FRONTIER TECHNICAL ASSOCIATES INC.

ENGINEERING HAZARD ANALYSIS
OF
RESIDENTIAL LP-GAS FUEL USAGE

W.A. Bullerdiek

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8675 Sheridan Drive. Buffalo. New York 14221 (716) 634-2293

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We would also like to thank members of the National Fire Protection Association staff and Liquefied Petroleum Gases Technical Committee; Underwriters Laboratories, Casualty & Chemical Hazards Dept; Gas Appliance Manufacturers Association; National Board of Boiler & Pressure Vessel Inspectors; AGA Laboratories Staff; ANSI Accredited Standards Committee Z21 and Subcommittees, including specifically the subcommittee on Outdoor Portable Cooking Appliances; the National Institute for Burn Medicine, and many individual manufacturers for their cooperation.

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Abstract

Liquefied Petroleum (LP) Gases are flammable hydrocarbons sold in a compressed or liquefied form. Propane is the predominant LP-Gas fuel. The ease with which LP-Gas liquefies to a limited volume of high energy content, and will re-vaporize for use as a fuel in gaseous form gives the product high utility where convenient storage, transport and use features are desired. Principal markets as a primary fuel for residential heating and cooking are in non-urban locations without ready access to natural gas service. Another major market area in terms of customer base (as opposed to volume) is as a fuel in recreational applications, particularly with outdoor portable cooking equipment. The recreational market is more cosmopolitan in character than that associated with the predominatly rural permanent, fixed-site installations.

Many of the characteristics which make LP-Gas desirable as a fuel can also pose a risk to users. Therefore a number of codes and standards have been developed addressing safety issues associated with the use of LP-Gas. The primary risk to the residential user of LP-Gas is severe burn injury. The objective of this study was the identification of the causes and means to reduce fires and explosions involving the residential use of LP-Gas. Focus was on activities and components in the fuel delivery train beginning at container fill and ending at the inlet manifold or primary control of the consuming appliance.

Analysis of accident patterns and frequency in fixed installations revealed, among other things, the following:

- On the basis of user population statistics, severe burn injuries associated with LP-Gas use were disproportionately greater than those associated with natural gas by a large margin. Factors leading to this difference were believed to include the rural character of the LP-Gas user population (distance from fire and medical assistance); physical properties of LP-Gas such as its heavier-than-air characteristic; the nature of the distribution chain, and different maintenance and use patterns viz a viz LP and natural gas. Continuity of supply differences were considered a major item.

- The prevalent activity at the time injury occurred was a pilot lighting sequence, frequently after a gas outage episode.

- Two of the major factors leading to control or appliance failure and subsequent injury relevant

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to this study were fuel supply pressure excursions and particulate contamination originating in the fuel supply system.

- Other major sources of subsequently ignited fugitive gas were leaks from fittings and connections, and leaks from corroded or physically damaged piping.

- Many of the contributing factors to injury accidents were slow-developing or latent hazards. This suggested intervention in the form of knowledgeable inspection and/or maintenance could be an effective injury prevention tool. This had obvious implications for the industry GAS Check program.

- Another observation was that non-professional installation, inspection and maintenance activities, whether by consumer or untrained or indifferent service personnel acted as major multipliers for accident severity probability to whatever intrinsic hazards already existed in a given system.

- The most striking feature of in-the-home tragedies involving LP-gas, regardless of type of home construction, appliance or supply system involvement was the failure of victims to detect the odor of the flammable/explosive mixture present. Clearly there was a major problem in this area.

The strategies to reduce the hazards of residential LP-gas use follow two courses:

- Reduce the potential for the escape of dangerous quantities of unignited gas, and

- Insure detection of leakage which does occur in time to take effective counteraction or at least to escape.

Recommendations were developed intended primarily to build upon the existing consensus standards base, addressing the concerns outlined above.

The greatest impact that could be made in reducing the hazard of LP-Gas use in the residential environment, with supply sytems already in place and consumer behavior patterns essentially unmodified, would be to insure timely and effective detection of the presence of unburned gas. Therefore this was considered the number one priority item for attention. Present odorants added to LP-Gas may go undetected due to physical/chemical effects occurring in the distribution chain, as well as for other technical and human factor considerations.

The study was supportive of proposed industry research efforts on odorants, but it was also recommended that the National LP-Gas Association (NLPGA) form a broadly based task group to undertake revisions of NFPA #58 to clearly delineate responsibility for verifying viability of odorization through the distribution chain, and how, at least in broad terms, this is to be accomplished.

It was considered important, however, that it be recognized that gas odorization is only part of the issue. It is likely that supplemental means of detection to the human olfactory senses, e.g. electronic detectors, may be technically and economically feasible for certain placement applications.

It was further recommended that task force consideration of quality assurance concerns expressed with regard to odorants be expanded to include other elements of LP-Gas specifications, such as the presence of corrosive contaminants.

Another area of incomplete coverage in NFPA #58 was cited with regard to inspection requirements for certain containers and appurtenances critical to safety. Therefore an additional key recommendation was the formation by NLPGA of a task group for an across-the-board review to establish requirements for in-service and other inspection of containers and associated equipment, including safety relief valves and regulators, where present coverage is limited or absent. Coverage should include, among other things:

- o Type of Inspection to be performed
- o Responsible Parties
- o Inspection Interval
- o Record Keeping Requirements
- o Quality Audit Procedures

A major impact item in reducing the hazard in the residential environment, and one that has the potential to produce the earliest results, was considered to be the vigorous pursuit on the broadest level of participation in the industry developed and sponsored Gas Appliance System (GAS) Check program. The National LP-Gas Association members and the Gas Appliance Manufacturers Association members supporting the program were commended for their efforts. The priority issue was to insure that the program does not falter in either depth of breadth of participation.

Suggestions for increasing leverage on presently non-participating groups included additional industry steps and a higher Commission and State regulatory authority profile on the subject.

Another major recommendation was to adopt code coverage requiring two-stage regulation for permanent installations. Recommendations regarding high pressure protection applied to regulators were also made.

Development of a voluntary standard to provide protection of appliance controls from particulate contaminants was included in the recommendation listing.

Other recommendations were made dealing specifically with customer owned containers and their principal application, self-contained outdoor portable cooking equipment. These addressed the key hazard elements identified, listed here in the approximate order of the risk they posed in terms of frequency and severity:

1) Overfilling of containers; improper purging

2) Improper transport/storage/maintenance of containers and fittings, and

3) Unsuitable component design for preventing minor operational upsets from escalating to major fires.

Major recommendations included the following:

1) Require automatic stop-fill devices on portable cylinders.

2) Prohibit 'self-serve' cylinder filling by customers. Introduce or upgrade as appropriate, training and certification of LP retail service station operators.

3) Revision of ANSI Z21.58 to define temperature limits on all gas carrying components where heat transfer from the burner box may affect component temperature. Specify performance tests appropriate to assure adequacy of affected components, including hose connectors, regulators and valving.

4) Require quick connect (automatic shut-off) coupling at cylinder valve outlet.

5) Require automatic thermal shut-off device(s) to interrupt uncontrolled gas flow developing from hose connector failure or regulator melt down from excessive heat (fire).

6) Require a high pressure shut-off rather than a safety relief vent on grill application regulators.

7) Set-up appropriate monitoring activites for early intercept and correction of any 'start-up' difficulties typically associated with newly adopted equipment.

Additional comment and recommendations concerning both fixed and portable LP systems are contained in the report.

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1.0 Introduction

1.1 Background

Historically the number and the severity of accidents involved with the use of liquefied petroleum (LP) gases for residential use have appeared out-of-proportion to the number of appliances and users of the fuel, compared to natural gas, for example. Certain physical properties of the gas, the nature of the distribution chain, particular maintenance and use patterns associated with the fuel have been considered contributory to a higher level of hazard.

Addressing the hazards, substantial focus in the past has been on the appliances involved and their appurtenant controls. Numerous LP-gas accidents involving appliance operation have their genesis in activities and/or malfunctions upstream from the appliance and its controls. Moreover, there are incidents with no appliance involvement at all, not even as a source of ignition.

1.2 Objective

This study had as its objective the identification of the causes and means to reduce fires and explosions involving the residential use of LP-gas. Focus was to be on the activities and components in the fuel delivery train beginning at container fill and ending at the inlet manifold or primary control of the consuming appliances.

1.3 Scope

Certain generally defined tasks and limitations were applicable to more closely delineate the broad scope and objective of the project. The contract was approximately nine months in duration and involved an expenditure of

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approximately 900 hours of personnel labor. Briefly the tasks included:

- o Collection and examination of information to determine the involvement and likely causes of accidents, considering among other things:
  - Activities related to the accident, including filling practices
  - LP-fuel properties, including contaminants
  - Containers, fittings and piping including regulators, relief valves, shut-off valves, connectors, etc.
- o Development of a hazard ranking of identified failure causes considering frequency and severity of risk.
- o Providing and ranking recommendations for any corrective actions as to expected positive impact in reducing hazards considering cost to the consumer.

The project was to exclude containers of less than one pound water capacity and related activities where this size container was involved. Similarly, use of LPG as a motor fuel was excluded from direct consideration. The exception to these exclusions was where a common problem or potential accident factor with an included activity or container was involved.

1.4 Methodology

1.4.1 Introduction:

Attacking a subject such as LP-Gas safety with its broad ranging and diverse issues in a manner which rapidly provides points of focus for achieving project objectives is always a challenge. Perhaps equally challenging is distilling the findings for report purposes in a manner which will be useful to a diverse readership. Recognizing that the technical familiarity of interested readers will vary sharply, and that some will be intensely interested in a narrow set of issues rather than the broad picture, we have selected a format to try an ease the burden for a variety of readers.

Basically, where necessary and practical, the reporting format provides two and sometimes three levels of depth on a given subject. In the latter case an overview of the subject will be given and then a more detailed technical discussion will follow in the main body of this report. Additional background material is then either referenced or contained in appendices to the main report. Section 2.0 of the report contains a summary of the key findings, conclusions and recommendations of the study. These are repeated with appropriate supplemental discussion by specific topics in the later text.

1.4.2 Accident/Injury Data - Hazard Ranking Development

One of the fundamental safety engineering principles is that any risk of serious injury or death is unreasonable and unacceptable if reasonable means to reduce or eliminate that risk are available.

Few would dispute the concept; however, defining what is "reasonable" can and does fill courtrooms. For the moment, however, consider what this principle says about numbers— numbers are not everything. Other factors need to be considered, such as severity of the risk. Modifiers to our tolerance of risk include perceived utility of the object or service and the expected complexity and/or cost of making it safer. Frequency and severity remain the key factors in establishing a hazard ranking, however. FTA utilized frequency and severity as the major elements for hazard ranking. However, qualitative assessments for emphasis and priority for correction were also made on the basis of likely availability and reasonableness of means to take corrective measures.

