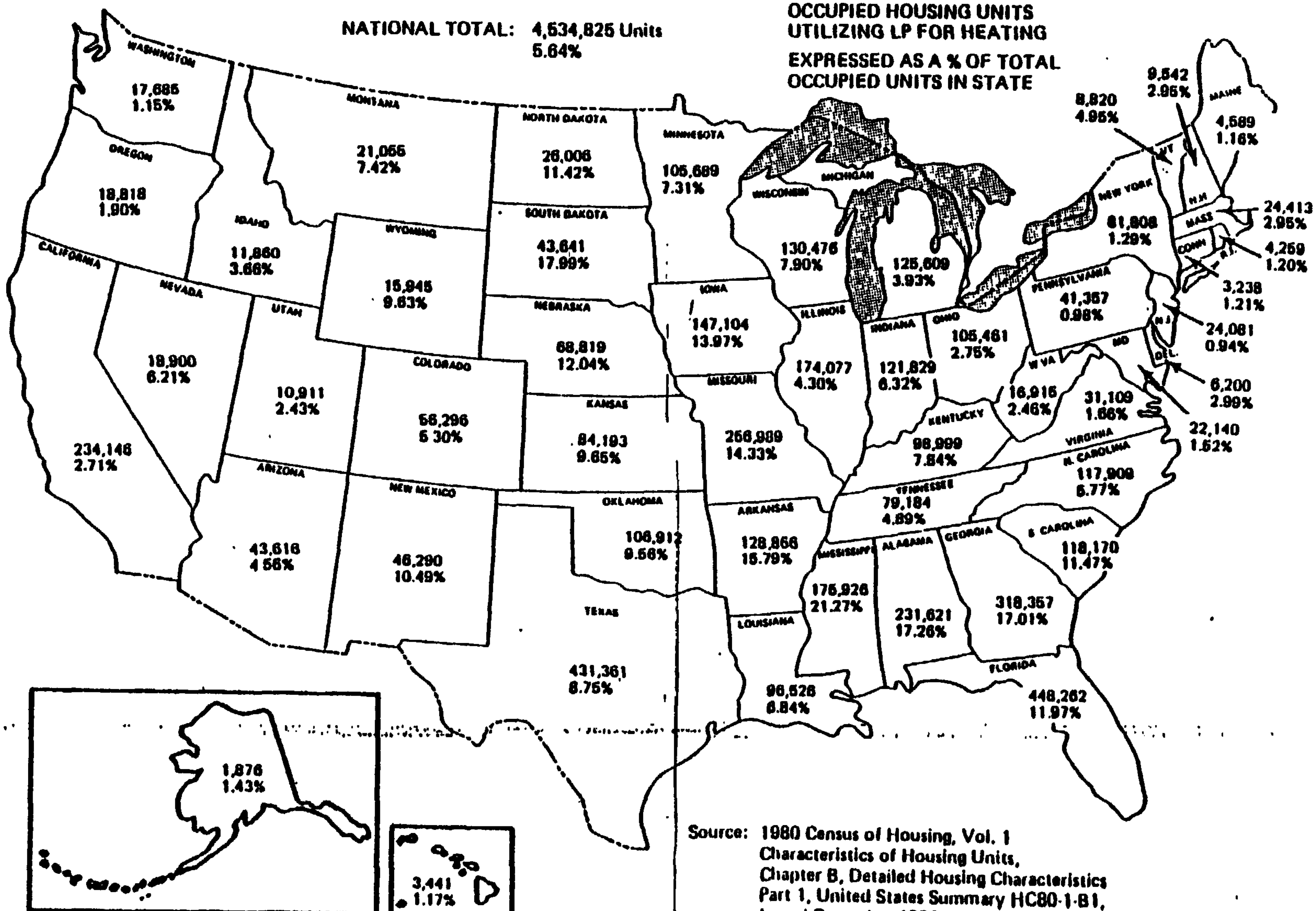

Source: 1980 Census of Housing, Vol. 1
Characteristics of Housing Units,
Chapter B, Detailed Housing Characteristics
Part 1, United States Summary HC80-1-B1,
Issued December 1980

Figure 3-2 HOUSE HEATING FUEL USE OF BOTTLED, TANK, OR LP GAS BY STATE

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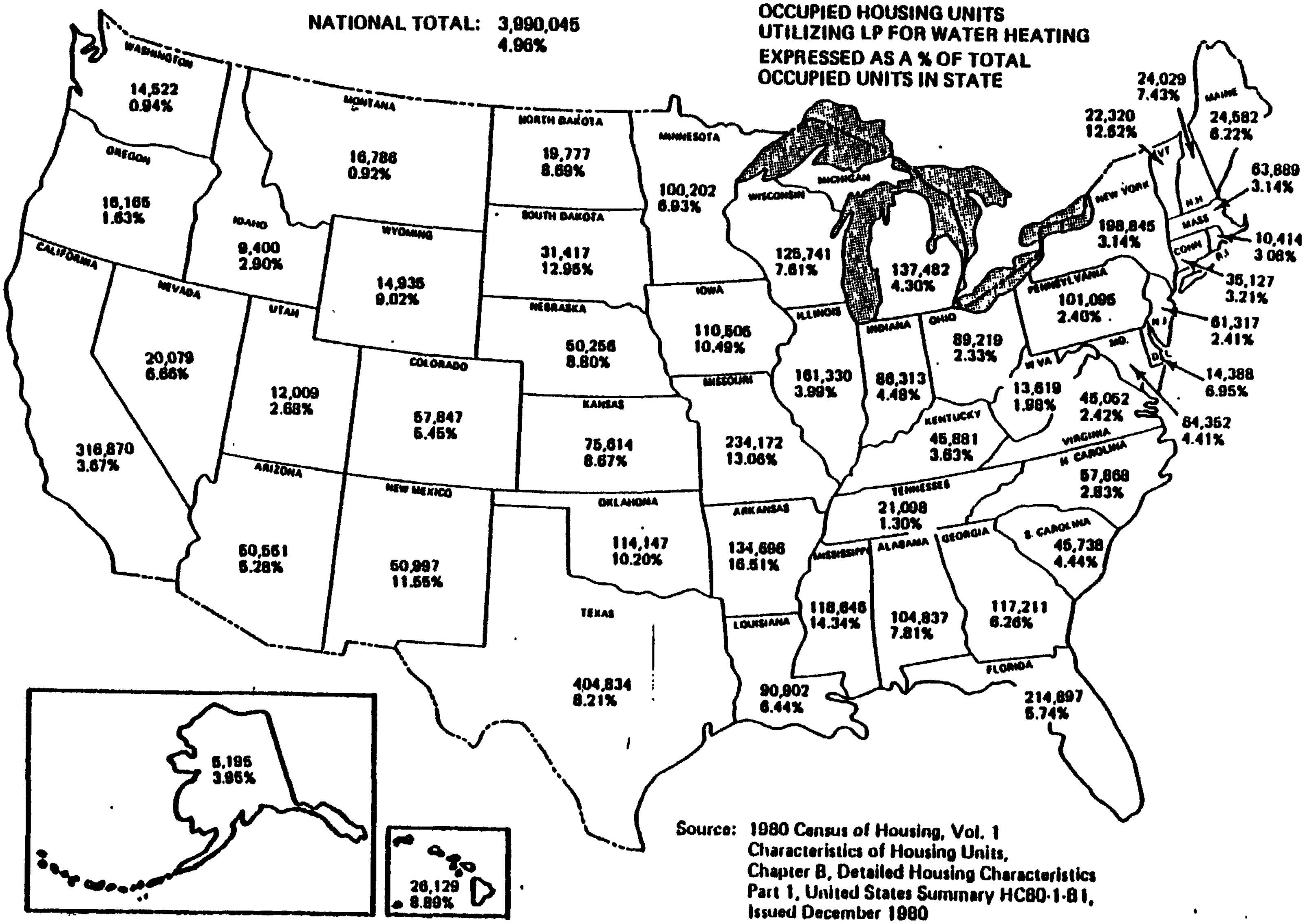

Source: 1980 Census of Housing, Vol. 1
Characteristics of Housing Units,
Chapter B, Detailed Housing Characteristics
Part 1, United States Summary HC80-1-B1,
Issued December 1980

Figure 3-3 WATER HEATING FUEL USE OF BOTTLED, TANK OR LP GAS BY STATE

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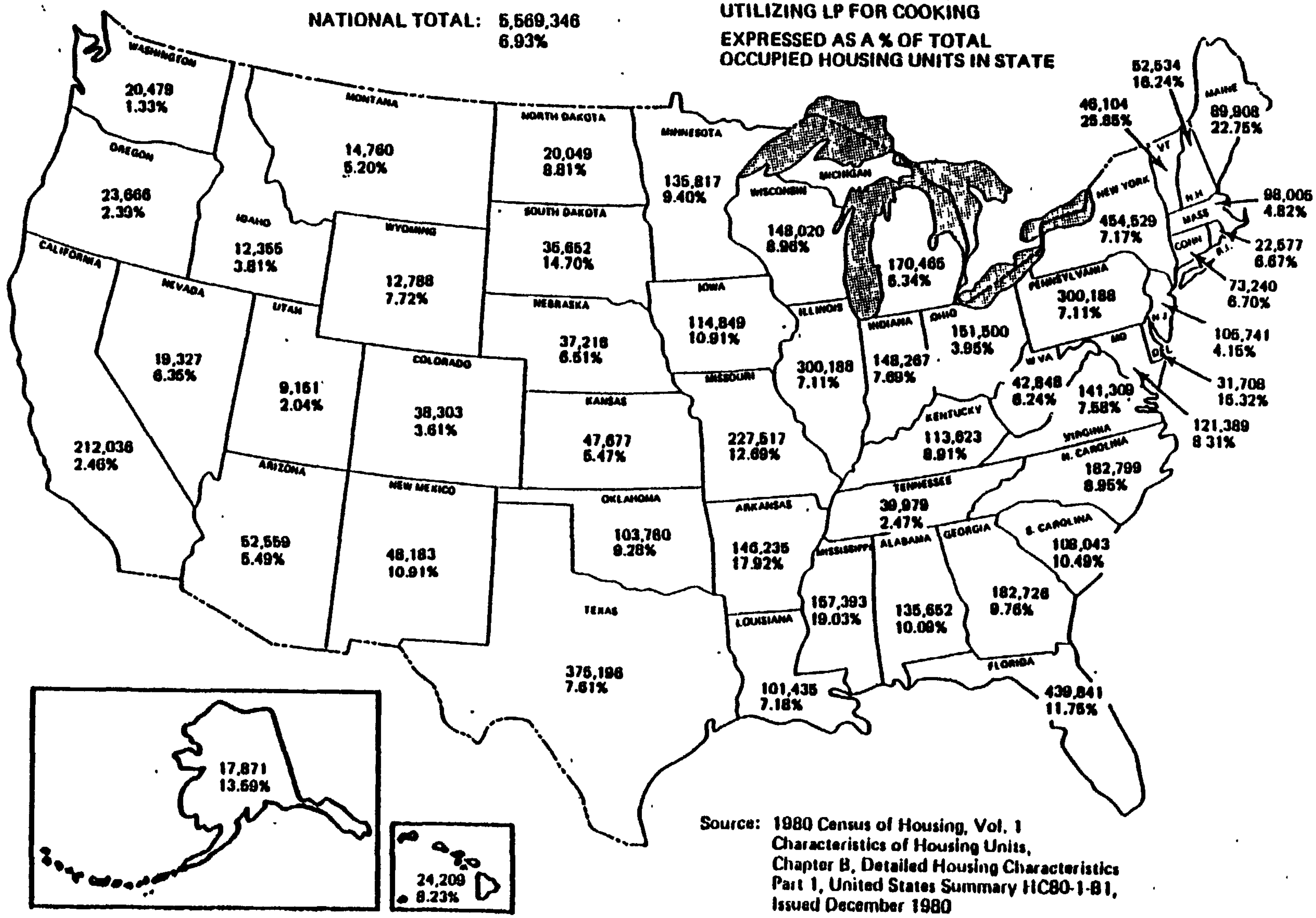
OCCUPIED HOUSING UNITS UTILIZING LP FOR COOKING

