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Classification and Trend Analysis of Fuel Gas Accidents in Korea between 1996 and 1999

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Abstract−Gas accidents between 1996 and 1999 were analyzed, which include LPG (liquefied petroleum gas) accidents and city gas accidents, and countermeasures were suggested to reduce them. A hierarchical method to classify gas accidents was suggested. Trend analysis followed by targeted countermeasures was carried out for main causes of accidents.

Key words: LPG Accident, City Gas Accident, Process Gas Accident, Hierarchical Method, Trend Analysis, Targeted Countermeasures

INTRODUCTION

LPG (liquefied petroleum gas) or natural gas is serviceable and handy as fuel, but dangerous as well. In Korea, it has been 40 years since such gases became public fuels; LPG began to be used by the wealthy in the beginning of 1960. Natural gas started being served as fuel gas in 1987 around Seoul. It is expected that natural gas consumption will be up to 10% of primary energy use in 2010 [Korea Ministry of Commerce, Industry, and Energy, 2000].

With the increase of energy consumption, the number of gas accidents has also increased drastically from about 100 in 1990 to about 600 in 1995. Although the number of gas accidents has decreased rapidly from 1996, more systematic safety management together with countermeasures is required since 225 accidents were reported in 1999 [Korea Gas Safety Corporation, 1996-1999].

Korea Gas Safety Corporation (KGS) is exclusively responsible for gas accident management in Korea; the main function of KGS is accident reporting and analysis to develop countermeasures in order to reduce accidents. A gas accident could be classified according to its characteristics as shown in Fig. 1. According to facilities' property, it can be classified by LPG accident, city gas accident, and industrial gas accident. LPG accident is defined as the accident occurring at LPG and butane gas facilities, while city gas accident is defined as the accident occurring at a natural gas facility served through a piping network. Air-mixed LPG supplied by piping network is also classified as city gas. Industrial gas accident is defined as the accident at high pressure gas-processing plant such as chemical plant and refinery plant. Between 1996 and 1999, LPG and city gas accidents took up 95.4%, while industrial gas accidents took up only 4.6%.

According to where the gas is served, gas accidents could be further classified as accidents at consuming facilities such as individual residences, apartment residences, and restaurants, and accidents at supply installations such as commercial gas businesses including production, filling up, and storage of gas, pipe, governor, transporting truck, etc. The third hierarchy of accident classification is the cause of the accident. According to the causes, the accident could

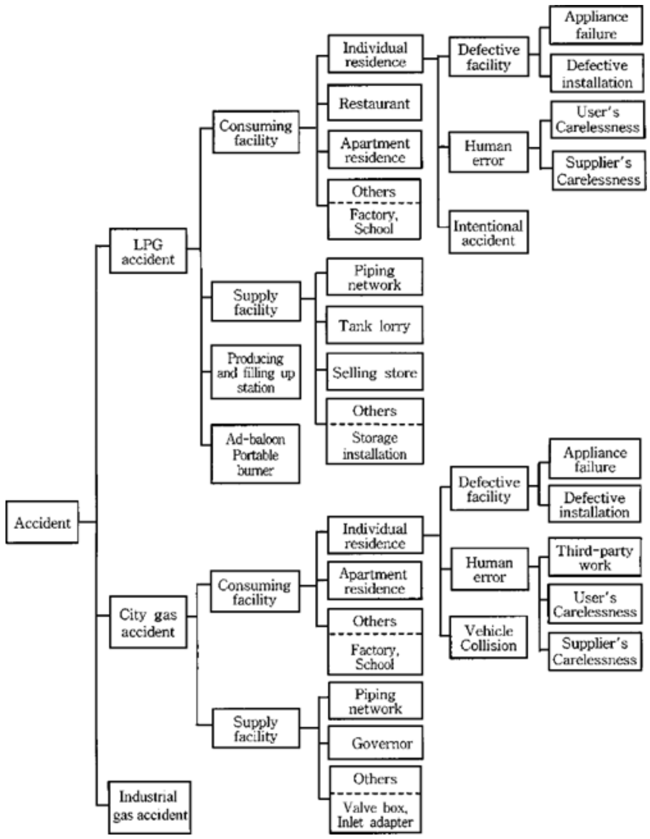

Fig. 1. Accident classification hierarchy.

be classified as user's carelessness, supplier's carelessness, third-party work, appliance failure, defective installations, and intentional accident. According to accident's damage to people and properties, the accident could be classified as the first, the second, the third, and the fourth grade accident, respectively [Korea Gas Safety Corporation, 1996-1999, 1999].

