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A Summary of Accidents Related to Non-Nuclear Energy

United States Environmental Protection Agency
Office of Research and Development
Office of Energy, Minerals and Industry

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Foreword

This report is based on a study of Accidents and Unscheduled Events Associated with Non-Nuclear Energy Resources and Technology. The study was sponsored by the Environmental Protection Agency under the guidance of Dr. Stephen J. Gage, Deputy Assistant Administrator of the Office of Energy, Minerals, and Industry. The study was performed in support of the Committee on Nuclear and Alternative Energy Systems of the National Academy of Sciences. The Committee is studying the energy future of the United States from 1980 to 2010 for the Energy Research and Development Administration.

The Purpose of the study is to assist the American people and the legislative and executive branches of government in formulation of an energy policy, by pointing out the nature of the choices the nation may wish to keep available in the future and by listing the actions and research and development programs that may be required to do so.

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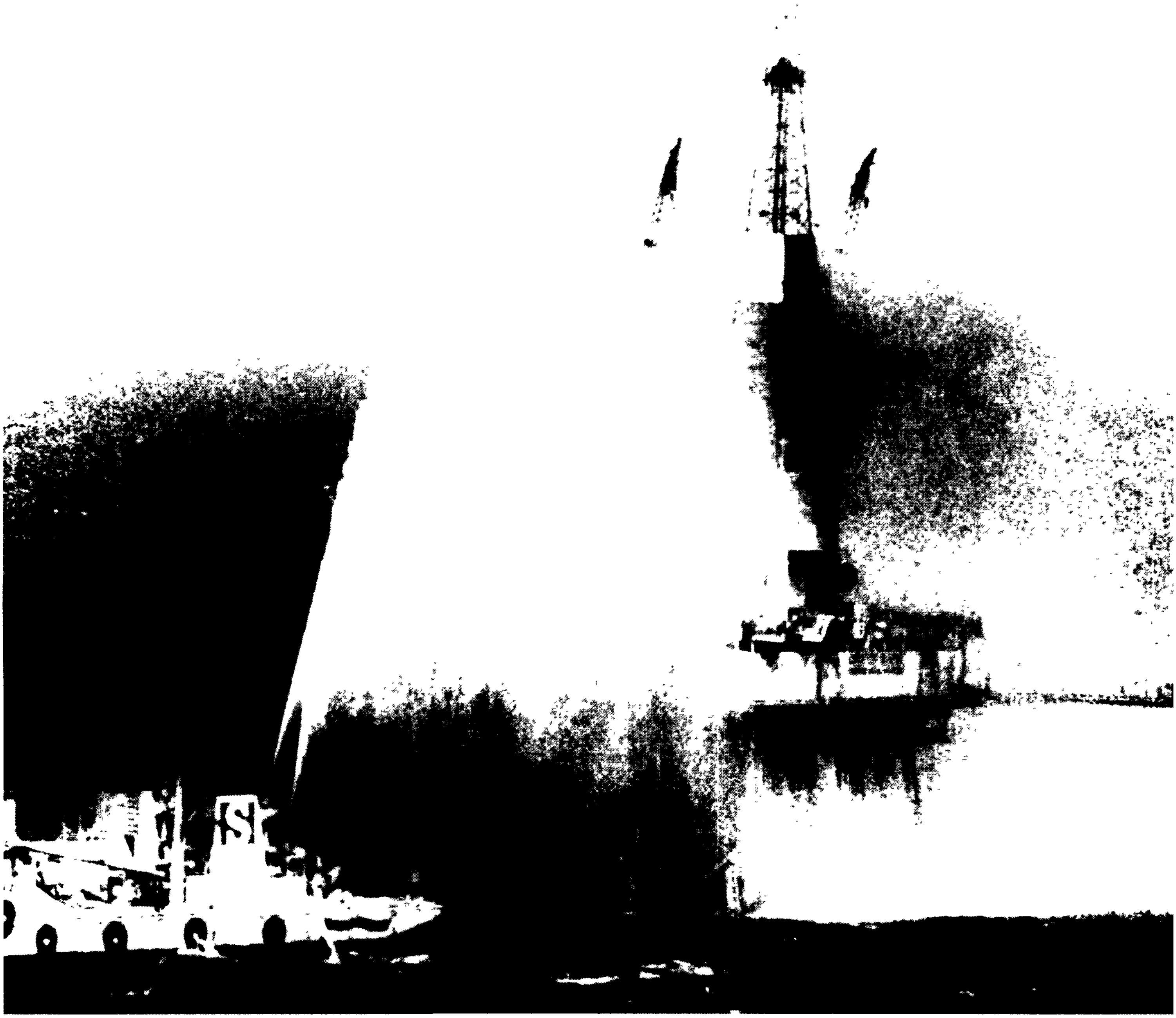


UPI PI

Norwegian fireboat pours water on oil platform to contain a 4,000 ton-a-day oil spill in the North Sea. April, 1977 (UPI)

Introduction

At present, various means of reducing U.S. dependence on foreign energy sources have been investigated in the United States. Most of the discussion has concerned availability of various energy resources, availability and cost of technology, and environmental effects.

Among those systems which have received much attention is nuclear energy. Nuclear energy could supply a significant part of the nation's electrical energy needs. Safety concerns, however, have proven to be a major impediment to the development of nuclear energy.

In order to choose intelligently among the energy alternatives available, the safety of using non-nuclear energy resources must be considered. Although some hazards such as oil spills and coal mine explosions have received significant attention from the public and the regulatory agencies, no comprehensive assessment similar to that performed for nuclear energy exists concerning the safety of developing non-nuclear resources.

