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A Risk Comparison

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ABSTRACT

This report presents data for the comparison of societal risk from natural and man-made hazards. Only fatalities resulting from the hazards are used in the comparison, with the data and the comparative analysis taken from current literature. In comparing societal risks for most of the hazards, both expected values and frequency vs. consequence curves are presented. For a subset of hazards, notably the power generation technologies (nuclear, coal, oil, and gas), which have not exhibited high consequence events (catastrophes), the comparisons are based on estimated expected values only.

Individual risk data are presented in two ways, a probability of death within a year and the amount of life shortening of an average life span.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd.)

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

The data and comparisons of hazards compiled in this report were generated as background and support for the studies of risk criteria at present underway at Brookhaven National Laboratory (BNL). All of the data and some of the comparisons were taken from current literature, and the references are listed at the end of this report. The data on natural hazards are primarily actuarial, with some extrapolated estimates at the extreme high consequence, low probability end of the scale. The extrapolations are differentiated from the acturarial by dashed lines. Some of the presentations on man-made hazards are also based on actuarial data where available (primarily those on transportation and other activities involving a high frequency of fatal accidents). Other man-made hazards, however, have such a low frequency of accidents or events involving fatality that the presentations are mainly estimates based on predictive "risk assessments." The predictive estimates are depicted as dashed lines in graphical presentations and by estimate ranges in tables (Liquified Natural Gas, chlorine, and all the power generation techlogies are examples of this type).

Only fatalities resulting from the hazards are used to compare the risks of the various hazards in this report. No attempt has been made to include morbidity (illness) or economic loss (property damage) in these comparisons; therefore, any discussion of risks refers only to the risk of death (see Definitions, Section 1.1). The reasons for this limitation is that most of the data available, both estimated and actuarial, are given in terms of fatalities. Morbidity data are scarce except for rare, large consequence accidents involving many injuries, whereas most events involving ten or more fatalities have been catalogued. Property damage estimates are usually order of magnitude appraisals for natural events such as hurricanes and floods. Insurance companies keep good records in cases of fire, but other risks such as air crashes cannot be assessed on the basis of property damage, since only the value of the aircraft is definitely known.

1.1 DEFINITIONS

For this report, the following definitions were adhered to:

- Risk - The probability of loss of life within a given time period, for a given hazard.

- Societal Risk - The frequency of fatalities for a given hazard and a given society (in this report, the U.S.A.)

- Individual Risk - The probability of loss of life within a given time period (usually one year) for a given hazard, for one individual subject to that hazard. Therefore, for each individual risk there is a population at risk which must be specified in order to differentiate this quantity from societal risk.

- Expected Values - For societal risks, the expected number of fatalities for a given time period (one year in this report). For hazards which exhibit a high frequency of events (hurricanes, plane crashes), the expected value can be approximated by the total number of fatalities over an extended time period (eg. 20 years), divided by the time period.

- Early Fatalities - Fatalities occurring within one year of the causative event.

- Latent Fatalities - Fatalities occurring from one to forty years after the causative event or the onset of causative events (start of operation of a nuclear or fossil fuel power plant, for example, for long latency period associated with low level exposure hazards).

- Hazard - An event or condition having the potential for unwanted consequences, which in this report are fatalities.

- Chronic Hazard - Hazard exhibiting a high frequency of events involving low number of fatalities (less than 10 per event, usually one per event). Examples are motor vehicle accidents, heart disease, and cancer. This definition incorporates a conditional probability concept, i.e. given fatalities do occur, they are generally low in number.

- High Consequence Hazard - Hazard exhibiting a large proportion of events involving a high number of fatalities (10 or more per event). Examples are airplane crashes, hurricanes, and earthquakes. The events themselves are commonly referred to as catastrophes or disasters. This definition also incorporates a conditional probability concept, i.e. given fatalities do occur, they can with relatively high probability be high in number.

1.2 HAZARDS STUDIED

Chapter 6 of WASH-1400 (ref. 19) presented a comparison of the potential risks associated with accidental radioactive releases from nuclear power plants that were predicted, to other risks to which society is exposed. The data presented includes comparisons of early fatalities, latent illnesses, and property damage on the basis of risk to individuals as well as overall societal risk. For societal risks, only high consequence risks were compared. For individual risk, both chronic and high consequence risks were compared, but only for accidents. Diseases and other natural causes were not included in the comparison.

Chapter 6 of WASH-1400 (ref. 19) was reviewed and all the hazards mentioned were researched to obtain the latest data on the most common hazards. Literature searches were conducted in other fields not included in WASH-1400, in particular the hazards of power-production technologies, and these were added. Some data on disease and natural causes of death are also given as a framework for comparison, and to put the risks discussed in perspective. In summary, data on the following hazards are presented for comparison:

Natural Hazards

- Flood
- Earthquake
- Hurricane
- Tornado

Man-made Hazards

- Aircraft
- Marine
- Motor Vehicles
- Railroad
- Mining
- Dam Failures
- Fires and Explosions
- Liquified Natural Gas Transport
- Liquified Propane Gas Transport
- Chlorine Transport
- Fossil fuel power generation
- Nuclear power generation

In comparing societal risks for most of the hazards stated, both expected values (see Definitions), and frequency vs. consequence curves, are available and are presented. For some hazards, notably the power generation technologies (nuclear, coal, oil, and gas), which have not exhibited high consequence events (catastrophes), the comparisons are based on estimated expected values only.

For individual risk, the data found in the literature are presented in several ways. In some cases it is given as a probability of death within a year (as per our definition) while others give the amount of life shortening of an average life span. This variety of presentation makes comparison somewhat difficult. Wherever possible we have attempted to extract the individual risk as defined here from the data presented in the references. The important variable which must be consistent for comparison is the estimate of the population at risk.

1.3 ORGANIZATION OF THIS REPORT

Section 2 of this report will summarize the data presented in Sections 3, 4, and 5.

Section 3 presents the data derived from various sources on Chronic Societal Hazards and includes comparisons of different power generation technologies, for the U.S. only.

Section 4 presents data on High Consequence Societal Hazards in the form of frequency vs. consequence curves. In most cases curves for both the U.S. and the World (excluding the U.S.) are presented for comparison.

Section 5 presents data on individual risk for the U.S. only.

Section 6 presents the author's concluding remarks.

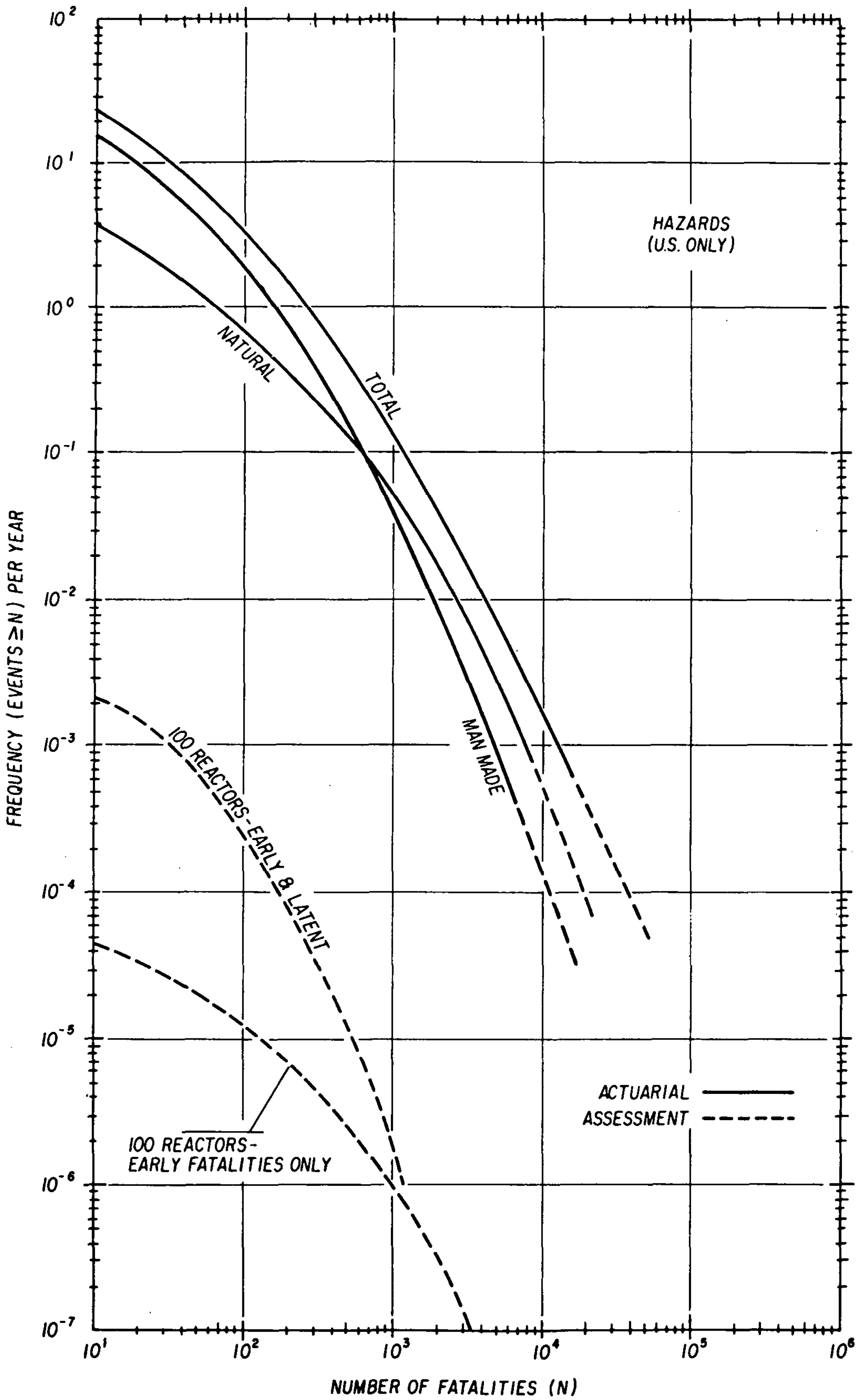
2. SUMMARY

Figure 1 presents a comparison of a portion of the societal risks due to common man-made and natural hazards with those due to the operation of 100 nuclear power plants in the continental United States. The term "Total" in the description for the man-made and natural hazards curves should be interpreted as the total of the risks covered in this report (see Section 4). The portion of the risk represented by these curves is that associated with high consequence or catastrophic events (according to our definition, greater than 10 fatalities). While these high consequence events receive more public attention and concern, they (or the "expected values" represented by the total curves) account for less than 1000 fatalities per year in the U.S., or less than one-tenth of one per cent of the present U.S. death rate. The usefulness of these curves is in illustrating the probability of high consequence events for the U.S. A comparison of risks for society would not be complete without a presentation of the risks from less traumatic, chronic hazards presented in Section 3, where it is shown that the accidental death rate for the U.S. is approximately 5% of the total death rate from all causes, or about 100 times the expected value of the total curve indicated in Fig. 1.

2.1 DIFFICULTIES IN RISK COMPARISONS

Comparing risks from different hazards might seem to imply a simple task of collecting data from various sources and presenting results suggested by the data. The major problem in making comparisons is that the basis for expressing risk varies in available risk assessments. In those areas of assessment involving catastrophic events resulting in fatalities (such as LNG fires, chlorine tank ruptures, or nuclear reactor core melts), where the events are rare, the risk is usually expressed as a predicted curve of frequency vs. severity of occurrence (i.e., frequency vs. consequence). Figure 12, taken from Simmons(9) is an example of the curve generated for the LNG Risk to the Continental U.S. These predicted curves have large uncertainties due to data and modelling uncertainties. Even within the group of hazards assessed on a similar predictive basis, important variations must be noted before comparisons can be made. Figure 12 includes only acute fatalities, since most will occur within weeks of the event (exposure to fire), whereas Fig. 18, from WASH-1400(19) shows the latent fatalities due to cancer, which may be displaced in time by 20 years or more. Figure 17 (also from WASH-1400) shows the predicted early fatalities from the same events used to generate the curves of Fig. 18. Obviously, some combination of the data in Figs. 17 and 18 must be made before comparison with Fig. 12 is warranted, if it is assumed that no latent fatalities are expected for LNG or LPG, and "total" fatalities are to be compared.

Some authors(11) assign a utility value to life, in order to differentiate between acute and latent fatality. This value may be simply the lost years of life expectancy, so that an acute fatality has a higher value than a latent fatality; in this way the consequences in Fig. 18, which involve latent fatalities are reduced by some factor (e.g. average lost years of life expectancy for acute fatalities divided by the average lost years of life expectancy for latent fatalities.)



HAZARDS
(U.S. ONLY)
NATURAL
TOTAL
MAN MADE
100 REACTORS-EARLY & LATENT
100 REACTORS-
EARLY FATALITIES ONLY
ACTUARIAL
ASSESSMENT
FREQUENCY (EVENTS ≥ N) PER YEAR
NUMBER OF FATALITIES (N)

Figure 1

Cohen and Lee(12) evaluated loss of life expectancies to produce a ranking of risks from various hazards and activities. (See Section 5.1). The risks evaluated go from a high of 3500 days' loss due to being an unmarried male to a low of 0.02 days' loss due to radiation from the nuclear industry. Included are data on all the common risks such as cigarette smoking, heart disease, accidents, etc., and some novel data such as lack of an eighth grade education (loss of 850 days of life expectancy).

Some authors assign a monetary value to life in order to allow the addition of morbidity (non-fatal results) and property damage to fatalities to compare total consequences. It is difficult to find an agreed upon monetary value for life, but some references give a corollary to this, cost per life saved, for some safety devices. Bick et al(14) cites costs ranging from $500 for mandatory safety belt usage to $7,680,000 for roadway alignment and gradient, for each life saved. Again, it is not easy to find agreement on how much should be spent to save a life.

Despite the inherent difficulties, risk comparisons continue to be pursued. Because of the public's concern with the growth of nuclear power, comparisons of different power generating systems are numerous. Except for portions of the hazards involved (such as mining and transportation of fossil fuel, which can be compared directly on an actuarial basis), most of these risk comparisons are based on predictions and extrapolations. Most of the analyses indicate that there is greater risk to society from normal operation than from catastrophic accidents when risk is measured as expected consequences (i.e. probability times consequence). The analyses vary from "worst case" assumptions such as that presented in (15) for nuclear vs. oil comparison, where regulatory limits on toxic effluents are used to estimate total mortality, to total risk-benefit analyses typified by (16) for nuclear vs. fossil fuel comparison. In most cases, the health risk, based on estimated expected fatalities, is one to two orders of magnitude higher for the non-nuclear alternative. Tables 1 and 2 are presented here as examples. The absolute values of the numbers shown on these tables represents a small risk to society (less than 1% of total mortality rate for the U.S.).

TABLE 1
PUBLIC RISK COMPARISON

Plant Type	Expected Annual Averages (Deaths per 10 million population per 1,000 MWe plant per year)	
	Continuous Operation at Regulated Exposure Limits	Total Risk from Accidents
Nuclear reactor (cancer deaths)	1	Negligible (0.00006)
Oil-fired plant (respiratory deaths)	60	Negligible (0.00002)

From Ref. 15

TABLE 2

RISK BENEFIT SUMMARY, 1000 MW(e)

Plant	Annual Excess Mortality: Normal Operation	Fuel Transportation	Accidents	Annual Benefit* $m (10% 20 yr)
Nuclear	0.0001-0.08	0.003 (train)	0.005	9.1
Conventional	2-5	0.008 (boat)	–	–

From Ref. 16

*Annual dollar savings (millions) per GWe based on 10% interest rate and 20 year amortization

2.2 CHRONIC AND HIGH CONSEQUENCE HAZARDS

When examining the expected value of fatalities for most hazards (all those considered in this report), one finds that this quantity can be divided into two separate components. One is the contribution made by low consequence events (chronic) and the other is the contribution made by high consequence events (catastrophic). For this report, the dividing line between low and high, or chronic and catastrophic is arbitrarily set at ten fatalities. This dividing line is simply an aid in classifying hazards and consequences. The term chronic usually implies high frequency, and many hazards exhibit this high frequency, low consequence dominance, that is, their expected value of fatalities consists of a large number of low consequence events (chronic) and a smaller number of high consequence events (catastrophic). Section 3 addresses chronic versus high consequence hazards and their associated risks. In some cases (fossil fuel power generation) there are no data on high consequence events either estimated or actuarial. In these instances the expected value consists entirely of chronic, low consequence events, and no frequency vs. consequence curves are shown for these hazards.

The expected values of natural and man-made hazards are tabulated in Section 3. For hazards which have exhibited or have estimated high consequence events, frequency vs. consequence curves are given in Section 4. Note that these curves, even when drawn on the same scale, should not necessarily be used to compare total risk since they show only the high consequence component.

3. SOCIETAL RISKS FROM CHRONIC HAZARDS

Table 3 is a recent summary of the major causes of death in the U.S. This table and caption were taken directly from "Accident Facts," 1979 edition, published by the National Safety Council, and shows the leading causes of death in 1977 for all ages and for males and females separately. The vast majority (over 90%) are due to disease. This number is made up of single fatalities unrelated by any specific event in time, therefore, according to our definition, they do not represent a high consequence hazard and can be considered chronic.

As seen in Table 3, approximately 5% of the total fatalities (100,000 out of 2,000,000) are caused by accidents of various types, of which motor vehicle, falls, drowning, fires and burns, and poison are the major contributors (80% of accidents). Most of these fatalities will also fit our definition of chronic hazards.

TABLE 3

ACCIDENTS VS OTHER CAUSES OF DEATH

Accidents are the leading cause of death among all persons aged 1 to 38. Among persons of all ages, accidents are the fourth leading cause of death. The following table shows the number of deaths and death rates for all ages and selected ages groups from leading causes in 1977 (latest official figures) separately for male and female.

For youths ages 15 to 24 years, accidents claim more lives than all other causes combined, and about five times more than the next leading cause of death. Four out of five accident victims in this group are males.

Cause	Total	Number of Deaths Male All Ages	Female
All Causes	1,899,597	1,046,243	853,354
Heart Disease	718,850	396,482	322,368
Cancer	386,686	210,459	176,227
Stroke (cerebrovascular disease)	181,934	77,351	104,583
Accidents	103,202	71,935	31,267
Motor-Vehicle	49,510	35,804	13,706
Falls	13,773	7,226	6,547
Drowning	7,126	6,006	1,120
Fires, burns	6,357	3,866	2,491
Poison (solid, liquid)	3,374	2,024	1,350
Pneumonia	49,889	27,109	22,780
Diabetes mellitus	32,989	13,632	19,357
Cirrhosis of liver	30,848	20,167	10,681
Arteriosclerosis	28,754	11,648	17,106
Suicide	28,681	21,109	7,572
Homicide	19,968	15,355	4,613
Emphysema	16,376	12,594	3,782

From Ref. 6.

3.1 CHRONIC VS. HIGH CONSEQUENCE EVENTS

Some of the accident hazards are associated with high consequence events, or catastrophes. These events receive far more public attention than most individual accident fatalities, but in general they account for only a small fraction of the total yearly fatalities for society.

Table 4 gives the ratios for some selected U.S. accident statistics for categories of accidents which will be examined in Section 4. It is apparent that the percentages shown depend on the cutoff point chosen for the definition of a catastrophe. If the number 5 (fatalities per event) had been chosen, the percentages or ratios would have been relatively unchanged in the case of air, marine, railroad and mining. Only motor vehicle accidents (up to 0.5%) and fire (up to 12%) would show any significant increase. (Derived from (18), U.S. Statistical Abstracts 1978.) In most technologies, chronic societal risks dominate catastrophic risks (i.e. risks from catastrophic events) but for some technologies the opposite is true.* For example, gas fueled power plant operation is estimated to cause only 7 "chronic" fatalities per year in the United States(3), but if the potential for explosion were considered, or if the plant were coupled with an LNG terminal, the projected catastrophic deaths per year might exceed this low number of "chronic" fatalities. Another example is that of Hydroelectric power, where the chronic effects are low or non-existent (too low to estimate), but the catastrophic effects in case of dam failure dominate the total risk to society. We will not give a table of statistics for these activities when catastrophic risks might dominate since data are sparse.

TABLE 4

SELECTED U.S. ACCIDENT STATISTICS 1959-78[(1)]

Average Yearly Fatalities 1959-78

Category	Chronic	High Consequence[(2)]	Total	% Catastrophic
Air	1130	252	1380	18
Marine [(3)]	7430	72	7500	1
Motor Vehicle	52,000	18	52,000	.03
Railroad	774	6.5	780	.8
Mining	310	23	330	7
Fire	2300	78	2375	3

[(1)]Derived from Ref. 6 and U.S. Statistical Abstracts, 1978.
[(2)]Derived from Ref. 1, over 10 fatalities per event.
[(3)]Drowning of individuals accounts for most of catastrophic and all of chronic statistics.

It must be emphasized that these statistics represent risk to society (the U.S.) and should not be naively used to calculate or infer individual risk. If a person were to choose a mode of transport between two cities in the U.S. on the basis of the presented societal risks, he might be misled by the statistics on railroad fatalities, where less than 2% of the reported fatalities are passengers, and over 98% are railroad employees and trespassers (pedestrians on the tracks).

*Our definition of risk does not include any risk aversion. If risk aversion were accounted for to indicate how society perceives a risk, then catastrophic events might always dominate.

The natural hazards such as hurricanes and earthquakes also exhibit a small proportion of chronic fatalities, while floods and tornadoes show a larger ratio of chronic to high consequence (catastrophic) events. It is not possible to derive tables such as Table 4 for these hazards since events involving single fatalities are generally not classified properly (i.e. single flood victim might be classified as a drowning).