In this work, countermeasures to reduce the number of gas accidents were suggested through analysis of accident trends in Korea between 1996 and 1999. For more systematic management of gas accidents, a systematical method to classify gas accidents was also suggested according to their characteristics, at which facility they

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occur and how it occurs.

GAS ACCIDENT CLASSIFICATION

In order to consider countermeasures more effectively and properly, the accident should be classified by the characteristics of the accident or distinctive feature of the facility. In order to learn more from past accidents, a computer database is needed and accidents should be classified by hierarchy [Chung and Jefferson, 1998]. Korea's gas accidents have three major hierarchies of classification: characteristics of the facility to which gas is served, type of residence or business where gas consumed, and how the accident occurred.

The first hierarchy is the characteristics of gas facilities. According to the characteristics of gas facilities, accidents can be classified into three domains: LPG accident, city gas accident, and high pressure industry gas accident, respectively. The distinctive features of each of these facilities in Korea are described elsewhere in detail [Park and Yoon, 1999; Korea Gas Safety Corporation, 1996a, b, c].

Among them, the LPG facility is considered to have the worst safety management system, such as underdeveloped distribution system, very small-scale business, and relatively poor detecting and regulating devices. LPG is served to end-users mostly via a small cylinder. This type of consuming is the most popular (upto about 90%) as it has a very simple system: a cylinder, a regulator, and short hose. It has the largest portion of the accidents, up to 90% of LPG accidents, which could be attributed to the simplest scheme of the supply system. LPG is also served via fill up station, and via small-scale piping network.

City gas is served through a piping network, the dominant part of a gas facility. As a result, 89% of city gas accidents of a supply facility occurred at the piping network. City gas companies are undertaking a geographical information system (GIS), which could be considered to decrease city gas accidents arising from a piping network.

Korea's industrial gas facility has a longer history than the other two, and is known to keep far better safety management system than the other two.

The second hierarchy is the type of residence. According to the type of residence or business, gas accidents can be classified into consuming and supply facility. Accidents of consuming facility consist of accidents at individual residences, at restaurants, at apartments, and at crowded buildings such as schools, public baths, and manufacturing factories. Accidents of supply facilities consist of accidents at piping networks including governors and valve boxes, transportation tank lorries, selling stations, and storage installations.

The third hierarchy is how accidents occur. Accidents can be classified by cause; bad appliance, defective installation, user's or supplier's carelessness, third-party work, vehicle collision, etc.

TREND ANALYSIS

Totally, 1,675 accidents have been reported between 1996 and 1999. The first grade accident, taking up 0.1%, is defined as incidents causing more than 5 people's death, or 10 people's heavy damage, or 500 million won property's loss. The second grade accident, taking up 19.3%, is defined as incidents causing between 1 and 4 people's death, or 2 and 9 people's damage, or 100 and 500 million won property's loss. Any other incidents causing damage to people or property are defined as the third grade accidents, which took up 54.5%. Harmless leakage of gas or happening is defined as the fourth grade accident, which took up 26.1%. As a result, more than 80% of accidents are harmless or have only slight damage to people or property.

LPG accident records (1,167) take up 68%, and city gas accident records (431) take up 27.4%, while industrial gas accidents take up only 4.6%. Therefore, Korea's countermeasures have been focusing on how to reduce LPG and city gas accidents. Industrial gas accidents were studied more specifically one by one [Chen and Lin, 1999; Suh et al., 1997; Kahn et al., 1998], and industrial gas accidents in Korea will be analyzed in further detail in the future.

As shown in Fig. 2, most of the LPG accidents occurred at consuming facilities such as individual residences, restaurants, and apartments, while most city gas accidents occurred at consuming facilities such as individual residences and apartments, and supply facilities such as piping networks. The number of accidents has decreased from 1996 monotonically as shown in Fig. 3. Although the rate of decrease for city gas was very rapid, that for LPG was rather slow. This may be attributed to the safety level improvement rate of consuming and supply facilities; city gas facilities are far better-equipped with safety devices such as fuse cock valves and multifunction gas meters than LPG ones. As shown in Table 1, a very large decrease was observed for LPG accidents caused by defective installation at individual residences, appliance failures at restaurants, user's carelessness at apartments, and human error at LPG supplying facilities. However, a slight increase was observed for accidents caused

Fig. 2. Gas accidents constitution of LPG and city gas between 1996 and 1999.