The first step in the assessment of the hazards of non-nuclear systems is a compilation of existing accident data. A report entitled *Accidents and Unscheduled Events Associated with Non-Nuclear Energy Resources and Technology*,[1] has been prepared in an effort to summarize available information on this subject. This paper summarizes the findings of that report. Numbers in parentheses refer to sections and pages in reference 1. Accidents or unscheduled events, whether natural or human-made, are considered. However, emphasis is placed on major accidents or minor accidents which have a cumulative major effect.

The availability of accident data for analysis is greater for well developed technologies such as oil, natural gas, and coal than for those systems in the developmental stage. Nevertheless, similarities between developing technologies and existing technologies and risk analysis studies provide a basis for comparison. Energy systems considered are coal, crude oil, natural gas, liquified natural gas (LNG), hydroelectric, oil shale, geothermal, and solar. Accidents in each energy cycle element (exploration, extraction, processing, transportation including transmission and distribution, and end use technologies) are considered. Excluded from consideration in this report are environmental effects or threats to human health, safety, or property resulting from normal operations. Impacts of normal operations such as instances of black lung disease in the coal mining industry must, of course,. be considered in choosing among available energy development options.

There are two major factors which make comparison of the accident potential of energy systems difficult. The first factor is the difference in the bases among systems from which accident predictions are made. Historical data provide the basis for established systems but for newly developing systems risk analyses and modelling must be performed to arrive at accident predictions. The second factor is the lack of a consistent system of reporting accidents. However, based on the best available estimate, there are probably a significantly greater number of deaths and injuries associated with the coal resource system per megawatt delivered than with the crude oil or natural gas system. The annual deaths and injuries associated with coal, oil, and gas fired electricity systems for a 1000 megawatt power plant are shown in Table I. Fatalities and injuries associated with the coal industry are an order of magnitude greater than those associated with the oil and natural gas industries.

TABLE 1

ANNUAL DEATHS AND INJURIES BY ENERGY SOURCE FOR A 1000 MEGAWATT POWER PLANT WITH A LOAD FACTOR OF 0.75

(PER UNIT ENERGY)

	COAL		*CRUDE OIL*			*NATURAL GAS*
	DEEP	*SURFACE*	*ONSHORE*	*OFFSHORE*	*IMPORT*	*TOTAL*
Fatalities	4.00	2.64	0.35	0.35	0.06	0.20
Injuries	112.30	41.20	32.30	32.30	5.70	18.30

Coal

Summary

Underground coal mining is more dangerous than surface mining with an injury frequency rate four times greater than surface coal mining.

Most people would identify fires and explosions as the most severe mining disasters. This is largely due to the sensational nature of such events and extensive news media coverage. In fact, fires and explosions account for only 10-12% of the annual fatalities. The majority of fatalities (50%) are caused by roof, rib, and face falls in underground mines.

In the developing technologies such as coal gasification and liquefaction systems, safety aspects must be considered in order to make intelligent decisions as to which technologies could most safely provide the needed energy. However, no historical data are available for these new technologies and extrapolations of accident rates can only be made from similar existing technologies.

TABLE II

COAL MINING ACCIDENT RATES

	Disabling Injuries/ Million Employee-Hours
Underground Coal Mining	35.0
Surface Coal Mining	10.0
Overall Industry Average (All member companies of National Safety Council)	9.8

Historically, coal mining has been a dangerous occupation. The threat to personal safety depends upon the extraction technique, location of the mine, the activity and location of the miner, experience of the mining crew, and equipment used. However, statistics show that underground coal mining is more hazardous than surface mining (Sec. 3.2.2, p. 46). National Safety Council data confirming this are presented in Table II. The percentage and kinds of accidents occurring in coal mining are presented in Table III.

Although fires and explosions are often emphasized by the news media, only 10-12% of the annual mining fatalities are attributable to these causes. Also, due to better safety regulations the number of miners killed annually in mine explosions has been steadily decreasing (Sec. 3.2.2 p. 58). Roof, rib and face falls account for the majority of accidents (50%). Surface mining accidents are approximately equally divided among fall of highwall, haulage truck operations, front-end loader operations, and electrical system malfunctions. Recently, there has been increased concern about the danger presented, by detonation of charges, to the surrounding population. These people may experience reverberations and possible home damage.

Transportation accidents account for 10-15% of mining fatalities. In underground mining operations, hauling is the most dangerous function. Although such accidents are not frequent, they are severe. Coal is transported to the consumer via rail, trucks and slurry pipelines. These three rank from most to least dangerous in terms of fatal injuries per 10^{12} BTU* equivalent tons shipped as follows: railroads are most dangerous at 0.06 followed by trucks at 0.032 and slurry pipeline at 0.0019[1] (Sec. 3.2.4 p. 64).

Remaining accidents involve processing/beneficiation and reclamation operations including subsidence of underground mines and collapse or combustion of refuse piles used as dams (Sec. 3.2.5 p. 66).

*This amount of energy is equal to that required to run a 1000 MW power plant for approximately 300 hrs, or to that needed to heat approximately 5000 homes for one season (October through April) in a temperate climate.

TABLE III
TYPES OF COAL MINING ACCIDENTS

Accident	*Percentage (%)*
Underground (total)	80
Roof, rib, and face falls	50
Fires and explosions	10-12
Transportation (coal haulage)	10-15
Surface (total) (Fall of highwall, equipment misoperation, electrical system malfunctions)	20

Crude Oil

Summary

Oil spills are the most frequent accident. Seventy-five percent of human-related spills come from vessels. However, of the total amount released, fifty percent comes from uncontrollable non-point sources.