FTA intended to simultaneously move in two directions in tackling the hazard ranking task. In one direction we would develop the broad outlines of the problem, establishing the population at risk, national injury totals, national fire totals, etc. Then we would move down from this point, disaggregating and categorizing causal factors, numbers and severity to the extent possible. From long experience in the field it was expected that the larger data bases would become less useful the finer the detail that was necessary to pinpoint specific components and causes.

FTA therefore intended to, and did in fact take a second direction, starting at the "bottom" and working up, as well. Here we started at the essentially anecdotal level of reported incidents and collected experience of those in the industry, moving up to levels where accident numbers and severity could be

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generated (though not projectable to a national basis) and aggregated to the extent possible. FTA basically followed this overall method with some modification in the "top down", broad outline approach. It became evident in the course of analysis that establishing national injury totals was not going to be possible. The National Electronic Injury Surveillance System (NEISS) provides national projections of injury totals for given product codings on the basis of population demographics. Available codings and certain unique characteristics concerning the distribution of the LP-Gas user population limited the utility of this source for such projections.

In response to the problem of securing national projections, hence being unable to quantify a specific injury rate (injuries per unit population exposed), FTA expanded other data base reviews to further qualitatively and semi-quantitatively develop the areas for priority attention. Amalgamating the total findings, a picture of the overall extent of the problem areas emerged, as well as more detailed points of concern. In establishing hazard rankings we looked for repetitive incident patterns, causative factors and the severity of consequences.

Government and private data bases were utilized as sources for accident/injury information. These included:

1) National Fire Protection Association (NFPA) National Fire Incident Reporting System (NFIRS) general data and specific residential/LP data runs using the Fire Incident Data Organization (FIDO) data base

2) National Burn Injury Information Exchange (NBIE) special data runs with etiological data

comparisions between LP and natural gas accidents resulting in severe burn injuries.

3) CPSC In-Depth Investigations (initial screening of computer summaries followed by complete document review)

4) CPSC Death Certificate Summaries

5) CPSC NEISS Estimates (used sparingly)

6) CPSC Reported Incidents File (briefly examined)

In addition, special reports issued by government and private agencies (see References) and FTA's own investigative experience were utilized for analysis.

Appendix "A" has additional background information on accident/injury data and sources.

1.4.3 Characterization of the LP Industry and Residential Use Patterns

Information on LP served residences, "population- at-risk" and specific use patterns were developed prinicipally from Bureau of Census data (Detailed Housing Characteristics and Energy Use Surveys)[1-3]. National LP-Gas Association (NLPGA) statistics[4] were also used independently and combined with data derived from Census information to establish demographics of the user population, quantitative data on containers by type and size, regulator production and related information. Other sources such as the Gas Appliance Manufacturers Association (GAMA) and the National Barbecue Grill Association were utilized for other specialized data requirements.

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Much of the statistical data derived from these sources has utility beyond the hazard analysis consideration. Appendix B contains numerous statistical tables and figures developed in the course of this investigation.

The NLPGA, principal trade association of the industry, was a key organization for establishing specific contacts on issues of interest. Contact was made with staff members, members of their Technology and Standards Committee and Subcommittees for the purpose of discussion of the many codes, standards and general practices of the industry affecting safety. Numerous other organizations, each representing some industry segment and/or relevant standards activity were also points of contact. Appendix C provides additional detail on some of the organizations of interest.

1.4.4 Standards & Practices

An understanding of the standards and practices of the industry was key to FTA's approach in undertaking the hazard analysis project. There are a number of consensus standards, some codified and made mandatory in some jurisdictions, and government specifications which are minimum standards covering many of the components and activities of interest to the study. Some of the components are also listed or certified by Underwriters Laboratories (UL), Factory Mutual System (FM) or the American Gas Association (AGA) Laboratories.

Knowledge of the standards established where we are today. Contact with the organizations and people actively working with these standards established a feel for their perceptions of problems and how they expect to address them. Independently, FTA assessed the hazards based on injury patterns and established whether the problems found are remnants of something long since addressed, recognized but arguably ineffectively addressed, or emerging and not yet the subject of remedial action.

National Fire Protection Association (NFPA) Standard No. 58, "Storage and Handling Liquefied Petroleum Gases"[5] covers, for the purposes of this study, the design, construction, installation and operation of LP-gas systems except that portion of the system covered by NFPA #54 (ANSI Z223.1), National Fuel Gas Code[6]. The latter coverage extends from the outlet of the first stage pressure regulator and covers the piping and gas utilization equipment downstream from that point (Figure 1-1). Membership in the Code committees is shown in Appendix D, along with the NLPGA Technology & Standards committee.

NFPA #58 incorporates by reference container specifications suitable for LP gas by the Department of Transportation (49 CFR 178)[7] and the American Society of Mechanical Engineers (ASME) under Section VIII of the Unfired Pressure Vessel Code[8]. Filling specifications may be found in 49 CFR 173 as well as NFPA #58. Other code and standard cross-references with NFPA #54 and NFPA #58 may be found in Appendix E. Additional information regarding the relevant codes and standards are included in subsequent technical discussion.

1.4.5 Recommendations for Improvements

Recommendations for corrective measures arising from this study included: 1) new approaches; 2) new emphasis on known solutions non-uniformly applied; 3) suggestions as

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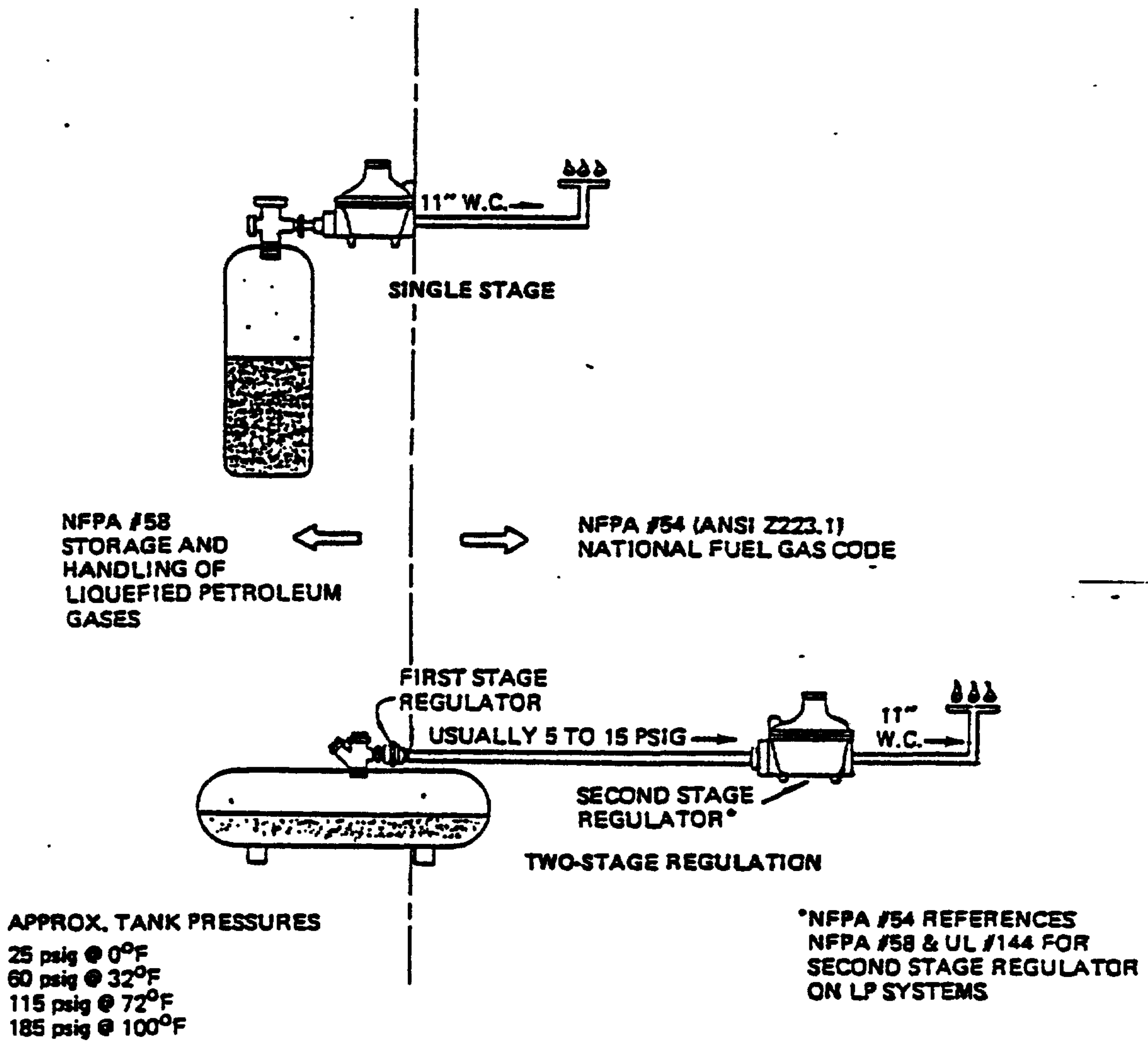

Figure 1-1 DIVISION OF CODE COVERAGE LP GAS SYSTEMS

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to new approaches, or a fresh look at solutions previously rejected on cost or technical grounds; 4) reinforcement and stimulation of already planned efforts, and 5) suggestions for redirection of existing effort to more productive areas of pursuit. Within the scope of the proposed effort cost/benefit analyses could not be performed. However, order of magnitude positive impact versus cost evaluations were performed to properly rank recommendations.

Recommendations were arrived at by an iterative process. Postulated courses of action were assessed and in many cases reaction from external sources sought. No general consensus was sought or expected, however.

The needs for corrective measures identified, FTA feels are clear. However, the proposed routes to solution are not always "set in concrete". In these cases we have sought to provide a catalyst in provoking thought and movement to achieve the safety objective.

2.0 Summary of Key Findings, Conclusions and Recommendations.

2.1 Introduction

The broad ranging nature of this study resulted in a myriad of potential points of comment. This section was prepared to pull together some detailed, particular issues containing common threads into a more cohesive form. Also the key priority issues and recommendations are separated from the pack and highlighted. Both general and specific findings and recommendations of major concern are presented. The following sections of the report then address the issues in more detail by individual subject matter.

As the study progressed it became evident that the characteristics and distribution of the population whose primary LP-Gas utilization pattern was for recreational use was separate and distinct from those using LP Gas as a primary fuel for heating and cooking. Accordingly, these groups were considered separately.

