With this issue Environment *begins a series of articles on hazards and hazard management.*

The hazards of technology are nothing new to readers of this magazine. Discussions of the risks from energy production, pesticides, nuclear weapons, and transportation have formed a steady diet over the years. What is new in this series is the integration of risk assessments with a coherent discussion of hazard management. This is highly appropriate since in the last fifteen years the industrialized countries have developed an immense and growing hazard management bureaucracy. Also new in the present series is the inclusion of hazards arising from nature. These, though no major threat in the United States, are a major burden to developing countries.

Risk assessment and hazard management inevitably involve a combination of scientific understanding and social judgment as to which risks to accept, which to reduce (and by how much), and when to forego or limit the use of a technology or natural location. In practice, we marshal our science and make our judgments one at a time, addressing a specific hazard or class of hazards. In this series of articles, we address the entire range of hazards, and focus sharply on the technological ones that confound our industrialized society. To offer needed perspective, we begin with an interim report on our current best estimates of the scope of the technological hazard burden in the United States. In a companion article we review some of the problems that currently confound hazard management. Later in the series we will return to most of these problems in the context of specific case studies, both of natural and technological hazards.

Much of the work to be discussed has been or is being done at Clark University, by the Hazard Assessment Group or by individuals and organizations associated with it.

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Our Hazardous

HAZARDS ARE THREATS TO HUMANS AND WHAT THEY VALUE: life, well being, material goods, and environment. Today hazards originating in both nature and technology are a major concern in developing and industrial nations alike. Coping with hazards involves a wide range of adjustments— from learning to live with hazard, to sharing the burden of hazard, to controlling and preventing death, injury, property loss, and damage to human and natural environments.

In the industrialized countries in particular, major efforts to combat the hazards of human existence are being made on two complementary fronts— risk assessment and hazard management. *Risk assessment* involves the identification of hazards, the allocation of cause, the estimation of the probability that harm will result, and the balancing of harm with benefit. *Hazard management* involves the choice of options to be used in controlling and reducing hazardous occurrences. As practiced in the industrialized world, hazard management also involves an immense and growing bureaucracy, a series of seemingly irresolvable political battles, and an interplay between science and values that often confounds rational discussion. A key question in this discussion is, "How safe is safe enough?"

Natural and Technological Hazards

For the majority of the world's people, living in rural portions of the developing nations, the hazards which most concern them are ancient ones and are predominantly rooted in nature. These natural hazards arise most often in connection with agriculture, food supply, or settlement, and they constitute a major burden. For example, the losses from geophysical hazards (floods, droughts, earthquakes, and tropical cyclones) each year in the developing world involve an average of 250,000 deaths and $15 billion in damage and costs of prevention and mitigation.[1] This is equivalent to two to three percent of the gross national product (GNP) of the affected countries. Losses from vermin, pests, and crop disease are widely regarded as a larger problem,[2] and involve destruction of as much as fifty percent of food crops.[3] And infectious disease, though declining, typically accounts for ten to twenty-five percent of human mortality, concentrated among the very young.[4]

In contrast, for industrialized nations, natural hazards are relatively a much smaller problem. Thus, for the United States geophysical hazards produce less than one thousand fatalities per year, and property damage and costs of prevention and mitigation are on the order of one percent of GNP. Vermin, pests, and crop disease, while leading to serious losses, are kept in bounds by pesticides and other techniques, and infectious disease

Environment

BY ROBERT C. HARRISS, CHRISTOPH HOHENEMSER AND ROBERT W. KATES

Natural hazards, such as floods, have become a relatively less important part of the hazard burden of industrialized countries, although they continue to be of predominant concern in the developing world.

Hazards rooted in technology now constitute the major portion of the hazard burden in industrialized nations. The United States currently spends more than $40 billion a year to control air, land, and water pollution.

Soil Conservation Service

Soil Conservation Service

NOAA

Soil Conservation Service

Expenditures and losses due to technological hazards may be as high as 10 to 15 percent of GNP. The cost of automobile accidents alone is estimated to be $37 billion or almost 2 percent of the gross national product of the United States.

accounts for less than five percent of human mortality. However, while controlling natural hazards to this extent, the industrialized nations have not escaped unscathed.