3.2 CHRONIC RISKS ASSOCIATED WITH ELECTRIC POWER PRODUCTION

Much work has been done by various groups on comparing the risks to society from the major electric power generation fuel cycles, most notably the coal, gas, oil, and uranium cycles. In all cases, the estimation of fatal effects (both early and latent) from these activities is difficult and controversial.

For the nuclear reactor case, WASH-1400(19) is the most exhaustive study available, but the predicted risk of fatality covers only the area of power generation. Other areas of the fuel cycle are not examined. The results given in the WASH-1400 study concentrate on fatalities expected from high consequence events (core melts and class 9 occurrences), and are discussed in Section 4.

Studies concerning fossil fuel cycles do not account for high consequence events but they do deal with the complete fuel cycle (mining or acquisition, transportation, power generation, and waste handling, etc.).

The uncertainties in the predicted chronic risks from fossil fuel cycles arise from the difficulties in attempting to correlate increased mortality with air pollution such as SO_2/particulate concentration due to the operation of fossil fuel plants, and are summarized in reports such as that by Christman, et al(2). Nonetheless, some evaluations have been made, and some of the more comprehensive are the ongoing studies at the National Center for the Analysis of Energy Systems at BNL, particularly the numerous reports issued by L.D. Hamilton, S. Morris and other staff members of the Biomedical and Environmental Assessment Division. Their predictions are summarized in Table 5, taken from Ref. 3. The ranges of values given for deaths and disabilities indicate the uncertainties assigned to calculations of deaths due to low level air pollution.

The estimated yearly deaths per 1000-MW(e) plant shown in Table 6, were derived from the more recent data in Table 7(4). The fatalities shown in Tables 6 and 7 for fossil fuels include both immediate fatalities due to mining, transportation, and industrial accidents and latent fatalities due to increased air pollution contributed by the fossil fuel plants. The proportion of latent fatalities (approximately to 80%) is a cumulative effect and depends on continued operation of these plants for extended periods (more than 20 years). The latent fatalities would be of the type listed in Table 8 (attributed to diseases), and would be indistinguishable in mortality tables such as in Table 3.

TABLE 5

***Estimated Health Effects in 1973**
Associated with Production of Electric Power*

Fuel	1973 kwhe x 10	Equivalent No. 1000 MWe plants	Estimated deaths	Estimated disabilities	Unknowns
Coal	846.0	128.2	2,000-16,000	26,000-39,000	increased cancer, other chronic disease, mutation
Oil	310.7	47.1	100-5,000	4,000-9,000	increased cancer, other chronic disease, mutation
Gas	336.0	50.9	7	700	increased cancer, other chronic disease, mutation
Nuclear	83.3	12.6	9-20	60-300	increased risk of catastrophic accident
Hydro	271.1	41.1	**	**	increased risk from dam failure accident
Wood, waste, Geothermal	2.3	0.3	**	**	
TOTALS	1849.4	280.2	2,100-21000	31,000-49,000	

Approximate annual total deaths in U.S.	= 2,000,000
Percent associated with electricity production	= 0.1 – 1%
Approximate number of deaths in U.S. ages 1-74	= 1,100,000
Percent associated with electricity production	= 0.2 – 1.9%

*Calculated from estimates of health effects of 1000 MWe plant operating at 75% power factor for one year.
**Not calculated.

From Ref. 3

These estimates were published in 1974 and 1975 when most operating fossil fuel plants did not meet EPA reqirements. Later estimates, shown in Tables 9 and 11 for coal, show a reduction of more than half due to the new EPA air quality standards.

The additional deaths due to cancer caused by the operation of nuclear power plants shown in Table 6 and 7 would also be indistinguishable in mortality tables.

TABLE 6

Estimated Deaths Per Year Per 1000 MWe Power Plant

Fuel	No. Fatalities
Coal	15-120
Oil	2-100
Gas	0.13
Nuclear	0.7-1.6

Derived from Table 7.

TABLE 7

*Estimated Health Effects in 1975
Associated with Production of Electric Power

Fuel	1975 [a] kWh x 10	Equivalent No. 1000-MW(e) plants	Estimated deaths	Estimated disabilities
Coal	844	128	1,900-15,000	25,000-39,000
Oil	292	44	88-4,400	4,000-7,900
Gas	297	45	6	600
Nuclear	168	26	18-42	130-470
Totals	1,604	243	2,000-19,000	29,000-48,000

[a]Preliminary.
Data from Electrical World, 185(6), 54, 1976.

*Calculated from estimates of health effects of 1000 MW(e). Plant operating at 75% power factor for one year.

The numbers for nuclear power in Table 7 include only 2.4 deaths due to radiation induced cancers. There are no catastrophic deaths included (due to major core melt accidents), and the majority of the expected deaths are due to mining, industrial, and transportation accidents.

Just as for the nuclear case, no high consequence events due to power plant operation are included in the figures presented for coal, oil, or gas. This does not imply that there are no high consequence events associated with these activities. Episodes such as those in London in 1952 and Donora, PA, in 1948 have been extensively studied and are classified as air pollution catastrophes. The London fog of 1952 began on December 4 and lasted over one week. The heavy fog and attendant temperature inversion with no wind caused many tons of particulate matter from industrial and residential furnaces to

TABLE 8

Increase in Mortality in the London Fog of December 1952

Cause of death	Seasonal norm (deaths per week)	Deaths in week after fog	Excess deaths	Percentage of total excess deaths
Bronchitis	75	704	629	39
Other lung diseases	98	366	268	17
Coronary artery disease, myocardial degeneration	206	525	319	20
Other diseases	508	889	381	24
Total	887	2484	1597	100

become trapped in the stagnant atmosphere which changed the color of the sky from yellow to dark brown. Some sources attribute as many as 4000 to 8000 excess deaths to this occurrence in the weeks following, for the area of greater London (population 8.3 million)(21). Table 8, taken from Ref. 20, gives figures for the smaller area of the county of London.

Catastrophes of this type are not included in the fossil fuel mortality predictions for the following reasons:

- During such an episode it is difficult to ascribe the correct quantity of pollutants to the proper source (motor vehicle emissions, household heating, etc., could contribute).

- Some experts feel that with today's detection methods, and the constant monitoring of air quality in industrial areas, such episodes are unlikely to recur because the monitoring authorities could eliminate the sources of pollution when alarm levels are reached.

With regard to the second argument it should be noted that since both the means of detection and the decision to eliminate the sources of pollution at a critical time involve people and machines, the probability of occurrence under certain atmospheric conditions is amenable to analysis in the same way as the probability of a class 9 nuclear catastrophe.

Table 5 also gives the annual total deaths and the estimated percent (0.1 to 1%) associated with electrical power generation. This low proportion makes it difficult to separate fatalities due to power plant operation from those due to chronic natural causes. As shown in Table 8, the deaths attributable to the excess pollution during the London fog were similar in nature to fatalities commonly occuring throughout the year. Only when the rates of death due to causes such as bronchitis and coronary disease increase dramatically during limited periods can they be easily differentiated and ascribed to pollution.

More recent estimates made by the BNL group, based on new EPA standards and more recent mine accident data (Tables 9 and 10), indicate that the fatal effects per plant for both coal and nuclear power plants will decrease in the future. These tables, taken from Ref. 20, summarize the estimates of health effect on a unit plant basis and assume the plants are operated within currently mandated environmental standards. Most of the work done by the BEAD* group at Brookhaven was directed toward quantifying coal-mining accidents and occupational disease, coal transport accidents, and air pollution from coal combustion.

Estimates of total societal risk due to coal plants, however still show net increases for the years 1985 and 1990 (Table 11) because of the older plants in operation and the projected increased use of coal.

*Biomedical and Environmental Assessment Division, National Center for Analysis of Energy Systems.

TABLE 9 (From Ref. 20)

Coal Fuel Cycle Effects Summary
(Per 1,000 MW(e) Plant-Year, 65% Capacity)*

	Deaths	Disease/Injury
Mining[1]		
Public	—	—
Workers		
Accidential Injury[2]	0.6	42
Occupations Disease	0.02-0.4	0.5-1.0
Processing		
Public	—	—
Workers		
Accidental Injury	0.05	2.9
Occupational Disease	—	—
Transport[3]		
Public and Workers		
Accidental Injury	0.3-1.3	1.2-5.9
Electricity Generation		
Public		
Air Pollution (50 Mi radius)[4]	0.6 (0-3)	Not Estimated
Air Pollution (total U.S.)[5]	6 (0-30)	Not Estimated
Workers		
Accidential Injury[6]	0.1 (0.02-0.3)	3.3 (2.7-4.0)
TOTAL	7.7-9.1	

1. Assumes 62% underground, 38% surface mining (the ratio of Applachian coal production, source U.S. Bureau of Mines, Mineral Yearbook 1974, U.S. Government Printing Office, 1976, Vol. 1, pp. (367-76).

2. Coal Miners Accidental (non-fatal) Injury (1965-73 MEN)
   Underground Mining - 27.6 Injuries Per 10^6 tons
   Surface Mining - 5.2 Injuries Per 10^6 tons
   $[(27.6 \times 0.62) + (5.2 \times 0.38)] \times 2.2 \times 10^6 = 42$ Injuries Per Plant-Year
   From Morris, S.C., Novak, K.M. and Hamilton, L.D.[45]

3. Assumes rail transport, 300 mile trips. Range is due to different methods of estimation.

4. Assumes 3 million people within 50 mile radius, sulfur oxide emission rate of 0.12 lbs. SO_2 per 10^6 Btu input (low sulfur coal combined with 90% removal of sulfur in flue gas). Results are approximately linear for SO_2 emissions.

5. Assumes total effect 10 x local effect.

6. Estimates from Bertolett and Fox, with Poisson 95% confidence limits.

*A 1000 MW(e) power plant operating with an average capacity factor of 65% produces 0.65 GWy, or 2.05 10^{16} J, or 1.94 10^{13} Btu in a year.

TABLE 10 (From Ref. 20)

Nuclear Fuel Cycle Effect Summary

	Deaths	Disease/Injury
Mining		
Public	0.08	0.08
Workers		
Radiation Induced Cancer	0.06	0.03
Non-Radiation Induced		
Occupational Disease	0.07	0.14-2.8*
Occupational Accidents	0.31	11.96
SUBTOTAL	0.52	12.21-14.87
Processing		
Public	0.002	0.002
Workers		
Radiation Induced Cancer	0.034	0.034
Occupational Accidents	0.004	1.3
SUBTOTAL	0.04	1.34
Electricity Generation		
Routine Public	0.017	0.017
Workers		
Radiation Induced Cancer	0.07	0.07
Occupational Accidents	0.013	1.13
Catastrophic Accidents	0.1	–
SUBTOTAL	0.20	1.217
Waste Management		
Public	5.1×10^{-5}	5.1×10^{-5}
Workers	7.45×10^{-4}	7.45×10^{-4}
SUBTOTAL	7.96×10^{-4}	7.96×10^{-4}
Transport	6.1×10^{-4}	6.1×10^{-4}
Routine Public		
Workers		
Radiation Induced Cancer	8.5×10^{-4}	8.5×10^{-4}
Occupational Accidents	0.01	0.1
Catastrophic Accidents		
Cancers	8.3×10^{-5} to 7.1×10^{-4}	8.3×10^{-5} 7.1×10^{-4}
Prompt Deaths	2.1×10^{-7} to 9.3×10^{-5}	
SUBTOTAL	0.01	0.10
Decommissioning		
Public	5.3×10^{-9}	5.3×10^{-9}
Workers		
Radiation Induced Cancer	4.2×10^{-3}	4.2×10^{-3}
Occupational Accidents	8.0×10^{-4}	0.07
SUBTOTAL	5×10^{-3}	0.07
TOTAL	0.07	14.9-17.6

* Based on ratio of occupational disease/death in coal miners. Lower estimate is used in total.

** A 1000 MW(e) power plant operating with an average capacity factor of 65% produces 0.65 GWy, or $2.05\ 10^{16}$ J, or $1.94\ 10^{13}$ Btu in a year.

TABLE 11 (From Ref. 20)

Estimated Incremental Health Effects of Air Pollution From Coal Combustion for National Coal Utilization Assessment Utility and Industrial Emissions

Region	1975-1985 Pop. exp. increment 10 person-$\mu g/m^3$	1975-1985 Estimated Deaths	1975-1990 Pop. exp. increment 10 person-$\mu g/m^3$	1975-1990 Estimated Deaths★
1	9.6	48-770	17.9	90-1400
2	42.8	210-3400	78.5	390-6300
3	(-7.3)	(-36)–(-580)	24.2	120-1900
4	16.3	82-1300	51.5	260-4100
5	(-55.3)	(-280)–(-4400)	2.2	11-180
6	18.1	91-1400	28.5	140-2300
7	(-5.9)	(-30)–(-470)	2.0	10-160
8	1.2	6-96	2.8	14-220
9	7.9	40-630	13.0	65-1000
10	0.5	3-40	0.9	5-70
U.S. Total	28	140-2200	221.6	1100-18000

★60% range includes estimated error in health-damage function only.

Population exposure increments are due partly to the increased number of people exposed in 1985 and 1990 because of population growth. Parentheses indicate decreases.

4. HIGH CONSEQUENCE SOCIETAL RISKS

The societies of the world face many common hazards, both natural and man made. Some of these hazards have demonstrated their ability to produce high consequence events and are well publicized. These include natural hazards such as hurricanes and earthquakes, and man-made hazards such as aircraft and dams. For these hazards, actuarial data exists which can be used to derive tables and curves useful in describing their effects. The representation chosen for this report is frequency vs. consequence curves, which are given in this section (the tables used to construct these curves appear in Appendix A).

Some hazards, such as the newer man-made ones, have not yet demonstrated an ability to cause high consequence events (catastrophes) but are believed to have this ability because of analyses based on proven lethal effects and extrapolations. Included in these hazards having predicted high consequences are chemical hazards, nuclear hazards, and new fuels such as (LNG) liquified natural gas. Probabilistic analyses, consisting of engineering evaluations coupled with estimates of lethal effects are used to derive frequency vs. consequence curves for some of these newer hazards. Only a few of the hazards having potential for high consequences have been analyzed in this manner. Some, including the hazards from Love Canal and from other chemical dumps do not lend themselves readily to this type of analysis. Since only hazards having available actuarial data or calculated high consequence risks are dealt with here, the "total" curves shown must be viewed as totals only of the individual hazards discussed.

For the natural hazards where actuarial data exists, Refs. 6, 17, 18, and 19 were used to develop lists of high consequence events, with *Disaster!(17) being the most complete reference for the U.S. and the world, especially for the 40 years 1938 to 1977. The hazards recorded included hurricanes, earthquakes, tornadoes, floods, landslides, avalanches, storms, and other weather phenomenon such as heat waves, cold waves and blizzards. Volcano eruptions were also reviewed, but except for the recent eruption of Mt. St. Helens, which claimed more than 20 lives, the 40 year period chosen showed no events with ten or more deaths due to this cause in the U.S. The same was true of lightning. Of the natural hazards, floods, earthquakes, hurricanes and tornadoes were chosen for inclusion in this report. These are the natural phenomena considered in WASH-1400. Landslides and avalanches were not used because only four events with more than ten fatalities occurred within that period.(17) Storms, blizzards and weather-related phenomena such as cold or hot spells are responsible for as many deaths as hurricanes or tornadoes, but the numbers of fatalities seem to be more closely related to the duration of the abnormal weather, than to any degree of severity. A prime example is the recent (June-July 1980) heat wave in the south central U.S., which, according to news reports, has claimed more than 1000 lives and could qualify as the greatest single catastrophe in the U.S. in the last 40 years. However, since these occurrences require comparatively longer periods of time, and seem to affect the old and disabled much more than the general population, and their

*Compiled by the editors of Encyclopedia Brittanica from Smithsonian Inst., Center for Short Lived Phenomena Annual Reports from 1969, UNESCO Annual Summary of Information on Natural Disasters from 1966, and other publications.

consequences seem to require other contributing factors, it is difficult to attribute fatalities to single events, and no frequency vs. consequence curves were generated for them.

World data (excluding the U.S.) for hurricanes, floods, and earthquakes were tabulated and curves were generated for them. Each is presented in the appropriate section with the U.S. curves. Where the time period chosen affected the resultant curve (e.g. hurricanes, the period 1938-1977 omits the largest consequence ever recorded for a U.S. catastrophe, 6000 fatalities) an additional curve covering a longer period is given for the U.S., to show the difference, and the advantages and disadvantages of using either curve are discussed.

For the man-made hazards, the choice of specific hazards to include is much wider. For the hazards for which actuarial data are available, tables of frequency vs. consequence (given in the Appendix) were compiled from Refs. 1, 6, 18, and 19. *Catastrophe!(1) provided the most comprehensive listing of high consequence events, including data on aircraft, railroad, marine, mining, fire and explosion (combined), and motor vehicle hazards. Actuarial data on all these hazards for the 20-year period 1959 to 1978 are presented here for the U.S. and the rest of the world. For most man-made hazards this shorter, more recent period is considered more appropriate because technological changes affect the frequency and consequences of fatal events. Certain man-made hazards, such as dam failures, are not considered as dependent on technological changes because many of the structures stay in place for many years with no improvements made; therefore, the data for dams cover a longer period (90 years).

The newer man-made hazards that are considered capable of producing catastrophes are represented here by probabilistic assessments taken from current literature. These include the hazards associated with the transportation of liquified natural gas (LNG), liquified propane gas (LPG), chlorine, and with nuclear power plants. These were included because reports are available which estimate their risks to the entire U.S. population. These are predictive and generally have large associated uncertainties. Other man-made hazards have been assessed for particular areas or segments of the population, but these have not been included since U.S. societal risk is of concern here.

Because all man-made technologies and activities have not been included, it is again emphasized that "total" curves generated here represent sums of the risk curves of the individual hazards examined and do not represent risks from all the conceivable hazards which exist.

4.1 UNCERTAINTIES

The uncertainties associated with the actuarial data and the resultant curves presented here may be expressed as confidence factors which are a function of the number of observations. For the probability vs. consequence curves, the number of observations (r) is the number of events with consequences greater than a particular value. The values for r are also equivalent to a certain frequency if the time span for all the observations is known.

*Compiled by the editors of Encyclopedia Brittanica.

For example, for a 20 year span (man-made hazards) r = 1 = a frequency of 0.05 events/year and for a 40 year span (natural hazards), r = 1 = a frequency of 0.025 events/year. By using this relationship, Table 12 can be used to estimate the confidence factors (error factors) for all the actuarial curves given here. These uncertainties are derived assuming the occurrence rate is constant over the time period examined (the number of occurrences is thus assumed to follow a Poisson distribution).

Table 12

Confidence Factors

r	Equivalent Frequencies (Events/Year)		Confidence Factors	
Number of Observations	Natural Hazards (40 yr. interval)	Man-made Hazards (20 yr. interval)	95% Upper Bound	5% Lower Bound
100	2.500	5.000	1.2	1.2
50	1.250	2.500	1.3	1.3
20	0.500	1.000	1.4	1.5
10	0.250	0.500	1.7	1.8
5	0.125	0.250	2.1	2.5
1	0.025	0.050	4.7	19.4

For natural and man-made hazard curves based on actuarial data.

For the LNG and LPG curves, the uncertainties are given, in detail, by Simmons(9) and are summarized as follows: "The overall uncertainty in the risk of fatalities from LNG tanker spills is estimated to be a factor of 2 to 1/100, mainly because of the disregard of the protection afforded by the tankship's double hull. For LPG spills, the overall uncertainty is estimated to be a factor of 10 to 1/10."

These uncertainty factors are to be applied to the frequency or probability as further explained in the authors summary as follows: "There are too few historical data to verify the predictions of frequency of accidents with a given number of fatalities. Nevertheless, based on the quality of the data used to develop the frequency values for the four variables, the overall uncertainty for the LP-Gas spills was estimated to be a factor of 10 to 1/10. For LNG tanker spills an uncertainty of a factor of 2 to 1/100 was estimated. The latter factor primarily reflects the disregard of the protection afforded by the double hull design."

For the nuclear power plant curves, the uncertainties are taken from WASH-1400(19) and given on the figure for the curve. These uncertainties have been criticized as being understated.(25)

For the chlorine assessment, Simmons et al(22) state: "The uncertainty associated with these numbers on this basis (average conditions of weather, tank car temperature, terrain and population density) is estimated to be a factor of ten, being dominated primarily by the uncertainty associated with the frequency of tank car accidents." The numbers referred to in this quote are the accident frequencies used in the report.

4.2 NATURAL HAZARDS (HIGH CONSEQUENCE)

The most common natural hazards which produce high consequence events for the U.S. are hurricanes, tornadoes, floods, and earthquakes. Their frequency vs. consequence curves, with pertinent comments, are presented in the following paragraphs. Lines are drawn through the points to group associated points and aid in presentation, but they do not represent any formal statistical fit.

4.2.1 Hurricanes

Cyclones originating over warm waters (80°F) are known as hurricanes in the Western Hemisphere and typhoons in the Eastern. Hurricanes develop usually in the Caribbean Sea and the Gulf of Mexico, from June to October. About ten storms a year are large enough, or have winds exceeding 75 mph, to be given names by the U.S. Weather Service and are tracked as possible risks to the mainland. A few form west of Mexico, but these seldom cause any damage to the U.S. The worst hurricane experienced in the U.S. was that which hit Galveston, Texas, in 1900. It claimed the lives of 6,000 people in the Galveston area alone.

The potential for death and destruction in any hurricane or cyclonic storm is large. The greatest disaster of this century occurred in Bangladesh in 1970 when between 200,000 and 1,000,000 lives were lost and over 1 million acres of rice paddies were destroyed by a cyclone. The destruction of the rice fields caused famine and suffering for months after the event. In the last 40 years, in the U.S., the fatalities per event have tended to decrease because of improved tracking and warning systems, but the property damage has increased dramatically, due to the continuing development of hurricane-prone areas.