2.2 Selected Key Injury Patterns & Causative Elements

The primary risk to the residential user of LP-gas was severe burn injury. Approximately 2% of patients admitted to severe burn treatment facilities were victims of LP-gas burns. The average area of the body burned was substantialy greater than the average burn treatment center patient. Average percentage of full thickness burns and survival rates were not significantly different from the general population of severe burn victims. Over 80% of the victims were males. This data was drawn from statistics of the National Burn Information Exchange (NBIE). Appendix "A" provides additional information from this source.

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On the basis of user population statistics, LP-gas was "over-represented" in the severe burn category by over 4:1 using natural gas as a comparison. However, the analysis would indicate that about half of this difference may be attributable to the rural nature of the user population, with distance from fire and medical assistance being a factor. Also, solid fuels were higher contributors to fire death rates than any gaseous fuel. This latter point is a consideration with regard to possible fuel switching which might occur if the use of LP-Gas was inhibited in some manner.

The apparent "excess" loss anomaly noted above for rural locations was reported in Reference 9. The "over-representations" of LP-Gas vis a vis natural gas in severe burn cases was derived from NBIE data. Figures 2-1 and 2-2 illustrates the point for severe burn injuries occurring at home. Figure 2-1 is a frequency index for the two fuels where the data is "normalized" to account for the size differences in the respective user populations. Census data[1-3] and American Gas Association (AGA) data[10] was utilized to establish user populations. Figure 2-2 plots the actual reported injuries in the NBIE sample for natural gas and LP-gas, plus an "expected" total for LP-gas. The "expected" value is an estimate based on natural gas reported injuries and the ratio of customers served by LP-gas and natural gas. In other words the "expected" value is the number of injuries one would anticipate if there was no difference in accident frequency associated with the type of gas fuel used——irrespective of actual cause of the accident.

Considering permanent installations the overwhelmingly prevalent activity at the time of injury was a pilot lighting sequence, frequently after a gas outage episode. The kitchen was the most likely location for an injury to

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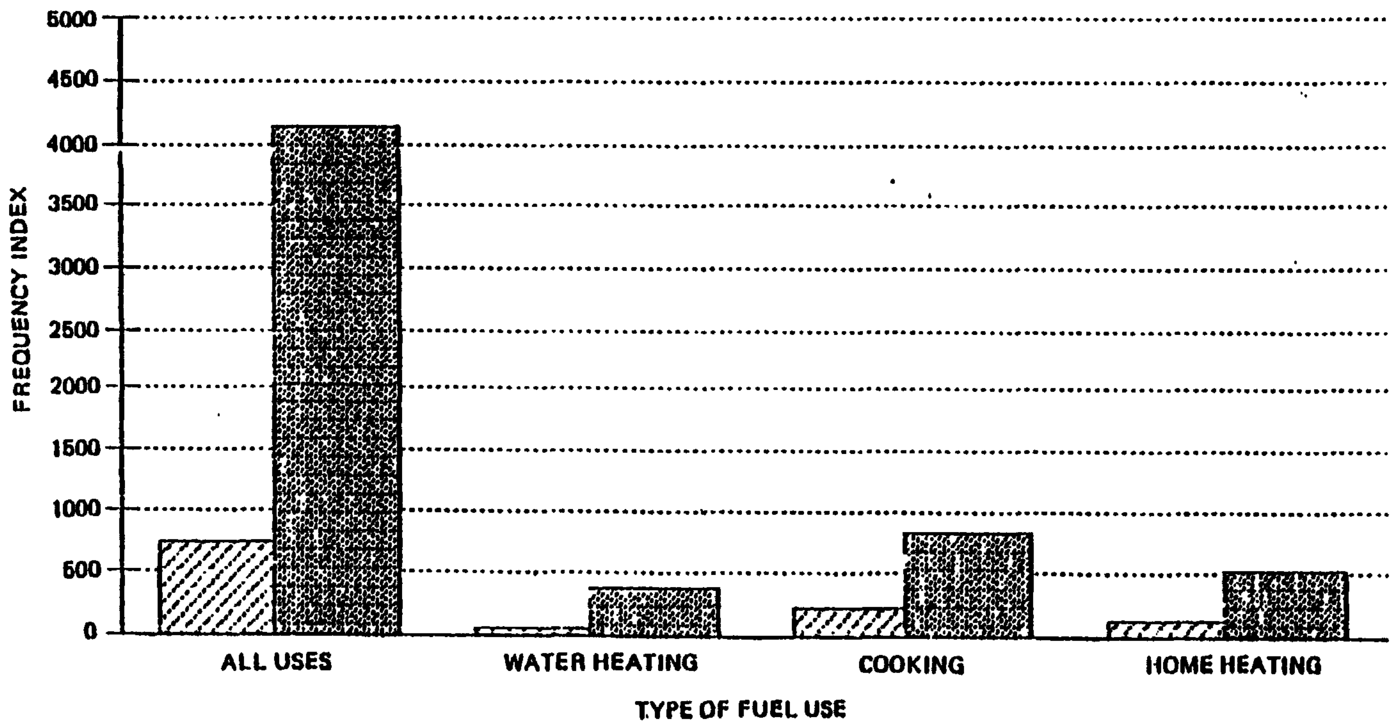
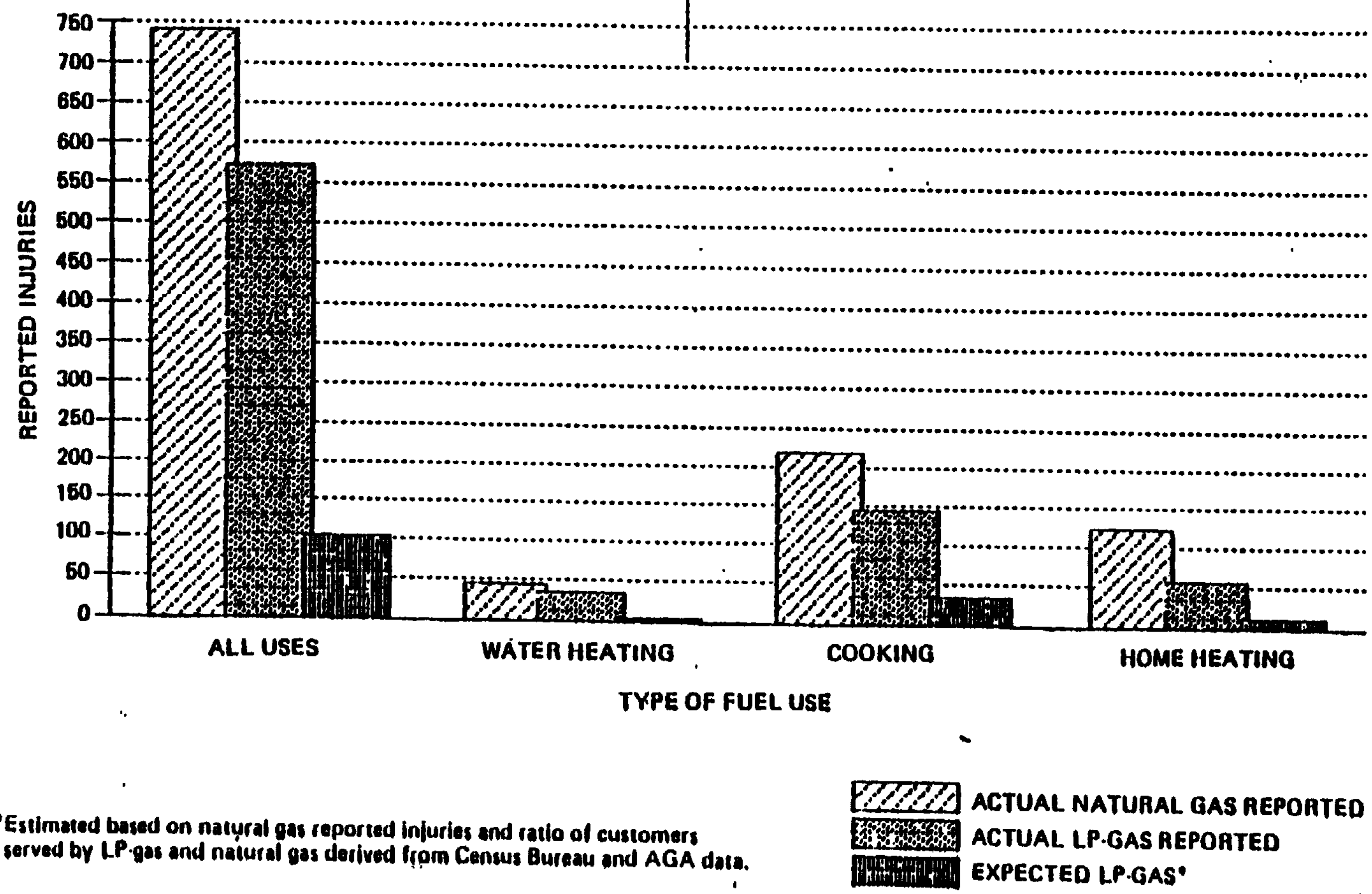


Based on NBIE totals 1967-1984 for natural gas and adjusting the totals from NBIE for 1967-1984 for LP-gas to normalize for the user group size

Figure 2-1 NORMALIZED FREQUENCY INDEX FOR ACCIDENTS RESULTING IN SEVERE BURN INJURIES



*Estimated based on natural gas reported injuries and ratio of customers served by LP-gas and natural gas derived from Census Bureau and AGA data.

Figure 2-2 REPORTED SEVERE BURN INJURIES OCCURRING AT HOME (NBIE TOTALS - 1967 THRU 1984)

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occur considering all causes. Eliminating injury from "controlled" fires the basement or cellar was the principal location of injury. Over-representation of injury in basements vis a vis LP and natural gas was consistent with the overall differences. Variation in use pattern (more outages due to non-continuous supply of fuel) and specific gravity differences in the fuels were considered principal contributors to the difference.

A series of plots (Figures 2-3 through 2-8) have been prepared to illustrate and compare by fuel, activity, location and product the associated relative accident percentages where severe burn injuries were involved. This information was derived from NBIE data. Additional information may be found in Appendices "A" and "B".

The pie chart depiction in Figure 2-3 clearly shows the lighting sequence contribution with both LP and natural gas fuels. The substantial percentage of injuries occurring with maintenance, inspection and installation activities is also demonstrated. Note also that the victim was usually directly involved in the activity leading to injury, rather than being a bystander. Figure 2-4 plots the same information found in Figure 2-3 in a manner making it easier to visualize proportions.