The release of oil itself does not constitute an immediate hazard to human life. The greatest damage is to ecological systems. This damage may not be permanent, and many areas that have suffered from an oil spill appear to have recovered within three to four years. However, longer term ecological disruptions also have been observed.

Transportation of oil via tankers accounts for a greater number of fatalities and injuries annually than transportation of oil via pipeline. Pipeline accidents number approximately 135 per year, and cause approximately one fatality and one injury per year. Tanker accidents number approximately 640 per year and cause approximately 75 fatalities and 35 injuries per year.

Tanker spill rate does not appear to depend upon size of tanker or age of tanker, but mainly upon the number of voyages.

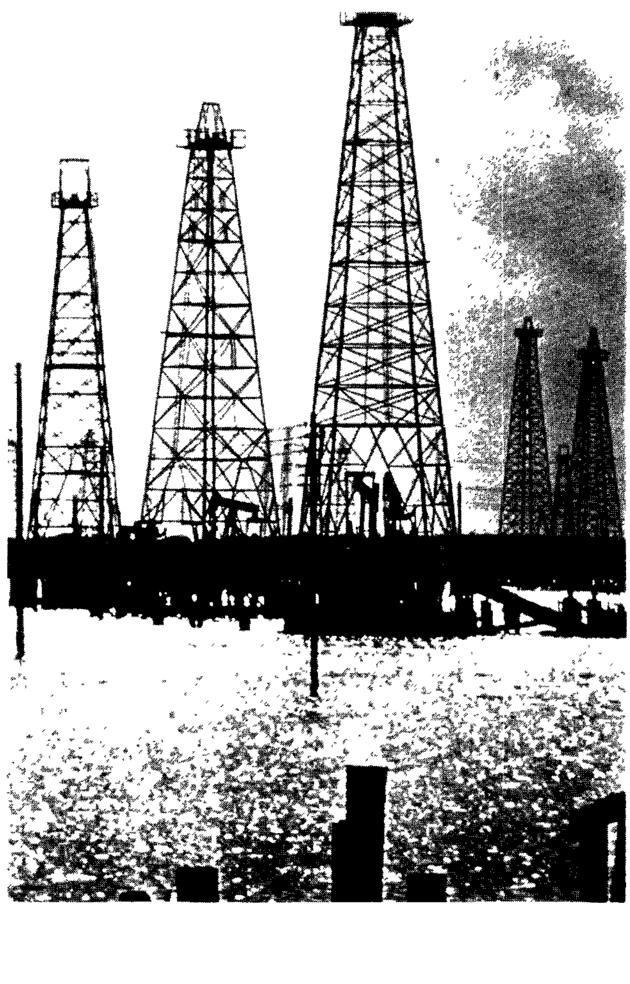
The relative merits of developing offshore oil and gas reserves versus the continued or increased importation of foreign oil and gas depends in part on safety considerations. Safety estimates as to the importation of oil can be derived from tanker accident statistics of the past. Without proper regulation the use of super-tankers may cause an increase in accident rates. Transportation of offshore oil by tanker will probably involve a greater frequency of spills than transportation by pipeline. Safety records of offshore production facilities indicate that offshore operations are safer than onshore operations. However, the increased exploration and use of deep-water areas and areas which are prone to seismic activity and extreme weather changes may cause an increase in the accident rates. Table IV summarizes the accident data available for the oil industry.[2]

TABLE IV

OIL INDUSTRY ACCIDENT DATA

	Accidents/ year	*Fatalities/ year*	*Injuries/ year*
Shipping	636	76	37
Blow-outs	11	*	*
Offshore rigs	5	6	*
Pipelines	135	1	1
Refineries	*	3	5915
	*	1	8155

*Unknown



Contributions of various sources of oil to the oceans are shown in Table V.[3] Uncontrolled non-point sources such as runoff and natural seeps contribute as much as accidents within the oil industry. Of industry-related spills, transportation is responsible for more than half.

Seventy-five percent of oil spills involve vessels. From 1969 through 1973 there were 3,183 shipping accidents. Three hundred eighty-one fatalities and 178 injuries resulted from these accidents. Collisions and groundings accounted for about half of the accidents and 44% of the outflow. Structural failures accounted for 16% of the accidents and one third of the outflow. The median size of a spill was 25,000 bbl. Spills usually occurred within 10 miles offshore and the median duration of a spill was seventeen days[2] (Sec. 4.2.1 p. 80).

TABLE V

SOURCES OF OIL IN THE OCEANS

SOURCE	*ESTIMATED CONTRIBUTION (TONS/YR)*	*(%)*
Transportation	2,350,000	34.9
Tankers, Dry Docking, Terminal Operations, Bilges, Accidents		
Coastal Refineries, Municipal and Industrial Waste	875,000	13.0
Offshore Oil Productions	87,500	1.3
River and Urban Runoff	2,100,000	31.2
Atmospheric Fallout	660,000	9.8
Natural Seeps	660,000	9.8
TOTAL	6,732,500	100.0

Blow-outs and well-casing ruptures are other sources of oil spills. The National Petroelum Council reported 106 blow-outs in drilling 273,000 wells in the 1960-1970 decade.[2] Fires may ensue and uncontrolled seepage of oil may continue for several months afterwards (Sec. 4.2.1 p. 91).