Figure 2 gives the curve of frequency versus fatalities for hurricanes. The general U.S. experience parallels that of the rest of the world if the data from 1900 to 1977 are used.(16,19) If only the data from 1938 to 1977 are used (16), the curve for the U.S. shows a lower frequency of events causing 100 or more fatalities and no events causing more than 750 fatalities. In examining the data (Appendix A) the overall frequency of hurricanes has not changed significantly, and the lower number of high consequence events is compensated for by a higher number of lower consequence events (10 to 100 fatalities). If this trend continues, the curve for hurricanes will approach that for tornadoes, and the expected number of fatalities per year are very similar for these two hazards.

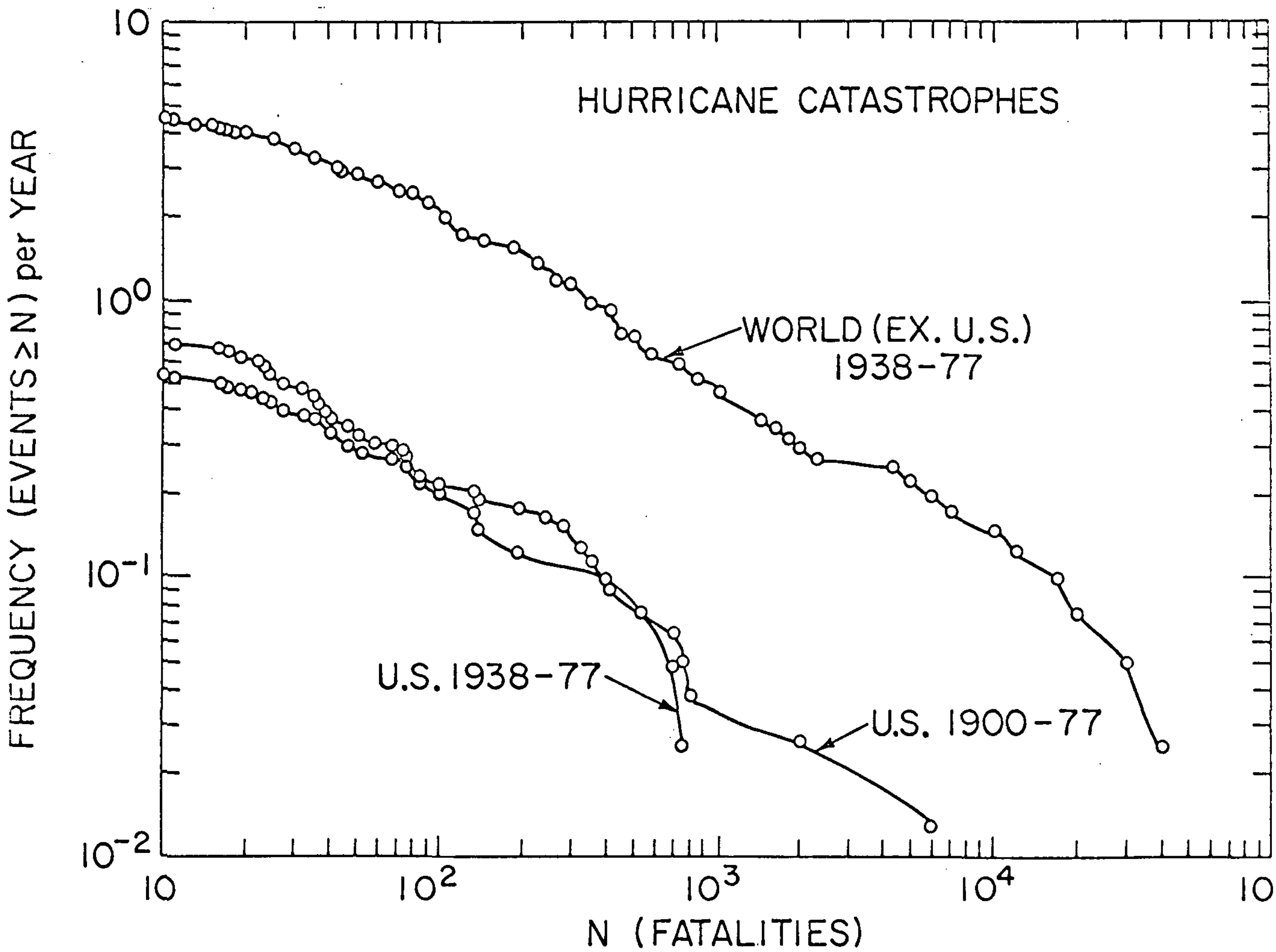

HURRICANE CATASTROPHES
WORLD (EX. U.S.) 1938-77
U.S. 1938-77
U.S. 1900-77
FREQUENCY (EVENTS ≥ N) per YEAR
N (FATALITIES)
10
10^0
10^{-1}
10^{-2}
10
10^2
10^3
10^4
10^5

Figure 2

4.2.2 Tornadoes

A tornado is an intense cyclone, affecting a small area, occurring primarily over the mid-latitudes of large land masses. Velocities within a tornado's funnel exceed those of a hurricane (~200 mph) and the destructive force within its path is greater, but just outside this intense area (200 to 400 yards wide) the damage is small to negligible. Also, tornadoes are short lived (generally minutes compared to days or weeks not unlikely for a hurricane). These characteristics serve to keep the fatality count low for any one group of tornadoes or single tornado compared with that for a hurricane, but the difficulty in predicting where and when a tornado will hit keeps the expected fatalities per year fairly constant. Figure 3 gives the frequency versus fatality curve for tornadoes.

Tornadoes are sometimes thought of as uniquely North American since few are reported on other continents. They occur most often in the mid-western states, although every state is subject to them. Figure 3, therefore, does not show a curve for the rest of the world since so few are reported outside of the U.S. and Canada.

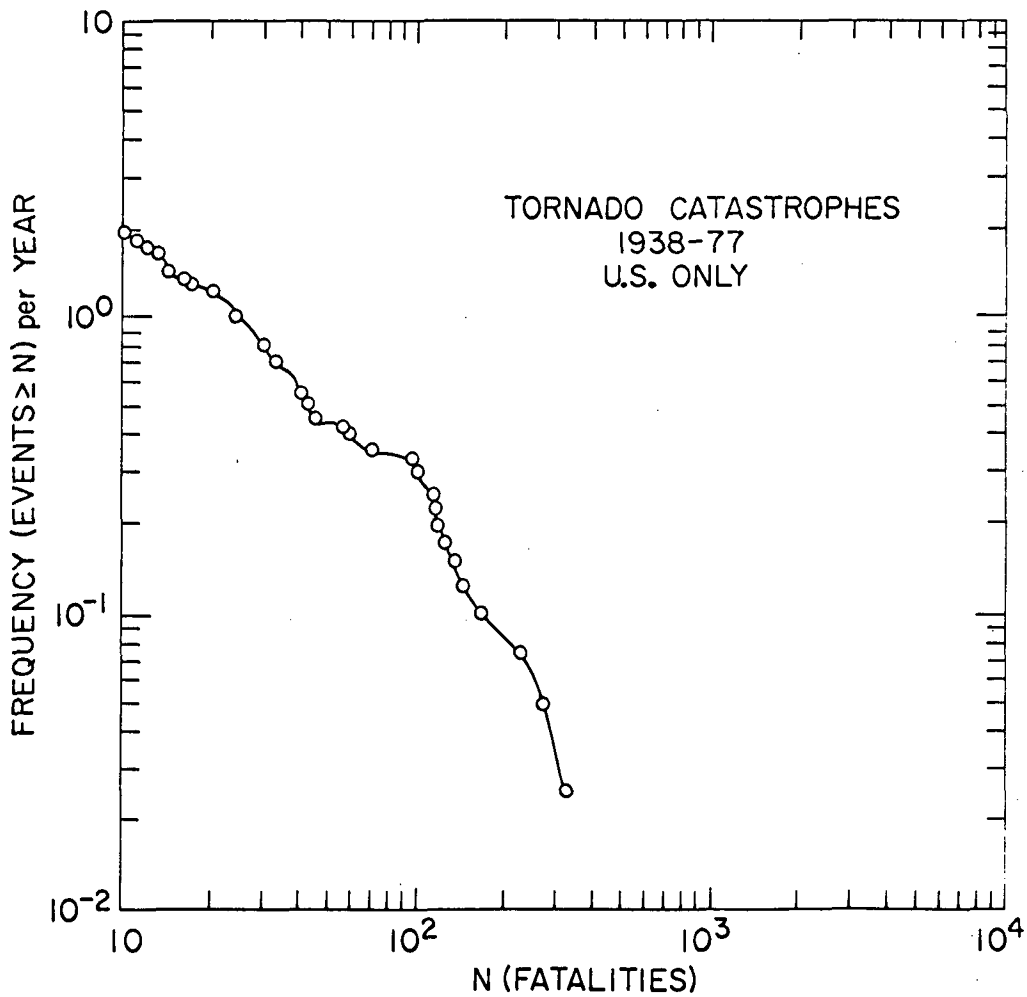


Figure 3

4.2.3 Floods

Figure 4 gives the frequency versus fatality curve for floods. The U.S. has spent massive amounts of money on flood control, mostly in the form of dams and irrigation projects.

Also, Federal and State authorities have been established to provide monitoring and warning services for every major flood plain. Because of this, there is considerable divergence in the higher consequence area of the frequency vs. consequence curves for the U.S. and the rest of the world (Fig. 4). Although the average death per flood in the U.S. have shown a marked decrease since the turn of the century, the amount of property damage per flood has steadily increased, which reflects increasing development of flood plains.(21) The average number of fatalities due to floods in the U.S. has gone down to 80 per year, while the average yearly property damage has gone up to one billion dollars.(21)

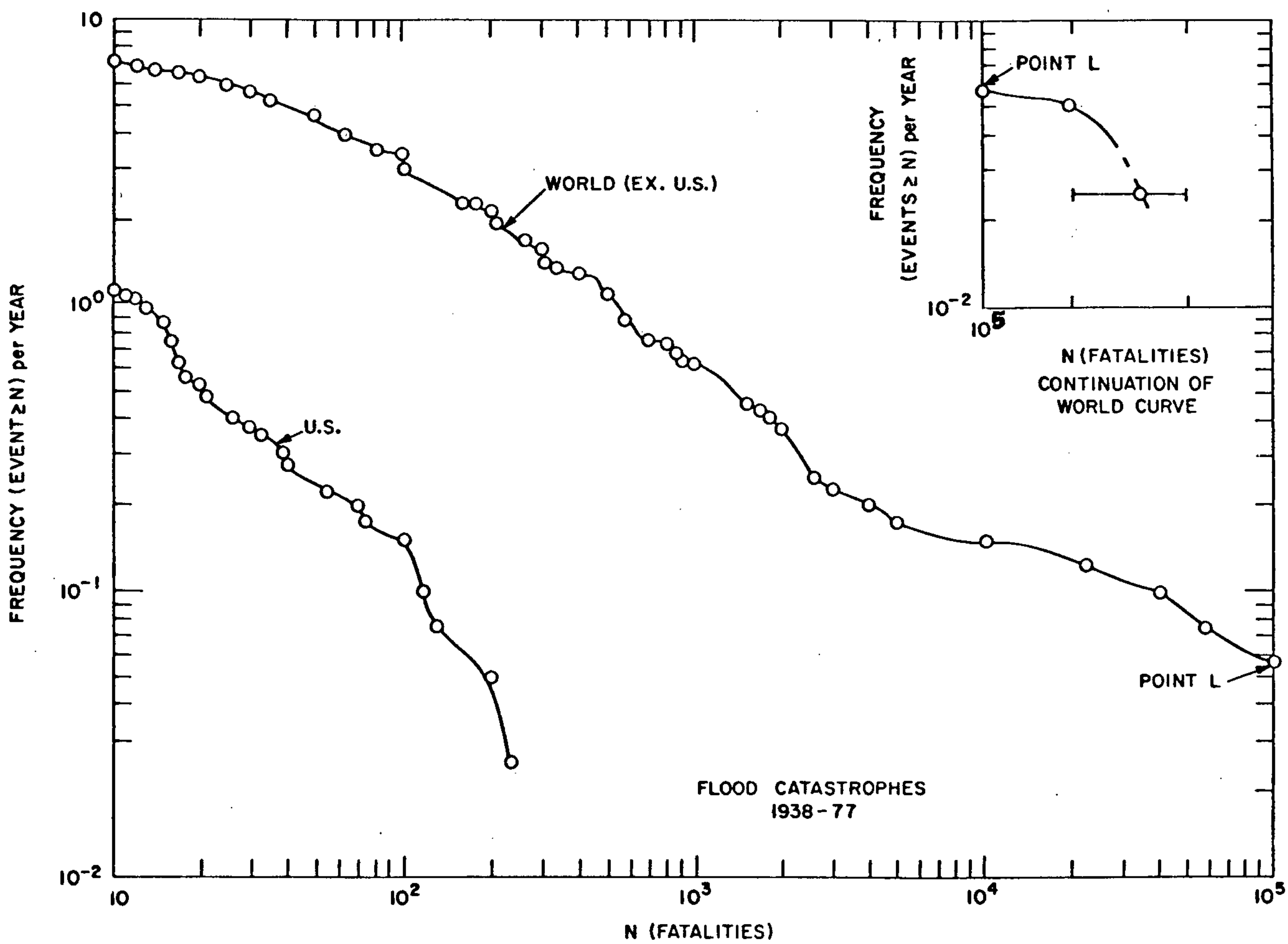


Figure 4

4.2.4 Earthquakes

Figure 5 gives the frequency versus fatality curve for earthquakes. Earthquakes are perhaps the most frightening of natural disasters because of their suddenness. Studies are presently underway at Columbia University and other seismological centers on the feasibility of predicting them. In the U.S., most quakes occur on the west coast, particularly along the fault lines in California. Most are of low intensity and cause little damage and few deaths, but a few have been catastrophic, including the recent (1964) quake in Alaska that claimed 131 lives. The San Francisco quake of 1906 claimed 750 lives, and a number geologists feel that California is due for another quake of similar magnitude.

The tremendous increase in population in California raises the possibility of tens of thousands of fatalities resulting from a large earthquake. Figure 5 shows the world and U.S. experience for the period 1938 to 1977, using data from Disasters!(17) Adding data from other sources for the U.S. gives the curve shown for the period 1906 to 1977. Unlike the two hurricane curves for which the better experience of the more recent past can be interpreted as a possible future trend because of better communications and ability to evacuate an area, the two earthquake curves for the U.S., which both parallel the world curve, can only be interpreted as being slightly different because the return frequency for the larger consequence events is greater than 40 years.

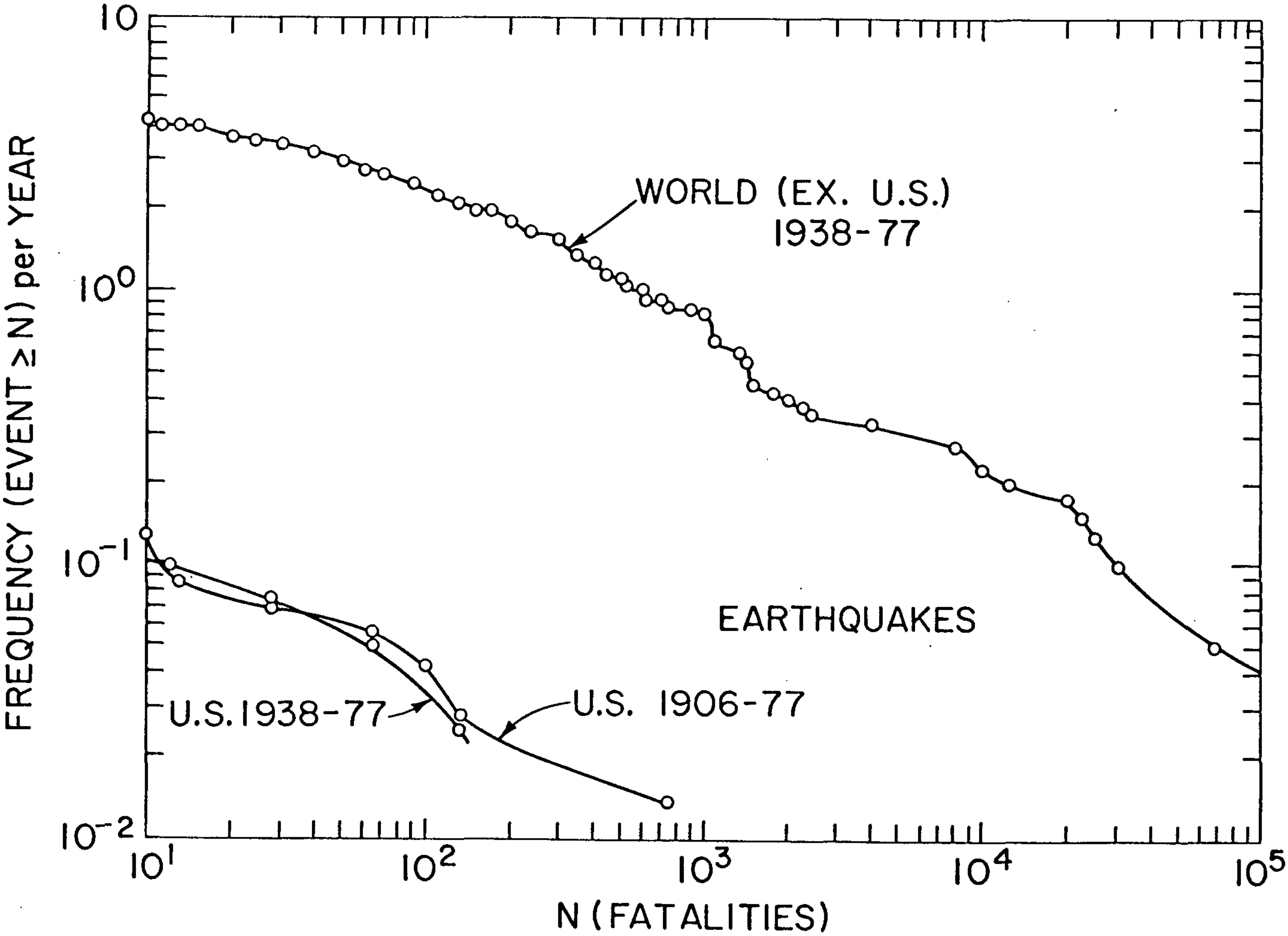


Figure 5

4.3 MAN-MADE HAZARDS (HIGH CONSEQUENCE)

From events listed in Catastrophe!(1), frequency vs. consequence tables were derived for the following hazards:

- Aircraft
- Marine
- Motor Vehicles
- Railroad
- Mining
- Fire and Explosions

The tables are presented in the Appendix as are tables developed for natural hazards. Curves of frequency vs. consequence were constructed using these tables and are presented in this section under the appropriate paragraphs. The curves were drawn to aid in presentation and are not formal statistical fits.

Frequency vs. consequence curves for LNG, LPG, Chlorine, and Nuclear Power Plants are taken from the other references and also presented here under the appropriate paragraphs.

4.3.1 Aircraft

Statistics on fatalities from aircraft accidents would be expected to vary directly with increased numbers of aircraft in use, increased mileage flown, and increased loading. They might vary either directly or inversely with new technology such as new families of aircraft. These statistics are a good example of a relatively large, high consequence risk (approximately one order of magnitude greater than motor vehicles), but with a relatively low "chronic" risk component (more than one order of magnitude lower than motor vehicles). This latter relation would probably not be true if the number of aircraft in operation approached the number of motor vehicles in operation.

Figure 6 gives the frequency versus fatality curve for aircraft accidents. The time period covered by the data is particularly significant and appropriate since it covers the introduction and growth of commercial jet aviation. The curves (Fig. 6) are shown to converge at the highest consequence point (dotted lines), which represents the Canary Islands disaster: the collision of two jumbo jets on the ground, one U.S. and one Dutch. This one point seems to be off the curve, but it is a significant indication of the potential for higher consequences introduced by the larger planes in use today.