Taking the place of the ancient hazards of flood, pestilence, and disease are new and often unexpected hazards, predominantly rooted in technology. These hazards now have an impact as large or larger than the natural hazards they have replaced (see Table 1).[5] As concrete examples of the cost of technological hazards and their management, consider that the United States currently spends $40.6 billion per year or 2.1 percent of its GNP on air, land, and water pollution[6]; that the cost of automobile accidents is estimated to be $37 billion, or 1.9 percent of GNP[7]; and that the death toll alone from technological hazards involves, in our estimate (see below), 20 to 30 percent of all male deaths and 10 to 20 percent of all female deaths, and a value in medical costs and lost productivity of $50 to $75 billion, or 2.5 to 3.7 percent of GNP. Overall, expenditures and losses due to technological hazards may be as high as $200 to $300 billion, or 10 to 15 percent of GNP.[8]

Technological hazards are thus a big business, comparable in scope to such major sectors of the national effort as social welfare programs, transportation, and national defense. And the impacts of technological hazards go well beyond mortality. Table 2 details the various groups, sectors, and environments affected, along with the dimensions of the consequences considered in our work on technological hazard assessment and management.

How can the full scope of technological hazards be evaluated? Only by determining the sum of all of the impacts and consequences outlined in Table 2. This is a formidable task, one which no group to our knowledge, has accomplished, or even attempted. In this article, and those that follow. we concentrate on human mortality and ecosystem impacts (particularly impacts on biological species and communities). Human mortality is based on well defined data and, of all impacts, is most susceptible to quantification; the ecosystem

Table 1
COMPARATIVE HAZARD SOURCES IN U.S. AND DEVELOPING COUNTRIES

| | PRINCIPAL CAUSAL AGENT[a] | | | |
| | NATURAL[b] | | TECHNOLOGICAL[c] | |
	Social cost[d] (% of GNP)	Mortality (% of total)	Social cost[d] (% of GNP)	Mortality (% of total)
United States	2-4	3-5	5-15	15-25
Developing countries	15-40[e]	10-25	n.a.[f]	n.a.[f]

a. Nature and technology are both implicated in most hazards. The division that is made here is made by the principal causal agent, which, particularly for natural hazards, can usually be identified unambiguously.
b. Consists of geophysical events (floods, drought, tropical cyclones, earthquakes and soil erosion); organisms that attack crops, forests, livestock; and bacteria and viruses which infect humans. In the U.S. the social cost of each of these sources is roughly equal.
c. Based on a broad definition of technological causation, as discussed in the text.
d. Social costs include property damage, losses of productivity from illness or death, and the costs of control adjustments for preventing damage, mitigating consequences, or sharing losses.
e. Excludes estimates of productivity loss by illness, disablement, or death.
f. No systematic study of technological hazards in developing countries is known to us, but we expect them to approach or exceed U.S. levels in heavily urbanized areas.

Table 2
TECHNOLOGICAL HAZARD IMPACTS

HAZARD EXPOSURE RECEPTORS	DIMENSIONS OF CONSEQUENCES
HUMAN POPULATIONS: individuals, groups, cohorts	well-being (diminution, loss) morbidity (acute, chronic, transgenerational) mortality (acute, chronic, transgenerational)
ECONOMY: activities, institutions, production	individual and collective loss cost of control adjustment cost of mitigation
SOCIETY: activities, institutions, values	activity disruption institutional breakdown value erosion
ENVIRONMENTS:	
natural	landscape transformation air and water quality loss recreational opportunities lost
built	community loss architectural deterioration
ECOSYSTEMS: population, species, communities	species extinction productivity reduction resistance/resilience diminution
natural	landscape transformation air and water quality loss recreational opportunities lost
built	community loss architectural deterioration

impacts are at best difficult to judge, and nearly impossible to quantify. These two thus delimit the range of current scientific understanding within which other impacts and consequences fall.