Besides causing injury and loss of life to persons in the vicinity, oil spills (both inland and offshore) also cause ecological damage. The extent of such damage depends upon the volume, composition and toxicity of oil spilled, effects of weathering, marine transport, existing ecosystems, physiography, and clean-up operations employed. Effects of a spill on estuarine or marine environments include immediate death to indigenous organisms such as fish, clams, snails, and crabs, disruption of feeding, reproduction, orientation, and migration patterns of marine organisms, incorporation of carcinogenic compounds into the food chain, and alteration of habitat so as to force relocation of species. Also, large numbers of sea birds may be killed by physical coating of feathers. Potable water, irrigation, and industrial water supplies may also be threatened. (Sec. 4.2.1.2 p. 92).

The length of time required for an area to recover from the effects of an oil spill cannot be specified. Some believe there are few long term effects; others believe permanent ecosystem disruption can occur.[4] However, the time for recovery is dependent upon volume and kind of oil spilled, meteorological conditions, and clean-up measures. A study of several areas showed that recovery was underway 6 months after the oil spill and nearly complete 3 years after the oil spill.

Since 1955 there have been 100 accidents involving offshore rigs, each with losses exceeding $500,000. There were 121 fatalities. Jack up platforms are the type most susceptible to failure. Major causes of accidents are moving of rigs and storms (Sec. 4.2.3 p. 102).

In 1975, 135 oil pipeline accidents caused approximately $3.2 million in property damage, the loss of one life, one injury, and spillage of 105,871 barrels of oil. Pipeline accidents are caused by equipment rupturing lines, internal and external corrosion, structural defects, human operating errors, vandalism, and adverse natural events (Sec. 4.2.4 p. 105).

Refinery accidents involve fire and explosions. Sources (API and National Petroleum Refiners Association) differ as to the number of accidents in 1975. One indicates there were 5,915 injuries and 3 fatalities. The other says there were 8,155 injuries and 11 fatalities.

Hydrorefining units have the greatest potential for accidents. Losses for 1965-1969 are summarized in Table VI. Of these units, hydrocrackers have the worst accident record. Since 1970 hydrocracker losses have averaged more than $1,000,000 per year.

Secondary problems associated with refinery accidents are oil spills and air pollution problems. Release of carbon monoxide, sulfur dioxide, oxides of nitrogen, hydrocarbons, and particulates may cause illnesses (Sec. 4.2.7 p. 117).

TABLE VI

ACCIDENT LOSS SUMMARY FOR VARIOUS PROCESSES, 1965-1969

Process	*Loss Summary No. of Accidents*	*1965-1969 Total Amount of Losses*	*Approximate Average Loss*
Catalytic Cracking	32	$3,308,000	$103,000
Catalytic Reforming	59	3,134,000	53,000
Hydrocracking	19	6,402,000	337,000
Crude/Vacuum Units	57	1,366,000	24,000

Natural Gas and LNG

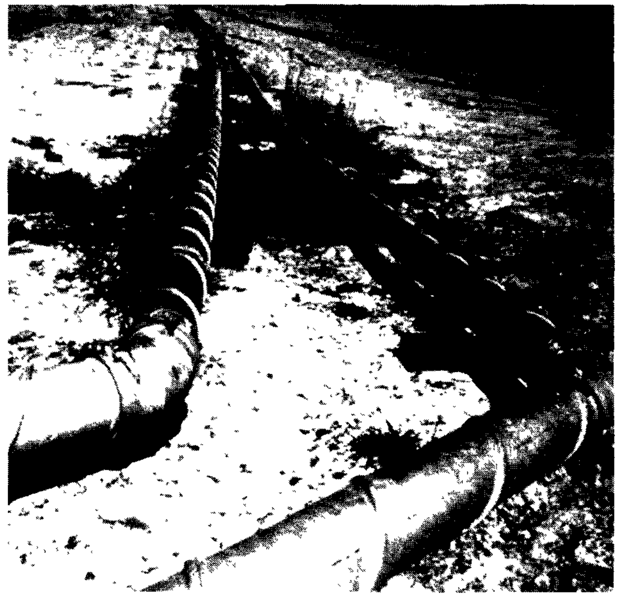
Summary

Since natural gas and oil often occur together, extraction and processing technologies are similar. Therefore, the accidents identified in the oil section related to these technologies are the same for natural gas.

More members of the public than employees are injured or killed by natural gas pipeline accidents. This is because pipelines transect residential, industrial and commercial areas.

If natural gas reserves are exhausted in the United States, alternative domestic resources must be exploited or natural gas must be imported. Importation of natural gas currently necessitates its reduction to the liquid state. The transport of liquified natural gas (LNG) is a subject of controversy and safety aspects in the transportation and storage of LNG are paramount. Hazards stem from its cryogenic nature requiring maintenance of extreme temperatures.

Limited data on LNG transport and storage make evaluation of risk difficult. Risk analyses are highly site specific and different models use different assumptions. Consequently, estimates of risk at specific sites differ by several orders of magnitude.



Since oil and natural gas are frequently found together, extraction and processing accidents involving one also involve the other. Therefore, the types of accidents identified in the oil section related to these technology steps are the same for natural gas. Blowouts of wellheads during the drilling of exploratory and production wells, release of sulfur compounds during processing, and failures of pipelines due to corrosion or outside forces comprise the bulk of the accidents occurring from this energy source. Table VII summarizes the accident data available for the natural gas energy system:[5]

Pipeline distribution accounted for the greatest number of injuries per 10^{12} BTUs.[5] Accident rates for offshore extraction, gathering, and processing are an order of magnitude lower. Onshore extraction accounted for the greatest number of fatalities per 10^{12} BTUs.[5] Drilling operations were responsible for the highest frequency of disabling injuries at 48.93 accidents per million man hours worked (Sec. 5.2 p. 127).