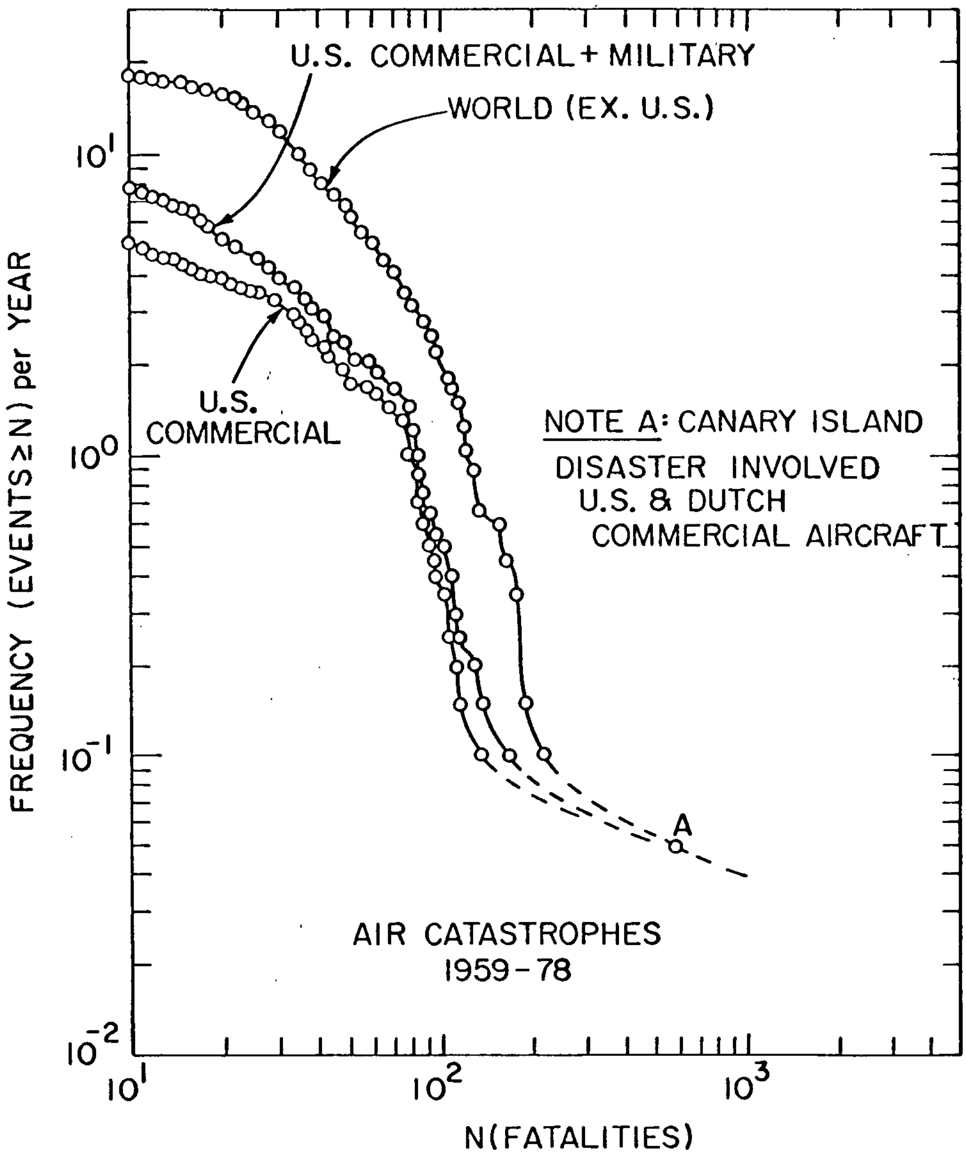

U.S. COMMERCIAL + MILITARY
WORLD (EX. U.S.)
U.S. COMMERCIAL
NOTE A: CANARY ISLAND DISASTER INVOLVED U.S. & DUTCH COMMERCIAL AIRCRAFT
A
AIR CATASTROPHES 1959-78
FREQUENCY (EVENTS ≥ N) per YEAR
N(FATALITIES)
10¹
10⁰
10⁻¹
10⁻²
10²
10³

Figure 6

4.3.2 Marine

Figure 7 gives the frequency versus fatality curve for marine accidents. The data used to generate the marine hazard curve for the U.S. are probably too low by a significant amount. The reason for this is that most Americans travel on ships under foreign registration, and in foreign waters when they do travel. The true risk is probably represented by a curve lying between that for the U.S. and that shown for the rest of the world (Fig. 7). This risk is not expected to vary appreciably in the near future because both the technology and the use by Americans of this mode of transport change very slowly. Since these statistics include only events with 10 or more fatalities, most pleasure boating accidents are excluded. Most of the fatalities in these lower consequence events are due to drowning and appear in statistics such as those in Table 3, (Section 3).

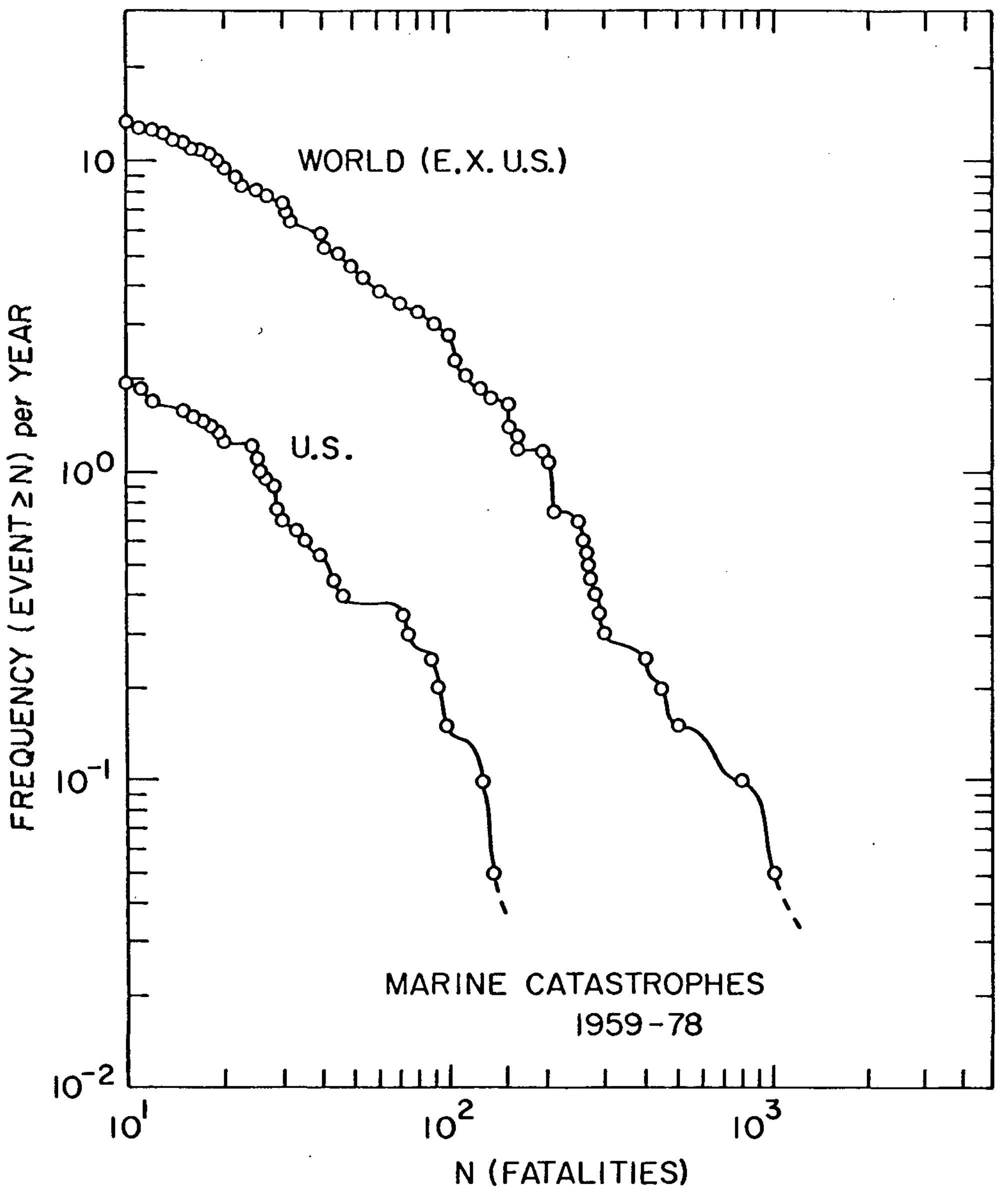


Figure 7

4.3.3 Motor Vehicle

Figure 8 gives the frequency versus fatality curve for motor vehicle accidents. The statistics on high consequence motor vehicle hazards may show an increase in the near future, as rising fuel prices induce more people to use buses and van pools. Even if they tripled however, they would still not be a significant proportion of the total motor vehicle risk, which in the U.S. is dominated by the private auto (see Table 3, Section 3 and Table 14, Section 4.4). Technological advances such as the energy absorbant auto or air bags could have a significant effect on the total motor vehicle risk in the future.

The relatively large difference between the U.S. and world curves (compared to other man-made risks), indicates the greater usage of buses in the rest of the world, since most of the accidents representd by these curves involve passenger carriers such as buses.

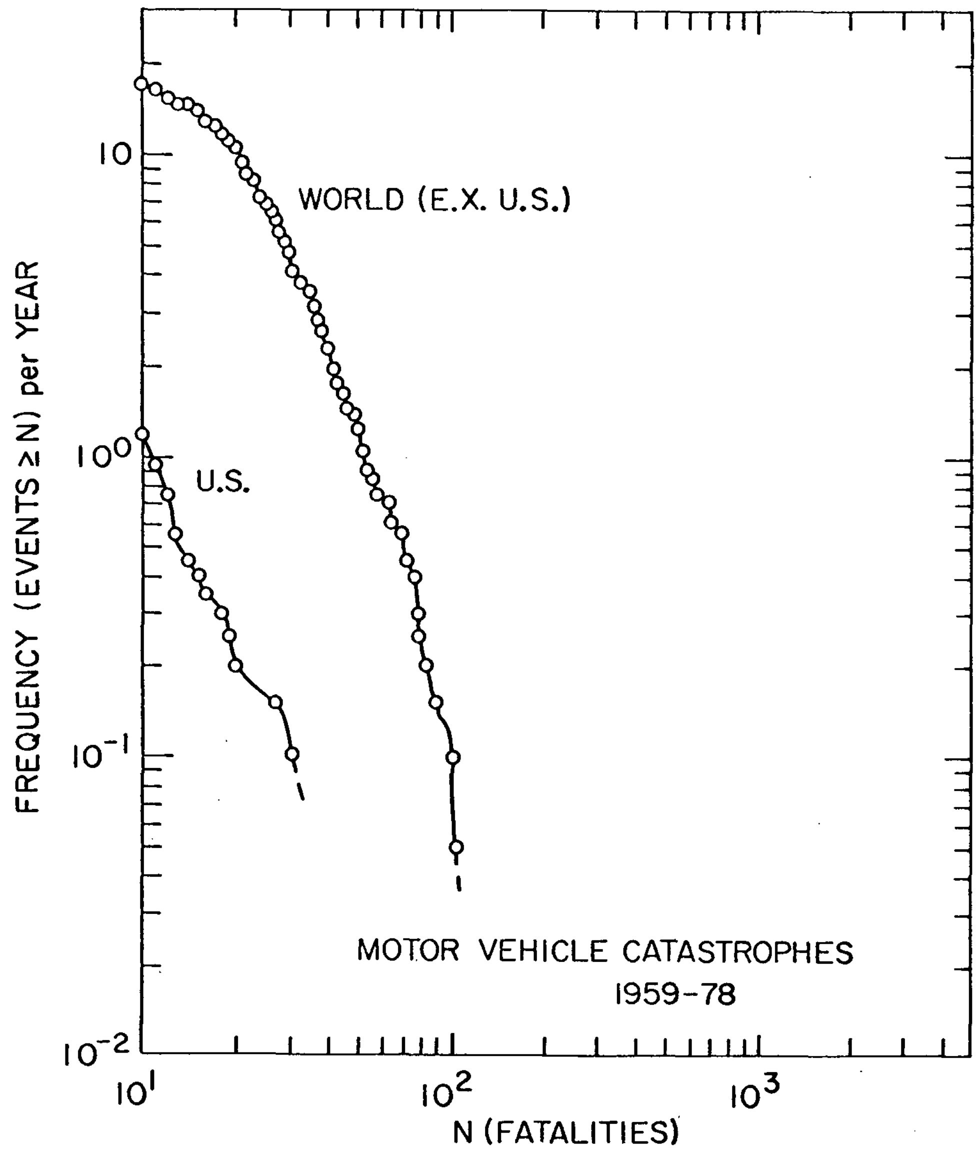


Figure 8

4.3.4 Railroad

Figure 9 gives the frequency versus fatality curve for railroad accidents. Even with increased fuel costs, the use of railroads in the U.S. seems resistant to increase. No significant change in these statistics (Fig. 9) is expected. The proportion of passenger deaths is higher in catastrophes than for chronic fatalities (Section 3), but the total number of fatalities is lower for railroads than other means of transportation.

Again, the relative large difference between the U.S. and world curves is due to the greater use of mass transportation in the rest of the world.

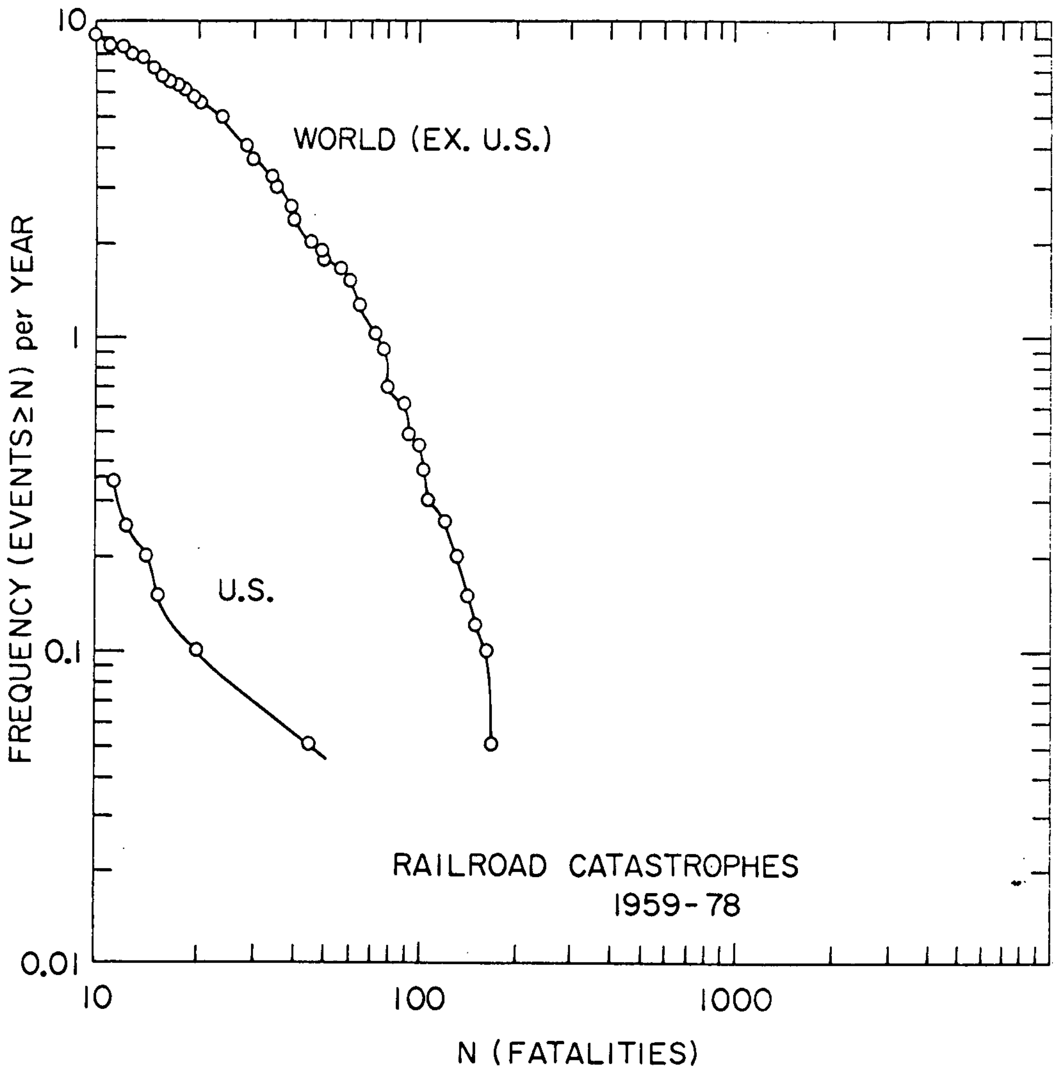


Figure 9

4.3.5 Mining

Figure 10 gives the frequency versus fatality curve for mining accidents. The statistics on mining hazards have declined dramatically in the last 20 years under the influence of new government regulation and enforcement both in the U.S. and abroad.(18) The use of coal, however, is being given new encouragement, and the increased usage is expected to counteract the decline in these statistics. While the data represented by these curves represents all types of mining, the largest single contributor is coal mining.(1)

One aspect of coal mining not included in this data is the latent fatalities due to black lung disease. While this contribution to the "chronic" component of risk is expected to decrease, due to improved working conditions, it has never been properly documented as part of the total mining risk.

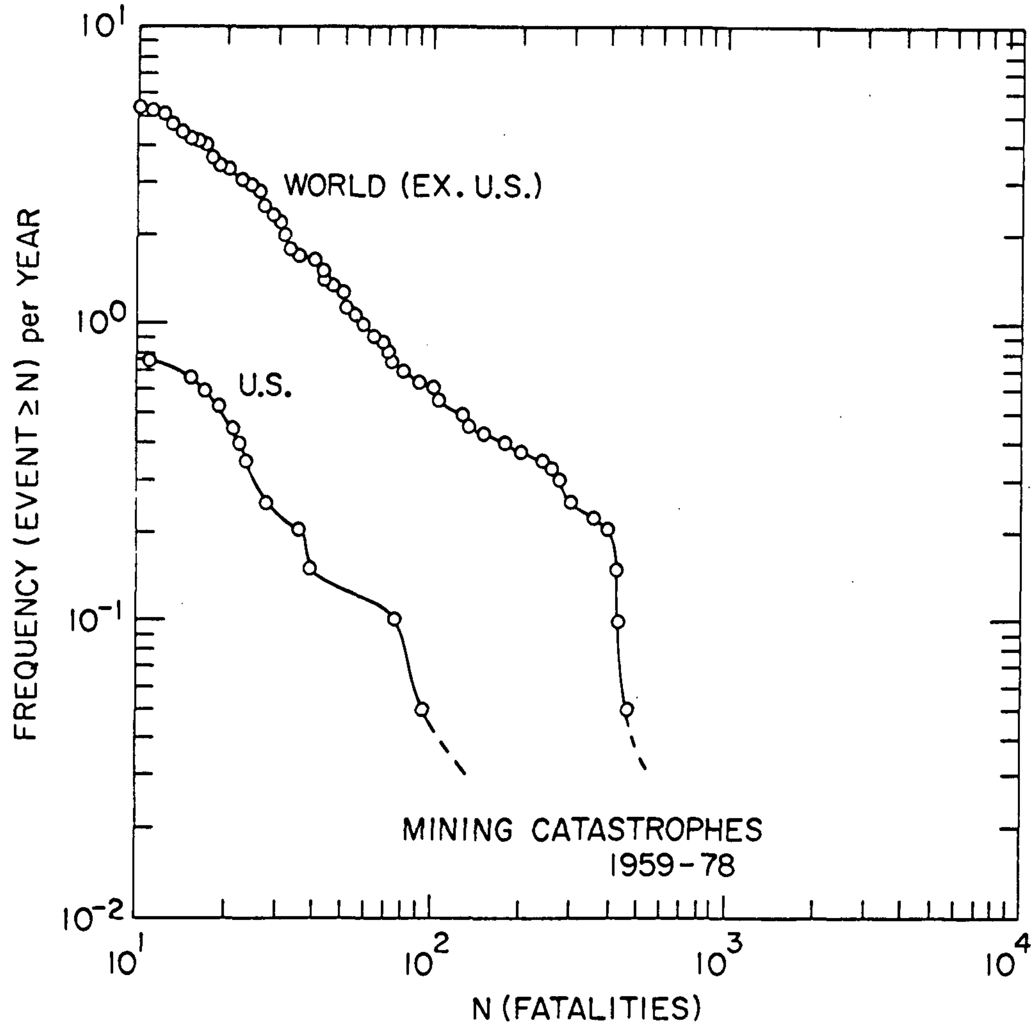


Figure 10

4.3.6 Fire and Explosion

Figure 11 gives the frequency versus fatalities curve for fires and explosions. The U.S. experience is essentially parallel to that of the rest of the world, indicating that there are no major differences for this hazard.

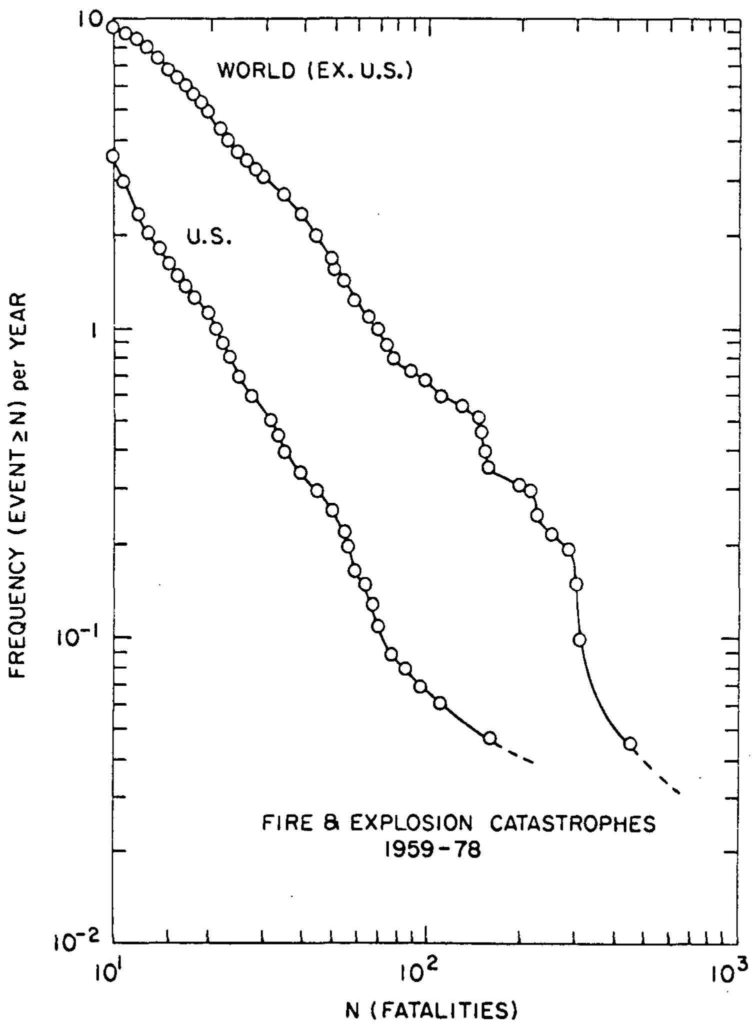


Figure 11

4.3.7 Liquified Natural Gas and Liquified Propane Gas - Risk Assessment

There have been several studies on the risks involving transportation of LNG and LPG, most commissioned by commercial interests for specific licenses at particular locations, for example the docket (7) for the licensing of Distrigas operation on Staten Island in New York Harbor. The conclusions of this specific report are given in terms of probability of catastrophic spills over a 10 year period due to ship and barge traffic in the harbor. It has been criticized as not conservative by Fairley (8) who finds fault with some of the assumptions made, such as reduced risk effects assumed for "double hull" construction of LNG tank ships and by special traffic provisions when they are under way in the harbor. This report and, in general, the other available reports on LNG and LPG assessments are site-specific and do not give any estimates of fatalities (societal risk), and therefore do not meet the criteria for comparison used here.