EXPRESSED AS A % OF TOTAL OCCUPIED HOUSING UNITS IN STATE

NATIONAL TOTAL: 5,569,346 6.93%



Source: 1980 Census of Housing, Vol. 1 Characteristics of Housing Units, Chapter B, Detailed Housing Characteristics Part 1, United States Summary HC80-1-B1, Issued December 1980

Figure 3-4 COOKING FUEL USE OF BOTTLED, TANK OR LP GAS BY STATE

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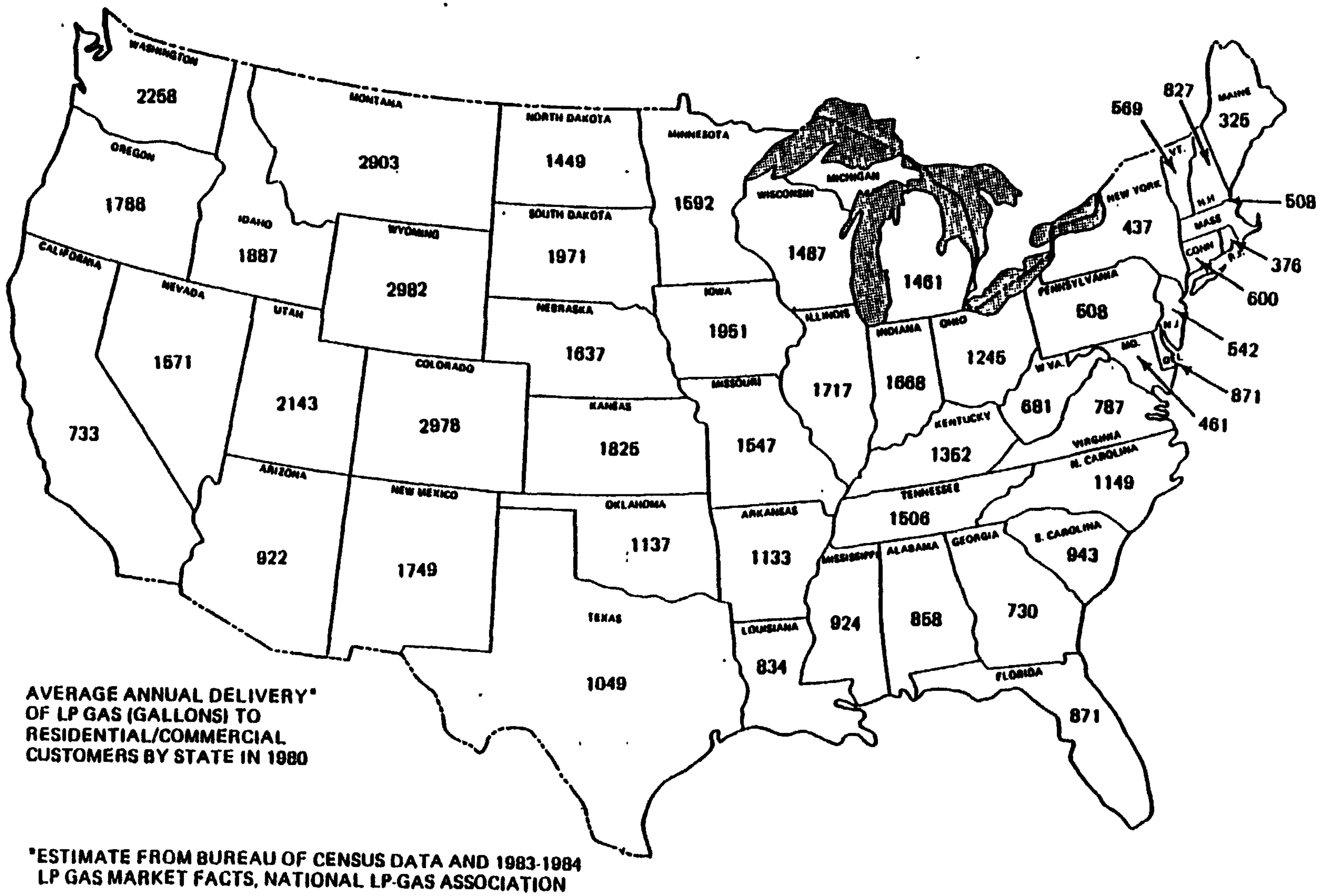

Figure 3-5 AVERAGE ANNUAL DELIVERY* OF LP GAS (GALLONS) TO RESIDENTIAL/COMMERCIAL CUSTOMERS BY STATE IN 1980

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Table 3-4. State By State Annual Delivery To Residential/Commercial Customer of LP Gas in 1980.

STATE	LP Gas Delivered (A) 1,000 Gal	Estimated Customers	Maximum Type of Use	Estimated Consumption (C) Gal/Yr
Alabama	198,788	231,621	House	858
Arizona	48,456	52,559	Cook	922
Arkansas	165,679	146,235	Cook	1133
California	232,420	316,870	Water	733
Colorado	172,275	57,847	Water	2978
Connecticut	43,950	73,240	Cook	600
Delaware	27,624	31,708	Cook	871
Florida	327,179	448,262	House	730
Georgia	231,963	318,357	House	729
Idaho	23,314	12,355	Cook	1887
Illinois	298,966	174,077	House	1717
Indiana	247,310	148,267	Cook	1668
Iowa	287,015	147,104	House	1951
Kansas	153,662	84,193	House	1823
Kentucky	152,226	112,623	Cook	1352
Louisiana	84,635	101,435	Cook	834
Maine	29,191	89,908	Cook	325
Maryland & DC	58,187	126,307	Cook	461
Massachusetts	49,828	98,005	Cook	508
Michigan	249,008	170,465	Cook	1461
Minnesota	216,160	135,817	Cook	1592
Mississippi	162,479	175,926	House	924
Missouri	397,578	256,989	House	1547
Montana	61,125	21,055	House	2903
Nebraska	112,651	68,819	House	1637
Nevada	31,542	20,079	Water	1571
New Hampshire	43,428	52,534	Cook	827
New Jersey	57,338	105,741	Cook	542
New Mexico	89,207	50,997	Water	1749
New York	198,788	454,539	Cook	437
North Carolina	210,021	182,799	Cook	1149
North Dakota	37,681	26,006	House	1449
Ohio	188,666	151,500	Cook	1245
Oklahoma	129,826	114,147	Water	1137
Oregon	42,318	23,666	Cook	1783
Pennsylvania	152,422	300,168	Cook	508
Rhode Island	8,490	22,577	Cook	376
South Carolina	111,410	118,170	House	943
South Dakota	86,007	43,641	House	1971
Tennessee	119,247	79,184	House	1506
Texas	452,434	431,361	House	1049
Utah	25,730	12,009	Water	2143
Vermont	26,252	46,104	Cook	569
Virginia	111,149	141,309	Cook	787
Washington	46,236	20,479	Cook	2258
West Virginia	29,191	42,848	Cook	681
Wisconsin	220,078	148,020	Cook	1487
Wyoming	47,542	15,945	House	2982
TOTAL	6,496,672	6,203,867		1047

A) Source 1983-84 LP-Gas Market Facts: National LP-Gas Association

B) Reviewed 1980 Census Data "Characteristics of Housing Units; Detailed Housing Characteristics United States Summary", HC80-1-B1 And Selected the Number of Housing Units Utilizing Bottled, Tank; or LP Gas For House Heating Fuel, Water Heating Fuel and Cooking Fuel Based on Taking The Highest Number.

c) Divide Column 1 By Column 2

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Table 3-5.