Processing accidents are those occurring during the separation of oil and gas and the removal of impurities. One of the greatest problems is removal of the highly toxic gas hydrogen sulfide. In 1975, gas processing was responsible for 921 injuries and 3 fatalities (Sec. 5.2.3 p. 137).

Almost all pipeline accidents can be attributed to corrosion, damage by outside forces, construction defects, or material failure. The Eighth Annual Report of Pipeline Safety summarized gas pipeline accidents during 1975 by distribution and transmission and gathering categories. This is shown in Table VIII.[6] With a total of 1,373 failures this amounts to 0.01 fatality per failure and 0.11 injury per failure. Pipeline transportation poses a significant hazard to the general public because pipelines transect residential and commercial areas (Sec. 5.2.4 p. 137).

TABLE VII

NATURAL GAS ACCIDENT DATA

Technology	*Fatalities/10^{12} Btu*	*Injuries/10^{12} Btu*	*Fatalities/year*	*Injuries/year*
Pipeline distribution	0.000040	0.0138	8	220
Extraction				
offshore	0.000007	0.0030	—	—
onshore	0.000080	0.0040	16	—
Transmission and gathering	0.000006	0.0010	6	17
Processing				
natural gas liquid	0.000040	0.0040	3	921
hydrogen sulfide	0.000002	0.0020	—	—

TABLE VIII

PIPELINE ACCIDENT DATA—1975

Mode	*Non-Employee Injuries*	*Non-Employee Fatalities*	*Employee Injuries*	*Employee Fatalities*
Distribution	191	8	29	0
Transmission and Gathering	9	1	8	5
Total	200	9	37	5

Liquified natural gas, LNG, is composed primarily of methane (95%) with small impurities of light hydrocarbons. The technology for reducing gaseous methane to the liquid phase has been known for several decades. It has been used since the 1940's for storage purposes. There are now 23 liquefaction plants, 49 operational peak shaving plants, and 49 satellite storage facilities in the United States.

Recently there has been increased interest in transporting natural gas in this form across the seas. Liquefaction is desirable because liquified methane occupies only 1/600 of its gaseous volume and large quantities can therefore be transported. Currently, there is only one functioning LNG terminal in the United States. It is located in Everett, Massachusetts and operated by DISTRIGAS. Several terminals are in the planning and early approval stages. Alaska, California, the Gulf of Mexico and Mid Atlantic states are the most likely sites (Sec. 6.1 p. 150).

There exist no accident data on transport of LNG via tanker and only four accidents are known to have occurred at LNG storage facilities. Consequently, there exists an inadequate data base from which to predict frequency and severity of accidents. Caution generally has been exercised by those individuals responsible for approving construction on LNG terminals. This is due in part to questions concerning the need for LNG and the potential for a catastrophic accident.

The most severe accident occurred in Cleveland, Ohio in 1944. A large storage tank containing 38,000 barrels of LNG collapsed because of brittle fracture. A spreading pool fire resulted. The burning pool flowed into the surrounding community. The fire and resulting explosions killed 130 people, injured 300, and caused property damage of $10,000,000. The likelihood of an accident caused by brittle fracture recurring is very low because of the development of materials able to withstand the extreme cold of cryogenic temperatures.

Three other accidents involved LNG storage facilities. In February 1973 an empty LNG storage tank on Staten Island exploded and burned. Forty workers died. The explosion was attributed to ignition of trapped vapors by a welder's torch. In Oregon, a tank exploded during construction before LNG was introduced. Four workers died. Investigators attributed the accident to careless work practices. In 1972, gas leaked through an air line to the control room of an LNG plant in Montreal, Canada. A large fire resulted.

Besides failure of a storage tank, those accidents which are considered to have the greatest potential for harm are collisions of tankers at sea where the contents of one or two LNG tanks are released. (The average tank size is 37,500 cu. m.).[7] Minor accidents include release of refrigerants, solids blocking the transfer pipeline, malfunctions onboard tankers, leaks in the transfer system, and maintenance accidents.

Since a sufficient body of historical data does not exist, risk analyses have been performed to determine the probabilities and consequences of accidents involving LNG terminals. Three studies are presented which considered three sites—Los Angeles, Oxnard, and Point Conception, California. The models were developed by the Federal Power Commission (FPC), Science Applications, Inc. (SAI), and the El Paso Alaska Company (EAC). The differences in risk estimates are the results of different assumptions and modelling procedures. These risk estimates apply only to the sites for which calculations were made. The risk of fatalities at other sites may be substantially different (Sec. 6.3 p. 165). Results appear in Table IX. Estimates range from one fatality in 10,000 years to one fatality in 1,000,000,000 years.