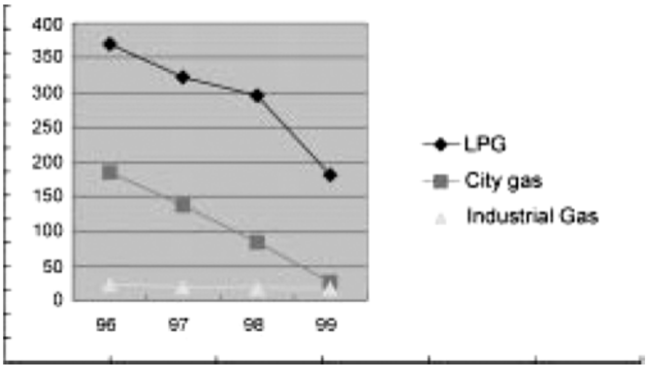

Fig. 3. Gas accidents trend between 1996 and 1999.

by defective installation at restaurants. A very large increase was observed for accidents caused by supplier's carelessness. As mentioned above, most city gas accidents decreased very rapidly, and the number of accidents caused by piping networks showed the largest decrease rate of all. Rate of accidents occurring per number of users is also analyzed; LPG consuming restaurant businesses have the highest (up to 10 times the individual and apartment residence rate). This could be attributed to the longer use time of gas appliances.

An intentional accident is caused by a person who intends to hurt and get hurt by gas accidents; these could be excluded from analysis work because of its mechanism, and more detailed and specific analysis will be required.

1. LPG Accident Analysis

As has been mentioned above, individual residences (33.6%), restaurant businesses (22.5%), and apartment residences (18.2%) consists most of the LPG accidents. As shown in Table 1, the most dominant and common causes are appliance failure, defective installation, and user's carelessness. Others are accidents occurring in the LPG manufacturing industry, LPG fill-up stations, and factories using LPG as fuel and/or raw material. Accident cause is analyzed and classified further to prepare more appropriate countermeasures.

1-1. Analysis of Accident at Individual Residence

As described in Table 2, accidents at individual residences recorded the highest. Main factors causing appliance failure are weld-

Table 1. Gas accidents in detail between 1996 and 1999

Classification	Facility	Cause	Accident number	Average decrease rate (%)
LPG Accident	Individual residence	Appliance failure	90	29.9
		Defective installation	82	51.5
		User's carelessness	81	29.4
		Others	33	-
	Restaurant business	User's carelessness	70	12.0
		Defective installation	51	−2.5
		Appliance failure	33	45.0
		Others	37	-
	Apartment residence	Appliance failure	45	16.4
		Defective installation	49	20.6
		User's carelessness	31	45.0
		Supplier's carelessness	22	−44.2
		Others	8	-
	Supply facility	Transportation	25	25.3
		Poor facility	22	30.7
		Human error	14	50.0
		Others	3	-
	Others (LPG producer, Fill-up station, Factory)		154	-
Subtotal			850	
City gas accident	Apartment residence Individual residence	Defective installation	81	52.4
		Appliance failure	39	42.5
		Others (User's carelessness, Unignited release)	87	-
	Supply facility	Piping network	152	59.6
		Others	12	-
	Others (Restaurant business, Crowded building, Factory, Hospital)		50	-
Subtotal			421	-
Intentional accident			329	-
Others (Refrigerant producer, LPG Vehicle, Refinery, Chemical)			74	-
Total			1,675	-