One report that does estimate societal risk was prepared by Simmons(9) for the EPA and assesses the risk of LNG and LPG transport for the U.S. in terms of fatalities. The results are shown in Fig. 12. This report does not deal with all the hazards involved in the manufacture, transportation and storage of LNG/LPG. It chooses specific aspects of transportation which are considered most hazardous, namely, tank ship movements within a harbor for LNG, and tank truck traffic on highways for LPG. Because the study is predictive, a discussion of the modelling used follows.

- Liquified Natural Gas

The assessment is based on petroleum tanker spill experience in the U.S. harbors and does not reduce the risk of spill by any amount due to double hull design or special traffic provisions. This study does not include any risk of spill and/or catastrophic deflagration due to storage tank operation, nor does it include any risk due to barge shipment within a harbor. The tank catastrophe is considered unlikely and the barge risk is not addressed.

The frequency of barge spills and accidents is larger according to (7), while the amount of spillage and consequences of each spill are lower. The effect of both of these unaccounted for risks would be to raise the entire risk curve shown in Figure 12. Since no data equivalent to the tankship data are available, the amount of the increase can only be estimated. If we use the comparative frequencies between significant tankship and barge spills given by Distrigas(7) as 10 (actually 9.3), this raises the origin of the LNG risk curve by one order of magnitude as seen in comparing the "estimated" and "tankers" curves of Fig. 12. This proportion, however, is valid only for the Port of New York. At other locations, such as the California sites, barge traffic will be small or nonexistent. This is therefore a conservative upper bound for this activity.

For the high consequence portion of the curve, we have one historical data point involving a storage tank event in Cleveland in the 1940s which resulted in the death of 128 people. The frequency attached to this event would again be additive since it was not used in deriving the "tankers" curve shown in Figure 12. In order to use this data point, we need to have an estimate of the number of tank years of operation in the U.S.

An examination of the tables listing early history LNG storage tanks (10) and for proposed LNG storage terminals as of 1974(7) shows that up until publication of Ref. 7, the number of tank years of operation in the U.S. was less than 100. Using an estimated frequency of 10^{-2}/year for the Cleveland accident raises the probability of the high consequence portion of the curve by roughly one order of magnitude, which is similar to the increase in the low consequence end of the curve.

Again this increase in the probability for the high consequence end is considered conservative, since the tank involved in the Cleveland event was not diked and all present or planned tanks are. Some would argue that this event should be neglected because the error in design of this early tank has been corrected; however, the arguments made here are only used to estimate rough upper bounds. More detailed evaluations would be required if more precise results are desired.

- Liquified Propane Gas (LPG)

The assessment made for LPG is based on actuarial data. The LPG frequency versus fatality curve shown in Figure 12 was based on data from overland tank truck, storage, and distribution facilities, and is much broader in scope than the LNG study. A much larger data base over a longer period (approximately 40 years) is available in this area and the data come from the LPG industry itself rather than a "sister" industry such as gasoline handling and transport. LPG is not shipped to the U.S. from overseas. It originates in this country and is generally transported over land via tank truck. Therefore, there are a much greater number of shipments and storage facilities than for LNG, but each is much smaller in size. For this reason the risk assessment curve is three orders of magnitude higher in the low consequence area and drops off rapidly so that it crosses the LNG curve at approximately 10 fatalities. If the size of storage and transport facilities were increased, the higher consequence portion of this curve would increase.

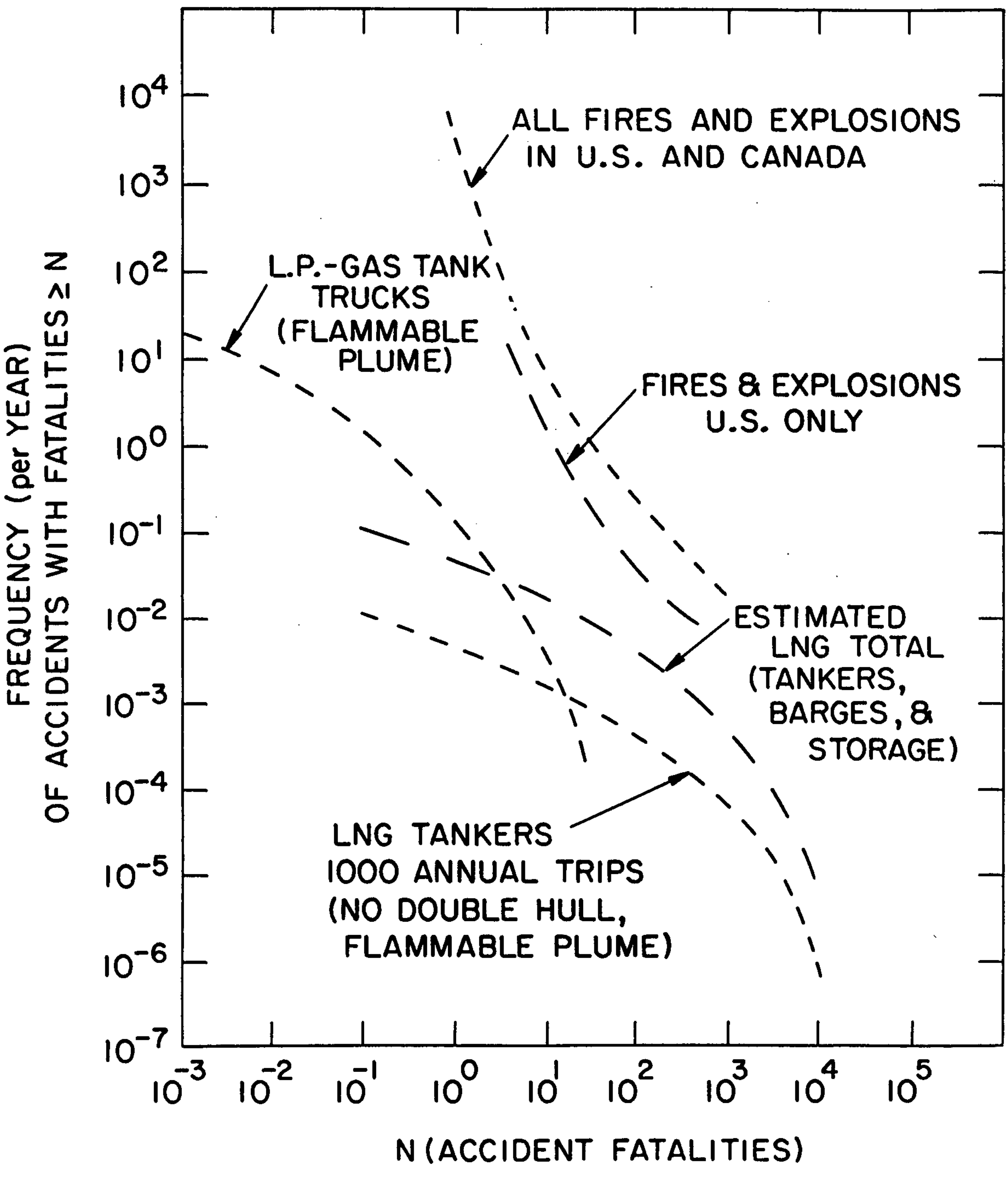


Fig. 12: LNG and LPG Risk Assessment
---- from Ref. 9
— — estimated (by authors)

4.3.8 Chlorine - Risk Assessment

A literature search revealed no additional data on this subject other than that given by Simmons et al(22), which was also used in WASH-1400.(19) Simmons sought to study all of the major toxic chemicals used in the U.S., and made a detailed study of the risk of transporting chlorine in railroad tank cars (90-ton capacity) which they used as a comparison model for other toxic chemicals. The histogram resulting from their chlorine assessment with no credit for evacuation (Fig. 13) showed fatalities far in excess of actual experience (one fatality in 50 years), and they repeated their assessment with the mitigating factor of evacuation, (Fig. 14). Both of these were converted into frequency vs. consequence curves in Ref. 19, (Fig. 15).

For a discussion of uncertainties associated with these assessments, see Section 4.1.

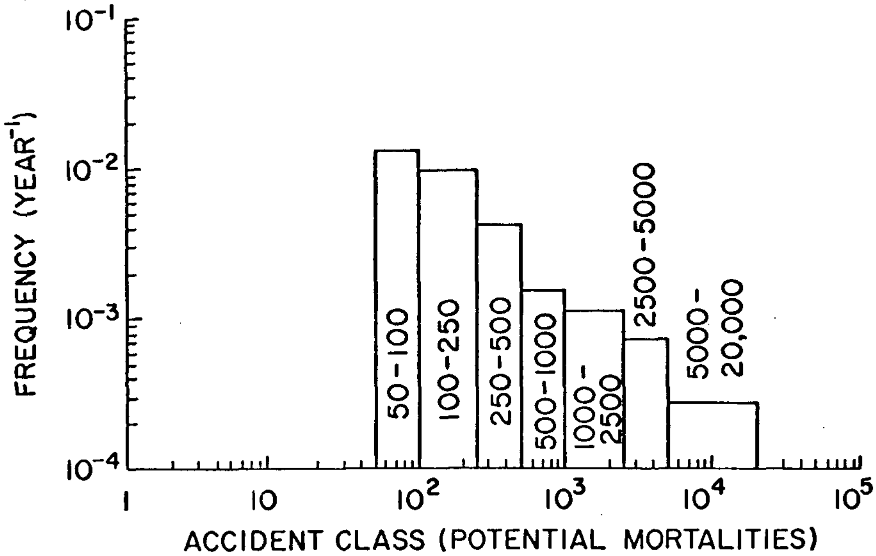


Fig. 13. Chlorine Transport Hazard. Frequency of accident class without evacuation (from Ref. 2).

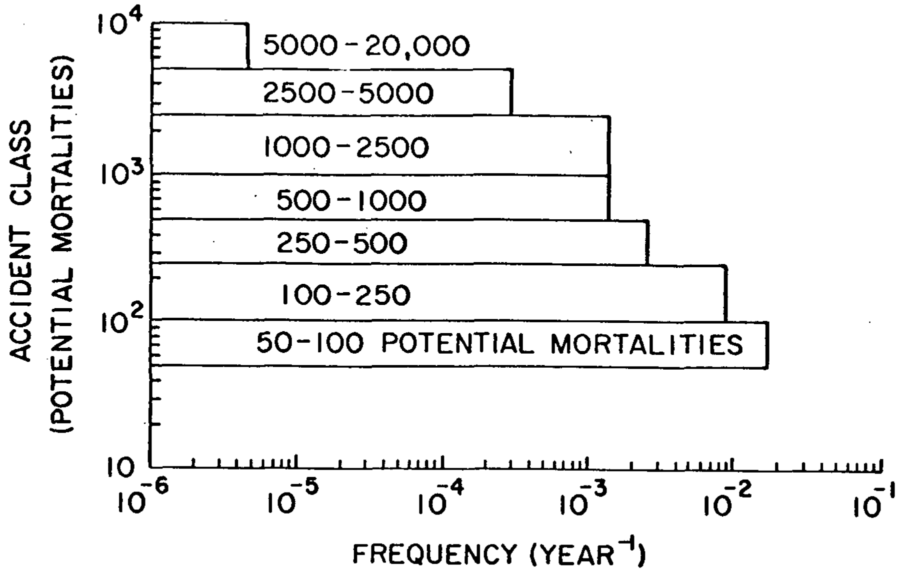


Fig. 14. Chlorine Transport Hazard with Mitigation. Frequency of accident class with evacuation (from Ref. 22).

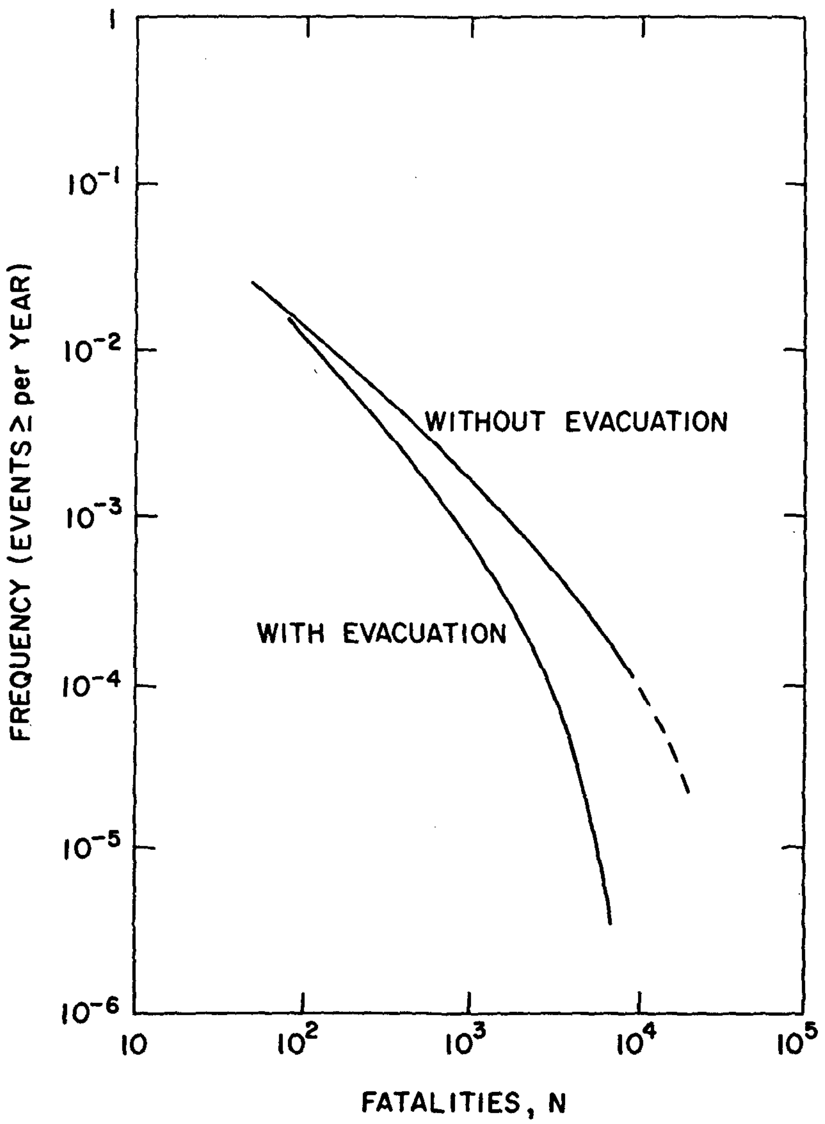


Fig. 15. Frequency of chlorine accidents involving fatalities (from Ref. 19).

4.3.9 Dam Failures

Several references were consulted for data on catastrophic dam failures (1, 6, 17, 19 and 21). Table 13 is a listing of the failures resulting in fatalities in the U.S. The additional data do not significantly alter the curve of Fig. 16, taken from WASH-1400 (19) nor the uncertainties associated with this curve.

TABLE 13

Dam and Levee Failures in the U.S.

Year	Location	Structure	Lives Lost
1874	Williamsburg, Mass.	Earth Dam	144
1889	Johnstown, Pa.	Earth Dam	∿ 2000(2209)
1890	Walnut Grove, Prescott, Ariz.	Dam	150
1894	Mill River, Mass.	Dam	143
1900	Austin/Austin, Pa.	Dam	8
1928	St. Francis Dam/Ca.	Dam	∿ 450 (up to 700)
1955	Yuba City, Ca.	Levee	38
1963	Baldwin Hill, Los Ang., Ca.	Earth Dam Reservoir	5(3)
1972	Buffalo Creek, W. Va.	Slagheap Dam	125
1972	Rapid City, S.D.	Dam	200
1976	Newfound, N.C.	Earth Dam	4
1976	Teton, Idaho	Earth Dam	14
1977	Toccoa, Ga.	Earth Dam	35
1874-Present			3525-3775

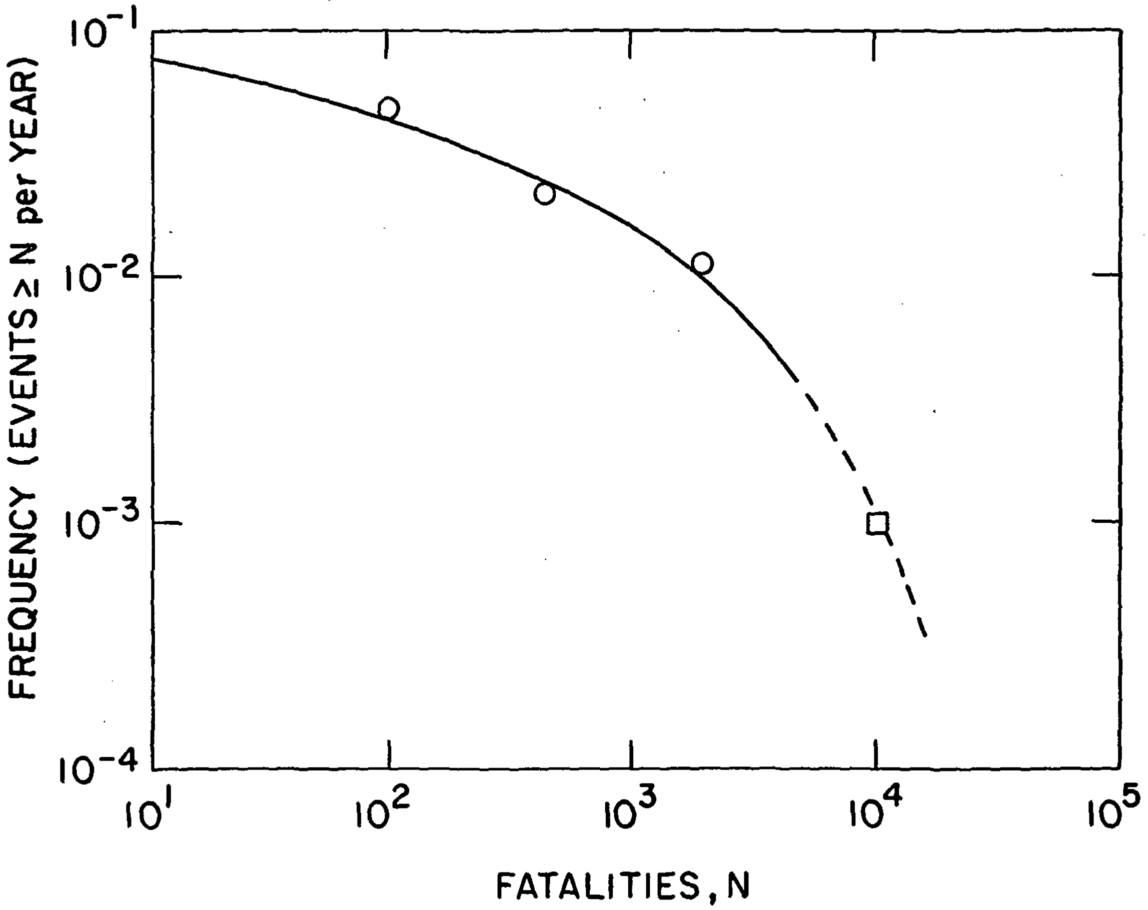


Fig. 16. Dam Failures (from Ref. 19)

4.3.10 Nuclear Power Plants - Risk Assessments

In Section 3 the chronic risks of the nuclear fuel cycle were compared with other power generating technologies. Catastrophes or high consequence accidents affecting the public during plant operation were not included in the analyses. WASH-1400(19) is one of the most exhaustive studies to date on the assessment of risks due to major core melt accidents (class 9 accidents) at nuclear power plants of the present designs. Figures 17 and 18 taken from (19) show the estimated probability (frequency) distributions for early and latent fatalities respectively for a population of 100 reactors in the U.S. of the size used in the study, 1000-MWe. Again, according to our definition, early fatalities occur within a short time of the causative event (generally less than one year) and latent fatalities occur over an extended time period after the event (generally one to forty years). There are at present over 70 reactors in operation (some under 1000 MWe), and there could be as many as 150 to 200 in operation by 1990. Note that the ordinates for the two curves are different. For early fatalities the ordinate, like those for all the other curves in this section, represents fatalities per event. For latent fatalities, the ordinate represents fatalities per event per year. The fatalities per year are integrated over the associated latent time period.