Figure 2-5 depicts the distribution of locations where severe burn injury ocurred. The higher percentage of accidents in the yard with LP-Gas compared to natural gas reflect the significantly greater usage of LP-Gas in outdoor recreational activities such as barbecuing. The figures shown are for accidents occurring at home and do not reflect away-from-home activities such as camping. Figure 2-6 plots the Figure 2-5 data in bar chart form.

Figure 2-7 illustrates product involvement (though not necessarily a causal factor) in severe burn injury

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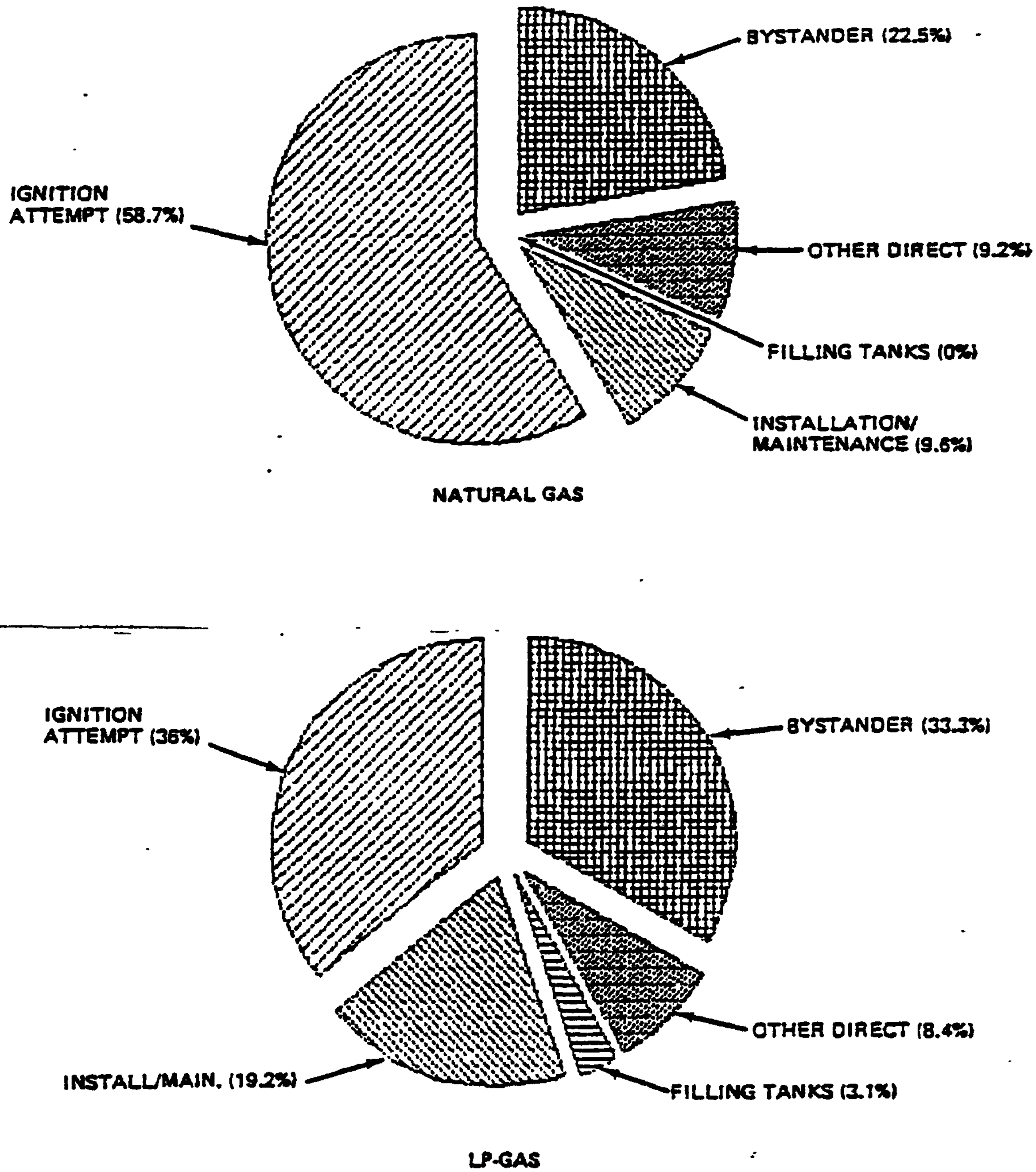

Source: NBIE

Figure 2-3 ACTIVITY OF INDIVIDUAL IN GAS IGNITION ACCIDENTS RESULTING IN SEVERE BURN INJURIES, HOMES (OTHER THAN MOBILE HOMES) 1967-1984

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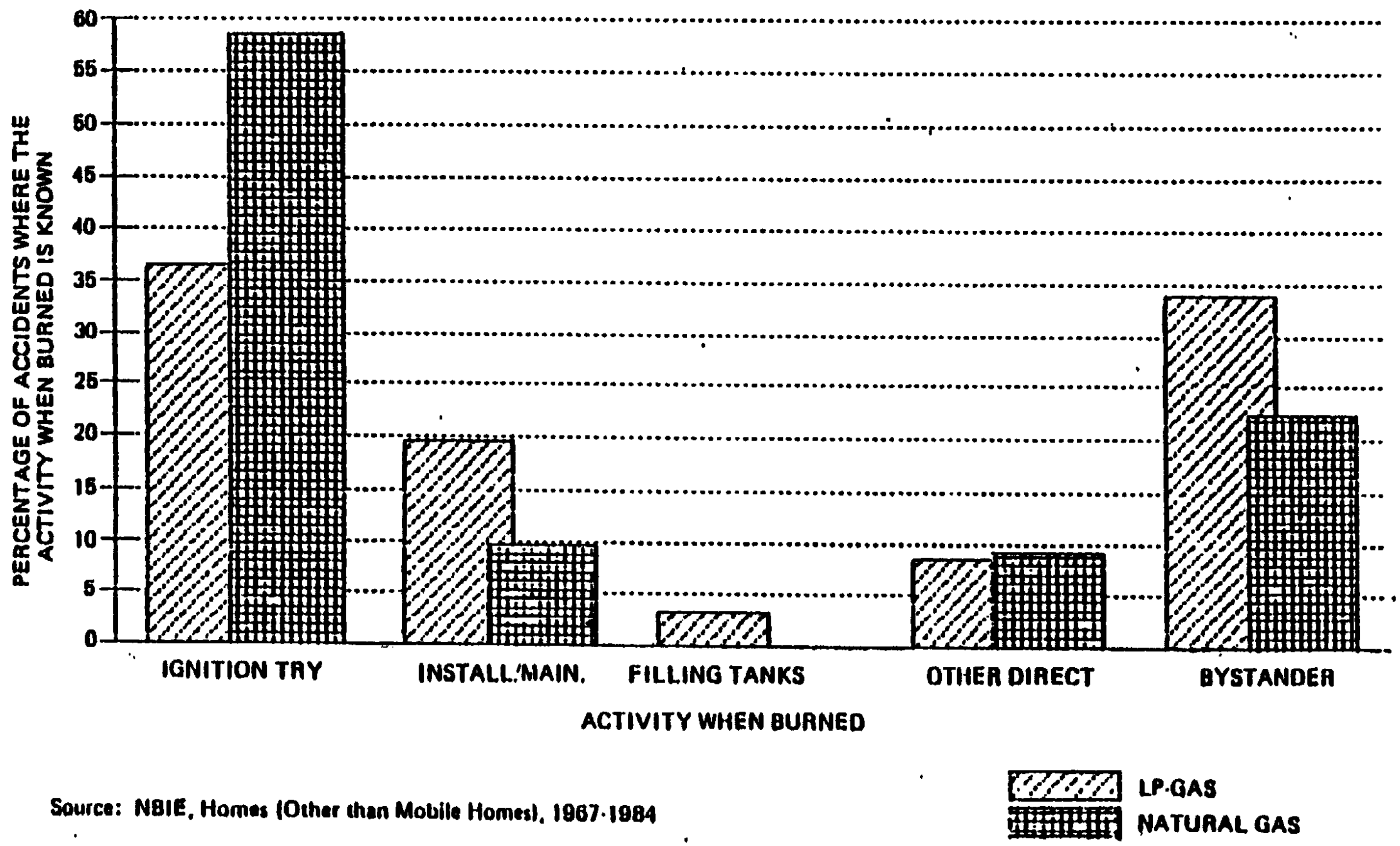

Source: NBIE, Homes (Other than Mobile Homes), 1967-1984

Figure 2-4 COMPARISON OF PERCENTAGE OF ACCIDENTS BY ACTIVITY WHEN BURNED FOR GAS IGNITION ACCIDENTS RESULTING IN SEVERE BURN INJURIES