Table 2. LPG accidents in detail between 1996 and 1999

Facility	Cause	Cause in detail	'96	'97	'98	'99	Subtotal	Total	Total
Individual residence	Appliance failure	Welding	14	13	5	0	32		
		Regulator	16	7	0	3	26	71	90
		Valve	9	3	1	0	13		
		Others (Gas range, Hose)						19	
	User's carelessness	Misconnection	8	9	10	6	33	44	
		Butane-can overheating	4	6	1	0	11		82
		Others (External Impact, Unignited release, Hose disconnection, Valve misopen)						38	
	Defective installation	Misplugging	7	5	10	8	30		
		Boiler	7	8	3	0	18	64	81
		Pipe and connection	6	8	2	0	16		
		Others (Miscoupling, Regulator, Connection leakage)						17	
		Others (Poor installation, clogging, or pipe damage by worker)							33
Restaurant business	User's carelessness	Misconnection	12	8	5	5	30		
		Butane can overheating	4	4	2	2	12	61	70
		Unignited release	5	4	2	4	15		
		Others (Poor exhaust, Valve misopen, External Impact, Hose disconnection)						9	
	Defective installation	Misplugging	4	2	3	10	19	28	
		Pipe and connection	4	6	1	1	12		51
		Others (External impact, Cylinder upset, Connection leakage)						23	
	Appliance failure	Regulator & valve	7	5	4	2	18	25	
		LPG Cylinder	3	1	1	0	5		33
		Others (Butane cylinder, Burner)						8	
		Others (Poor installation, plugging, or pipe damage by worker)							37
Apartment residence	Appliance failure	Welding	6	6	2	0	14		
		Regulator & valve	7	5	1	2	15	41	45
		Burner	1	1	1	1	4		
		Others (Ignitor malfunction, Clogging)						4	
	Defective installation	Misplugging	4	6	8	4	22		
		Regulator & valve	4	6	0	0	10	38	49
		Boiler	2	2	1	0	5		
		Others (Unignited release, Hose disconnection, pipe)						11	
	User's carelessness	Misconnection	3	9	1	4	17	19	31
		Others (External impact, Unignited release, Valve misopen)						12	
	Supplier's carelessness	Miscoupling	6	6	6	4	22	22	22
		Others (Poor installation, plugging, or pipe damage by worker)							8
Supply facility	Transportation	LPG tank lorry	7	13	8	2	30	30	
	Poor facility	Multiuser facility	11	6	5	0	22	22	58
	Human error	Miscoupling	8	6	2	0	16	16	
		Others (Vehicle collision, Ground sinking)							3
Others (LPG producer, Fill-up station, Factory)									154

ing, regulators, and valves; welding zone, cylinder regulator, and valves become deteriorated to lead leakage. Others are failure of gas ranges and/or hoses. Main factors causing user's carelessness are misconnection, and butane-can overheating; gas appliances are not tightly connected during installation or removal; fuel butane-can could be overheated by radiant energy from too large kitchen ware being heated on portable gas range. Others are external impact, unignited release, hose disconnection, and valve misopening; cylinder upset during children's play; LPG being released from burner through nozzle not having been ignited; hose disconnected by external impact; valve open by error. Main factors causing defective installation are misplugging, boiler, and pipe/connection; hose or pipe ends not properly finished or plugged on removal of gas appliances; boilers not properly installed or operated to lead suffocation or boiler explosion; leakage from pipe and/or valve connection. Others are miscoupling; appliances are not correctly coupled to pipe or hose on installation. Additionally, gas appliances are installed by unskilled workers, or pipes are clogged by materials or damaged by other work. Attention should be paid to misconnection and misplugging since only little decrease was observed.

1-2. Analysis of Accident at Restaurant Business

As described in Table 2, main factors involved with user's carelessness are misconnection, butane-can overheating, and unignited release. Others are poor vents, regulators, and connection leakage; boiler vent cracked or not rightly installed; improper installation of regulator and connection part leading to leakage. Main factors causing defective installation are misplugging and pipe/connection. Others are external impact and cylinder upset; radiant energy from neighboring fire could damage hoses or cylinders; cylinder upset to rupture regulator and/or valve leading to leakage. Main causes of appliance failure are regulators, valves, and LPG cylinder; malfunctions lead to leakage. Others are butane cans and burners, which sometimes malfunction, leading to leakage. Additionally, gas appliances may be installed by unskilled workers, or pipes are clogged by materials or damaged by other work. Among these, since only a slight decrease was observed, countermeasures should be prepared for the following causes: misconnection, butane-can overheating, unignited release, misplugging, and regulator and valve failure.