Analysis of LP Fuel Use And Population Exposed To Hazards Associated With Its Use

U.S. TOTALS

	U.S. Total	Inside SMSA's Total	Inside SMSA's Central City	Inside SMSA's Non Central	Outside SMSA's Total	Outside SMSA's Rural Farm	Outside SMSA's Non-Farm
Persons in Occupied Units	220,796,160	165,282,890	64,989,230	100,293,660	55,513,276	5,615,977	49,891,299
Occupied Units	80,389,673	60,497,589	25,275,851	35,221,738	19,892,084	1,820,528	18,071,556
Occupancy Person/Unit	2.75	2.73	2.57	2.85	2.79	3.08	2.76
House Heating Fuel							
Utility Gas	42,657,625	35,135,754	16,309,072	18,826,682	7,521,871	149,634	7,372,230
All Other Excluding LP	33,397,223	23,532,887	8,646,009	14,886,878	9,664,336	1,101,754	8,562,582
LP	4,534,825	1,828,948	320,770	1,508,178	2,705,887	569,140	2,136,737
LP As % Of Total	5.64	3.02	1.27	4.28	13.60	31.26	11.82
Exposed Pop.	12,497,254	5,005,470	829,597	4,287,438	7,563,821	1,746,298	5,916,641
Waterheating Fuel							
Utility Gas	42,148,105	35,625,185	16,855,744	18,769,441	6,522,920	118,261	6,404,659
All Other Excluding LP	34,251,523	23,013,494	7,951,578	15,061,921	11,238,037	1,278,046	9,959,991
LP	3,990,045	1,858,910	468,529	1,390,381	2,131,135	424,221	1,706,914
LP As % Of Total	4.96	3.07	1.85	3.95	10.71	23.30	9.45
Exposed Pop.	10,975,043	5,081,684	1,206,696	3,958,197	5,941,838	1,304,803	4,704,255
Cooking Fuel							
Utility	32,375,170	27,818,072	14,733,068	13,085,004	4,557,098	86,497	4,470,601
All Other Excluding LP	42,445,157	30,238,360	10,163,795	20,074,565	12,206,797	1,276,701	10,930,096
LP	5,569,346	2,441,157	378,988	2,062,169	3,128,189	457,335	2,670,854
LP As % of Tot.	6.93	4.04	1.50	5.85	15.73	25.12	14.78
Exposed Pop.	15,331,575	6,679,107	977,864	5,879,622	8,729,432	1,412,360	7,374,402

Derived From:

1) 1980 Census of Housing, Vol. I Characteristics of Housing Units, Chapter B Detailed Housing Characteristics, Part 1 United States Summary. HC80-1-B1, Issued December 1983.

2) 1980 Census of Housing, Vol.1 Characteristics of Housing Units, Chapter A General Housing Characteristics, Part 1 United States Summary HC80-1-A1, Issued May 1983.

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Table 3-6. Distribution of Occupied Housing Units and Occupied Units Utilizing LP For House Heating Fuel By Type of Housing Unit.

	Occupied Housing Units			LP House Heating Fuel Use				
	Owner	Rental	Total	Owner	Rental	Total	% of LP Users	Cumulative %
One Unit Detached	43,253,057	7,285,635	50,538,692	2,449,976 5.80%*	672,080 9.22%*	3,122,055 6.18%*	68.85	68.85
One Unit Attached	1,868,095	1,439,690	3,307,785	26,341 1.41%*	26,109 1.81%*	52,450 1.59%*	1.16	70.01
Mobil Homes or Trailers	3,103,849	785,305	3,889,154	746,818 24.06%*	187,833 23.92%*	934,651 24.03%*	20.61	90.62
Two Unit Structures	1,510,899	3,375,819	4,886,718	40,615 2.69%*	77,043 2.28%*	117,658 2.41%*	2.59	93.21
3 & 4 Unit Structures	656,497	3,292,024	3,948,521	26,378 4.02%*	66,744 2.03%*	93,122 2.36%*	2.05	95.26
5 to 9 Unit Structures	406,143	3,036,221	3,442,167	21,657 5.33%*	54,321 1.79%*	75,978 2.20%*	1.68	96.94
10 to 19 Unit Structures	312,927	3,231,111	3,544,038	14,632 4.68%*	45,560 1.41%*	60,192 1.70%*	1.33	98.27
20 to 49 Unit Structures	273,122	2,446,337	2,719,459	7,457 2.73%*	30,283 1.24%*	37,740 1.39%*	0.83	99.10
Over 50 Unit Structures	411,806	3,701,136	4,112,942	7,199 1.75%*	33,779 0.91%*	40,978 1.00%*	0.90	100.00
Total 3 & 4 Units and Smaller	50,392,397	16,178,473	66,570,870 82.81% of U.S. Units	3,290,128	1,029,809	4,319,936		95.26

* $\frac{\text{LP Using Units By type of Unit}}{\text{Total Units By Type}} \times 100$

Derived From: 1980 Census Of Housing, Vol. 3 Subject Reports Chapter 4 Structural Characteristics Of The Housing Inventory, HC80-3-4 Issued Aug. 1984.

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disproportionate contributor to fire death rates. Eliminating this source, the rural/non-rural fire death ratio for heating equipment changes to essentially 2:1, a rural/non-rural ratio that is roughly in-line with other major fire scenarios.

Kitchen/cooking equipment involvement in scenarios leading to severe burn injury quantitatively leads the list. Eliminating fabric ignition from controlled flames, and controls not within the scope of this study, injury occurrences related to activities or fire origin in the kitchen would drop sharply. The report cited above, however, noted that installation/maintenance problems with cooking equipment, particularly those fueled with LP-Gas, resulted in leaks contributing to significant casualty producing fires. The rural picture was substantially worse than the non-rural picture.

Manufactured housing (MH) has a disproportionate fire/casualty record compared to conventional housing on a historical basis. A NFPA study[9] showed a significant reduction in fatalities and severity of fires in mobile homes constructed to Federal Standards adopted in 1976 (24CFR280). These regulations promulgated by Housing and Urban Development (HUD) were in part based on NFPA 501B, a voluntary standard. Following Federal adoption, NFPA and the Manufactured Housing Institute (MHI), sponsors of NFPA 501B dropped this part of their activity. Recently, part of the Title 24 regulations dealing with heating systems was excised from the code. Hence, a vacuum may exist with respect to MH heating system safety exclusive of that related to certain Underwriters Laboratories (UL) and ANSI standards of somewhat different scope.

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Ignition of wood components or other combustibles in the alcoves housing gas furnaces or water heaters is a major fire scenario with manufactured housing, and there is a definite LP-Gas bias. This is based on analysis of CPSC and NFPA data. Though this study excluded direct consideration of appliances and controls, there is a relevant link due to possible supply pressure excursions. The pressure excursion factor is discussed more fully in Section 5.4 of the report.

The observations and conclusions summarized in the succeeding paragraphs are based on an amalgamation of information from the various cited data resources in Appendix "B" and FTA's investigative experience.

With regard to accidents in homes of conventional construction, the overwhelming user activity at the time of injury was an attempted pilot lighting sequence on a major appliance, usually a water heater, central heating furnace or boiler. Basement or cellar locations were the site of the most frequent and devastating occurrences. Space heating equipment, frequently old and installed in jurisdictions with no codes or codes with limited safety coverage (predominantly in the Southeastern United States) were also major elements in burn injury accidents of all types, including pilot lighting incidents.

The injured party in a pilot lighting sequence was seldom a serviceman. Usually a consumer, predominately males, were the injured parties. The occasion for pilot lighting was most often routine in nature, typically a re-light when the fuel supply was replenished after complete exhaustion. Other frequent scenarios were pilot relighting after a period of erratic appliance operation with relatively frequent outages, or at the close of an attempted repair or maintenance operation conducted by other than professional service personnel.

Factors leading to control or appliance failure and subsequent injury relevant to this study were fuel supply pressure excursions and particulate contamination originating in the fuel supply system. Other major sources of fugitive gas which were subsequently ignited were leaks from fittings and connectors, irrespective of location, and leaks from corroded or physically damaged underground piping seeping into below-grade locations. Problems with fixed site containers were limited in number compared to other problem scenarios cited. Principal supply container difficulties at fixed site locations were noted with DOT (ICC) cylinders and their shut-off valves as compared to ASME stationary tank installations. Frequently the problems were believed to be age and/or deficiencies in inspection related, rather than a problem in basic design.

Overfill problems were occasionally noted with fixed site containers, but were far rarer than those experienced with portable gear.

Aboveground container installations far outnumber underground installations, smothering the statistics. However, anecdotal information suggests that the increasingly popular underground installation in some locales may be overepresented in problem occurrences. Failure to provide adequate protection from flooding or damage by "outside forces" (vehicles, construction activities, etc.) were most often cited.

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Problems with outdoor located equipment centered around the pressure regulation systems employed. This is not surprising since regulators are relatively complex mechanisms with numerous dynamic components, unlike much of the rest of the supply system. Environmental challenges, internal in nature (fuel supply contamination) and external (weather-particularly wet, freezing conditions) were key elements in most accident scenarios. Section 5.4 contains more detailed discussion regarding pressure regulation.

The most striking feature of in-the-home tragedies involving LP-gas, regardless of type of construction, appliance or supply system involvement was the failure of victims to detect the odor of the flammable/explosive mixture--either at all, or the intensity was so faint the concentration was believed to be non-dangerous. Clearly there is a major problem in this area. Section 4.2.3 discusses the issue further.

Two additional general observations are worthy of comment. First, many of the contributing factors to injury accidents were slow-developing or latent hazards. This suggests intervention in the form of knowledgeable inspection and/or maintenance could be an effective injury prevention tool. This has obvious implications to the industry GAS Check program.

The second observation is that non-professional installation, inspection and maintenance activities, whether by consumer or untrained or indifferent service personnel acted as order-of-magnitude multipliers for severe accident probability to whatever intrinsic hazards already existed in a given system.

3.4 Hazard Ranking and Priority Issues: Overview

3.4.1 Introduction

Reduced to its simplest terms the principal hazard with respect to the use of LP-Gas is uncontrolled fire or explosion. Accordingly, the strategies to reduce this hazard can follow two basic courses:

- o Reduce the potential for the occurrence of dangerous leaks, and
- o Insure the detection of leaks which do occur in time to take effective counteraction or at least to escape.

From this all else follows.

During the course of this study over eighty broad categories of ignition sources, leak sources, and probable causative factors were identified from prior accident data. A more detailed breakdown would increase the categories geometrically. Despite the large number of factors which constitute some measure of hazard contributing to the general risk of burn injury or fire loss, there are a few items which clearly stand out as priority issues in terms of hazard reduction. These major, broad issues are discussed below. Narrower issues, their priority and possible corrective measures follow with the technical discussions in Sections 4.0 and 5.0.

3.4.2 Hazard Ranking & Priority Issues

The greatest single impact that could be made in reducing the hazard of LP-Gas use in the residential environment, with supply systems already in place and

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consumer behavior patterns essentially unmodified, would be to insure timely and effective detection of gas leaks. Therefore we consider this the number one priority item for attention.

It is important that it be recognized that gas odorization is only part of this issue, not the whole issue. It is likely that supplemental means of detection to the human olfactory senses, e.g. electronic detectors, may become technically and economically feasible for certain applications. An example application would be placement of detectors invulnerable, but frequently unattended locations such as basements with fuel burning appliances.