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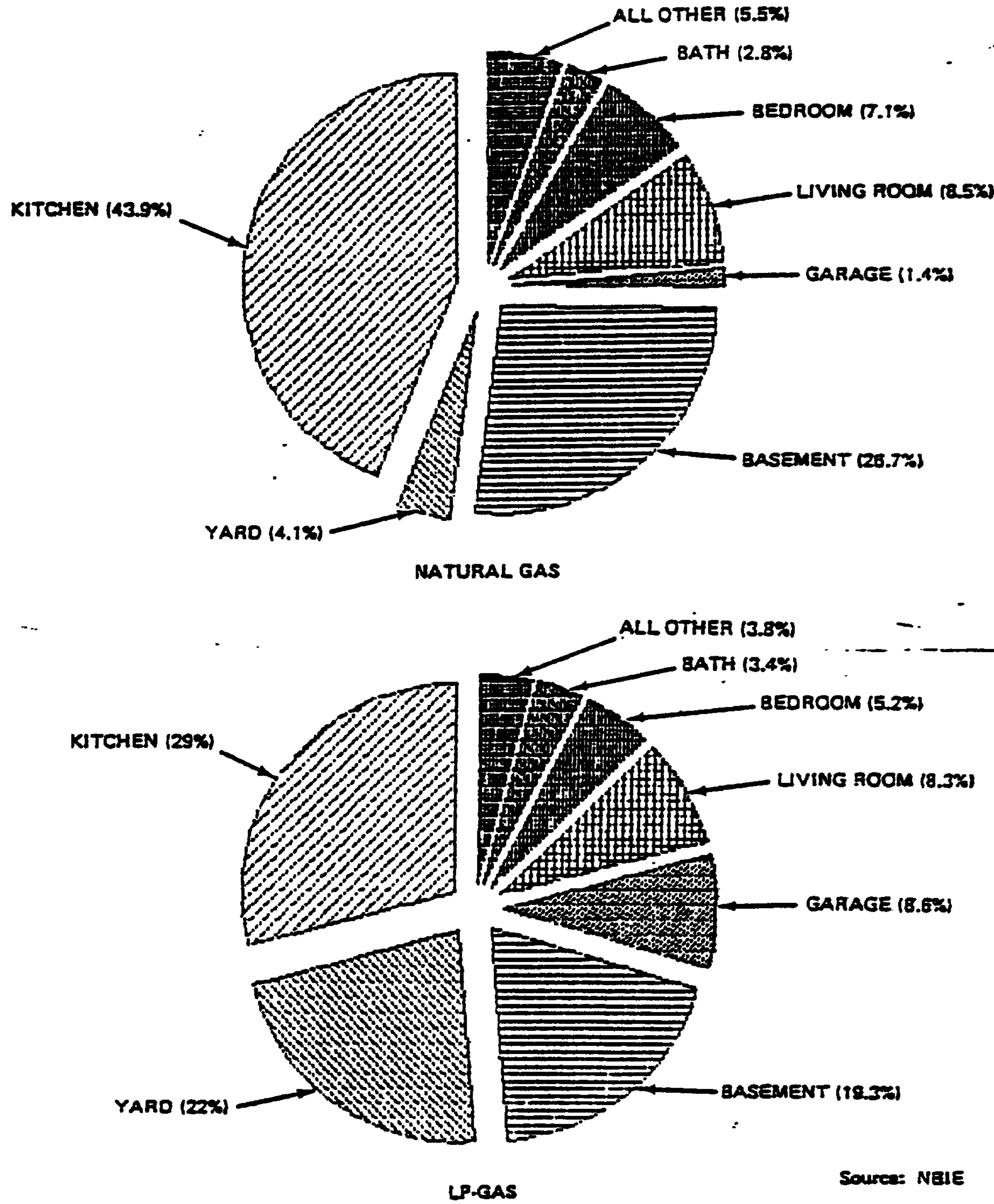

Figure 2-5 THE LOCATION OF GAS IGNITION ACCIDENTS RESULTING IN SEVERE BURN INJURIES, HOMES (OTHER THAN MOBILE HOMES) 1967-1984

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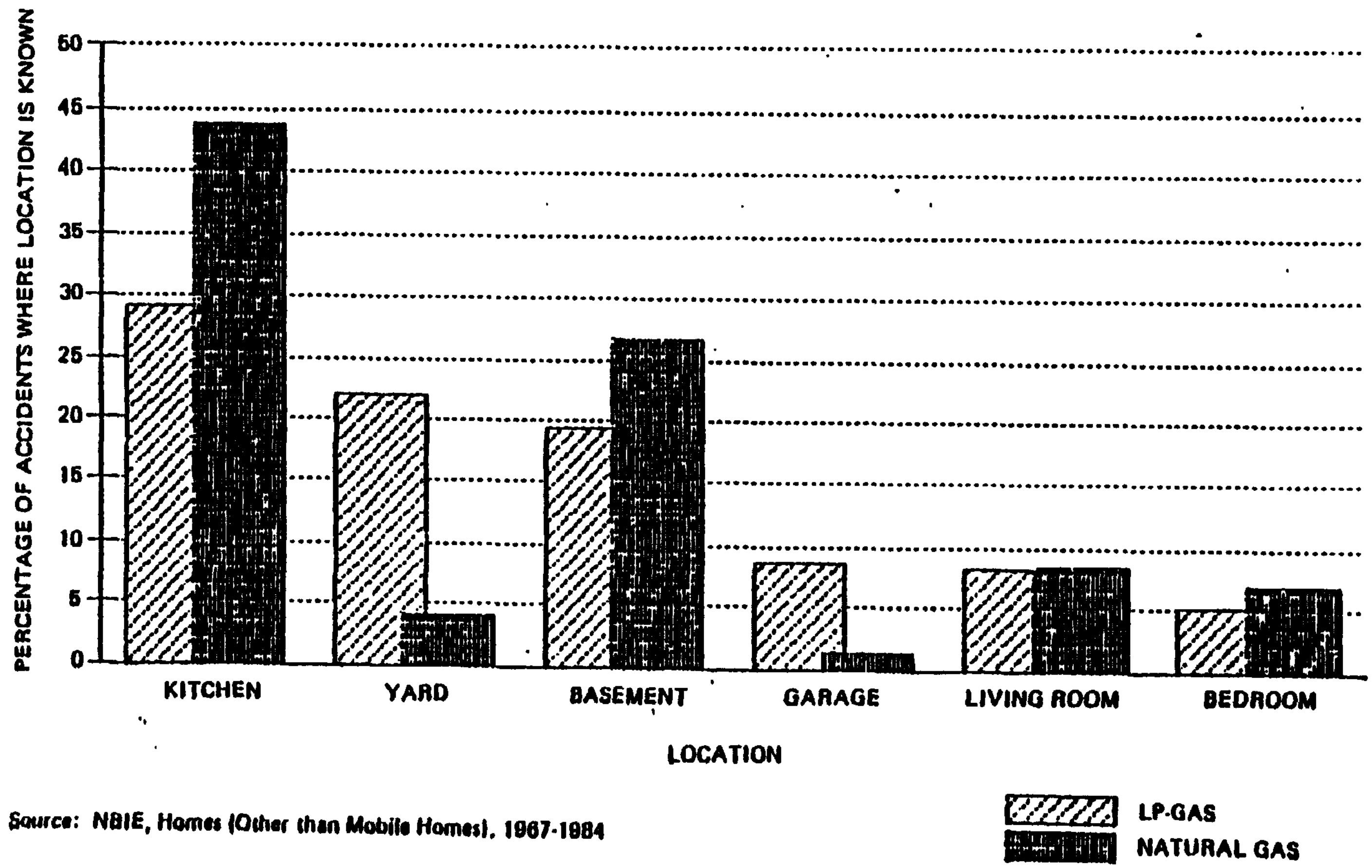

Source: NBIE, Homes (Other than Mobile Homes), 1967-1984

Figure 2-6 COMPARISON OF PERCENTAGE OF ACCIDENTS BY LOCATION FOR GAS IGNITION ACCIDENTS RESULTING IN SEVERE BURN INJURIES

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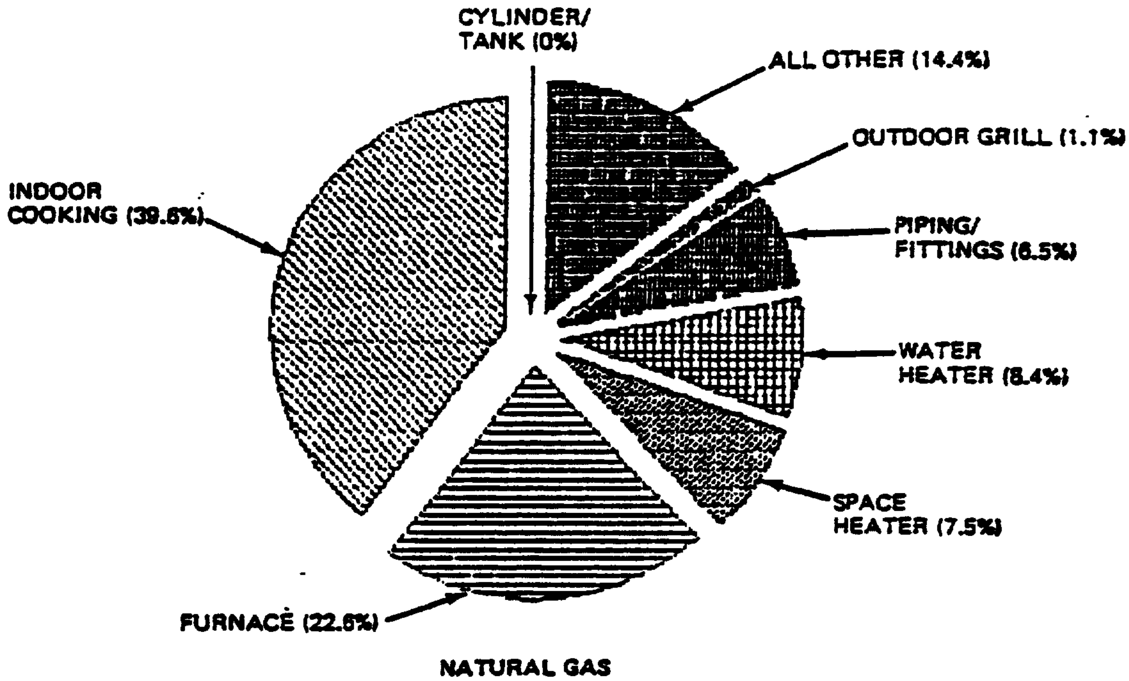

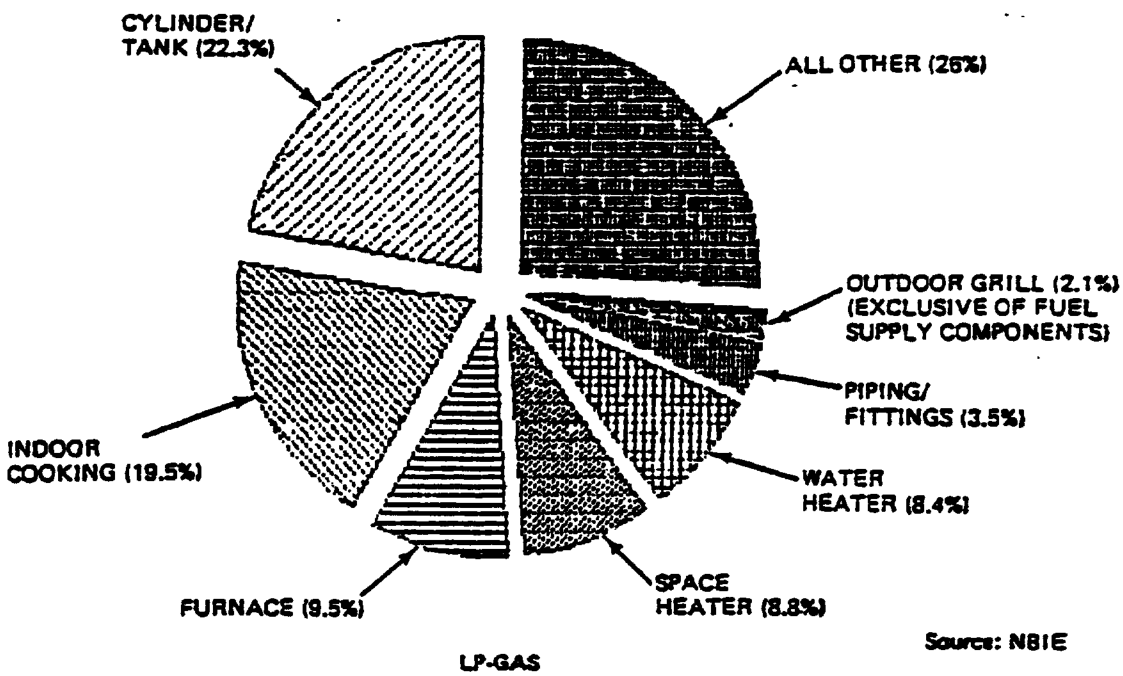

Figure 2-7 PRODUCT INVOLVED IN GAS IGNITION ACCIDENTS RESULTING IN SEVERE BURN INJURIES, HOMES (OTHER THAN MOBILE HOMES) 1967-1984