1-3. Analysis of Accidents at Apartment Residences

As described in Table 2, the main factors causing appliance failure are welding, regulators/valves, and burners; welding zones, cylinder regulators, valves, and burners become deteriorated resulting in leakage. Others are ignitor malfunction and clogging; gas released unignited; hoses or pipes clogged by alien substances. Main factors causing defective installation are misplugging, pipe/connection, and boiler. Others are hose or pipe disconnection. Main factors causing user's carelessness are misconnection; external impact, unignited release, and valve misopening. Additionally, supplier's carelessness took a considerable part, most of which was miscoupling. Attention should be paid to misplugging and miscoupling since only little decrease was observed. Other causes include gas appliances being installed by unskilled workers, or pipes are clogged by materials or damaged by other work.

1-4. Analysis of Accidents at Supply Facilities

As described in Table 2, main factors causing accidents are transportation, poor facility, and human error; LPG tank lorry overturning while transporting; multiusers supply pipe or regulator causing trouble; misplugging by human error. Others are vehicle collision and ground sinking.

2. City Gas Accident Analysis

As shown in Table 3, the trend of city gas accidents showed a much simpler pattern than LPG. Unlike LPG accidents, accidents at restaurants do not consist the main part, taking up only 2.1%, while accidents at a supply facility took up 39.0%. Individual and apartment residences showed a similar pattern in accident cause, *i.e.*, defective installation and appliance failure are main cause.

2-1. Analysis of Accidents at Individual and Apartment Residences

As described in Table 3, main factors causing defective installation are misconnection, boiler, and vehicle collision; gas appliance not rightly connected during installation; boiler installed wrongly, leading to poisoning by carbon monoxide; vehicle colliding with outdoor pipe line. Other accidents are caused by poor installation of packing, flange, union, and/or elbow. Main cause of appliance failure is a boiler that is not properly installed or operated, which leads to suffocation or boiler explosion. Others are malfunctioning of gas ranges, ignitors, and regulators. Clogging or contamination of filter sometimes occurred. Additionally, user's carelessness and unignited release took some part of consuming facilities' cause.

2-2. Analysis of Accidents at Piping Networks

Most of the accidents at a supply facility occur at the supply piping network (up to 87.0%). The piping network could be damaged in construction, deterioration, ground sinking, vehicle collision, and sand blast; gas pipes damaged or punctured on the way of third-party work such as water work, drainage work, and/or electric work; gas pipes corrode by deterioration; ground sinks on external impact such as third-party work; vehicles collide with outdoor pipe line.

Table 3. City gas accidents in detail between 1996 and 1999

Cause	Cause in detail	'96	'97	'98	'99	Subtotal	Total	Total
Defective installation	Misconnection	17	13	4	1	35	90	120
	Boiler	12	13	4	4	33		
	Vehicle collision	11	5	6	0	22		
	Others (Packing, Flange, Union, Elbow)						30	
Appliance failure	Boiler	12	7	8	2	31	39	50
	Others (Gas range, Igniter, Regulator, Clogging)						11	
Consuming facilities' others (User's carelessness, Unignited release)								71
Piping network	Damage under construction	39	21	16	7	83	130	147
	Deterioration	16	5	2	1	24		
	Ground sinking	4	2	1	0	7		
	Vehicle collision	1	4	2	1	8		
	Sand blast	6	2	0	0	8		
	Others (Regulator, Valve box, Governor)						17	
Supply facilities' others (Safety valve, Clogging)								22
Others (Restaurant business, Factory, Crowded building, School)								11

Other accidents are caused by malfunction of regulators, valve boxes, and/or governors. Additionally, safety valves malfunctioned and led to venting, or clogging or contamination of filter.

SUGGESTION OF COUNTERMEASURES TO REDUCE ACCIDENTS

Countermeasures are suggested to prevent or reduce accidents which have the largest number or haven't decreased remarkably. Also suggested are ways to manage gas accidents for further study; every item that has to be included in an investigation report; uniform and patterned terminology to describe incidents; more accurate and systematic handling of related data such as inspection results, dissemination rate of safety device and volumetric supply system.