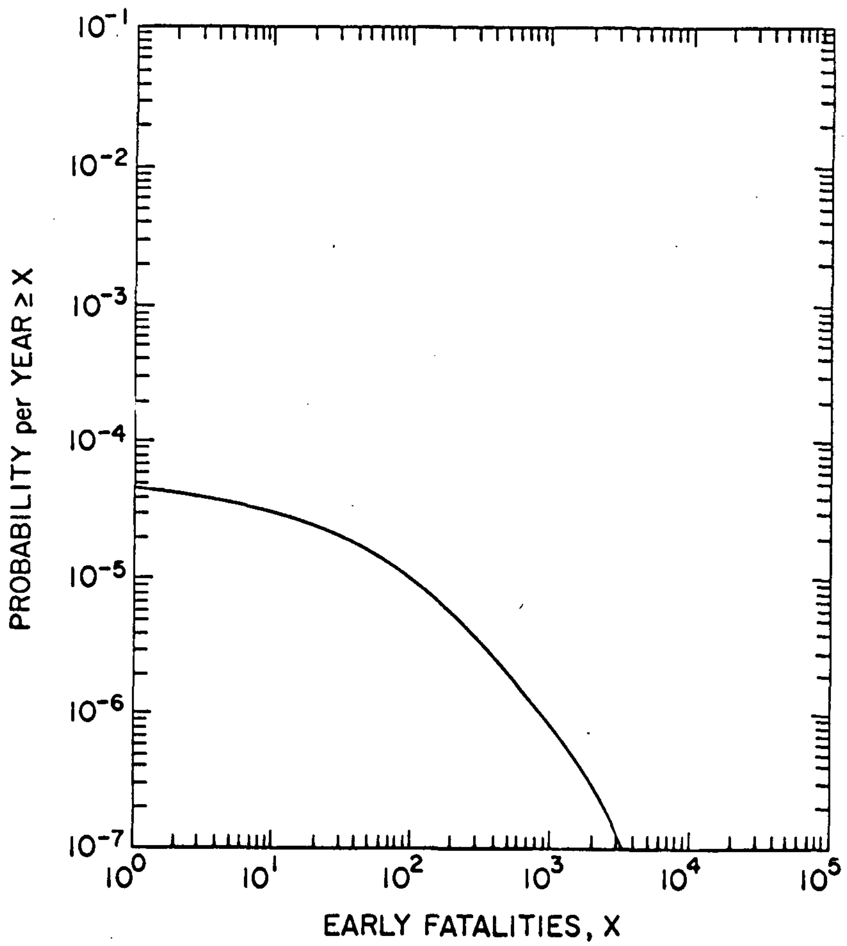


Fig. 17. Probability distribution for early fatalities per year for 100 Reactors (U.S.). Note: Approximate uncertainties are estimated to be represented by factors of 1/4 and 4 on consequence magnitude and by factors of 1/5 and 5 on probabilities.

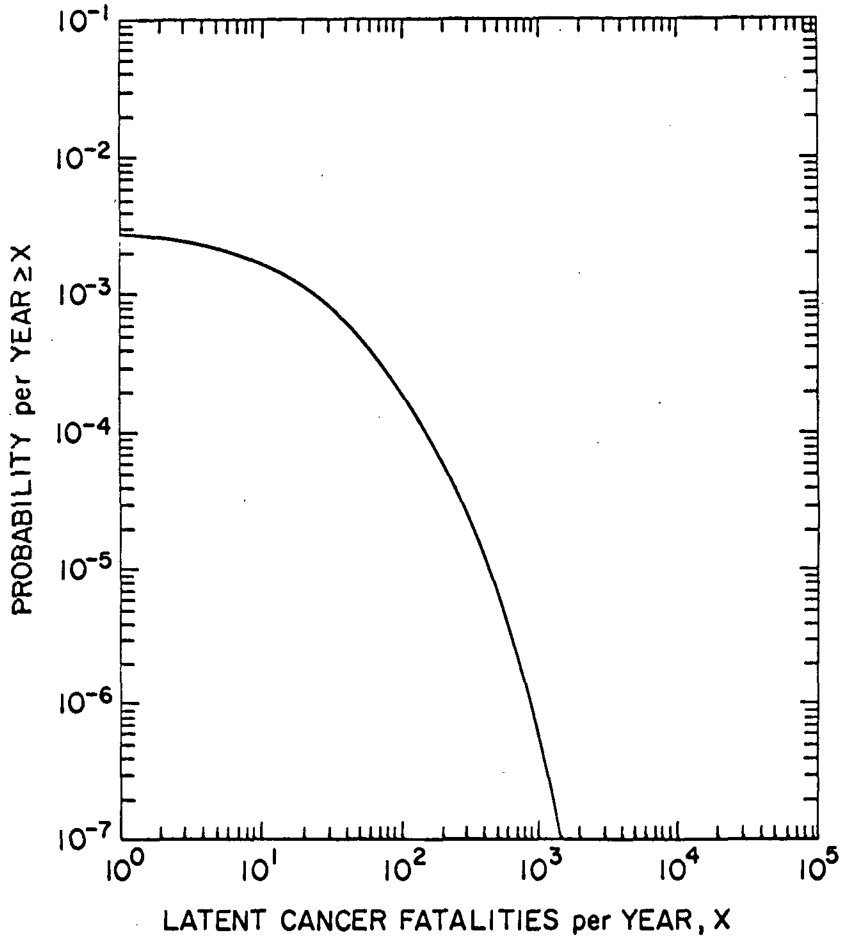


Fig. 18. Probability distribution for latent cancer fatality incidence per year for 100 Reactors (U.S.). Note: Approximate uncertainties are estimated to be represented by factors of 1/6 and 3 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.

These curves are the only ones so far presented that make a distinction between early and latent fatalities. For all the other hazards considered in this section, only early fatalities were counted in developing curves, both from actuarial data and from assessments such as those for chlorine and LNG/LPG. Several reasons can be given for latent effects not being evaluated in the other risk calculations:

- For most man-made and natural hazards, the latent fatalities are only a small fraction of the immediate fatalities and are not easily traceable to a specific event.

- For hazards having a high proportion of latent fatalities (e.g. fossil fuel power plants), the consequences are generally of a chronic nature and are due to continuous low-level pollution and not to a single catastrophic event.

Some authors, in trying to find a means for valid comparison, or addition, of the effects of latent and early fatalities, would reduce the latent fatalities by some factor -- Kinchin(24) suggests 30, and add them to the early fatalities. Some of the reasons given for the reduction in latent fatalities are as follows:

- The loss of life expectancy is less for latent fatalities than for immediate fatalities.

- Public perception of future death is less disturbing or more acceptable to society than that of immediate death - in other words the public "discounts" future life in terms of immediate life, much the same as an economic value.

These concepts of latent fatalities are not universally accepted, and in some comparisons (see Section 2 on fossil fuel power plant fatalities) latent and early fatalities are not differentiated. Levine(23) uses a factor of 30 reduction for latent fatalities and data from WASH-1400(19) on man-made hazards to produce a curve combining early and latent fatalities for nuclear power plants which can be plotted on the same axis as immediate fatalities per event from other hazards (Fig. 19). Levine cites Ref. 26 which gives arguments for the factor 30 reduction. The curve labelled "Early and Latent Fatalities" in Fig. 19 is the sum of the early curve plus 1/30 the latent fatality curve.

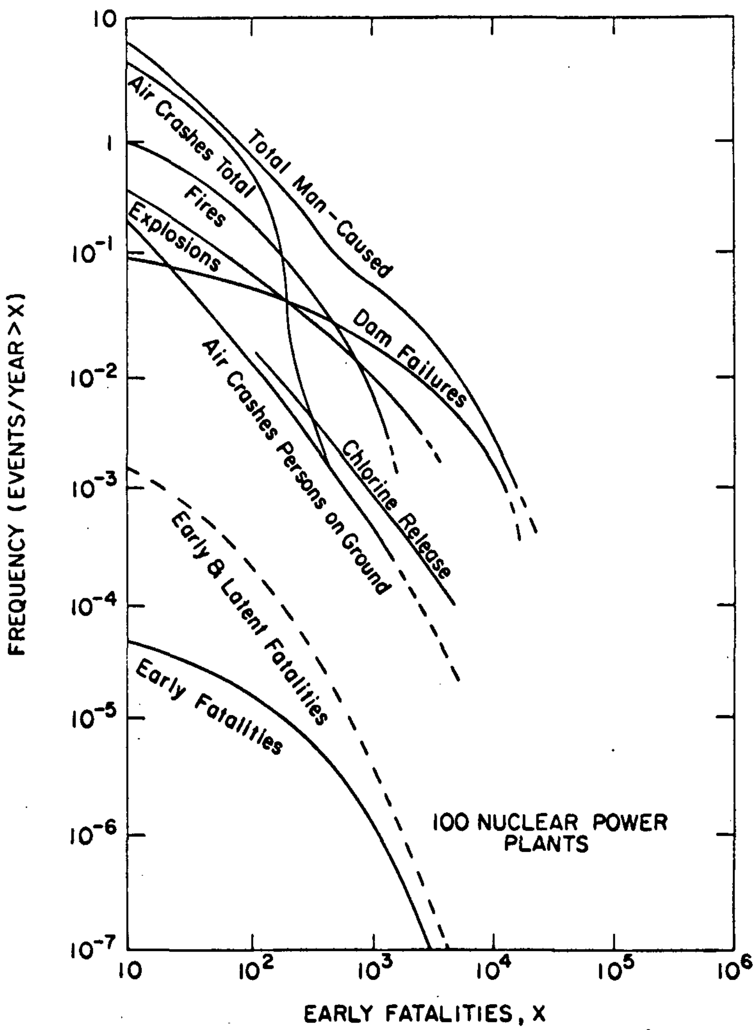


Fig. 19. Hazard Summary from Levine (Ref. 23)

It is worth noting again that WASH-1400 has been criticized, not only by opponents of nuclear power such as the Union of Concerned Scientists(27), but also by the Lewis committee(25), the ad hoc review group chartered by the NRC to review the WASH-1400 study. One of the major criticisms is that the uncertainty bands are thought to be larger than stated in WASH-1400. For the UCS, the uncertainties "appear to dwindle and vanish"(27), while for the Lewis report, they are "understated"(25).

4.4 LATENT VS. EARLY FATALITIES

In the case of nuclear power, we have emphasized the difference between early and latent fatalities and added the two results to obtain total fatalities in any year due to nuclear accidents. As defined in this report, early fatalities are deaths occurring within one year of an event, and latent fatalities are deaths occurring one to forty years after an event. For a nuclear incident, the number of latent fatalities in general dominates the number of early fatalities and therefore must be accounted for. For the other accidents listed in Table 14, the data on latent fatalities are sparse, but as previously stated, those available tend to show that latent fatalities are a small portion of the total (e.g. about less than 1%).

TABLE 14

Accidental Deaths According to the International List of Causes of Death (U.S. only) (Derived from Ref. 6, page 12)

Type of Accident or Manner of Injury	1977	1976	1975	1974
All Accidental Deaths	103,202	100,761	103,030	104,622
Transport Accidents	53,286	50,644	49,838	50,659
(Motor Vehicle)	49,510	47,038	45,853	46,402
Poisoning by Solids and Liquids	3,374	4,161	4,694	4,016
Poisoning by Gases and Vapors	1,596	1,569	1,577	1,518
Falls	13,773	14,136	14,896	16,339
Fires and Flames	6,357	6,338	6,071	6,236
Natural and Environmental Factors	1,751	1,299	1,268	1,427
Other Accidents	19,158	18,827	20,737	20,711
Surgical and Medical Complications and Misadventures	3,107	3,009	3,184	3,021
Late Effects (death more than one year after accident)	800	778	765	695

Even though, in general, latent effects may be small, such as those of fossil fuel power plants, the expected number of latent effects are likely to dominate the expected number of early fatalities. A principal hazard posed by fossil fuel plants is that due to increased air pollution (mainly sulfates, particulates and other carcinogens), which increases mortality due to lung cancer and cardiovascular impairment. These effects take long periods to be manifest in any individual, but they add up to a constant, chronic increase in mortality for the society. These fatalities are not easily definable or separated from other causes, i.e. one cannot distinguish a lung cancer victim from power plant operation or from other causes, and hence data are not available which discriminate causes.

4.5 COMPARISON OF HIGH CONSEQUENCE RISKS

Figures 20 and 21 show comparisons of all the high consequence risks discussed in this section. Figure 20 shows the data for natural hazards plus an estimate for meteorites taken directly from WASH-1400 (19). Figure 21 shows the data for man-made hazards, with dam failures taken from WASH-1400 and the chlorine curve (without evacuation) derived from the same source as used in WASH-1400. In order to compare the risks on the basis of fatalities, a method of combining latent and early fatalities is performed here.

In the previous section, one method of summing latent and early fatalities was presented in order to be able to compare hazards on the same axis; this method involved reducing the latent fatalities by a factor of 30. Simple addition of the curves in Figs. 17 and 18, gives the resultant curve for "100 REACTORS-EARLY & LATENT" in Fig. 20. This curve is very similar to Levine's curve, for the following reason. The derivation of the curve for latent fatalities per year in Fig. 18 also involves a factor of approximately 30 reduction over the total latent curve. This is due to the fact that all latent fatalities due to one event, after a certain period of latency (during which few deaths occur) are spread out over a long period of approximately 30 years. Thus when the per year curve given in Fig. 18 is added to the early fatalities shown in Fig. 17, the result (Fig. 20) is very similar to Levine's curve.

If the reader wants to use any other discount factor for latent fatalities, he may do so; we have simply combined them in the manner described as one approach for comparison. Latent fatalities for all the other hazards have not been included because they are negligible in comparison with the early fatalities for these hazards, as documented by the National Safety Council(6), which attributed only 800 deaths to "late effects" (death more than one year after the accident) in a total of 103,202 accident fatalities in the U.S. in 1977. If, however, even a small fraction, say 10%, of these deaths were attributable to catastrophic events, the "expected value" of 80 would be large compared with the expected value of less than 1 for 100 nuclear power plants. Therefore, although the number of latent fatalities should be included in some manner in the results for nuclear power plants because it is large compared with the number of early fatalities due to nuclear power plants, the number of latent fatalities for nuclear plants is small compared with the latent effects of other hazards which have not been counted.

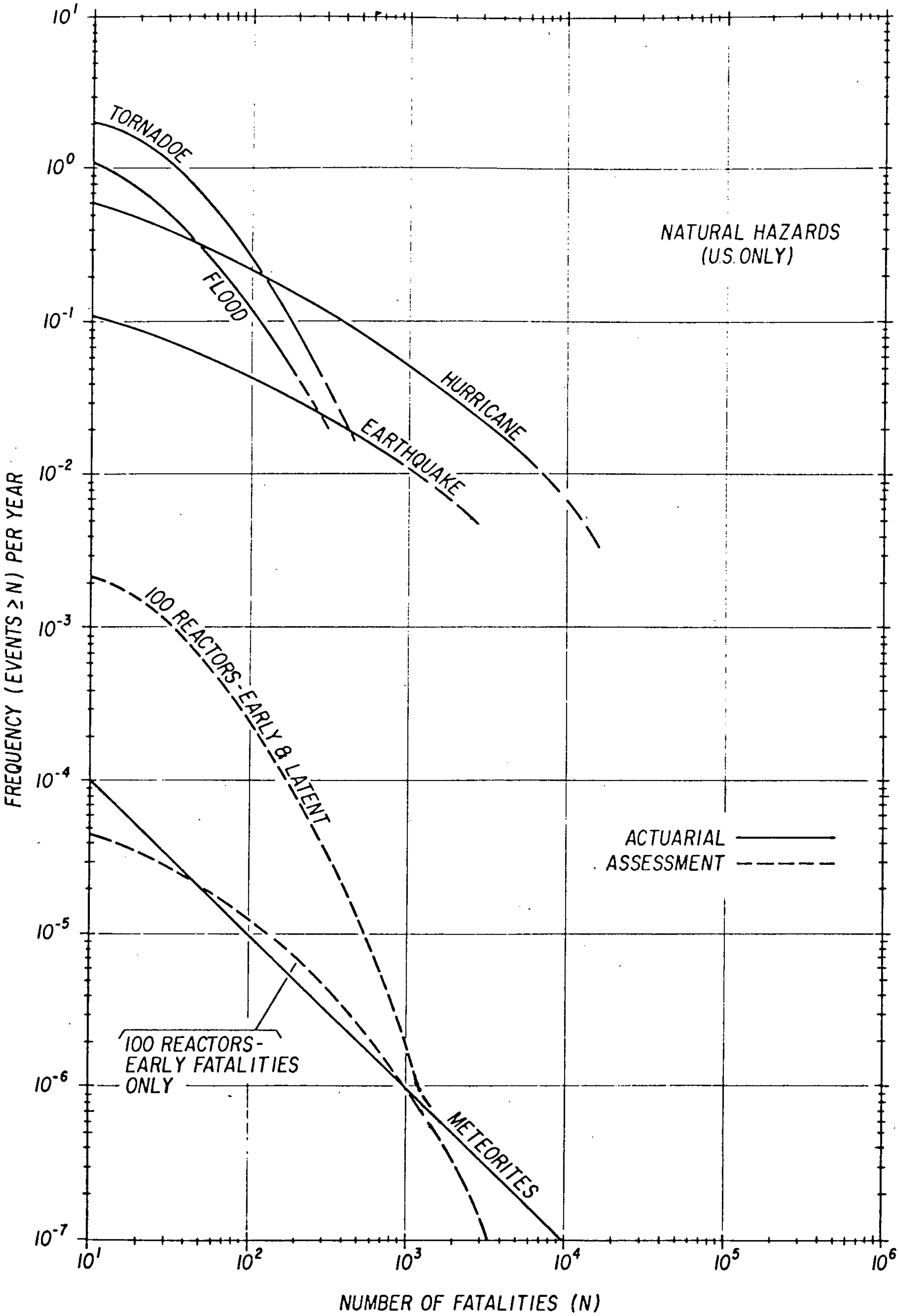

FREQUENCY (EVENTS ≥ N) PER YEAR
NUMBER OF FATALITIES (N)
NATURAL HAZARDS
(U.S. ONLY)
TORNADOE
FLOOD
HURRICANE
EARTHQUAKE
100 REACTORS-EARLY & LATENT
100 REACTORS-
EARLY FATALITIES
ONLY
METEORITES
ACTUARIAL
ASSESSMENT

Figure 20

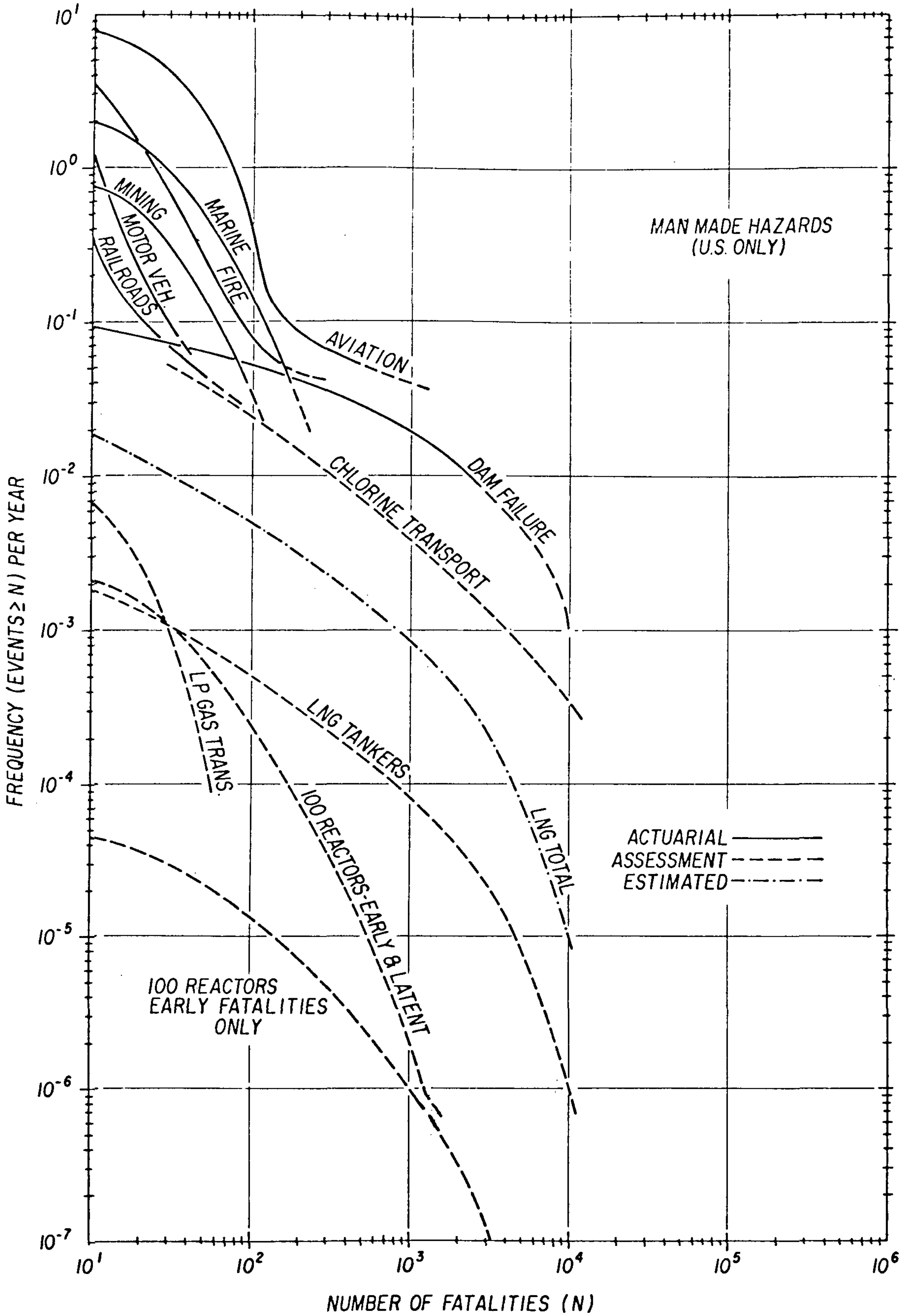

10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
FREQUENCY (EVENTS ≥ N) PER YEAR
MAN MADE HAZARDS
(U.S. ONLY)
MINING
MOTOR VEH.
RAILROADS
MARINE
FIRE
AVIATION
DAM FAILURE
CHLORINE TRANSPORT
LP GAS TRANS.
LNG TANKERS
LNG TOTAL
100 REACTORS-EARLY & LATENT
100 REACTORS
EARLY FATALITIES
ONLY
ACTUARIAL
ASSESSMENT
ESTIMATED
10^1
10^2
10^3
10^4
10^5
10^6
NUMBER OF FATALITIES (N)

Figure 21

5. INDIVIDUAL RISK

Table 15(6) gives a breakdown by age of death rates for the most common causes of death for the U.S. population. This table is an expanded version of Table 3 in which the frequencies of fatalities are divided by the population at risk to obtain the death rates for Table 14. Both Table 3 and 14 are obtained from statistics for the year 1977 when the total U.S. population was 216 million. The death rate can be translated to be a probability of death from a specific cause for a member of a given age group in a specific year. Some view this as a measure of individual risk. For example, in 1977 the average U.S. person between the ages of 45 to 64 years of age had a probability of death in that year due to a motor vehicle accident of 18/100,000 or 1.8×10^{-4}. For the entire population, the probability of death per year due to a motor vehicle accident for any person in the U.S. was 2.3×10^{-4}, an increase of approximately 30%, and for females only, the probability was 1.2×10^{-4}, a decrease of approximately 33%.