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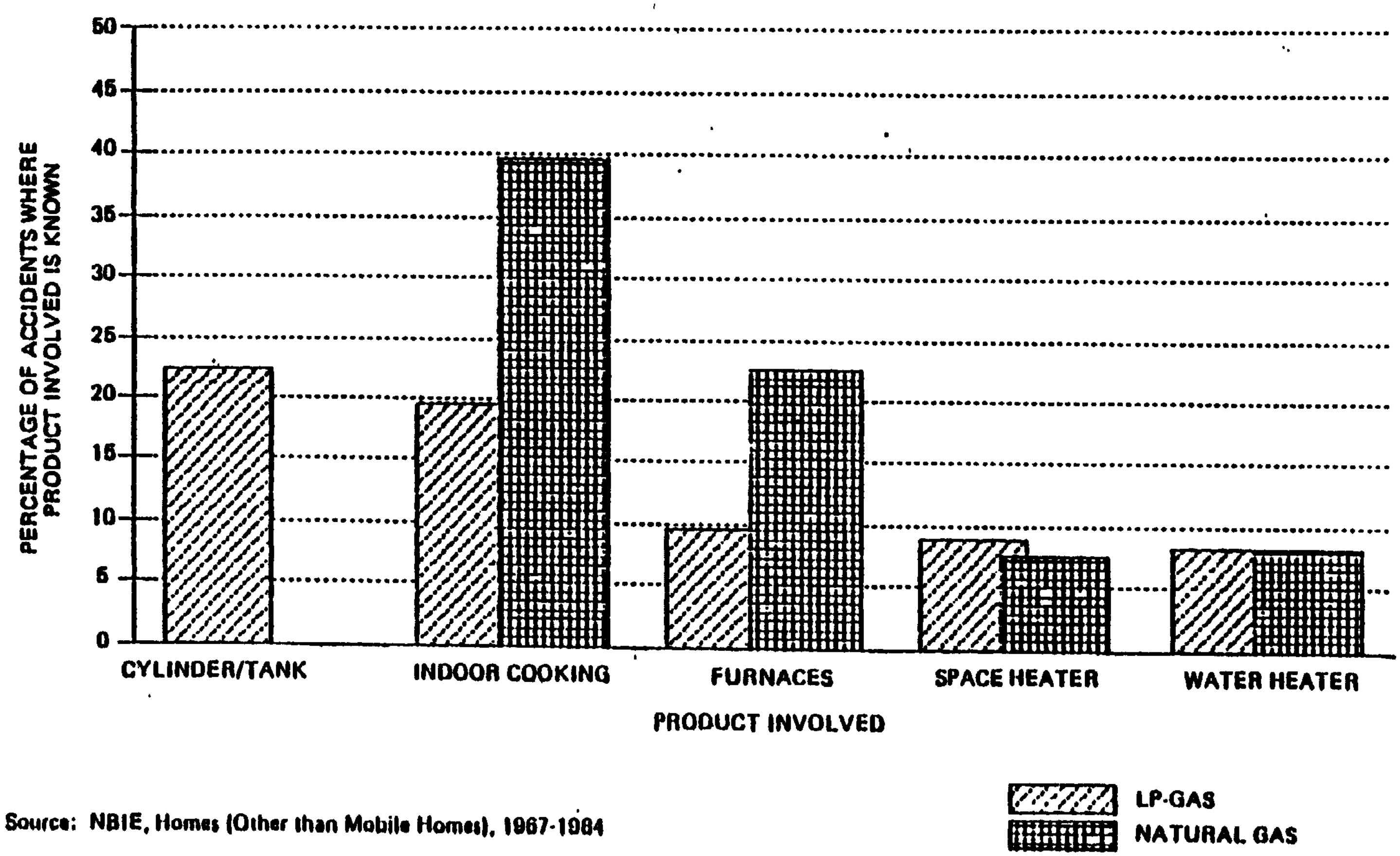

Source: NBIE, Homes (Other than Mobile Homes), 1967-1984

Figure 2-8 COMPARISON OF PERCENTAGE OF ACCIDENTS BY PRODUCT INVOLVED FOR GAS IGNITION ACCIDENTS RESULTING IN SEVERE BURN INJURIES accidents. Leakage from piping and fittings associated with an appliance will typically be reported by NBIE with the equipment. Similarly, equipment associated with the activity at time of injury, not actual source of ignited fuel may be reported. Grill accidents associated with the fuel supply cylinder and associated valving however, may be reported with the cylinder category. Reporting variations such as these make the activity and location statistics more reliable than the product numbers from this data source. Gross trends may be assessed, however, and correlated with other source data. The percentage of LP accidents associated with fuel containers and accessories, for example, is relevant. Figure 2-8 shows the Figure 2-7 data in bar chart form.

On the basis of FTA analysis and observation, two of the major factors leading to control or appliance failure and subsequent injury relevant to this study were fuel supply pressure excursion and particulate contamination originating in the fuel supply system. Other major sources of fugitive gas which was subsequently ignited were leaks from fittings and connections, and leaks from corroded or physically damaged piping seeping into below-grade locations. Problems with containers and their immediate valving and appurtenances serving fixed locations were fewer in number than those associated with customer owned, small portable containers. Principal difficulties were noted with DOT (ICC) cylinders and shut-off valves. Frequently the problems were age and/or deficiencies-in-inspection related, rather than basic design problems.

Overfill problems were occasionally noted with fixed site containers, but were far rarer than those reported with portable gear. By comparison, overfill and/or purge problems with customer containers, principally 20 lb. cylinders, are of major proportions. Table 2-1 is a breakdown of 89 LP-Gas fuel container cases which were the subject of in-depth investigations (IDI) by CPSC. Shown are incidents involving 20 lb. or smaller DOT cylinders, larger than 20 lb. DOT cylinders, stationary ASME tanks, and a single incident of an ASME mobile tank converted to stationary use. Virtually all the 20 lb. and under category cylinders were 20 lb. units. The larger cylinders were nearly all 100 lb. units. This would be consistent with their relative numbers in the field. Table 2-1 suggests that cylinders, particularly portable ones, dominate the number of overall incidents and incidents where purge/overfill problems are an identifiable causative factor. Further, it indicates that purge/overfill problems are a substantial contributor to small container accidents.

IDI data is not necesssarily statistically representative of actual field experience. However, there was no indication of particular container bias in this data. The CPSC data conforms in general with our own observations and experience, except that the CPSC data may tend to understate the purge/overfill contribution due to the lack of information on many incidents to establish causal elements.

Section 4.2 and 5.0 provide additional technical information relevant to this subject.

Severe, and growing troubles are seen with the loss of control in professional training for filling, handling, storage, inspection and maintenance of customer owned gear. What might be termed the ultimate in non-professional practice, cylinder filling by customers at retail "self-serve" LP-Gas dispensing outlets should be prohibited.

Outside equipment problems tended to center around the regulation systems employed. This was expected since regulators are relatively complex mechanisms with several dynamic components. Fuel supply contamination, weather

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Table 2-1

CONTRIBUTION OF OVERFILL/PURGE PROBLEMS TO ACCIDENTS INVOLVING LP-GAS CYLINDERS OR TANKS

	ALL CAUSES		OVERFILL/PURGE		
CONTAINER TYPE & SIZE	NO. OF INCIDENTS	% OF TOTAL INCIDENTS	NO. OF INCIDENTS	% BY CONT. TYPE	% OF TOTAL INC.
20 lb. OR SMALLER DOT	64	72	14	22	16
DOT LARGER THAN 20 lb.	10	11	4	40	4
MOBILE TANK	1	1	1	100	1
STATIONARY TANKS — ASME	14	16	1	7	1
TOTALS	89	100	20	—	22

Source: CPSC IDI Reports

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conditions and old or poorly protected equipment were key elements in the accident scenarios. Section 5-4 contains additional technical discussion with regard to regulation systems.

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 present. Clearly there is a major problem in this area. Section 4.2.3 of the report addresses this topic.

Many of the contributing factors to injury accidents were slow-developing or latent hazards. This suggested intervention in the form of knowledgeable inspection and/or maintenance could be an effective injury prevention tool. This had obvious implications for the industry GAS Check program. This is discussed further in Section 2.3, following.

Another observation was that non-professional installation, inspection and maintenance activities, whether by consumer or untrained or indifferent service personnel acted as order-of-magnitude multipliers for accident severity probability on whatever intrinsic hazards already existed in a given system. Recalling earlier discussion and Figure 2-3 in particular, a substantial number of injuries occur while the victim is directly performing some installation, inspection or maintenance activity. Substantial as that percentage is, it represents only a fraction of the problem. Many of the other accident scenarios showed a clear contribution from earlier incorrect or omitted installation, maintenance or inspection activities. This was particularly evident with regulators, valves, piping and fittings.

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Recreational uses in general and self-contained barbecue grill use in particular were considered significant sources of injury. Due to the high growth rate of the market for this equipment a major increase in the number of total injuries is foreseen.

Figures 2-9 through 2-12 permit visualization of some of the factors involved in portable grill accidents. Figure 2-9 provides a breakdown of ignition or intensity factors related to the fuel supply as accident contributors. Note that nearly a third of the sample reports were related to an excess pressure event. It may also be observed that nearly a fourth of the incidents were escalated in intensity due to continuing or high rate fuel releases.

Figure 2-10 illustrates the high level of involvement of the fuel supply conveyance and control system between the supply cylinder and the grill proper.

Figure 2-11 is an analysis of excess pressure incidents illustrating the high percentage of initial or first use after refill events. This is indicative of purge/overfill problems and in some cases overheating of the container and contents.

Figure 2-12 breaks out accident locations which tended to be involved in high loss accidents due primarily to their proximity to the principal residential structure. Section 5.6 is directed specifically to the outdoor portable cooking appliance subject.