TABLE IX

LNG RISK ANALYSIS—MILLION YEARS PER FATALITY

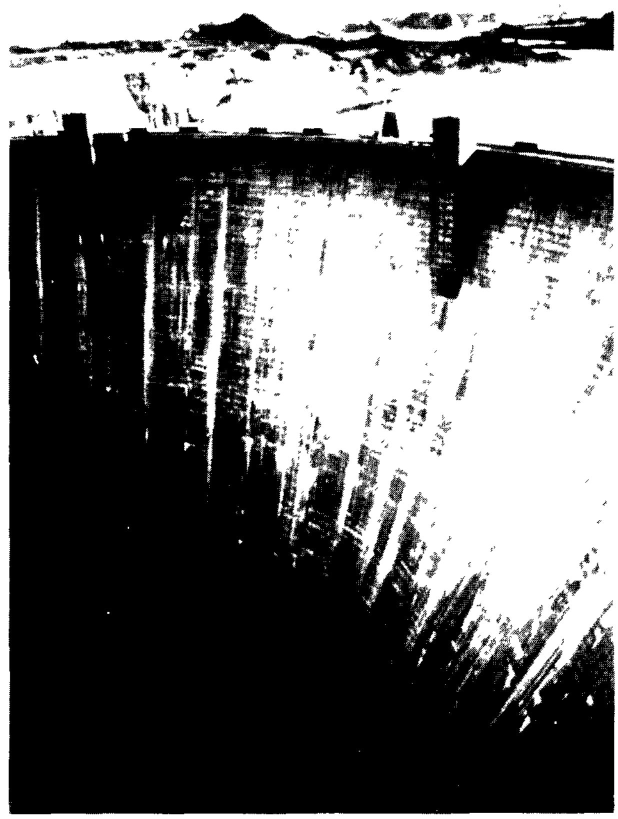
	Los Angeles		*Oxnard*		*Pt. Conception*	
Model	*Marine*	*Terminal*	*Marine*	*Terminal*	*Marine*	*Terminal*
Federal Power Commission	—	0.01	1	—	0.1	—
Science Applications, Inc.	10	10.00	100	10	1000.0	10
El Paso Alaska Company	—	—	—	—	100.0	—

Hydroelectric and Other Electric Power

Summary

Hydroelectric power is the safest method of power generation. However, this resource is capable of supplying only 25% of the nation's requirements. Although only one failure has occurred of the more than one thousand operating hydroelectric dams in the United States, 11 lives were lost and more than $1 billion of property damage occurred. Failures of other dams could have similar consequences. Consequently, there is a need to examine the potential for failure of other hydroelectric dams.

Utilities rank tenth in frequency of injuries among all industries. In terms of frequency of accidents the following ranking occurs: oil> coal> hydroelectric> nuclear.



In 1974 hydroelectric facilities generated about 16% of the electricity used in the United States. The North Pacific area accounted for more than one-third of the United States capacity. If the source were developed to its full potential, it could supply about 25% of the nation's present electrical needs.

Although more than a thousand dams supply hydroelectric power in the country, only one failure has occurred. This was the Teton Dam in Idaho which failed in June 1976. The breaching caused $1 billion in damage, caused 11 deaths and killed 13,000 cattle. The Department of Interior determined that the cause of the failure was improper design. A study of thirteen problem dams has been initiated (Sec. 7.2 p. 178).

Other possible causes of dam failure are undermining caused by erosion, forces exceeding design for water pressure, ice pressure, earth pressure, and earthquake forces. A severe loss of water without dam failure can occur through seepage.

The estimated effects of damage in terms of fatalities and monetary losses upon the failure of selected dams appears in Table X.[8] Fatalities could reach hundreds of thousands and monetary losses approach hundreds of millions of dollars.

Within the hydroelectric plant several types of accidents can occur. The most serious would be plant inundation caused by conduit failure, extreme river flow or conventional openings within equipment, resulting in failure of turbine and damage to the electrical circuits and generator.

Personnel accidents involving construction, maintenance, and normal operations are the most frequent. A survey of four types of power plants (coal, oil, hydroelectric, and nuclear) indicates that for hydroelectric plants, the occupational injuries occur at approximately one-half the frequency and one-tenth the severity associated with all electric generating plants. The survey, covering 1969-1972 reported 4.1 disabling work injuries per 1 million employee-hours exposure.

Approximately 25% of the total energy consumed today is used for electric power generation. By the year 2000 it is expected that this figure may increase to 40%.[9] Electricity production from all energy sources in 1974 totaled 1.86 x 10^{12} KWh_e and the projection for 1990 is 4.7 x 10^{12} KWh_e. In 1974, coal provided 44.5%, oil provided 16.0%, gas provided 17.2%, hydroelectric power provided 16.1%, and nuclear power provided 6.0% of the electric power generated in the United States.

Data on accidents associated with electrical power generation are sparse. Federal Power Commission (FPC) regulations require accidents be reported only in the case of a power outage. Thus, accidents in which power is maintained but which cause death or injury would not be reported.

A serious accident which can occur at a boiler-fired plant is explosion of the boiler. Operation at elevated temperatures and pressures increase the chances of this happening. Fires and explosions can also occur in the

TABLE X

ESTIMATED EFFECTS OF TOTAL FAILURE OF DAM FILLED TO CAPACITY

	*FATALITIES**		
NAME	*DAY*	*NIGHT*	*DAMAGE IN U.S. DOLLARS*
Van Norman Dam	72,000	123,000	300,000,000
San Andreas Dam	21,000	33,000	110,000,000
Stone Canyon Dam	125,000	207,000	530,000,000
Encino Dam	11,000	18,000	50,000,000
San Pablo Dam	24,000	36,000	77,000,000
Folsom Dam	260,000	260,000	670,000,000
Chatsworth Dam	14,000	22,000	60,000,000
Mulholland Dam	180,000	180,000	720,000,000
Lake Chabot Dam	36,000	55,000	150,000,000
Shasta Dam	34,000	34,000	140,000,000

*No allowance for evacuation.

handling of fuel. Other additional but infrequent accidents that can occur in a boiler fired plant are implosion of the condenser and tube and steam line rupture.