There is an odorization problem. In many cases it can be reasonably determined that the gas was initially odorized, and that the victims did not smell a high concentration of gas. Many victims had an apparently unimpaired sense of smell and were unlikely to be lying about the matter. In other words, the odor "faded" somewhere in the distribution chain. The so-called "fade" phenomenon and a host of technical and human factors issues relating to odorant detectability have been studied in the past. The LP industry is presently considering sponsoring additional research. We are supportive of this effort. However, we are also concerned with the situation as it exists and is likely to exist for a significant time into the future.

The requirements in NFPA #58 regarding odorant detectability and suggested levels of odorizing are a microcosm of a more pervasive deficiency in NFPA #58, whether it be in "mandatory" or "recommended" provisions. The deficiency is the frequent absence of any clear assignment or protocol for whom is responsible for meeting a stated requirement, how is it to be carried out, who and how is it to be verified that the provisions are met, even stated in very broad terms.

In the odorization case the absence of delineation and fixing of responsibility may mean the only check is literally a check mark on a sheet of paper prepared at the loading rack at the beginning of a tortuous trail of shipping, commingling of gases, storage, etc. through many hands to the user. This lack of requirements for monitoring or verification of a key safety element occurs despite the fact that odorant materials with known stability problems in environments likely to be seen in the distribution chain are utilized.

Similar examples can be cited with regard to inspection requirements for certain containers and appurtenances critical to safety. A specialty case is the conversion of 100 lb. DOT cylinders to on-site volumetric filling. Without considering the wisdom of filling operations at near zero separation distances from an occupied structure, the interpretation has been made that the DOT rules on filling/verifying by weight do not apply because the cylinder is no longer "in transportation". Some apparently have extended that interpretation to mean DOT cylinder inspection rules no longer apply as well. In most locales that is tantamount to eliminating inspection all-together. Similarly, protocols for verification of inspection by qualified personnel of customer owned cylinders are weak—and the story could go on.

The next overall major impact item on reducing the LP-gas use hazard in the residential environment, and the earliest likely to produce an beneficial effect, is considered to be the vigorous pursuit on the broadest level of participation in the industry sponsored GAS Check program. The National LP-Gas Association and the Gas

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Appliance Manufacturers Association should be commended in this effort. The priority issue here is to insure that the program does not falter in either depth of breadth of participation. As a participating member aptly put it, the problem (of NLPGA) is now largely one "of preaching to the converted". Active participants in Association affairs have already been reached and convinced. How does one reach the significant remainder? It would appear that some justifiable discrimination by insurance carriers might be an effective approach in bringing clients up to minimum standards with respect to custom and practice. Additional suggestions involving possible participation by CPSC, State regulatory authorities, and wholesale LP-gas suppliers to encourage participation were described in Section 2.3.

A currently significant problem and a potentially major problem in the making--therefore needing priority attention--revolves around customer owned containers and their principal use, self-contained outdoor portable cooking equipment. Engineering analysis and accident studies suggest the key hazard elements in approximate order of the risk they pose in terms of frequency and severity are:

1) Overfilling of containers
2) Improper transport/storage/maintenance of containers and fittings, and
3) unsuitable component design to prevent minor operational upsets from escalating to major fires.

A series of recommendations regarding Outdoor Portable Cooking Equipment may be found in Section 5.6.

A final general priority issue, which is in reality a combination of lesser issues, deals with regulation systems and the prevention of downstream overpressure in particular. Section 5.4 deals with the individual issues involved.

3.4.3 Hazard Ranking by LP-Gas System Employed

An earlier table (Table 3-5) provided an analysis of LP use by major class of utilization equipment. The "exposed population" numbers shown were the product of occupied housing units by average number of persons per occupancy times the percentage of occupancies using LP-gas. The resulting potential "exposed population" figures are not additive since appliances in each category may be present in a single occupancy. The 1980 appliance population of ranges, househeating equipment and waterheating equipment aggregated to approximately 14 million units. This total would be slightly higher in 1986. Among stationary appliances the "mix" i.e. use of multiple appliances in a single occupancy significantly affects the type of LP distribution equipment used. Exchange cylinders and predominance of single stage regulation will often be found in areas with light duty loads such as cooking. When central space heating is involved the use of stationary tanks will predominate. LP-gas utilization has a strong regional bias. These factors made it necessary to be careful in interpreting data which may be unbiased in terms of demographics but may be biased due to the distinctly non-uniform distribution patterns by specific fuel use, types of supply and utilization equipment employed. These can correlate poorly with general population distribution.

Exclusive of portable outdoor cooking equipment and recreational vehicle (RV) use, an approximate ranking of LP systems by hazard presented to the residential user may be described as follows.

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Systems using an above ground stationary tank, filled on site by a primary LP distributor supplying gas to a single family residence of conventional construction through a two-stage regulation system, with the service entry and using appliances above grade, represents the system with the least risk to the residential consumer.

At the other end of the spectrum, a single cylinder (exchange or user owned) filled off-site by a secondary distributor, supplying gas through a single stage regulator to a manufactured (mobile) home appears to represent the highest risk setting. Another high risk arrangement involves the previously described supply system serving below grade appliances in homes of conventional construction. If the below grade appliance installation is in a semi-finished, unheated or poorly heated area, e.g. "Michigan" cellar, the risk is increased, regardless of supply system type. Below grade entry of the service line increases the risk with any construction.

Hazard level jumps very sharply with user or "handyman" intervention to hook-up, modify or repair the supply system or utilization equipment.

Between the extremes of risk one may not statistically prove the precise order of hazard presented by particular supply arrangements; however, a reasonable determination can be made from observed accident patterns and engineering evaluation. Table 3-7 provides a generalized evaluation providing approximate rankings for common (and some atypical but accident prone) arrangements found in the field.

Briefly, for those unfamiliar with LP-Gas supply systems arrangements, we will provide short, simplified descriptions to assist in following Table 3-7.

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Table 3-7

APPROXIMATE SAFETY RANKING – RESIDENTIAL LP GAS SYSTEMS

	CONTAINER TYPE	REGULATION SYSTEM	PIPING	SERVICE ENTRY	SUB-FLOOR ARRANGEMENT	TYPE OF STRUCTURE
Approximate order of increasing risk ↓	ASME - aboveground DOT - twin/auto-changeover ASME - underground DOT - twin/manual changeover DOT - single	2-stage w/vent relief each stage (full relief final stage) 2-stage w/full capy final stage relief 2-stage (non-piggyback) 2-stage (piggyback) 1-stage full capy relief 1-stage	Highly variable* See note	Above grade Below grade	Slab Crawl space (no appliance) in space Basement - concrete Basement - block Crawl space w/ appliance; dug-out or "Michigan" cellar	Conventional Manufactured housing
Risk Multipliers (no order of priority)	• Increasing age • Customer owned • "Secondary" supplier serviced	• Increasing age • Customer owned & serviced • Lack of weather protection • Coastal and/or wet/freezing rain climate	• Lack of drip leg sediment trap at appliances - particularly if copper piping involved	• Lack of entry sleeve & seal	• Porosity or cracks of below grade walls near service entry • Poor or no heating of sub-floor areas where appliances located	• Increasing age • Geographic location - cold weather high demand area - Southeast (substandard housing) • Seasonal use

Non-professional (consumer or other) installation & maintenance activities are a major risk multiplier

*Note: Cathodically protected, coated and wrapped steel good. Copper generally acceptable except in certain soil conditions, plus potential for copper sulfide formation damaging unprotected controls; insufficient information on approved plastic piping. Length of run and protection from physical damage crucial.

ASME stationary containers of above and underground type are typically used with larger loads, such as central heating applications. Below ground containers have a rigid protective sleeve providing aboveground access to the tank fittings. Regulators on underground tanks need to have special vent line protection from flooding. Water or debris entry into the regulator via the vent can cause over-pressure problems. All regulators installed outdoors require weather protection, either separate or as part of intrinsic design. Tank construction and regulator protection are discussed in Section 5.2 and 5.4

DOT cylinder installations for intermediate and low demand requirements serviced by professional LP-Gas distributors are typically twin cylinder systems. One tank serves as the active supply and the second tank is a reserve supply. When the supply from one tank is exhausted the system is "changed-over" to the reserve tank. The changeover can be accomplishd automatically or manually. Automatic changeover systems have the virtue of being a more reliable supply from uninterrupted service and stable pressure level standpoints.

The term "two-stage" regulation means that the pressure reduction from container pressure to utilization pressure is accomplished in two discrete steps, or stages. This method of regulation tends to provide more stable outlet presures under varying supply pressure and utilization demand conditions. Two stage regulation in a twin cylinder automatic changeover system can be accomplished in an integral housing or with separate regulators. Two-stage regulation applied to systems supplied by ASME tanks may be close-coupled ("piggyback" style) units mounted at the tank, or the first stage regulator may be mounted at the tank and the final stage regulator located at the service entrance to the residence. The latter design is preferred for longer service runs in particular, since the higher intermediate pressure (typically 10 to 15 psig) allows smaller service line piping to be used without excessive pressure drop. Discussion of pressure regulation and dewpoint effects in multi-stage systems may be found in Section 5.4.

Spring loaded, residential pressure regulators have communication from the diaphragm case to the atmosphere for proper operation. This vent outlet may also be utilized as the external discharge port for an internal relief. All final stage regulators are required by current standards to have a relief or high pressure shut-off system, and first-stage regulators may have a relief system. At the present time the vent relief option is virtually universal. The relief is intended to operate when excessive outlet pressures occur. The relief discharge capability, hence ability to limit excessive downstream pressure under various failure conditions, varies from one regulator design to another. Typically, both "Standard" and "Full Capacity" Relief designs are offered by a given manufacturer. Section 5.4 provides additional detail on regulator relief requirements.

Care must be taken in the interpretation of Table 3-7 . The order of ranking does not mean items at the top of the table are "safe" and those at the bottom are "unsafe". What it does mean is that the probability of an accident on a generalized basis tends to be higher when equipment or conditions lower in the list are present. The listing, in conjunction with the risk multipliers, can assist in establishing priorities of concern for reducing hazards.