The grill market, along with RV applications, makes the 20 lb. DOT cylinder the overwhelmingly dominant container. In terms of numbers, 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,

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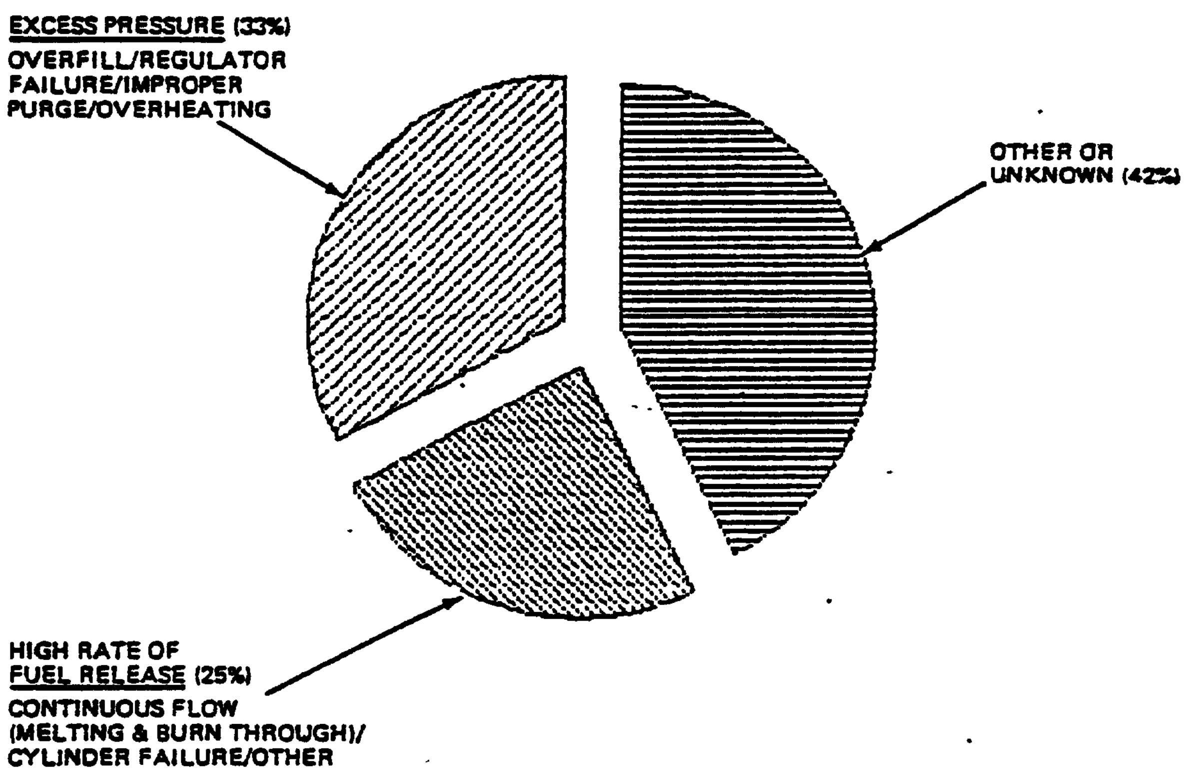

Source: CPSC - IDI Files

Figure 2-9 FUEL SUPPLY RELATED IGNITION OR INTENSITY FACTOR IN PORTABLE GRILL ACCIDENTS

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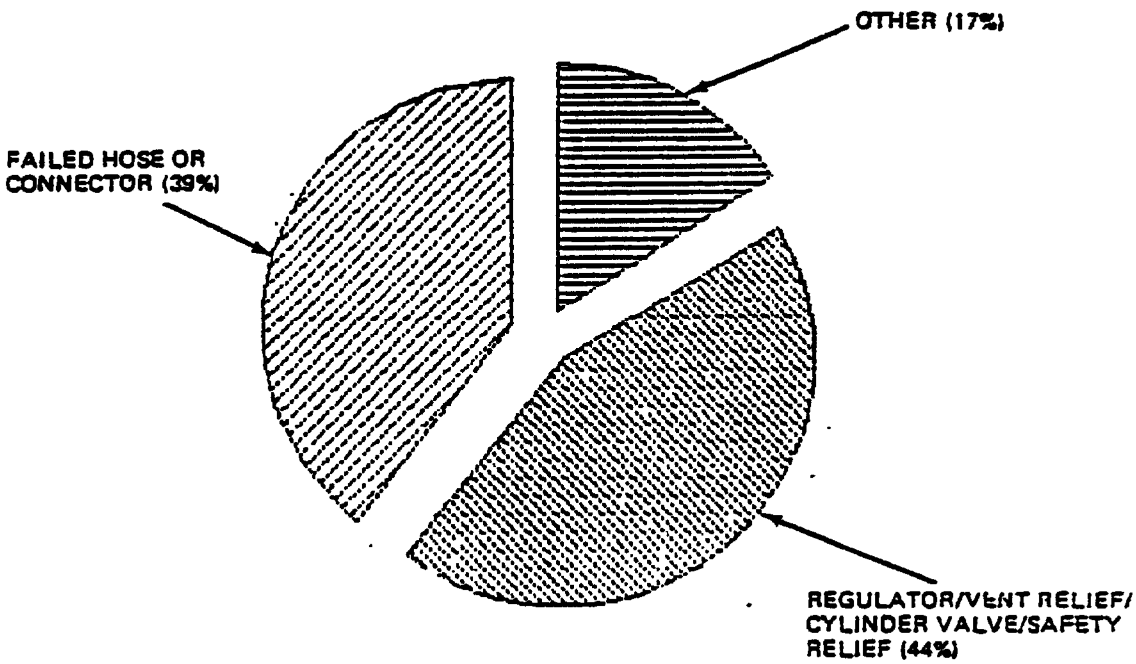

Source: CPSC - IDI Files

Figure 2-10 SOURCE OF GAS IN PORTABLE OUTDOOR COOKING EQUIPMENT ACCIDENTS

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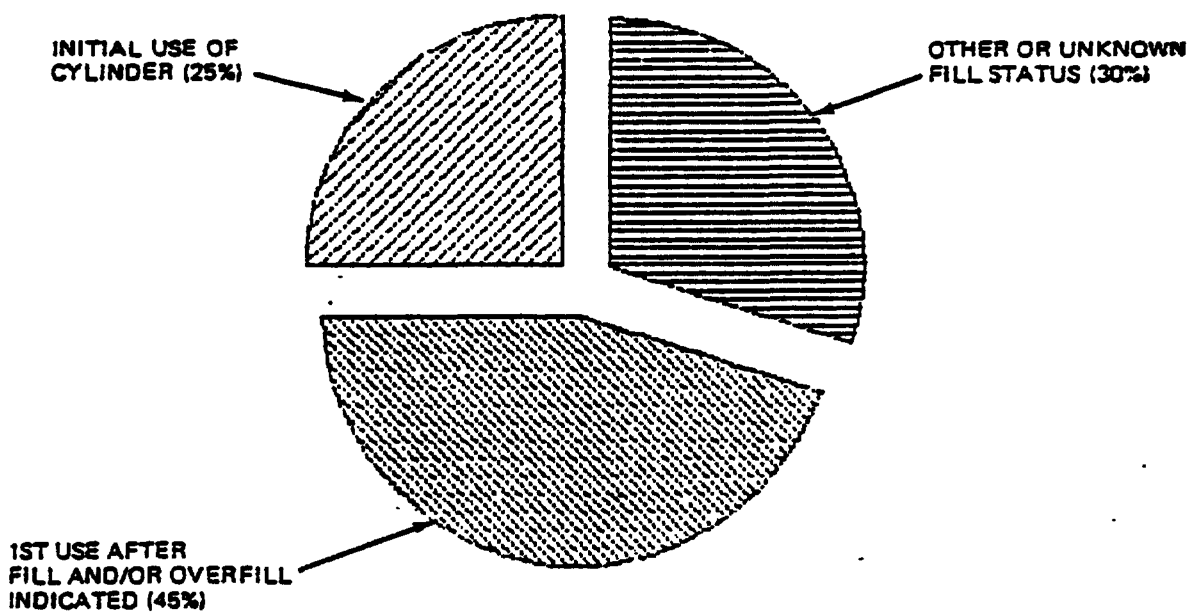

Source: SPSC - IDI Files.

Figure 2-11 ANALYSIS OF EXCESS PRESSURE INCIDENTS RELATED TO PORTABLE GRILL ACCIDENTS

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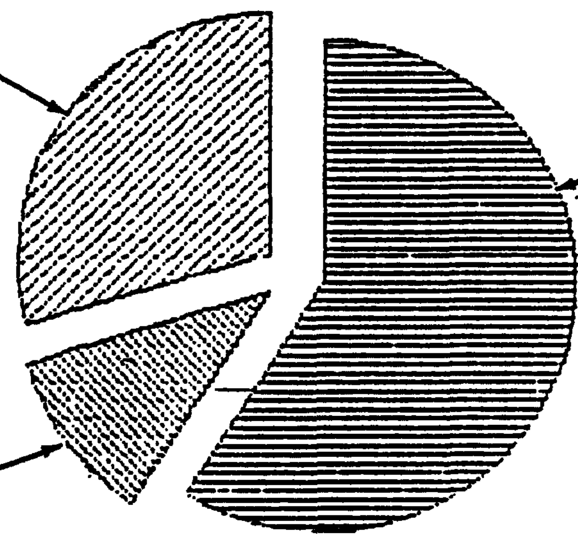

Source: CPSC - IDI Files

Figure 2-12 LOCATION REPORTED FOR PORTABLE GRILL ACCIDENTS

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storage and handling, plus restrictions on immediate sources 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. The adoption of codes, specifications and equipment not adequately considering the use environment were believed to be major contributors to current problems. Section 4.2.1 and 5.2, along with Section 5.6 develop the technical relationships between fuel properties, container and equipment standards relevant to these issues.

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2.3 Priority Issues & Recommendations

2.3.1 General

The strategies to reduce the hazards of residential LP-gas use follow two courses:

- o Reduce the potential for the occurrence of dangerous leaks

- o Insure detection of leaks which do occur in time to take effective counteraction or at least to escape.

Leaks as defined here means any undesired release of fuel into an environment where it may become ignited and result in death, injury or other loss. Thus it would include releases due to such things as malfunctioning controls, for example, as well as from loose connections, corrosion holes, etc.

The greatest impact that could be made in reducing the hazard of LP-Gas use in the residential environment, with supply systems already in place and consumer behavior patterns essentially unmodified, would be to insure timely and effective detection of leaks. Therefore we consider this the number one priority item for attention.