Age and sex are not the only factors that can affect the calculation of risk. For the major causes of death such as heart disease and cancer, heredity, life-style, eating, smoking and drinking habits, plus many more factors can influence individual risk. There are enough differences in people so that the "average individual risk" obtained when the frequency is divided by the defined population at risk may not be very meaningful for a particular individual in that population. The individual risks thus calculated are averages over certain defined populations and this fact must be remembered when reading the table.

Table 15 . Leading Causes of All Deaths, U.S., 1977 [From Nat. Safety Council (6)] (Rate = deaths per 100,000 population in each age group; Stroke = cerebrovascular disease; numbers for drownings are partly estimated. Data from USPHS).

	No.	Rate
All Ages	1,899,597	878
Heart disease	718,850	332
Cancer	386,686	179
Stroke	181,934	84
Accidents	103,202	48
Motor vehicle	49,510	23
Falls	13,773	6
Drowning	7,126	3
Fires, burns	6,357	3
Other	26,436	13
Under 1 Year	46,975	1,485
Anoxia	10,604	335
Congenital anomolies	8,420	266
Complications of pregnancy and childbirth	5,786	183
Immaturity	3,714	117
Pneumonia	1,665	53
Accidents	1,173	37
Ingestion of food	275	9
Motor vehicle	253	8
Mech. suffocation	206	6
Fires, burns	159	5
Other	280	9
1 to 4 Years	8,307	69
Accidents	3,297	27
Motor vehicle	1,219	10
Drowning	650	5
Fires, burns	608	5
Ingestion of food	168	1
Falls	121	1
Other	531	5
Congenital anomalies	1,066	9
Cancer	631	5
5 to 14 Years	12,579	35
Accidents	6,305	17
Motor vehicle	3,142	9
Drowning	1,110	3
Fires, burns	550	1
Firearms	344	1
Other	1,159	3
Cancer	1,733	5
Congenital anomalies	676	2
15 to 24 Years	47,986	117
Accidents	25,619	63
Motor vehicle	18,092	44
Drowning	2,150	5
Poison (solid, liq)	709	2
Firearms	665	2
Other	4,003	10
Suicide	5,565	14
Homicide	5,196	13
Poison (solid, liq)	709	2
Firearms	665	2
Other	4,003	10
Suicide	5,565	14
Homicide	5,196	13
25 to 44 Years	103,042	182
Accidents	23,460	42
Motor vehicle	13,031	23
Drowning	1,690	3
Poison (solid, liq)	1,349	2
Fires, burns	1,081	2
Falls	956	2
Other	5,353	10
Cancer	16,753	30
Heart Disease	14,392	25
45 to 64 Years	437,795	1,000
Heart disease	153,552	351
Cancer	132,514	303
Stroke	22,925	52
Accidents	19,167	44
Motor vehicle	8,000	18
Falls	2,245	5
Fires, burns	1,481	4
Drowning	940	2
Surg. complications	865	2
Other	5,636	13
Cirrhosis of liver	17,166	39
Suicide	8,368	19
65 to 74 Years	445,595	3,054
Heart Disease	182,354	1,250
Cancer	115,587	792
Stroke	37,896	260
Diabetes mellitus	9,611	66
Accidents	9,006	62
Motor vehicle	3,060	24
Falls	1,995	14
Fires, burns	843	6
Surg. complications	767	5
Ingestion of food	447	3
Other	1,894	13
Pneumonia	8,335	57
Cirrhosis of liver	6,208	43
75 Years and Over	797,318	8,941
Heart Disease	366,141	4,106
Stroke	116,753	1,309
Cancer	116,675	1,308
Pneumonia	30,487	342
Arteriosclerosis	23,683	266
Accidents	15,175	170
Falls	7,762	87
Motor vehicle	2,713	30
Surg. complications	1,030	12
Fires, burns	1,023	11
Ingestion of food	723	8
Other	1,924	22
Diabetes mellitus	13,993	157
Emphysema	6,190	69

5.1 Life Shortening

In order to compare the individual risks due to air pollution, cigarette smoking and other "nontraumatic" causes with those due to motor vehicle accidents and other immediate effects, some authors have converted the statistics on individual fatalities to life shortening times for each hazard considered. Table 16, taken from Ref. 12, gives life shortening times for various causes.

The loss of life expectancy (ΔE) for a particular cause is defined as the difference between life expectancy of an individual in our society (U.S.) subject to that cause and the life expectancy of that same individual in the absence of that particular cause. The basic information required for the calculation of ΔE for a particular cause is a revised mortality rate. This revised mortality rate is obtained by subtracting the mortality rate for the particular cause in question from the general mortality rate which includes all causes. A more complete derivation is given in Ref. 12 for the data shown in Table 16.

TABLE 16

Loss of Life Expectancy (ΔE) Due to Various Causes

Cause	Days	Cause	Days
Being unmarried — male	3500	Drowning	41
Cigarette smoking — male	2250	Job with radiation exposure	40
Heart disease	2100	Falls	39
Being unmarried — female	1600	Accidents to pedestrians	37
Being 30% overweight	1300	Safest jobs — accidents	30
Being a coal miner	1100	Fire — burns	27
Cancer	980	Generation of energy	24
20% overweight	900	Illicit drugs (U.S. aver.)	18
< 8th grade education	850	Poison (solid, liquid)	17
Cigarette smoking — female	800	Suffocation	13
Low socioeconomic status	700	Firearms accidents	11
Stroke	520	Natural radiation (BEIR)	8
Living in unfavorable state	500	Medical X-rays	6
Army in Vietnam	400	Poisonous gases	7
Cigar smoking	330	Coffee	6
Dangerous job — accidents	300	Oral contraceptives	5
Pipe smoking	220	Accidents to pedalcycles	5
Increasing food intake 100 cal/day	210	All catastrophes combined	3.5
Motor vehicle accidents	207	Diet drinks	2
Pneumonia — influenza	141	Reactor accidents — UCS	2★
Alcohol (U.S. average)	130	Reactor accidents — Rasmussen	0.02★
Accidents in home	95	Radiation from nuc. industry	0.02★
Suicide	95	PAP test	-4
Diabetes	95	Smoke alarm in home	-10
Being murdered (homicide)	90	Air bags in car	-50
Legal drug misuse	90	Mobile coronary care units	-125
Average job — accidents	74	Safety improvements 1966-76	-110

★These items assume that all U.S. power is nuclear. UCS is Union of Concerned Scientists, the most prominent group of nuclear critics.

From Ref. 12

6. DISCUSSION

This report summarizes the author's detailed review of current actuarial data and analysis results in the general area of societal risk. Throughout the text there has been an attempt to discuss the usefulness and limitations of various sources of information, however, the author's generalized opinions have been purposely omitted. This will allow the user to objectively determine, on a case by case basis, the specific applicability of the results presented to his or her analysis.

With the increased interest in the use of Probabilistic Risk Assessment (PRA) in the decision making process of nuclear power generation, there has developed a need to baseline the results. Without such a numerical anchor to which the results of analyses can be relatively compared, the assessment of the societal impact of a technology becomes difficult. One method of placing the results of a PRA in perspective is to compare the risks to those of other natural and man-made hazards. The Reactor Safety Study(19) utilized this type of comparison. Therefore, the information presented by the authors in this report can be considered an updating of the WASH-1400(19) comparison.

When applying the information from this report, the reader is cautioned to review fully its applicability and ultimate goals of his or her study. In general, the results of nuclear power PRAs are based on analyses due to the lack of actuarial data and, as such, have relatively large uncertainties associated with them. Direct comparison to actuarial data requires great care since, in general, the reported events have different time constants than nuclear plant calculations. In addition, the comparison of man-made hazards to which the public has no choice, i.e. power generation, to other man-made hazards such as motor vehicles when the individual makes the conscious decision to accept the risk must be clearly defined. This also holds true when comparing technological hazards to natural ones to achieve a meaningful conclusion.

The use of this report should help the reader in placing the results of a PRA in perspective as related to overall societal risk. As work continues on collecting actuarial data, and as analysis techniques are refined, direct comparisons should become more apparent. However, until that time, engineering judgement will be a key factor in the use of comparative studies.

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APPENDIX A

This section contains the tables of frequency per year versus number of fatalities used to construct the curves given in Section 4. The tables also include values for number of events and cumulative totals. For all the common hazards except Tornadoes, both U.S. and World data are given. They are given in the same order as presented in Section 4.

LIST OF TABLES

TABLE A1
HURRICANES 1938-1977

Number of Fatalities	U.S. Number of Events	U.S. Cumulative Total	U.S. Frequency Per Year ≥N	U.S. (Plus WASH-1400 Data) Number of Events	U.S. (Plus WASH-1400 Data) Cumulative Total	U.S. (Plus WASH-1400 Data) Frequency Per Year ≥N	World (Ex. U.S.) Number of Events	World (Ex. U.S.) Cumulative Total	World (Ex. U.S.) Frequency Per Year ≥N
10				1	42	0.538	2	180	4.500
11	1	28	0.700	2	41	0.525	4	178	4.450
12									
13							3	174	4.350
14									
15							3	171	4.275
16	1	27	0.675	1	39	0.499	1	168	4.200
17	1	26	0.650	1	38	0.486	3	167	4.175
18							2	164	4.100
19	1	25	0.625	1	37	0.474			
20							2	162	4.050
21				1	36	0.461	1	160	4.000
22	1	24	0.600	1	35	0.448	2	159	3.975
23	1	23	0.575	1	34	0.435	3	157	3.925
24	2	22	0.550	2	33	0.422	2	154	3.850
25							2	152	3.800
26							2	150	3.750
27	1	20	0.500	1	31	0.397	3	148	3.700
28									
29							3	145	3.625
30							3	142	3.550
31							5	139	3.475
32	1	19	0.475	1	30	0.384	1	134	3.350
33							1	133	3.325
34									
35	1	18	0.450	1	29	0.371	3	132	3.300
36	1	17	0.425	1	28	0.358	1	129	2.225
37									
38	1	16	0.400	1	27	0.346	2	128	3.200
39							2	126	3.150
40	1	15	0.375	3	26	0.333			

TABLE A1 (Cont'd)
HURRICANES 1938-1977

	U.S.			U.S. (Plus WASH-1400 Data)			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N
41							2	124	3.100
42							1	122	3.050
43							4	121	3.025
44							1	117	2.925
45									
46	1	14	0.350	1	23	0.294			
47									
48									
49									
50							5	116	2.900
51	1	13	0.325	1	22	0.282			
52							1	111	2.775
53									
54							1	110	2.750
55							1	109	2.725
56							1	108	2.700
60							2	107	2.675
65							1	105	2.625
67							2	104	2.600
68	1	12	0.300	1	21	0.269			
69							1	102	2.550
71							1	101	2.525
74	1	11	0.275	1	20	0.256			
75	1	10	0.250	1	19	0.243	2	100	2.500
80							4	98	2.450
84	1	9	0.225	1	18	0.230			
86							3	94	2.350
90							3	91	2.275
99	1	8	0.200	1	17	0.218			
100							7	88	2.200

TABLE A1(Cont'd)
HURRICANES 1938-1977

	U.S.			U.S. (Plus WASH-1400 Data)			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N
105							7	81	2.025
110							2	74	1.850
115							2	72	1.800
120							1	70	1.750
130							1	69	1.725
134	1	7	0.175	1	16	0.205			
135							1	68	1.700
138	1	6	0.150	1	15	0.192			
145							1	67	1.675
160							1	66	1.650
170							2	65	1.625
175							1	63	1.575
185							1	62	1.550
191	1	5	0.125	1	14	0.179			
200							6	61	1.525
226							1	55	1.375
239							1	54	1.350
243				1	13	0.166			
250							5	53	1.325
260							2	48	1.200
275				2	12	0.154			
293							1	46	1.150
300							4	45	1.125
323				1	10	0.128			
343							1	41	1.025
350				1	9	0.115	2	40	1.000
400	1	4	0.100	1	8	0.102	3	38	0.950
408				1	7	0.090			
410							1	35	0.875
430							3	34	0.850

TABLE A1 (Cont'd)
HURRICANES 1938-1977

	U.S.			U.S. (Plus WASH-1400 Data)			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N
448							1	31	0.775
500							2	30	0.750
525							1	28	0.700
534	1	3	0.075	1	6	0.077			
545							1	27	0.675
579							1	26	0.650
650							1	25	0.625
700	1	2	0.500	1	5	0.064			
730							1	24	0.600
750	1	1	0.025	1	4	0.051			
769							1	23	0.575
787				1	3	0.038			
800							1	22	0.550
845							1	21	0.525
975							1	20	0.500
1000							4	19	0.475
1450							1	15	0.375
1600							1	14	0.350
1800				1	2	0.026			
2000							1	12	0.300
2300							1	11	0.275
4464							1	10	0.250
5000							1	9	0.225
6000				1	1	0.013	1	8	0.200
7000							1	7	0.175
10000							1	6	0.150
12000							1	5	0.125
17000							1	4	0.100
20000							1	3	0.075
30000							1	2	0.050
40000							1	1	0.025

TABLE A2
TORNADOES (1938-1977)

U.S.

Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥ N
10	5	79	1.975
11	4	74	1.850
12	3	70	1.750
13	9	67	1.675
14	3	58	1.450
15			
16	3	55	1.375
17	3	52	1.300
18			
19			
20	2	49	1.225
21	1	47	1.175
22	3	46	1.150
23	3	43	1.075
24	1	40	1.000
25	2	39	0.975
26	1	37	0.925
27	1	36	0.900
28	2	35	0.875
29	1	33	0.825
30	1	32	0.800
31	3	31	0.775
32			
33	1	28	0.700
34	0		
35	1	27	0.675
36	1	26	0.650
37			
38	2	25	0.625
39	1	23	0.575
40	1	22	0.550
41	1	21	0.525
42	1	20	0.500
43	1	19	0.475
45	1	18	0.450
56	1	17	0.425
59	1	16	0.400
61	1	15	0.375
70	1	14	0.350
97	1	13	0.325
100	2	12	0.300
114	1	10	0.250
115	1	9	0.225
116	1	8	0.200
125	1	7	0.175
136	1	6	0.150
145	1	5	0.125
167	1	4	0.100
250	1	3	0.075
270	1	2	0.050
323	1	1	0.025

TABLE A3
FLOODS 1938-1977

	U.S.			WORLD (EXCEPT U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year	Number of Events	Cumulative Total	Frequency Per Year
10	2	45	1.125	4	281	7.025
11	1	43	1.075	6	277	6.925
12	3	42	1.050	1	271	6.775
13	4	39	0.975	1	271	6.775
14				3	270	6.750
15	5	35	0.875	8	267	6.675
16	5	30	0.750			
17	3	25	0.625	2	259	6.475
18	1	22	0.550	1	257	6.425
19				1	256	6.400
20	2	21	0.525	8	255	6.375
21	3	19	0.475			
22				2	247	6.175
23				2	245	6.125
24				4	243	6.075
25				4	239	5.975
26	1	16	0.400	4	235	5.875
27				3	231	5.775
28				2	228	5.700
29				1	226	5.650
30	1	15	0.375	11	225	5.625
31				1	214	5.350
32						
33	1	14	0.350	1	213	5.325
34	1	13	0.325	2	212	5.300
35				2	210	5.250
36				6	208	5.200
37				2	202	5.050
38						
39	1	12	0.300	1	200	5.000
40	2	11	0.275	5	199	4.975
41				2	194	4.850
42				1	192	4.800
43						
44						
45				2	191	4.775
46				1	189	4.725
47				3	188	4.700
48						
49				1	185	4.625
50				10	184	4.600
51				4	174	4.350
52				1	170	4.250
53				2	169	4.225

TABLE A3
FLOODS 1938-1977

	U.S.			WORLD (EXCEPT U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year	Number of Events	Cumulative Total	Frequency Per Year
54				1	167	4.175
55	1	9	0.225			
56						
57						
58				1	166	4.150
59				1	165	4.125
60				6	164	4.100
64				1	158	3.950
66				1	157	3.925
68				1	156	3.900
70	1	8	0.200	2	155	3.875
71				1	153	3.825
73				1	152	3.800
75	1	7	0.175	2	151	3.775
76				1	149	3.725
77				1	148	3.700
80				6	147	3.675
82				1	141	3.525
86				1	140	3.500
87				1	139	3.475
90				1	138	3.450
92				2	137	3.425
94				1	135	3.375
100	2	6	0.150	16	134	3.350
101				1	118	2.950
104				1	117	2.925
106				1	116	2.900
107				1	115	2.875
113				2	114	2.850
118	1	4	0.100	1	112	2.800
119				1	111	2.775
120				2	110	2.750
122				1	108	2.700
123				3	107	2.675
124				1	104	2.600
130	1	3	0.075			
131				1	103	2.575
135				1	102	2.550
138				1	101	2.525
140				1	100	2,500
143				1	99	2.475
150				5	98	2.450
155				1	93	2.375
160				1	92	2.300
180				1	91	2.275

TABLE A3
FLOODS 1938-1977

	U.S.			WORLD (EXCEPT U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year	Number of Events	Cumulative Total	Frequency Per Year
182				1	90	2.250
184				1	89	2.225
186				1	88	2.200
187				1	87	2.175
198				1	86	2.150
200	1	2	0.050	7	85	2.125
207				1	78	1.950
208				1	77	1.925
215				1	76	1.900
218				1	75	1.875
225				1	74	1.850
226				1	73	1.825
235	1	1	0.025	0		
237				2	72	1.800
242				1	70	1.750
250				1	69	1.725
265				2	68	1.700
267				1	66	1.650
272				1	65	1.625
300				8	64	1.600
305				1	56	1.400
325				1	55	1.375
330				1	54	1.350
377				1	53	1.325
400				1	52	1.300
427				1	51	1.275
450				2	50	1.250
467				1	48	1.200
470				1	47	1.175
475				1	46	1.150
489				1	45	1.125
500				5	44	1.100
542				1	39	0.975
560				3	38	0.950
563				1	35	0.875
618				1	34	0.850
630				1	33	0.825
638				1	32	0.800
649				1	31	0.775
700				1	30	0.750
800				2	29	0.725
810				1	27	0.675
894				1	26	0.650
1000				7	25	0.625
1500				1	18	0.450

TABLE A3
FLOODS 1938-1977

	U.S.			WORLD (EXCEPT U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year	Number of Events	Cumulative Total	Frequency Per Year
1700				1	17	0.425
1800				1	16	0.400
2000				5	15	0.375
2600				1	10	0.250
3000				1	9	0.225
4000				1	8	0.200
5000				1	7	0.175
10000				1	6	0.150
22000				1	5	0.125
40000				1	4	0.100
57000				1	3	0.075
200000				1	2	0.050
2-500000				1	1	0.025

TABLE A4
EARTHQUAKES 1938-1977

	U.S.			U.S. (WASH-1400 Data 1906-77)			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N
10				2	9	0.127	5	165	4.125
11							1	160	4.000
12	1	4	0.100	1	7	0.098			
13				1	6	0.085	1	159	3.975
14									
15							2	158	3.950
16							4	156	3.900
17							2	152	3.800
18							2	150	3.750
19							1	148	3.700
20							2	147	3.675
21							1	145	3.625
22							1	144	3.600
23							1	143	3.575
24							1	142	3.550
25							1	141	3.525
26									
27							2	140	3.500
28	1	3	0.075	1	5	0.070	2	138	3.450
29									
30							4	136	3.400
31							1	132	3.300
32							1	131	3.275
36							1	130	3.250
39							1	129	3.225
40							2	128	3.200
44							2	126	3.150
45							1	124	3.100
47							3	123	3.075
48							1	120	3.000

TABLE A4(Cont'd)
EARTHQUAKES 1938-1977

	U.S.			U.S. (WASH-1400 Data 1906-77)			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N
50							3	119	2.975
53							2	116	2.900
54							1	114	2.850
57							2	113	2.825
60							2	111	2.775
62							1	109	2.725
64							2	108	2.700
65	1	2	0.050	1	4	0.056			
71							1	106	2.650
73							2	105	2.625
75							1	103	2.575
79							1	102	2.550
80							2	101	2.525
82							1	99	2.475
83							1	98	2.450
90							2	97	2.425
92							1	95	2.375
97							1	94	2.350
100				1	3	0.042	5	93	2.325
110							1	88	2.200
112							1	87	2.175
113							1	86	2.150
125							2	85	2.125
128							1	83	2.075
130							1	82	2.050
131	1	1	0.025	1	2	0.028			
133							1	81	2.025
145							1	80	2.000
150							1	79	1.975
172							1	78	1.950