The rationale for ranking follows a primary basic observation of accident patterns: the vast majority of injury producing accidents occur during an appliance relighting sequence, frequently after replenishment of the fuel supply. Hence, it follows that systems less susceptible to supply outages and less susceptible to outlet pressure excursions (which cause pilot outages, among other things), the lower the probability of injury. The container type and regulation system columns in Table 3-7 are ranked by this basic rationale.

The preference for above grade to below grade service entry recognizes, among other things, that outside service line gas leaks entry into the residence is more likely in the below grade case. Moreover, corrosion leading to service line failure often occurs at or close to foundation entries due to such factors as the disturbed and damp soil conditions often found there.

Sub-floor ranking considers the ability of fugitive gas to enter and/or accumulate, likelihood of discovery before dangerous accumulations occur, presence of a poor environment (unheated and/or damp) leading to deterioration of equipment, and potential for odorant adsorption.

4.0 LP-Gas as a Fuel in the Residential Environment: Risk Factor Relationships to Standards and Specifications

4.1 Introduction

Liquefied Petroleum (LP) gas is the term applied to certain gases derived from petroleum products and sold in compressed, or liquefied form. In the United States, about 65% of LP gas is extracted from natural gas, while 35% is refined from crude oil.[4] The make-up of the gas can, and does vary within certain specification limits assigned. The most common forms of LP-Gas are propane, butane, and propane/butane mixes. Propane (containing other compounds in minor amounts) constitutes by far the predominant residential LP-Gas fuel.

LP-gas is nearly odorless and an artifical smell (odorant) is added to fuels for safety purposes. The derivation of LP-gas can affect certain safety parameters as will be discussed later.

4.2 Fuel Specifications, Odorization and the Effects of Contaminants

4.2.1 Compositional Effects

In earlier text we referred to the GPA (Std. 2140) and ASTM (D-1835) specifications and test methods as the principal fuel specifications of interest. We have reproduced the GPA specification sheet (Table 4-1) again for ready reference with our discussion. The actual make-up of propane sold under commercial or HD-5 specification is assumed by some to have a "centrist" nature, in other words,

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Table 4-1
GPA LIQUEFIED PETROLEUM GAS SPECIFICATIONS

PRODUCT CHARACTERISTICS	PRODUCT DESIGNATION		
	COMMERCIAL PROPANE	PROPANE HD-5	TEST METHODS
Composition	Predominantly propane and/or propylene	Not less than 90 liquid volume percent propane; not more than 5 liquid volume percent propylene	ASTM D-2163-77
Vapor pressure at 100 F,* psig, max.	208*	208*	ASTM D-1267-79
Volatile residue:			
temperature at 95% evaporation, deg. F, max.	-37*	-37*	ASTM D-1837-64
or			
butane and heavier, liquid volume percent max.	2.5	2.5	ASTM D-2163-77
pentane and heavier, liquid volume percent max.	—	—	ASTM D-2163-77
Residual matter:			
residue on evaporation of 100 ml, max.	0.05 ml	0.05 ml	ASTM D-2158-65
oil stain observation	pass (1)	pass (1)	ASTM D-2158-65
Corrosion, copper strip, max.	No. 1	No. 1	ASTM D-1838-74
Volatile sulfur, grains per 100 cu ft, max.	15	10	ASTM D-2784-70
Moisture content	pass	pass	GPA Propane Dryness Test (Cobalt Bromide) or D-2713-76
Free water content	—	—	—

(1) An acceptable product shall not yield a persistent oil ring when 0.3 ml of solvent residue mixture is added to a filter paper in 0.1 increments and examined in daylight after 2 minutes as described in ASTM D-2158.

*Metric equivalents: 208 psig = 1434 kPa guage 70 psig = 483 kPa guage -37°F = -38.3°C 36°F = 2.2°C 100°F = 37.8°C

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tending to usually have properties close to pure propane. Constituent variation to the extremes of the specification have likewise been assumed by some to be rare. This is far, however, from the truth.

Refinery derived propane doesn't just "happen", it is a purposeful blend generated to maximize plant profit within the plants capabililty of altering its product mix from a particular feedstock. As alternative use values for constituents change so does the propane fuel blend. For example, in the winter of 1986, propylene had a worth as a chemical feed on the order of 12 cents a pound versus less than 7 cents as a propane blend:[3] exit propylene from propane. On the other hand ethane was worth more as a fuel than a feedstock in some sectors: maximize ethane in the blend. Consider declining gas fields and a slippage in "heavier ends". Hence, more ethane and less butane in the propane output. (Recovery of various compounds over the production life of a gas field will vary with original reservoir characteristics, production history, re-cycle, etc. Over time it would not be unusual to see the recovery of heavier molecular weight hydrocarbon gases dwindle. In such cases commercial propane produced will tend to have "lighter" minor constituents such as ethane, rather than "heavier" minor constitutents such as butane.)

These situations change by source location and market conditions on a month by month, year to year basis. The point to be made, however, is that extended runs and massive quantities of LP-gas fuel are made at the extreme limits of the specifications. As this report was being written ethane rich propane was much in abundance. The effect of this constituent on important safety parameters such as vapor pressure is very substantial. This will be demonstrated in later discussion when we tie together the progressive effects of changes in composition and common air

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contamination, for example.

The primary specifications for LP Gas fuels reflect the beginnings of the industry in "natural gasoline" derivatives from petroleum production, or products of simple petroluem refining "topping operations". Returning again to Table 4-1 we will concentrate on the HD5 propane specification .

Focusing for the moment on the corrosion specification (copper strip test), it should be remembered that this is essentially a test for a single contaminant , hydrogen sulfide, not a broad spectrum corrosion test. It is an old but quite appropriate test for propane produced from "sour", i.e. high sulfur content, gases or derived from sour crudes. It is not effective, however for detection of other corrosive contaminants foreseeably present in propane produced in modern refining operations. For example, a malfunction in an HF alkylation unit can result in hydrofluoric acid being mixed with the propane product. Thus, there is a risk of serious, and potentially dangerous contamination in an "in-spec" product.

The above shortcoming is an example of a more pervasive problem in assuring the quality of product is initially adequate, and then maintaining an adequate level of quality throughout the distribution chain. Even in the case of more explicit requirements in a specification, such as the odorant level requirements in NFPA #58, there are no follow-through requirements to insure to a reasonable degree an appropriate level exists at point of delivery, as pointed out earlier.

Continuing on the subject of contaminants, ammonia has proved particularly troublesome. Usually ammonia contamination is introduced in transportation, rather than at the refinery level. This most frequently occurs due to

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improper purge and cleaning of tank trucks or tank cars in dual service. Less pervasive is contamination by farm consumers switching service among nurse tanks. NFPA #58 states flatly that LP-gas in systems within the scope of the Standard shall contain no ammonia. A litmus test is prescribed if "the possibility exists". Considering major contamination events that have occurred, however, it would appear that who should be responsible for testing and what should be done if contamination is found needs to be better defined.

The most pervasive contaminant in LP-Gas at the ultimate user level is air. The presence of a non-condensable gas such as air, particularly with an in-specification, but high vapor pressure propane fill, makes "premature" safety-relief function a distinct possibility. Add to this overfilling errors known to occur, an apparently wide margin of safety vanishes—without even considering set-point tolerances on relief devices.

The increase in pressure in a closed vessel containing a mixture of liquid and gaseous propane subject to heating represents a vapor pressure increase only. It is not the result of compression of the vapor volume due to the increase in liquid volume upon heating. Thermodynamically, "saturation" conditions prevail. Condensation of propane vapor to re-establish equilibrium at the new higher temperature will occur. At a fixed temperature a change in the corresponding liquid and vapor volume would produce no pressure change at all. "Non-condensables", such as the constituents of air, present in the vapor volume are subject to compression upon expansion of the liquid volume. Therefore, their presence can lead to very high pressures if a substantial reduction in the vapor volume occurs either due to heating or container filling operations.

Air contamination as a significant safety threat is primarily a factor with small, customer owned containers. There are a number of scenarios of interest. The least consequential may be fill hose contamination which is likely to occur at a secondary distributor retail filling area. More of a problem is the entirely air-filled new tank which is not properly purged when first filled. Another ironic scenario is the user trying to follow his warning label instructions not to store LP gas indoors. He empties the tank at the end of the "barbeque season" and stores it inside for the winter with the cylinder valve open. The first use after filling in the following season, an unexpected gas release occurs and fire ensues. The accident record is replete with cases highly suggestive of improper purge techniques, quite likely abetted by overfill in some instances.

A series of charts have been prepared illustrative of the serious consequences of overfilling, compositional differences in the fuel, and air contamination. These are shown separately, and as combination events which can foreseeably occur.

The effect of high ambient temperatures, radiant heating from a normally operating portable grill, or heating from any other source are clearly seen.

Figures 4-1 and 4-2 show outage curves for a 20# tank with pure and ethane rich (but in specification) propane at various temperatures and fill conditions.
It will be observed that under specification fill conditions temperatures in the 150 degree to 160 degree F range would need to be reached for a liquid full condition to occur. Any further temperature increase would open the safety relief valve. An overfill condition drops the temperature danger point significantly. Note that a 10% overfill with