1. Suggestion on Installation and Appliance

LPG was supplied to end-users mostly by a cylinder until February of 1997. In order to improve the LPG supply system, a volumetric supply system was suggested and under enforcement from February of 1997. By September of 2000, only 15.7% of LPG end-users had been changed to the volumetric supply system, reflecting the slight decrease in LPG accidents at individual and apartment residences together with restaurant businesses. It has been reported that the rate of accident decrease shows an S-shaped curve with rate of facility improvement; it varies slowly at the beginning and near the end point, while it varies rapidly in the middle [The High Pressure Gas Safety Institute of Japan, 1995]. Therefore, the volumetric supply system, known to be better-equipped than a cylinder supply system, should be disseminated more actively. Safety devices such as multifunction gas meters which function not only as metering but also for shutting down in case of a sudden increase of the gas flow, should be disseminated. Poisoning by carbon monoxide could occur by wrong installation of a gas boiler. In order to prevent such accidents, a database is being prepared including installer's information. Also recommended actively is self-checking to user's installation by LPG sellers and suppliers.

Since it has been reported that number of accident decrease with dissemination of multifunction gas meter in Japan, it is recommended that safety device such as multifunction gas meter should be disseminated more actively [The High Pressure Gas Safety Institute of Japan, 1995].

2. Suggestion on Campaign

A targeted campaign is suggested for users, restaurant businesses, LPG sellers, and LPG tank lorries, respectively. For gas appliance users, the following campaign is recommended: a campaign to prevent accidents by misconnection, carelessness, and misplugging especially at movement season. That is, the right installation of a gas boiler could prevent poisoning by carbon monoxide; self-checking of leakage to their own installation such as hose and/or pipe and its connection is recommended. For the restaurant business, a campaign is required to prevent accidents by careless treatment of burners. LPG sellers should be trained well to prevent misconnection and misplugging during installation of LPG cylinders.

LPG tank lorry drivers should be trained to be very careful when driving to prevent turnover of their trucks.

3. Suggestion on Accident Management

It is strongly recommended that the accident management system should be reformatted. Accidents should be classified by their hierarchy in order to be managed more systematically. Checking and inspection results should be computerized into a database for easy handling and maintenance. Activities to reduce accidents such as rate of volumetric supply system and safety device dissemination should be quantified to induce accident reducing goals.

Focused countermeasures are prepared on main causes of accidents showing little decrease or increase in number: as shown in Table 1, user's carelessness and defective installation at restaurant business; appliance failure and supplier's carelessness at apartment residence.

Table 4. Comparison of hierarchical analysis with conventional analysis of gas accidents in detail between 1996 and 1999 in Korea

Classification		Hierarchical analysis	Conventional analysis
Gas accident type	Facility	Main cause	Main cause
LPG Accident	Individual residence	Appliance failure Defective installation User's carelessness	Defective installation User's carelessness Appliance failure Supplier's carelessness
	Restaurant business	User's carelessness Defective installation Appliance failure	
	Apartment residence	Appliance failure Defective installation User's carelessness Supplier's carelessness	
	Supply facility	Transportation Poor facility Human error	
City gas accident	Apartment/ Individual residence	Defective installation Appliance failure	
	Supply facility	Piping network	

SUMMARY

Fuel gas accidents such as LPG accidents and city gas accidents have been analyzed, and targeted countermeasures were suggested. Conventional classification of gas accidents is not hierarchical. All accidents are classified by characteristics of the facility to which gas serves in order to be analyzed. Then all accidents are classified plainly by type of residence or business where gas was consumed, and how the accident occurred.

Therefore, unspecific and untargeted countermeasures were introduced because of the plain analysis. For example, according to the conventional analysis, main causes of accidents were defective installation (26.9%), user's carelessness (21.0%), appliance failure (19.4%), supplier's carelessness (13.9%) regardless of characteristics of facility and type of residence or business where gas was consumed. In contrast, hierarchical analysis shows more specific results, which helps to suggest more targeted countermeasures. For individual and apartment residences using LPG, appliance failure is the most dominant cause, while defective installation is the most dominant cause for those using city gas. The pattern of restaurant business accidents for an LPG facility is quite different from that for a city gas facility, *ie.*, as shown in Table 1, accidents of restaurant businesses for LPG took a considerable part, and attention should be paid to user's carelessness and defective installation, while that for city gas consisted of a minor part. However, conventional analysis did not consider such differences and analyzed all accidents occurring at all facilities at the same time.

As a result, much better targeted countermeasures were introduced by hierarchical analysis, which has probably contributed to reducing gas accidents.

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