The most severe accidents which may occur at a gas turbine plant are explosion, asphyxiation, and ruptured lines. Explosions can occur in the turbine, compressor, combustor, and recuperator. Asphyxiation may be caused by accidental release of toxic substances such as hydrogen sulfide, carbon monoxide, and coal tar volatiles.

Other accidents which may occur in the generation of electricity include power failure, flooding, electrical fires, and occupational injuries. Power failures cause widespread but minor damage. Customers experience loss of electricity over a wide area. Power failures may be caused by factors internal or external to the power plant. Causes include generator malfunction or line failure caused by lightning strikes, falling trees, ice accumulation, and vehicles striking power poles. Occupational injuries include back strain, electrical burns, steam burns, and shock.

National Safety Council data for 1972 show that, for sampled electric utilities, the frequency rate for fatal and permanent total disability was 0.12 injuries per million person hours exposure. The utilities ranked tenth in the frequency of injuries among all industries. In terms of frequency of injuries (number of disabling work injuries per million employee-hours exposure) the following ranking occurs (1972 data); oil (13.69)>coal (10.8)>hydroelectric (4.1)>nuclear (3.0). In terms of severity of accidents (total days charged for work injuries per million employee hours exposure) the following ranking occurs (1972 data): coal (1950)>oil (461)>hydroelectric (149)>nuclear (43).

In addition to electric power generation, other end uses are transportation and industrial, residential, and commercial use. Transportation accounts for 25% of the energy consumption of the United States. The industrial sector consumes 28% and the residential/commercial use is 23%. Transportation accidents occur frequently and can be considered major. The most common is vehicle collision. Other accidents involve aircraft, motorized farm equipment, and ships. In the industrial sector, fires, explosions, and floods comprise a major proportion of the accidents. Commercial/residential sector accidents are frequent but minor. Most home accidents do not involve the use of energy. However, accidents involving appliances and heating and other equipment can cause injury, damage to equipment, or fire.

Developing Energy Systems

Summary

It is difficult to evaluate developing energy technologies in terms of safety. No operating data exists and extrapolations must be made from demonstration plants or from similar technologies.

The United States has vast deposits of oil shale, but current oil prices have not necessitated their development. The frequency and severity of accidents associated with oil shale development probably will be dependent upon the ratio of open pit to underground mining.

There has been little experience with solar energy systems in the United States. Although most accidents associated with solar energy use are expected to be minor, occasionally major accidents may occur.

Geothermal

The geothermal resources are based on the temperature distribution within the earth, ranging from very high temperatures at the core to mild temperatures at the surface. There is limited operating experience with this energy source, the longest United States experience being 15 years. A major accident which may occur in association with the development of geothermal energy is a blowout causing the release of hot fluids, steam, and other gases found in geothermal fluids. Blowouts may occur during drilling operations or during steady state operations. In the latter situation, the blowout would be caused by structural failure of the cements and casing materials in the well. A blowout can cause the loss of an entire rig with the drill string operator suffering possible injury or death. In the extreme, the ground may suddenly open and the entire rig collapse into the chasm. One type of blowout which occurred at the Geysers was caused by the instability of the formation (an old landslide) through which the well passes. The unconsolidated nature of the landslide allowed the steam to escape into the ground with the potential of eruption when attempts were made to cap the well.

Earthquakes could have a severe impact on a geothermal facility. They may cause pipeline ruptures and well splitting. The latter could cause contamination of potable water supplies. Pressure buildup due to silica precipitation may also cause pipeline leaks or ruptures (Sec. 8.2 p. 194).

Subsidence, a very slow process, is also a possibility. This has occurred at Wairakei, New Zealand where subsidence has totalled 4 meters since 1956. Subsidence can cause damage to buildings and equipment and flooding may occur in low lying coastal areas. Seismicity, a more sudden occurrence, may be induced by injection of spent geofluids. The likelihood and severity of such an event has not been evaluated.

Oil Shale

Oil shales are shales which have a high organic content. The organics are recoverable by pyrolysis at temperatures around 350°C. The United States has vast deposits of oil shale. The government has leased four tracts for development, but at current petroleum prices it is not yet clear that these leases will lead to production before 1985. An assessment of the potential for accident in the oil shale industry must be based on engineering judgment because there is no commercial scale development of oil shale (Sec. 9.0 p. 196).

Roof collapse, blasting accidents, dust explosions, and subsidence during extraction, explosions during processing especially during hydrogenation, pipeline ruptures during transportation, and loss of ground water control due to failure of retaining dams are possible major accidents (Sec. 9.2 p. 202). The accident record of this industry may be dependent upon whether surface or