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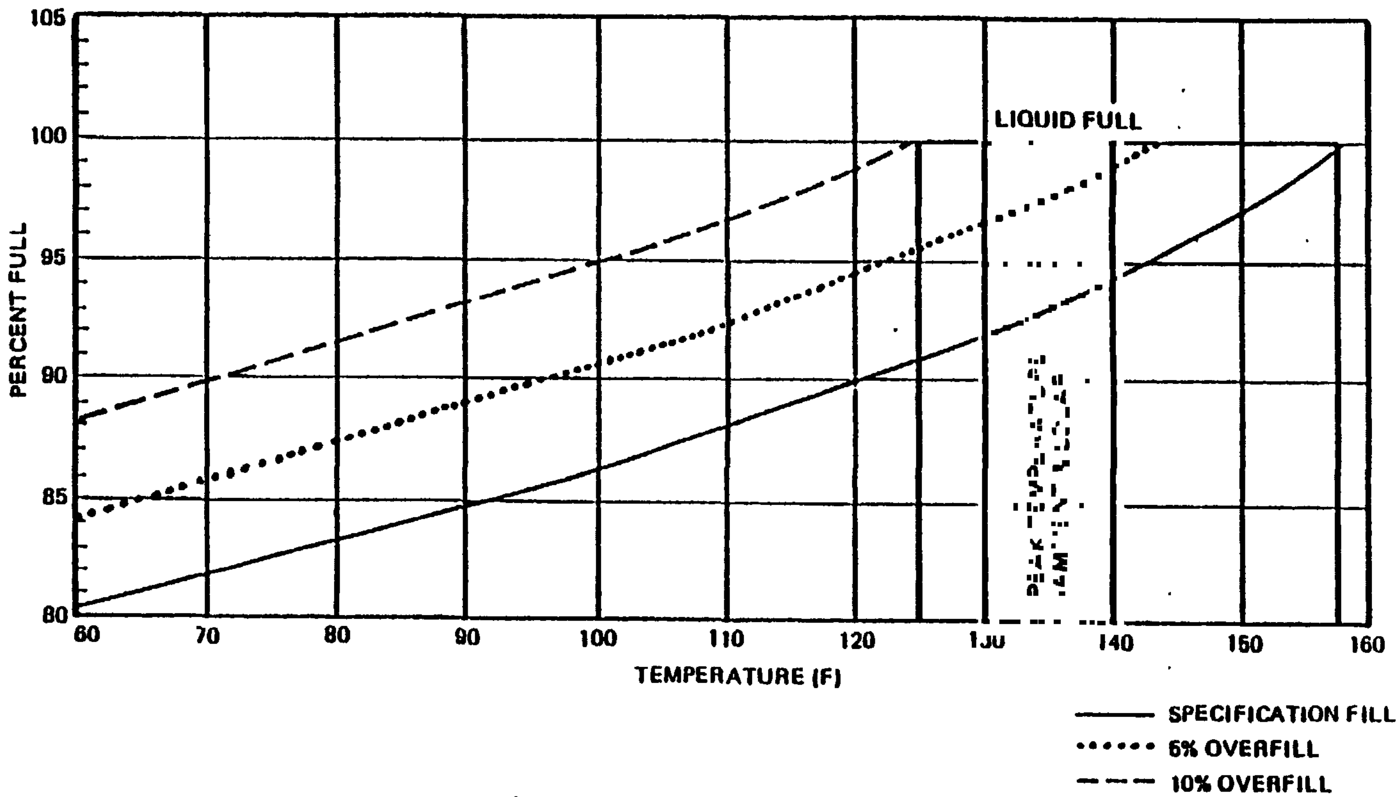

PROPANE IN A 20# CYLINDER

Basis: 20 lbs. of propane with a S.G. of 0.51 @ 60°F fills cylinder to 80%.

Therefore, propane occupies 0.6288 ft^3. Internal volume of cylinder is 0.7859 ft^3.

5 & 10% overfills simulated by increasing the volume of propane at 60°F by 5 & 10% respectively.

Properties of propane obtained from Table 3-254 of Perry's Chemical Engineering Handbook, 4th Edition.

Safety valve is taken as having properties such that it will release at 375 psi. This could result from liquid full condition or vapor phase pressures at 375+ psi.

Figure 4-1 OUTAGE CURVES FOR PURE PROPANE IN A 20 POUND CYLINDER

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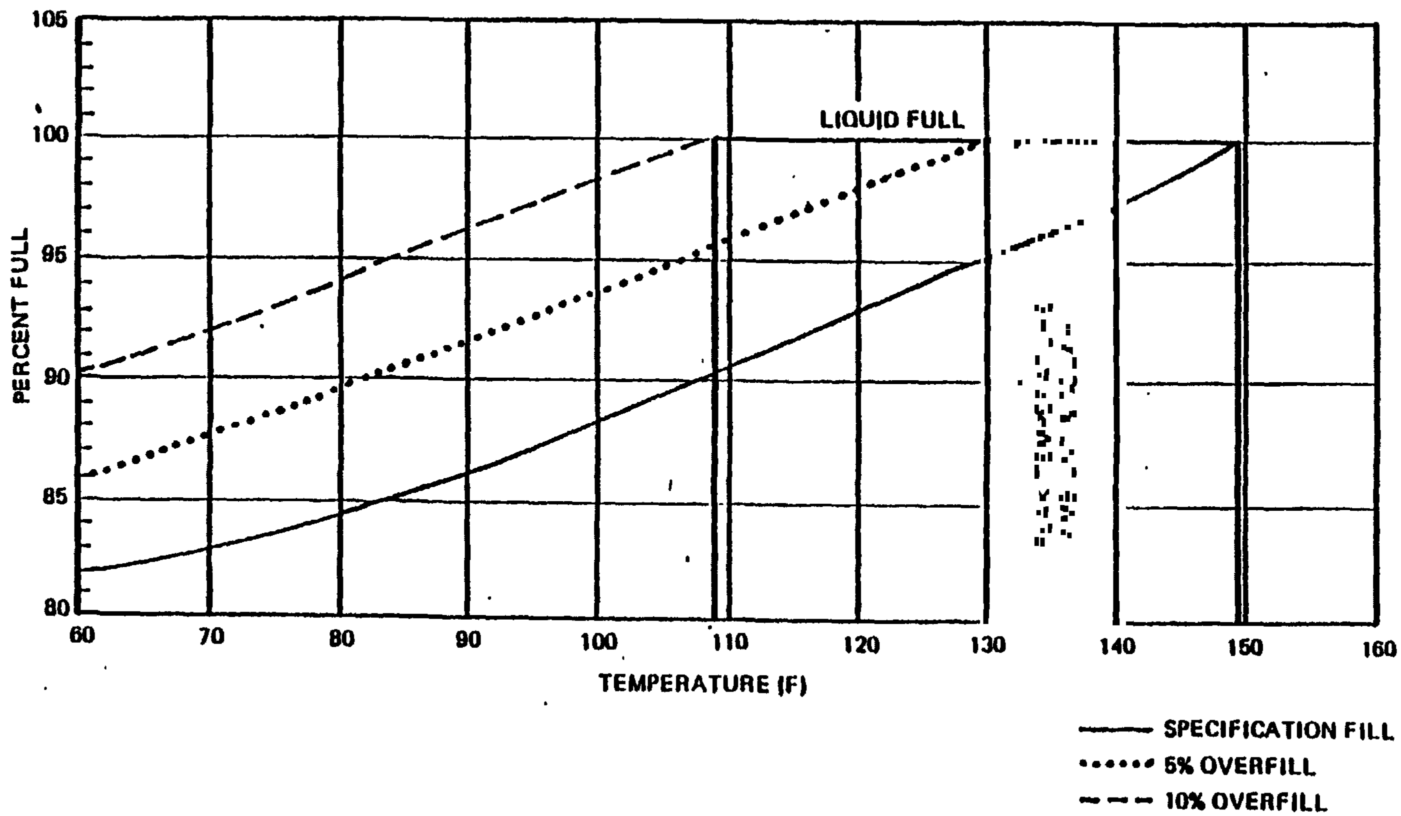

Figure 4-2 OUTAGE CURVES FOR 94.5 PROPANE/5.5 ETHANE IN A 20 POUND TANK

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the ethane rich product drops the liquid full point below 110 degrees F, well into the range of temperatures produced under local ambient conditions augmented by solar or other radiant heat sources.

The assumptions for the propane/ethane mixture for Fig 4-3 and subsequent charts was as follows:

Propane/Ethane Mixture

Ethane

Critical Temperature	89.96
Critical Pressure	708.psi
Critical Density	0.203 g/cc

A major portion of the temperature range of interest is above the critical temperature of ethane. A literature search for experimental phase and PVT data for the system Propane/Ethane was not fruitful for the concentration range of interest.

For purposes of this exercise we determined a pseudo-equilbrium pressure for ethane by extending the vapor pressure curve through the critical temperature. The density of the ethane liquid above the critical temperature is estimated by the critical density.

The maximum ethane concentration of 5.5 volume percent was calculated to meet the Reid Vapor Pressure (RVP) specification of 208 psi Max at 100 F from data for Propane obtained from Perry's Chemical Engineering Handbook,[13] using a simple law of mixtures approach with ethane properties estimated as discussed above. This model will not be perfect in the absence of data for the actual systems but it does give an estimate of ethane effect on the propane systems.*

* Actual gas chromatography (GC) data from a comercially produced propane run has indicated 93% propane, 7% ethane & <1% butane or greater material with an RVP of 210 psig. Results using latest revisions of ASTM D-2598 will give similar values to those calculated above.

Figure 4-3 illustrates the approximate behavior of a 250 PSIG design pressure ASME tank with pure propane and various assumed fill conditions. ASME tanks for other design pressures would respond differently than shown in Figure 4-3. The air contamination case is assumed as an initial "empty" tank at atmospheric pressure. Start-to-discharge pressure of the relief valve is 250 psig. Under these conditions discharge will always begin on temperature rise before the tank becomes liquid full except for the 10% overfill case.

Figure 4-4 illustrates the approximate behavior of a propane/ethane mixture under the same conditions of overfill and air contamination, with pure propane shown as a reference. Note the downward temperature shift in relief opening temperatures, right into the range potentially reached in a hot-dry climate zone. In effect, what this chart demonstrates is a justification of California requirements for a 275 psig relief setting, as applied to smaller tanks, where diurnal cycle heating lag is limited.