TABLE A4
EARTHQUAKES 1938-1977

	U.S.			U.S. (WASH-1400 Data 1906-77)			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N
174							1	77	1.925
176							1	76	1.900
187							1	75	1.875
191							1	74	1.850
197							1	73	1.825
200							5	72	1.800
228							1	67	1.675
233							1	66	1.650
240							1	65	1.625
276							1	64	1.600
277							1	63	1.575
293							1	62	1.550
300							5	61	1.525
330							1	56	1.400
350							3	55	1.375
375							1	52	1.300
400							3	51	1.275
424							1	48	1.200
431							1	47	1.175
437							1	46	1.150
474							1	45	1.125
500							3	44	1.100
521							1	41	1.025
556							1	40	1.000
574							1	39	0.975
600							1	38	0.950
620							1	37	0.925
700							1	36	0.900
750				1	1	0.014	1	35	0.875
900							1	34	0.850

TABLE A4 (Cont'd)
EARTHQUAKES 1938-1977

	U.S.			U.S. (WASH-1400 Data 1906-77)			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N
1000							5	33	0.825
1011							1	28	0.700
1087							1	27	0.675
1088							1	26	0.650
1300							1	25	0.625
1330							1	24	0.600
1392							1	23	0.575
1400							3	22	0.550
1460							1	19	0.475
1500							1	18	0.450
1800							1	17	0.425
2000							1	16	0.400
2312							1	15	0.375
2394							1	14	0.350
4000							2	13	0.325
8000							2	11	0.275
10000							1	9	0.225
12403							1	8	0.200
20000							1	7	0.175
22500							1	6	0.150
25000							1	5	0.125
30000							2	4	0.100
66794							1	2	0.050
700000 China 1976							1	1	0.025

TABLE A5
AIRCRAFT CATASTROPHES 1959-1978

N	U.S. (Civilian Only)			U.S. (Civilian and Military			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year >N	Number of Events	Cumulative Total	Frequency Per Year >N	Number of Events	Cumulative Total	Frequency Per Year >N
10	3	101	5.05	5	154	7.70	5	366	18.30
11	5	98	4.90	7	149	7.45	6	361	18.05
12	2	93	4.65	3	142	7.10	4	355	17.75
13	2	91	4.55	3	139	6.95	3	351	17.55
14	4	89	4.45	4	136	6.80			
15	1	85	4.25	3	132	6.60	7	348	17.40
16	3	84	4.20	9	129	6.45	6	341	17.05
17	2	81	4.05	4	120	6.00	1	335	16.75
18	2	79	3.95	8	116	5.80	10	334	16.70
19				3	108	5.40	4	324	16.20
20	1	77	3.85	3	105	5.25	8	320	16.00
21	1	76	3.80	3	102	5.10	6	312	15.60
22	2	75	3.75	2	99	4.95	11	306	15.30
23	1	73	3.65	2	97	4.85	8	295	14.75
24				1	95	4.75	10	287	14.35
25	2	72	3.60	3	94	4.70	3	277	13.85
26	2	70	3.50	4	91	4.55	7	294	13.70
27				2	87	4.35	9	267	13.35
28	3	68	3.40	3	85	4.25	9	258	12.90
29	2	65	3.25	4	82	4.10	10	249	12.45
30	1	63	3.15	2	78	3.90	8	239	11.95
31	2	62	3.10	2	76	3.80	11	231	11.55
32	1	60	3.00	1	74	3.70	6	220	11.00
33							7	214	10.70
34	3	59	2.95	4	73	3.65	4	207	10.35
35	2	56	2.80	2	69	3.45	5	203	10.15
36	1	54	2.70	1	67	3.35	8	198	9.90
37	3	53	2.65	4	66	3.30	8	190	9.50
38	2	50	2.50	2	62	3.10	6	182	9.10
39	2	48	2.40	2	60	3.00	5	176	8.80
40							6	171	8.55

TABLE A5 (Cont'd)
AIRCRAFT CATASTROPHES 1959-1978

N	U.S. (Civilian Only)			U.S. (Civilian and Military			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N
41							6	165	8.25
42	3	46	2.30	3	58	2.90	2	159	7.95
43	1	43	2.15	2	55	2.75	1	157	7.85
44	1	42	2.10	3	53	2.65	2	156	7.80
45	2	41	2.05	2	50	2.50	5	154	7.70
46				1	48	2.40	4	149	7.45
47							3	145	7.25
48	2	39	1.95	2	47	2.35	5	142	7.10
49							4	137	6.85
50	2	37	1.85	2	45	2.25	5	133	6.65
51	1	35	1.75	1	43	2.15	3	128	6.40
52							5	125	6.25
53				1	42	2.10	1	120	6.00
54							4	119	5.95
55							1	115	5.75
56							2	114	5.70
57							3	112	5.60
58	2	34	1.70	3	41	2.05	1	109	5.45
59							2	108	5.40
60							1	106	5.30
61	1	32	1.60	1	38	1.90	2	105	5.25
62							3	103	5.15
63	1	31	1.55	1	37	1.85	3	100	5.00
64							1	97	4.85
65	1	30	1.50	1	36	1.80	1	96	4.80
66							4	95	4.75
67							1	91	4.55
68	2	29	1.45	2	35	1.75	4	90	4.50
69									
70							2	86	4.30

TABLE A5(Cont'd)
AIRCRAFT CATASTROPHES 1959-1978

N	U.S. (Civilian Only)			U.S. (Civilian and Military			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N
71							1	84	4.20
72	1	27	1.37	1	34	1.65	4	83	4.15
73							3	79	3.95
74							1	76	3.80
75	2	26	1.30	2	32	1.60	1	75	3.75
76									
77	1	24	1.20	1	30	1.50	2	74	3.70
78	3	23	1.15	3	29	1.45	2	72	3.60
79				2	26	1.30	2	70	3.50
80							2	68	3.40
81	1	20	1.00	1	24	1.20	1	66	3.30
82	2	19		2	23	1.15	2	65	3.25
83	1	17		1	21	1.05	1	63	3.15
84	2	16	0.80	3	20	1.00			
85	2	14	0.70	2	17	0.85	2	62	3.10
86									
87							2	60	3.00
88	2	12	0.60	2	15	0.75	2	58	2.90
89							1	56	2.80
90							3	55	2.75
91									
92	1	10	0.50	1	13	0.65	1	52	2.60
93									
94							1	51	2.55
95	1	9	0.45	1	12	0.60	3	50	2.50
96	1	8	0.40	1	11	0.55	1	47	2.35
97							3	46	2.30
98							1	43	2.15
99							1	42	2.60
100							2	41	2.05

TABLE A5(Cont'd)
AIRCRAFT CATASTROPHES 1959-1978

N	U.S. (Civilian Only)			U.S. (Civilian and Military			World (Ex. U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N	Number of Events	Cumulative Total	Frequency Per Year ≥N
101	2	7	0.35	2	10	0.50			
102							1	39	1.95
106							1	38	1.90
107	1	5	0.25	2	8	0.40	2	37	1.85
108							1	35	1.75
109							1	34	1.70
111	1	4	0.20	1	6	0.30	1	33	1.65
112							2	32	1.60
113	1	3	0.15	1	5	0.25	1	30	1.50
117							2	29	1.45
118							3	27	1.35
120							1	24	1.20
121							1	23	1.15
122							2	22	1.10
124							1	20	1.00
126							2	19	0.95
129				1	4	0.20	1	17	0.85
130							2	16	0.80
133							1	14	0.70
134	1	2	0.10	1	3	0.15			
144							1	13	0.65
155							3	12	0.60
156							1	9	0.45
162							1	8	0.40
164							1	7	0.35
172				1	2	0.10			
176							3	6	0.30
188							1	3	0.15
213							1	2	0.10
582	1	1	0.05	1	1	0.05	1	1	0.05

TABLE A5(Cont'd)
AIRCRAFT CATASTROPHES 1959-1978

CONFIDENCE FACTORS

No. Fat.	95% UB	5% LB	No. Fat.	95% UB	5% LB	No. Fat.	95% UB	5% LB
						95	1.3	1.3
81	1.4	1.5	84	1.4	1.5	124	1.4	1.5
92	1.7	1.8	101	1.7	1.8	155	1.7	1.8
107	2.1	2.5	113	2.1	2.5	176	2.1	2.5
582	4.7	19.4	582	4.7	19.4	582	4.7	19.4

TABLE A6
MARINE CATASTROPHIES 1959-78

Number of Fatalities	U.S. Number of Events	U.S. Cumulative Total	U.S. Frequency Per Year	WORLD (EXCEPT U.S.) Number of Events	WORLD (EXCEPT U.S.) Cumulative Total	WORLD (EXCEPT U.S.) Frequency Per Year
10	2	39	1.95	8	262	13.10
11	5	37	1.85	4	254	12.70
12	1	32	1.60	8	250	12.50
13				8	242	12.10
14				8	234	11.70
15	1	31	1.55	7	226	11.30
16	1	30	1.50	6	219	10.95
17	1	29	1.45	6	213	10.65
18	1	28	1.40	7	207	10.35
19	2	27	1.35	9	200	10.00
20	1	25	1.25	7	191	9.55
21				5	184	9.20
22				9	179	8.95
23				4	170	8.50
24	2	24	1.20	4	166	8.30
25	2	22	1.10	2	162	8.10
26	1	20	1.00	5	160	8.00
27	1	19	0.95	1	155	7.75
28	3	18	0.90	4	154	7.70
29	1	15		5	150	7.50
30	1	14	0.70	10	145	7.25
31				3	135	6.75
32				5	132	6.60
33	1	13	0.65	3	127	6.35
34				1	124	6.20
35				2	123	6.15
36	1	12	0.60	2	121	6.05
37				2	119	5.95
38				1	117	5.85
39	2	11	0.55	4	116	5.80
40				8	112	5.60
41				1	104	5.20
42				1	103	5.15
43	1	9	0.45	1	102	5.10
44						
45				3	101	5.05
46	1	8	0.40	2	98	4.90
47				3	96	4.80
48						
49				1	93	4.65
50				4	92	4.60
52				2	88	4.40

TABLE A6(cont'd)
MARINE CATASTROPHIES 1959-78

Number of Fatalities	U.S. Number of Events	U.S. Cumulative Total	U.S. Frequency Per Year	WORLD (EXCEPT U.S.) Number of Events	WORLD (EXCEPT U.S.) Cumulative Total	WORLD (EXCEPT U.S.) Frequency Per Year
54				3	86	4.30
57				4	83	4.15
58				1	79	3.95
60				2	78	3.90
61				2	76	3.80
65				2	74	3.70
67				1	72	3.60
68				1	71	3.55
69				1	70	3.50
71	1	7	0.35	2	69	3.45
72				1	67	
74	1	6	0.30			
75				1	66	3.30
79				1	65	3.25
80				1	64	3.20
84				1	63	3.15
85				1	62	3.10
88				1	61	3.05
89	1	5	0.25	1	60	3.00
90				2	59	2.95
91	1	4	0.20			
94				1	57	2.85
95				1	56	2.80
98	1	3	0.15			
100				13	55	2.75
105				2	42	2.10
112				1	40	2.00
113				2	39	1.95
125				2	37	1.85
127				1	35	1.75
129	1	2	0.10			
132				1	34	1.70
134	1	1	0.05			
143				1	33	1.65
150				5	32	1.60
155				1	27	1.35
159				1	26	1.30
160				2	25	1.25
162				1	23	1.15
191				1	22	1.10
200				7	21	1.05
212				1	14	0.70

TABLE A6(cont'd)
MARINE CATASTROPHIES 1959-78

Number of Fatalities	U.S. Number of Events	U.S. Cumulative Total	U.S. Frequency Per Year	WORLD (EXCEPT U.S.) Number of Events	WORLD (EXCEPT U.S.) Cumulative Total	WORLD (EXCEPT U.S.) Frequency Per Year
250				2	13	0.65
259				1	11	0.55
261				1	10	0.50
264				1	9	0.45
275				1	8	0.40
279				1	7	0.35
290				1	6	0.30
300				1	5	0.25
400				1	4	0.20
450				1	3	0.15
500				1	2	0.10
1000				1	1	0.05

TABLE A7
MOTOR VEHICLE CATASTROPHIES 1959-78

	U.S.			WORLD (EXCEPT U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year	Number of Events	Cumulative Total	Frequency Per Year
10	5	24	1.20	9	336	16.80
11	4	19	0.95	19	327	16.35
12	4	15	0.75	12	308	15.40
13	2	11	0.55	7	296	14.80
14	1	9	0.45	11	289	14.45
15	1	8	0.40	21	278	13.90
16	1	7	0.35	11	257	12.85
17				9	246	12.30
18	1	6	0.30	16	237	11.85
19	1	5	0.25	15	221	11.05
20	1	4	0.20	18	206	10.30
21				16	188	9.40
22				9	172	8.60
23				19	163	8.15
24				6	144	7.20
25				4	138	6.90
26				9	134	6.70
27	1	3	0.15	14	125	6.25
28				6	111	5.55
29				9	105	5.25
30	2	2	0.10	13	96	4.80
31				4	83	4.15
32				2	79	3.95
33				5	77	3.85
34						
35				8	72	3.60
36				6	64	3.20
37				4	58	2.90
38				4	54	2.70
39				3	50	2.50
40				7	47	2.35
41						
42				4	40	2.00
43				2	36	1.80
44						
45				4	34	1.70
46						
47				1	30	1.50
48				2	29	1.45
49				1	27	1.35
50				4	26	1.30
52				3	22	1.10

TABLE A7(cont'd)
MOTOR VEHICLE CATASTROPHIES 1959-78

	U.S.			WORLD (EXCEPT U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year	Number of Events	Cumulative Total	Frequency Per Year
54				1	19	0.95
56				2	18	0.90
58				1	16	0.80
60				1	15	0.75
64				2	14	0.70
65				1	12	0.60
69				2	11	0.55
72				1	9	0.45
77				2	8	0.40
78				1	6	0.30
79				1	5	0.25
83				1	4	0.20
88				1	3	0.15
100				1	2	0.10
102				1	1	0.05

TABLE A8
RAILROAD CATASTROPHIES 1959-78

Number of Fatalities	U.S. Number of Events	U.S. Cumulative Total	U.S. Frequency Per Year	WORLD (EXCEPT U.S.) Number of Events	WORLD (EXCEPT U.S.) Cumulative Total	WORLD (EXCEPT U.S.) Frequency Per Year
10				10	180	9.00
11	2	7	0.35	4	170	8.50
12	1	5	0.25	9	166	8.30
13				7	157	7.85
14	1	4	0.20	8	150	7.50
15	1	3	0.15	6	142	7.10
16				7	136	6.80
17				4	129	6.45
18				4	125	6.25
19				2	121	6.05
20	1	2	0.10	8	119	5.95
21				3	111	5.55
22				5	108	5.40
23				1	103	5.15
24				5	102	5.10
25				8	97	4.85
26				1	89	4.45
27				3	88	4.40
28				4	85	4.25
29				1	81	4.05
30				7	80	4.00
31				2	73	3.65
32				3	71	3.55
33				1	68	3.40
34				4	67	3.35
35				3	63	3.15
36				1	60	3.00
37				1	59	2.95
38				3	58	2.90
39				1	55	2.75
40				9	54	2.70
41				2	45	2.25
42						
43				2	43	2.15
44				1	41	2.05
45	1	1	0.05			
46				1	40	2.00
47						
48				1	39	1.95
49				1	38	1.90
50				2	37	1.85
52				1	35	1.75

TABLE A8(cont'd)
RAILROAD CATASTROPHIES 1959-78

	U.S.			WORLD (EXCEPT U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year	Number of Events	Cumulative Total	Frequency Per Year
57				1	34	1.70
59				1	33	1.65
60				4	32	1.60
63				1	28	1.40
64				1	27	1.35
65				1	26	1.30
66				1	25	1.25
69				1	24	1.20
70				2	23	1.15
71				1	21	1.05
76				2	20	1.00
80				2	18	0.90
81				2	16	0.80
82				1	14	0.70
83				1	13	0.65
91				2	12	0.60
94				1	10	0.50
100				2	9	0.45
107				1	7	0.35
110				1	6	0.30
124				1	5	0.25
135				1	4	0.20
141				1	3	0.15
162				1	2	0.10
163				1	1	0.05

TABLE A9
MINING CATASTROPHIES 1959-78

	U.S.			WORLD (EXCEPT U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year	Number of Events	Cumulative Total	Frequency Per Year
10				3	106	5.30
11	2	15	0.75	1	103	5.15
12				8	102	5.10
13				4	94	4.70
14				2	90	4.50
15	1	13	0.65	4	88	4.40
16				3	84	4.20
17	1	12	0.60	8	81	4.05
18	2	11	0.55	2	73	3.65
19				3	72	3.60
20				1	68	3.40
21	1	9	0.45	5	67	3.35
22	2	8	0.40			
23	1	6	0.30	2	62	3.10
24				2	60	3.00
25				4	58	2.90
26				4	54	2.70
27				3	50	2.50
28	1	5	0.25			
29				2	47	2.35
30				3	45	2.25
31				4	42	2.10
32				3	38	1.90
33				1	35	1.75
34						
35						
36						
37	1	4	0.20	1	34	1.70
38	1	3	0.15			
39				1	33	1.65
40						
41				2	32	1.60
42				1	30	1.50
43				1	29	1.45
44						
45				1	28	1.40
46						
47				1	27	1.35
48						
49				1	26	1.30
50				2	25	1.25
51				1	23	1.15

TABLE A9(cont'd)
MINING CATASTROPHIES 1959-78

	U.S.			WORLD (EXCEPT U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year	Number of Events	Cumulative Total	Frequency Per Year
54				2	22	1.10
60				1	20	1.00
61				1	19	0.95
67				1	18	0.90
68				1	17	0.85
71				1	16	0.80
74				1	15	0.75
78	1	2	0.10			
79				1	14	0.70
89				1	13	0.65
91	1	1	0.05			
100				1	12	0.60
108				1	11	0.55
125				1	10	0.50
135				1	9	0.45
180				1	8	0.40
236				1	7	0.35
275				1	6	0.30
298				1	5	0.25
417				1	4	0.20
422				1	3	0.15
431				1	2	0.10
452				1	1	0.05

TABLE A10
FIRE AND EXPLOSION CATASTROPHIES 1959-78

Number of Fatalities	U.S. Number of Events	U.S. Cumulative Total	U.S. Frequency Per Year	World (Except U.S.) Number of Events	World (Except U.S.) Cumulative Total	World (Except U.S.) Frequency Per Year
10	13	72	3.60	11	189	9.45
11	8	59	2.95	9	178	8.90
12	7	57	2.55	11	169	8.45
13	3	44	2.20	9	158	7.90
14	4	41	2.05	11	149	7.45
15	3	37	1.95	8	138	6.90
16	4	34	1.70	6	130	6.50
17	1	30	1.50	5	124	6.20
18	2	29	1.45	9	119	5.95
19	1	27	1.35	6	110	5.50
20	3	26	1.30	9	104	5.20
21	1	23	1.15	6	95	4.75
22	3	22	1.10	4	89	4.45
23	2	19	0.95	4	85	4.25
24	1	17	0.85	2	81	4.05
25	3	16	0.80	5	79	3.95
26				1	74	3.70
27	1	13	0.65	1	73	3.65
28	1	12	0.60	3	72	3.60
29				3	69	3.45
30				2	66	3.30
31	1	11	0.55	2	64	3.20
32				3	62	3.10
33				3	59	2.95
34	1	10	0.50			
35				3	56	2.80
36	1	9	0.45			
37	1	8	0.40	1	53	2.65
38				3	52	2.60
39						
40	1	7	0.35	3	49	2.45
41				2	46	2.30
42				1	44	2.20
43						
44						
45				3	43	2.15
46				1	40	2.00
47				1	39	1.95
48				2	38	1.90
49						
50	1	6	0.30	2	36	1.80
51				2	34	1.70

TABLE A10 (cont'd)
FIRE AND EXPLOSION CATASTROPHIES 1959-78

	U.S.			WORLD (EXCEPT U.S.)		
Number of Fatalities	Number of Events	Cumulative Total	Frequency Per Year	Number of Events	Cumulative Total	Frequency Per Year
52	1			2	32	1.60
53		5	0.25			
54						
55				3	30	1.50
56						
57				1	27	1.35
58	1	8	0.20	1	26	1.30
59						
60				1	25	1.25
61						
62						
63	1	3	0.15	1	24	1.20
64				1	23	1.15
67				1	22	1.10
68				1	21	1.05
72				1	20	1.00
73	1	2	0.10			
75				2	19	0.95
78				1	17	0.85
80				2	16	0.80
100				1	14	0.70
103				1	13	0.65
117				1	12	0.60
138				1	11	0.55
146				2	10	0.50
152				1	8	0.40
157				1	7	0.35
164	1	1	0.05			
225				1	6	0.30
227				1	5	0.25
300				1	4	0.20
322				1	3	0.15
325				1	2	1.10
430				1	1	0.05

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16. ABSTRACT *(200 words or less)*

This report presents data for the comparison of societal risk from natural and man-made hazards. Only fatalities resulting from the hazards are used in the comparison, with the data and the comparative analysis taken from current literature. In comparing societal risks for most of the hazards, both expected values and frequency vs. consequence curves are presented. For a subset of hazards, notably the power generation technologies (nuclear, coal, oil and gas), which have not exhibited high consequence events (catastrophies), the comparisons are based on estimated expected values only.

17. KEY WORDS AND DOCUMENT ANALYSIS	17a. DESCRIPTORS
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A RISK COMPARISON

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