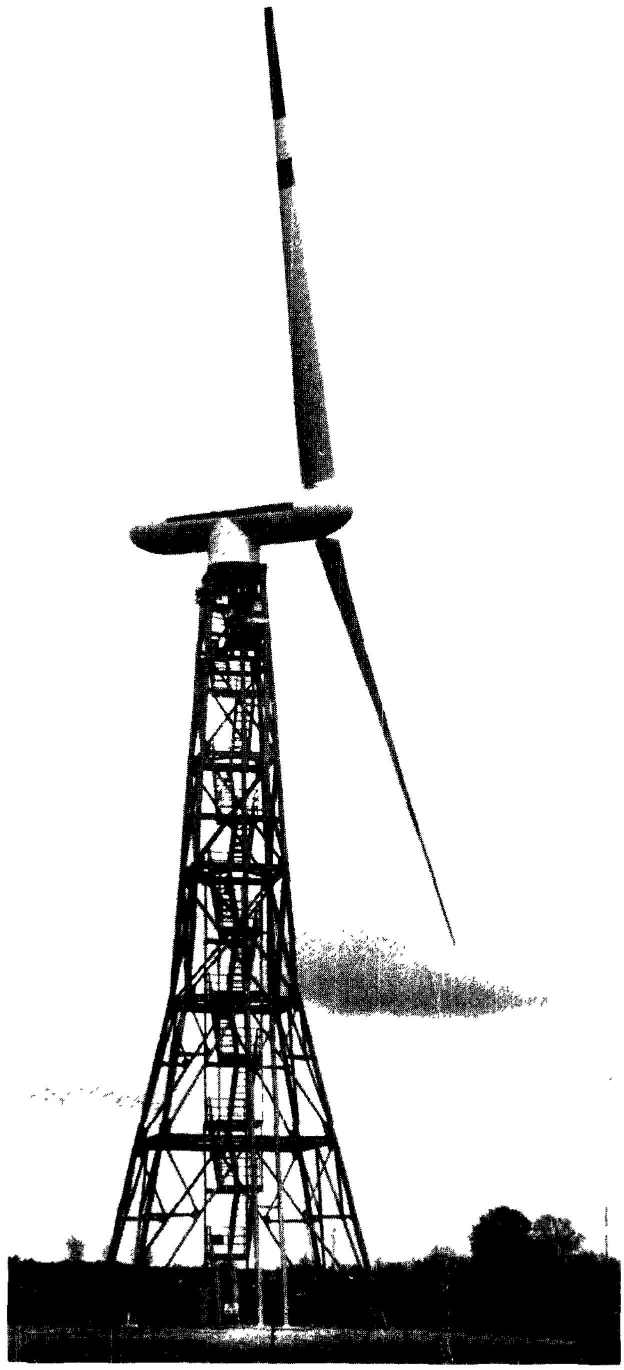
underground mining techniques are used. Both are possible but one cannot predict which will predominate. If open-pit mining should prevail, one study suggests that oil shale accident rates will be more similar to copper mining than to coal mining. Metal mining fatalities in the western states in 1972 totalled 14 and injuries totalled 1331. This amounted to 0.25 deaths/million employee-hours and 24 injuries/million employee-hours. The latter figure is intermediate between the injury rates given for surface mining of coal (10 injuries/million employee-hours) and for underground mining of coal (35 injuries/million employee-hours).

Solar Energy

Solar energy has not yet been used to an appreciable extent because the technologies have not been sufficiently developed and potential users have little experience in utilizing solar-type systems. Four types of solar energy have been considered. They are direct conversion, wind, tidal and wave, and biomass conversion.

The three methods of direct conversion of solar energy are photo-voltaic, solar-thermal, and ocean thermal energy conversion (OTEC). The accidents associated with photovoltaic conversion probably will be minor and infrequent. These accidents will involve solar cell breakage, wire failure, DC/AC converter failure, and electrical fires. Monetary losses associated with solar-thermal accidents may be major if the reflector was damaged or the boiler ruptured. OTEC accidents may be major if transmission pipelines suffer corrosion or if fires or explosions occur during the ocean based manufacture, storage or transport of the oxygen and hydrogen produced. Other possible injuries may result from glare or concentrated radiation. Occupational injuries for solar power are estimated at 0.5-1.6 man-days lost/MWe/year (Sec. 10.2 p. 218).

Accidents associated with wind energy systems include production of air turbulence, broken rotor blades, ice shedding from blades, and possible collapse of the unit as a result of design error, storm, or earthquake. Accidents associated with tidal energy systems may include flooding, structural collapse, control gate failure, and marine ship collisions. Biomass conversion systems may experience accidents such as explosions and fire linked to methane or hydrogen and oxygen production (Sec. 10.2 p. 220).



Adverse Natural and Other Incidents

Summary

Natural disasters cause many hundreds of deaths and billions of dollars of damage annually. Much of the nation's oil and gas resources are located in areas prone to hurricanes and seismic activity. Little can be done to stop these events and the best protection lies in building of structures to withstand these natural shocks, choice of optimum location and formulation of emergency procedures so as to minimize detrimental results.

Unintentional human-caused adverse events such as airplane or missile crashes do not present a significant threat to energy installations. However, improper siting could greatly increase the risk. Acts of sabotage could disrupt or destroy energy production or transportation in a given geographical sector.

Natural incidents include hurricanes, tornadoes, floods, tsunamis, snow and ice storms, earthquakes, land subsidence, avalanches and landslides, volcanic eruptions, and meteorite impact. Anthropogenic incidents include airplane and missile crashes, sabotage, terrorism, and war activities.

The effect of a natural disaster on an industrial installation can be as severe as a nuclear blast detonating a few miles from the plant. Up to 26 natural disaster areas are declared in the United States per year. They are responsible for about 500 to 600 fatalities annually and economic losses average $10-15 billion (Sec. 12.1 p. 240).

The types of damage produced by natural disasters include flood damage to storage facilities, processing facilities, and transmission lines, physical stress damage to processing facilities, rupturing of pipelines and explosions and fires resulting from escaped gases and highly flammable liquids.

The destruction potential of man-caused adverse events is great. No industrial installation is immune to sabotage but damage is usually minor and the act is considered as an irritant. However, a well-planned act of sabotage or a nuclear weapon could completely demolish all structures within an area. Unintentional events, i.e., aircraft and missile crashes do not usually present a significant threat to energy installations (Sec. 12.2 p. 252).

For Further Information

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