It would be desirable for a relief valve set-point pressure to be keyed so that at specification filling conditions relief would begin at no less than the threshold of liquid full conditions at a temperature no lower than the maximum service temperature anticipated. Considering local ambient temperatures, the peak daily temperature may not represent the design service temperature. The thermal capacitance effect of the tank and contents will tend to

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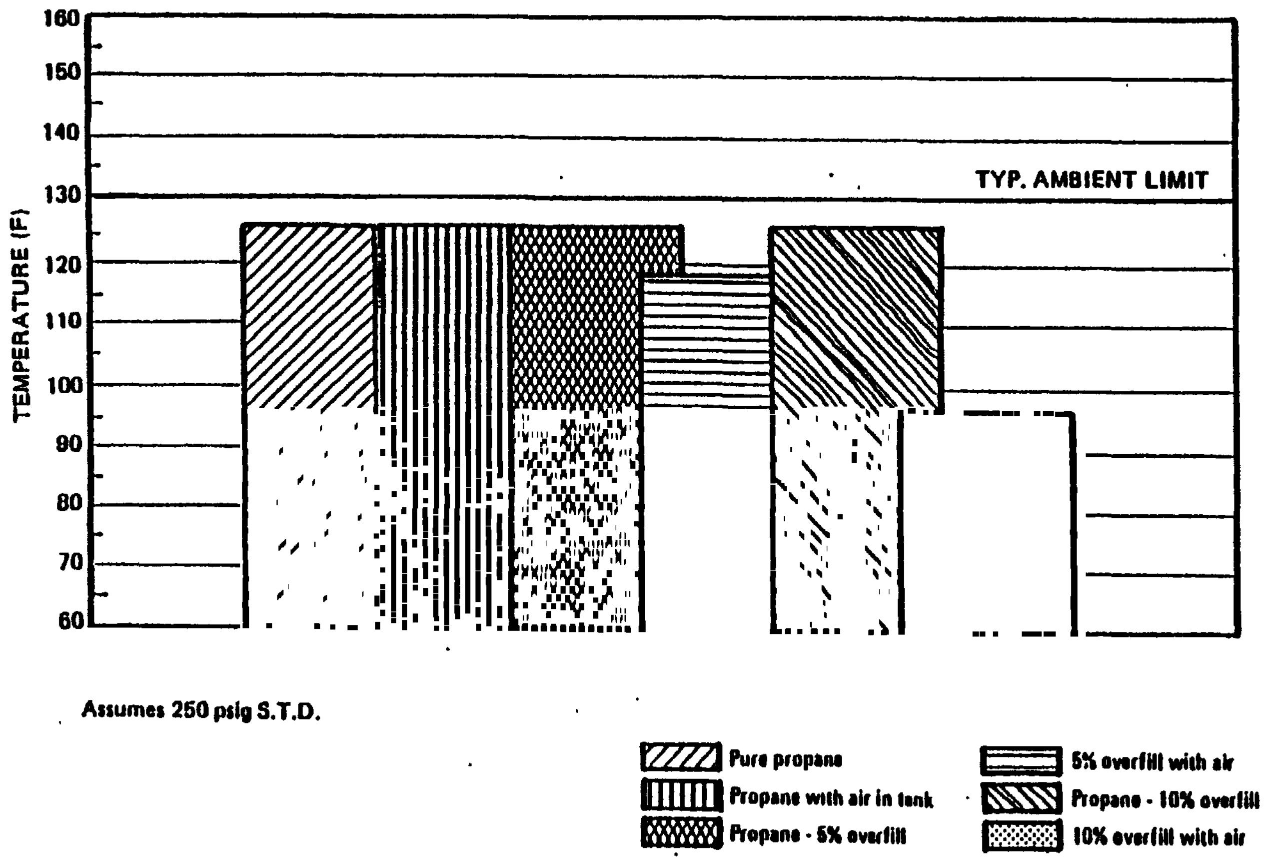

Figure 4-3 TEMPERATURE AT WHICH AN ASME TANK 250 psi RELIEF VALVE WILL FIRST OPEN WITH PROPANE

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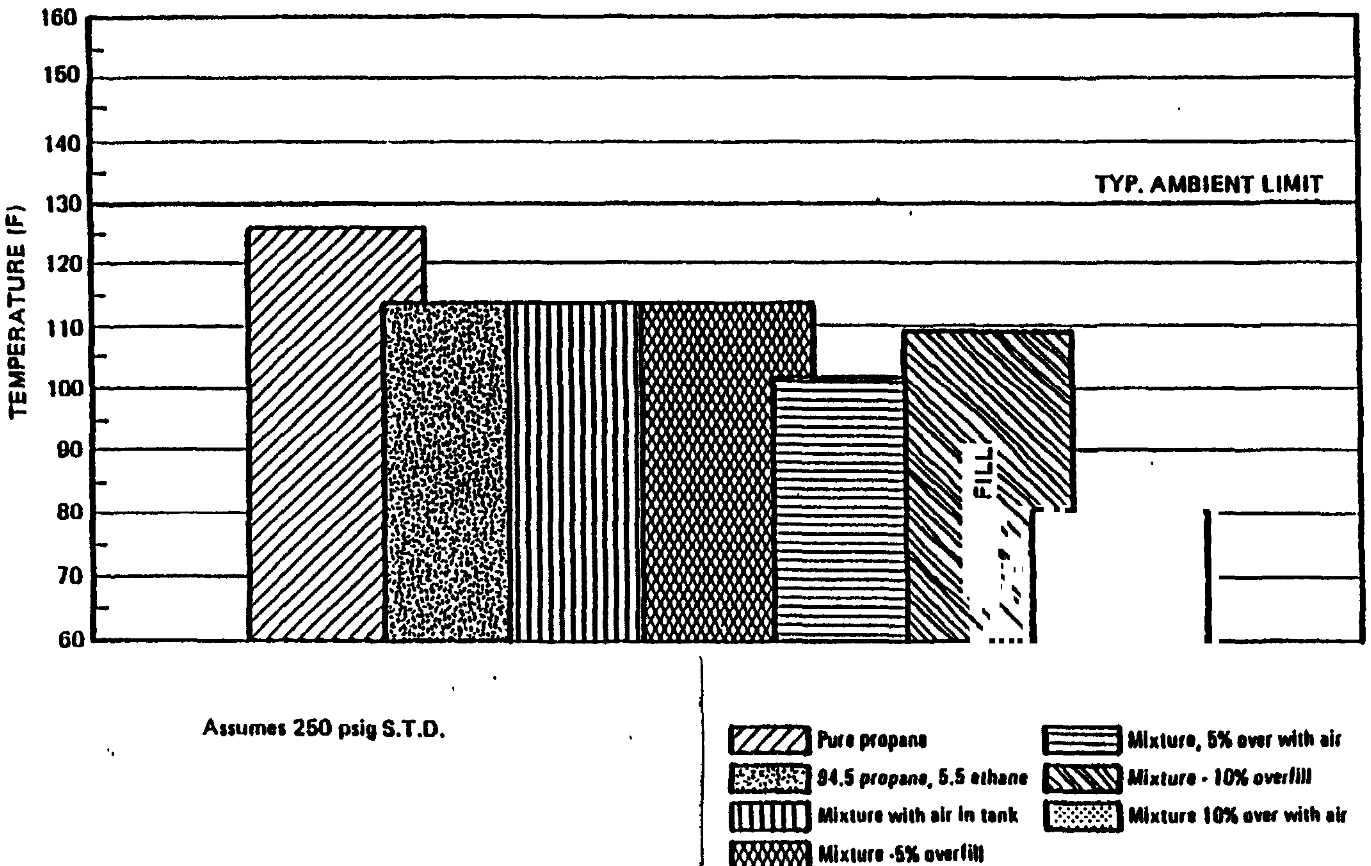
cause their temperature variation to be narrower than the prevailing daily high and low temperature. On the other hand, solar radiation has to be considered in some regions as additive to the shaded atmospheric dry bulb value. The net effect can be expected tank temperatures higher or lower than peak ambients depending on tank size, fill state,reflective surface, and geographic location. Practical requirements can mitigate against tailoring, rather than standardizing relief valve set-points, except in limited situations.

Figure 4-5 illustrates the earlier conditions with a pure propane fill in a DOT specification tank with a 375 psig start-to-discharge safety-relief setting. Note that for the majority of cases temperatures well above any expected ambient conditions would have to be reached for a discharge to occur. This is a desirable situation. In those cases where a liquid full condition is reached it is essentially immaterial what the discharge set-point is, since once the container is full a minor increase in temperature will result in a large increase in internal pressure, opening the valve.

Figure 4-6 illustrates the Figure 4-5 conditions with the ethane rich propane. Note that overfill or air contamination, alone or in tandem, dangerously drop relief valve opening temperatures. Air is assumed to be essentially insoluble in propane for the pressure changes of interest. This is a conservative assumption. On the other hand, new cylinders are sometimes shipped with residual air pressure in them. If these containers are then directly LP-gas filled without purge relief, opening could be at even lower temperatures than those shown.

These graphs are consistent with what we believe to be actual field experience. The conclusion then is that it is



Assumes 250 psig S.T.D.

Figure 4-4 TEMPERATURE AT WHICH AN ASME TANK 250 psi RELIEF VALVE WILL OPEN WITH MIXTURES

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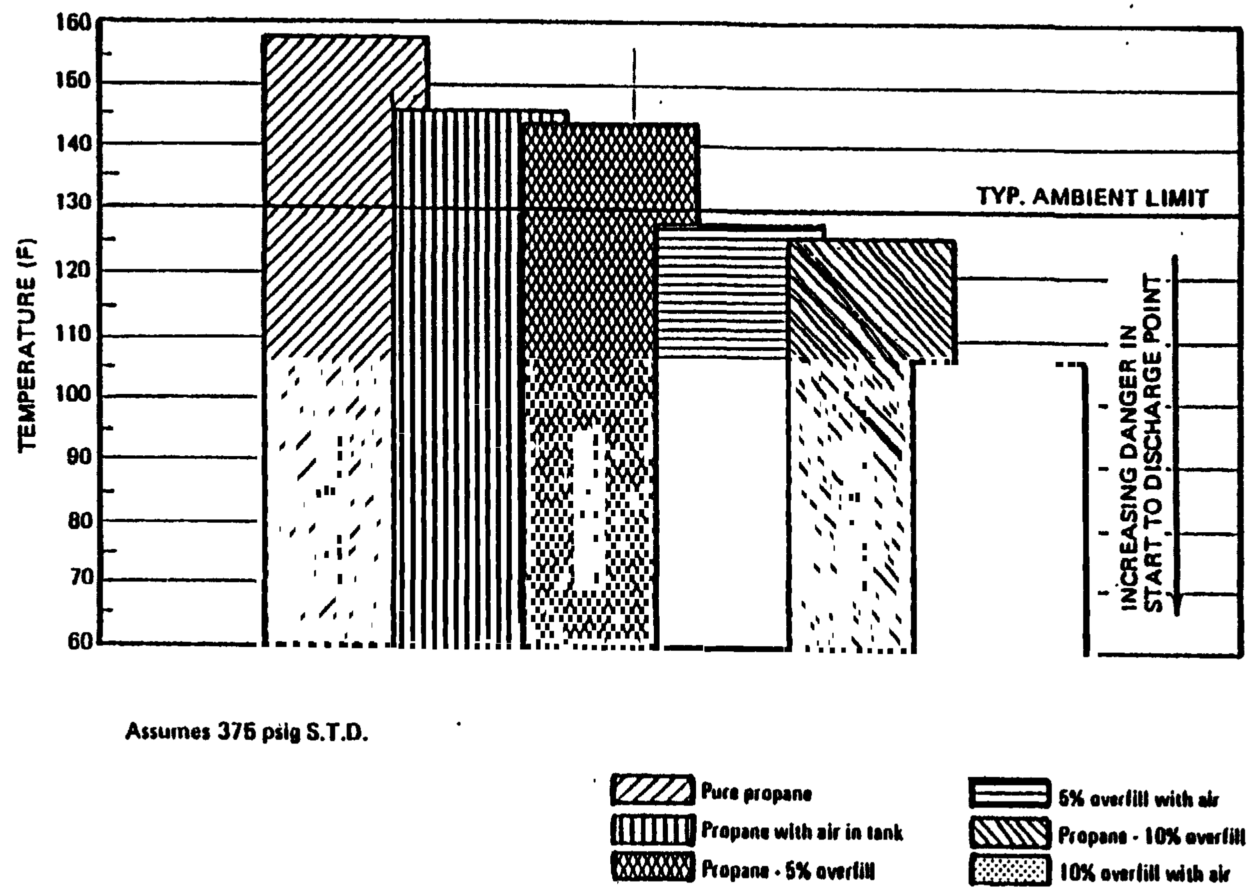