There is an odorization problem. In many cases it can be reasonably determined that the gas was initially odorized, and that knowledgeable and unimpaired victims did not smell a high concentration of gas. The odor "faded" somewhere in the distribution chain.

"Fade" is a non-technical, short-hand descriptive term for an observed effect not necessarily attributable to a

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single mechanism. LP-Gases are intrinsically essentially odorless, hence small quantities of malodorous compounds are added to LP fuel to act as a warning agent. The odorizing chemicals may break down chemically under certain conditions, radically altering or eliminating their effectiveness as a warning agent. There are additional physical factors, such as adsorption on contact surfaces which also may reduce the effective odorant concentration. Odorant may be present, but undetectable because the heaviest concentration of escaped fuel is below nose level; there may be impairment of the olfactory senses due to age, disease, presence of masking agents or collateral distractions. The "fade" phenomenon and a host of technical and human factors issues have been studied in the past. The LP industry is presently considering sponsoring additional research. We are supportive of this effort, and would place it high on the priority recommendation list. Additional discussion of odorization may be found in Section 4.2.3.

It is important, however, that it be recognized that gas odorization is only part of the 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 placement applications. An example would be frequently unattended locations such as basements with fuel burning appliances. Research and development efforts should encompass activity in the area of detectors and their appropriate application..

Meanwhile, we must be 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

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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, and 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 an unverified statement from the attendant 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 practice may occur with odorant materials with known stability problems in environments likely to be seen in the distribution chain.

We specifically recommend the ~~formation of a broadly~~ based task group to undertake revisions of NFPA #58 to clearly delineate responsibility for verifying viability of odorization through the distribution chain, and how, at least in broad terms, this is to be accomplished.

Similar examples of weak coverage in NFPA #58 can be cited with regard to inspection requirements for certain containers and appurtenances critical to safety. Therefore an additional key recommendation is the formation of a task group for an across-the-board review to establish requirements for in-service and other inspection of containers and appurtenances, including safety relief valves and regulators, where present coverage is limited or absent. Coverage should include, among other things:

- Type of Inspection to be performed
- Responsible Parties
- Inspection Interval

- Record Keeping Requirements
- Quality Audit Procedures

A major impact item in reducing the hazard in the residential environment, and one that has the potential to produce the earliest results, is considered to be the vigorous pursuit on the broadest level of participation in the industry developed and sponsored GAS Check program. The National LP-Gas Association members and the Gas Appliance Manufacturers Association members supporting the program should be commended for their efforts. The priority issue here is to insure that the program does not falter in either depth or breadth of participation.

According to NLPGA sources, participation in the GAS Check program as of 1 May 1986 was 1188 marketers, representing 38% of the association membership. The participating establishments as of this date were 4100, representing 62% of the member locations. In other words, participation of the larger, multi-location companies among NLPGA membership is substantial. NLPGA members may account for as high as 90% of the LPG volume sold. It is still important, however, to get smaller LP-Gas dealers involved, whether members of the Association or not. Their customer base and number of transactions with small-volume residential users is significant.

The following estimated breakdown of retail LP-Gas dealers was derived by FTA from proprietary data:

Estimated Total No. of Retail LP-Gas Establishments - 10,900
Estimated Retail Establishments (20 or more employees) - 830
Estimated No. of Companies (20 or more employees) - 450

From the above it may be seen that there are a very large number of smaller retail establishments, many apparently outside of the NLPGA active membership. Past

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experience shows that what might be termed "fringe" operators have more than their share of contribution to accidents, and are the least likely to participate in the program. A secondary concern is that residential LP systems of the type more likely to be involved in an accident are frequently associated with low volume applications. Hence, economic issues for both dealer and user in performing adequate checks enter the picture. As the GAS check program proceeds the situation will need to be monitored closely.

It is not intuitively obvious how to increase the leverage for achieving greater depth and breadth of participation in the GAS Check program. The NLPGA has, of course, been actively promoting the program with their state affiliated associations and individual members. The Commission perhaps should consider a more public posture on the matter and increase the level of liaison with State regulatory authorities.

Wholesale gas suppliers have a stake in the success of the GAS Check program considering "flow through" liability risks from certain types of accidents occurring at the retail/residential level. This is particularly true where proper odorization is an issue. They are perhaps in a position to influence their customers who are marketing at retail, including smaller marketers not presently participating. Another possibility is by differentiation of risk by insurance authorities among participating and non-participating companies.

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2.3.2 Specific

Turning now to more specific recommendations, a currently significant problem in the making—therefore needing priority attention—revolves around customer owned containers and their principal application, self-contained outdoor portable cooking equipment. The key hazard elements in approximate order of the risk they pose in terms of frequency and severity are:

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

Some of the predominant accident partterns leading to these conclusions were given earlier in this section. Supporting technical analysis for the conclusions and recommendations may be found in Sections 4.2.1, 5.2 & 5.6.

Major recommendations are the following:

1) Require automatic stop-fill devices on portable cylinders.

2) Prohibit 'self-serve' cylinder filling by customer. Introduce or upgrade as appropriate, training and certification of LP retail service station operators. (Note: Oklahoma presently requires licenses for fillers)

3) Revision of ANSI Z21.58 to define temperature limits on all gas carrying components where heat transfer from the burner box may affect component temperature. Specify performance tests appropriate to assure adequacy of affected

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components, including hose connectors, regulators and valving.

4) Require quick connect (automatic shut-off) coupling at cylinder valve outlet.

5) Require automatic thermal shut-off device(s) to interrupt uncontrolled gas flow developing from hose connector failure or regulator melt down from excessive heat (fire).

6) Require a high pressure shut-off rather than a safety relief vent on grill application regulators.

7) Discourage, via instructional material, maintaining "spare" cylinders and ban provisions for carrying same on equipment cart.

8) Set-up appropriate monitoring activities for early intercept and correction of any 'start-up' difficulties typically associated with newly adopted equipment.

9) Ban aluminum cylinders unless equivalent fire safety to steel alloy cylinders is established by test.

10) Conduct research on feasibility of ablative or intumescent coatings suitable for portable cylinder application.

This concludes the listing related to customer-owned portable cylinders and portable outdoor cooking equipment.

The following recommendations deal with service regulation issues:

- Provide necessary code revisions to require two stage regulation for new, permanent installations.

- Revise UL #144 and NFPA #58 to require automatic high pressure shut-off features. A limited capacity vent relief in conjunction with the high pressure shut-off is acceptable to limit nuisance shut-off with slight seat leakage under lock-up conditions.

- Set-up a coordination group among affected parties to establish acceptable limits of downstream pressure rise with regulator failure. Similarly a group to deal with particulate removal requirements should be formed.

Section 4.2.2 and 5.4 provide technical background with respect to these recommendations.

The following recommendations deal with pressure relief requirements:

- Revise UL #132 to specify popping and blowdown limits on pressure relief valves.

- Set-up task force (NLPGA) to review set-point and concomitant ASME container requirements for high ambient temperature exposures with smaller tanks and high risk relief applications. Section 5.2 provides descriptive technical discussion.

The following recommendations deal with vapor withdrawal (service) valve protection requirements in NFPA #58 for ASME stationary tanks under 2000 gallons capacity.

- Revise requirements for service valve protection to provide for 1) Preferred option of internal excess flow valve unless contraindicated by use

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conditions, or 2) mandatory minimum of restrictive orifice at valve inlet to prevent uncontrolled flow of gas with valve break-off. Section 5.2.1.1 discusses this issue in additional detail.

The following recommendation concerns LP-gas specifications:

o Set-up appropriate task group to coordinate inclusion of LP-Gas specifications into NFPA #58, with adoption of minimum test verification requirements, responsible parties for determination, and inclusive of tests for appropriate corrosive contaminants considering source of supply.

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3.0 Overview of Hazards Associated with the Residential Use of LP-Gas

3.1 Properties of LP-Gas Related to Safety

A good starting point in the discussion of hazard characteristics associated with LP Gas use is to examine some of the physical properties of LP gases themselves and compare them to methane, the prinicipal component of natural gas (Table 3-1). Propane and butane are the prinicpal LP-gases. Propane, sold under commercial or HD-5 specifications is the LP gas (LPG) residential fuel sold in the greatest quantities. Gas Processors Association (GPA) and related references to American Society for Testing and Materials (ASTM) Specifications are shown as Table 3-2. These gases are not pure, but have minor constituents which for present purposes of discussion we will disregard. However, these so-called "minor" constituents will be shown in later discussion to have major impact with regard to hazard in certain situations. Also, LPG and natural gas fuels are odorized by the minute addition of typically mercaptan compounds to aid in the detection of leaks. Odorants and their behavior have a profound effect on safety considerations, particularly with LP-Gas. This is addressed specifically in Section 4.2.3.

Referring to Table 3-1 note that the specific gravity of LPG vapors are greater than unity, hence are heavier than air (Air=1.0 by definition). Natural gas on the other hand is lighter than air. Therefore, natural gas has an intrinsic natural dispersion and venting characteristic (through an appliance venting system for example), whereas LPG vapors may move downward and tend to collect temporarily in low places (e.g. basements) prior to dispersing. Though useful to explain a difference in fundamental hazard characteristics, it must be remembered that the description is somewhat simplistic. The specific gravity differences of

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Table 3-1
PHYSICAL PROPERTIES OF PROPANE, BUTANE AND METHANE

	PROPANE	BUTANE	NATURAL GAS (METHANE)
Chemical Formula	C_3H_8	C_4H_{10}	CH_4
Specific Gravity (Liquid)	.509	.582	.3
Specific Gravity (Vapor)	1.52	2.01	.64
Weight per Gallon	4.24 lbs.	4.84 lbs.	–
Boiling Point (Atmospheric)	-44°F	31°F	-260°F
Ignition Temperature	920-1120°F	900-1000°F	1,150°F
Maximum Flame Temperature	3,595°F	3,615°F	3,400°F
Flammability Limits* (Upper)	9.60%	8.60%	14%
Flammability Limits* (Lower)	2.15%	1.55%	4%
Ideal Combustion Ratio (Air to Gas)	24 to 1	31 to 1	10 to 1
Heat Value per cu. ft. (Vapor)	2,516 BTU	3,280 BTU	1,000 BTU
Heat Value per pound (Liquid)	21,591 BTU	21,221 BTU	–
Heat Value per gallon (Liquid)	91,547 BTU	102,032 BTU	–
Cubic feet Vapor per gallon	36.4 cu. ft.	–	–
Cubic feet Vapor per pound	8.6 cu. ft.	–	–

NOTE: All properties are approximates from industry sources

*Percent of gas in air

Source: NTA&S, Inc.

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