Figure 4-5 TEMPERATURE AT WHICH DOT SPECIFICATION RELIEF VALVE WILL OPEN, SELECTED PROPANE CASES

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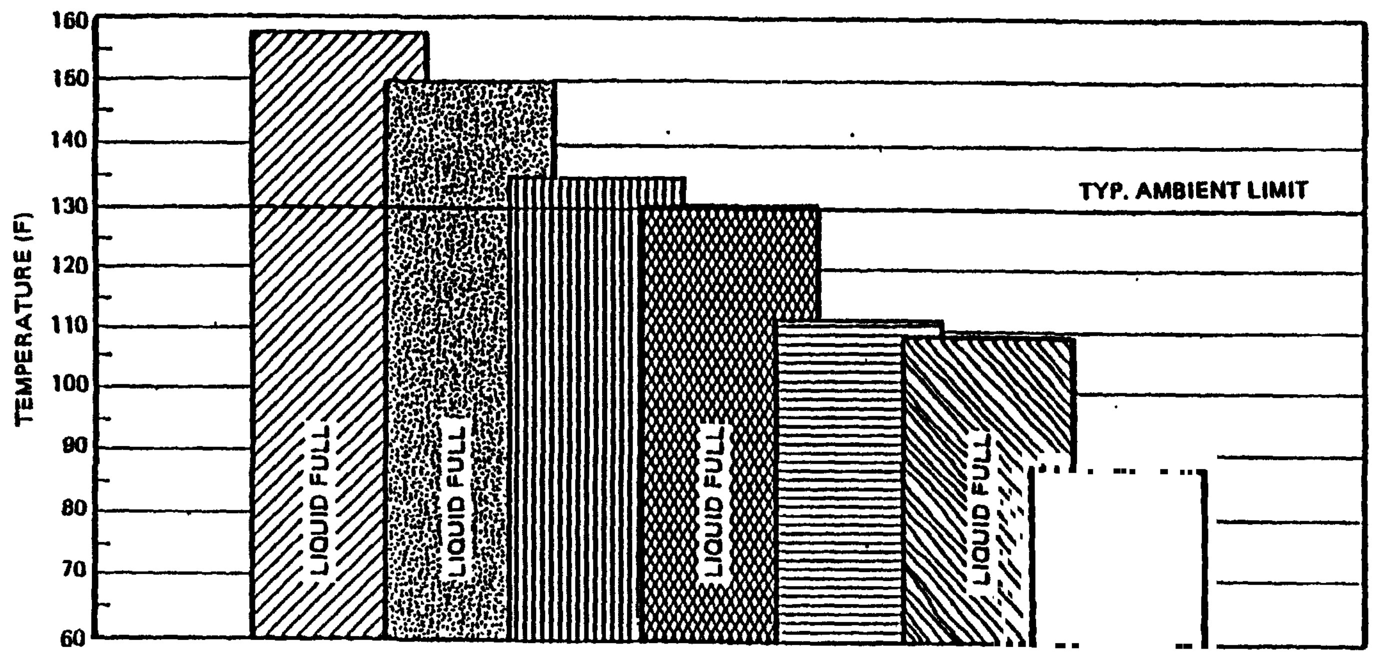

Assumes 375 psig S.T.D.

• Relief operation due to liquid full condition rather than high vapor pressure

- ● Pure propane
- ● 94.5 propane, 5.5 ethane
- Mixture with air in tank
- ● Mixture - 5% overfill
- Mixture, 5% over with air
- ● Mixture - 10% overfill
- Mixture 10% over with air

Figure 4-6 TEMPERATURE AT WHICH A DOT SPECIFICATION RELIEF VALVE WILL OPEN FOR SELECTED CASES

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absolutely crucial to get a handle on the overfill problem with small customer owned containers.

A further thought that is developed more fully in later safety-relief valve discussion (Section 5.2.2) is the false assumption that a small amount of non-condensable gas (air) will always produce an extremely limited valve opening period, with the tank pressure rapidly returning to normal vapor pressure levels. In fact, re-sealing of safety relief valves under blowdown conditions is well below set-point. Hence, if discharge takes place on a warm day, re-set may be delayed extensively until vaporization cooling takes effect. This may be permissible for an isolated back-yard tank, but for a tank connected to a grill with an immediate ignition source nearby it can be fatal.

4.2.2 Solid Contaminants

Solid contaminants may be present in the fuel supply. Frequently this type of contamination occurs in the distribution chain, including from chemical reaction, in service and house piping. Two of the major safety hazards are fouling of control valves, service regulators in the main supply, or controls at the utilization appliance. Problems in the service regulator portion of the line are covered in Section 5.4. The effect on downstream appliance controls and the sediment trap issue are dealt with here. Many of the same factors described relate to valve seating elements of service regulators as well. Presently there is no sediment trap standard for protection of appliance controls.

Foreign materials or objects entering a control valve can foul the sealing surfaces of normal operating or safety elements of the control, resulting in leakage and sometimes injury. A principal mechanism is the build-up of particulate matter, frequently over an extended period of time, on sealing surfaces, preventing tight shut-off of valve elements. Occasionally, valve guide or spring return elements may become jammed or sluggish as well.

Particulate contamination can be the result of factory contamination, e.g. slivers from threading operations, etc., but generally is the result of the introduction of contaminants from the fuel gas piping. This may be rust, scale, dirt or a variety of construction debris. Reaction products, such as copper sulfide are also found. The latter material is usually associated with LP gas systems, where copper piping is used with a very high frequency and many installations lack recommended sediment traps ("drip legs") in the supply run.

The relative vulnerability of a given control to particulate contamination which gives rise to a dangerous condition is very much a function of control design, as well as application. At the present time some controls intended for higher risk applications, such as LP gas-fired water heaters, incorporate highly specific features to prevent dangerous entry of foreign materials. Screens and/or inertial impingement plates can serve double-duty as blocking elements to physical entry of tools, etc, as well as acting as particulate removal devices. The vast number of appliances already in the field, plus the limited application of particulate matter filters on controls, even today, means that sediment traps in the supply piping will be a must well into the future.

It is not particularly important whether a control has a specifically identifiable "sediment trap", for example, or is intrinsically safe from reasonably foreseeable contamination levels. However, there must be a standard for determining the level of protection to be provided, and with that a standard for evaluating relative effectivenes. In introducing discussion of a "standard" it is useful to recall some of the basic concepts and considerations.

The typical automatic safety shut-off (ASO) component of a combination control is a spring-loaded, soft seat valve mating to a finished hard metal surface. The metal seating surface may be the bottom of a manual cock that is also a part of the combination control, or part of the control body. In normal operation the ASO is open and may be exposed to contaminants in the fuel gas stream, some of which may become lodged on the sealing surfaces or cause binding of the spring return mechanism. It is crucial that the ASO is sealed to near tightness when activated to prevent gas flow without a proven source-of-ignition for the main burner. Seating forces, seating area and relative compliance of the soft sealing surface have a great deal to do with the ability of the valve to close properly when contamination is present. The vulnerability of the valve to particulates may be increased by grease contamination, which enhances retention of particles, surface glazing, or loss of resiliency of seating surfaces with age, among other factors.

Given the above, the desired characteristic for a sediment trap is to insure that no particulate matter of sufficient size and quantity to impair the safety function of the ASO be permitted to enter the control valve. In a generic sediment trap standard it will be critical, then, to define the performance requirements and set up the test procedures to produce accurate results regardless of the mechanism the device employs to remove matter from the gas stream. A standard based upon a trap using a screen for separation may produce invalid results for a trap using purely inertial forces for separation, for example. The reverse case can also be true, a point to remember if the conventional pipe "drip leg" is used as the reference separating device.

It is possible to develop a test procedure capable of giving reproducible, but unfortunately meaningless---or worse, deceptive,---results with respect to determining relative effectiveness of a sediment trap in the real world.

There has been substantial effort by GAMA members to develop a sediment trap standard for ANSI Z21 Committee consideration. In essence an attempt was made to develop a specific test procedure whereby the pass/failure criterion was based on particulate removal efficiency expressed as a percentage. Great difficulty has been experienced. Appendix "F" has additional comment regarding sediment trap standard development.

The approach using inertial separation with a final screen is one currently used by manufacturers of water-heater controls intended for LP Gas service. Just as venting capability requirements in a specific appliance standard must be complementary with ANSI Z223.1 vent system standards, so must a sediment trap standard be complementary with a control standard. This suggests, then, that the control standard must have a defined level of contamination that the control must tolerate. Once that is defined a sediment trap standard can be established. One component of the trap standard would be an absolute size cut off above a certain size range. A second component of the sediment trap standard could define an efficiency of removal for material above that size range in a manner to prevent excessive loading of a final trapping or filtering element. In order to accomplish this, recognizing inertial separation may be used, it would be crucial to specify the density and particle size distribution (not just limits) of the contaminant material introduced in the test gas stream.

The complexity involved in developing an effective sediment trap standard is a perfect example of a wider spread problem involving other difficult technical questions. This indicates the need for specific research and development efforts directed to Standards development issues. The ad hoc voluntary working