Measuring Technological Hazard

Human death is the best defined of all hazard consequences. Even many impoverished societies keep reasonable mortality records and, for a large number of countries, including the United States, mortality statistics grouped according to "causes of death" are extensively tabulated by age, sex, and even race.[4,9] It would seem, therefore, that there is a direct and obvious answer to the question, "How much death is due to technological hazard?"—that it is simply necessary to add the contribution of each "cause of death" and note the relative magnitude of the sum.

Unfortunately, once we have added the toll of transportation and occupational accidents and the impact of violence, this approach ends in a quagmire of uncertainty for at least three reasons: (1) death rarely has a single cause and, in most cases technology is at best a contributing factor; (2) when chronic disease, such as cancer and heart disease, is given as "cause of death," one can deduce little directly about the role of technology, since the root causes of chronic disease are known in only a small percentage of cases; (3) much death is not accurately classified according to "cause," and this is true even in some cases of accidents and violence. Mortality statistics are further clouded by the fact that in many developing countries as much as fifty percent of all mortality is classified as of "unknown origin," and even for developed countries the practices in assigning causes vary widely.[10]

In this study of technological hazards we have sought to circumvent these problems by what amounts to an "end run." Instead of obtaining percentage of mortality resulting from technology by direct calculation and summing, we make an indirect estimate through a two-step process. First, we estimate the percentage of mortality that is preventable

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CORRELATION AND CAUSE

To observe a correlation is not to establish cause. A correlation is simply the regular change in one variable associated with a corresponding change in another variable. Cause is something stronger. Thus one cannot conclude that the rooster's crowing causes the farmer to brush his teeth, or that either of them causes the sun to rise, though crowing, brushing, and sunrise are correlated events or variables. Confusing cause and correlations can lead to useless action. Thus, if you are bothered by the crowing of roosters, it will do no good to hide the farmer's toothbrush. Yet, it might be worthwhile to lock the rooster in a darkened chicken-house or to persuade the farmer to stop raising chickens.

On a graph, cause and correlation look the same. How can they be distinguished? This is a question over which scientists often create confusion and philosophers are apt to argue for a day. The best answer seems to be that, to establish cause, one tries to establish as close a link as possible using, when available, generally established theory. Consider three examples.

• Today most scientists are willing to agree that the force of gravity *causes* the earth to orbit around the sun, the tree to fall in the forest, and the ocean's tide to flow and ebb. Yet not so long ago, before an adequate universal theory of gravitation was formulated and applied, these three events were viewed as disparate phenomena, each understandable only in terms of a series of ad-hoc assumptions, most of which turned out to be incorrect.

• A more difficult case is the correlation between cigarette smoking and lung cancer. Though many scientists are now willing to say "smoking causes lung cancer," this was for a long time a disputed case because no general theory of cancer was or is available. What eventually brought all but die-hard promoters of tobacco around was the great wealth of corroborating evidence that has been developed to buttress the initially observed correlation. For example, many of the substances in cigarettes and cigarette smoke have been isolated and laboratory animals have been exposed to them separately with the result that lung cancer developed.

• For cancer of the colon there is a strong correlation with per capita meat consumption. Here the causal situation is highly ambiguous. The "cause" may be the meat itself; but it may also be the absence of high grain consumption, which is normally present in cases of low meat consumption; and finally, it may be neither meat nor grain per se but the way the meat is cooked or some other unrecognized factor. One must conclude, therefore, that here turning correlation into cause is in its very early stages and that by taking action one runs a fairly high risk of pursuing an irrelevant goal, such as hiding the farmer's toothbrush.

The specific links that buttress the involvement of technology with chronic disease span the full range of "strong" to "weak" causation illustrated by the above three examples. The overall correlation of chronic disease with technological indicators is itself closer to the weak end of the spectrum but is probably the best that can be done at the present time.

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in principle or, equivalently, involves external or non-genetic causes. In the literature this is often called exogenously caused mortality.* Second, we estimate

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*The Latin meaning of "exogenous" is of external origin." As used in our discussion "exogenous mortality" does not necessarily exclude any genetic involvement. Rather, exogenous mortality refers to that fraction of mortality which, in a purely statistical or average sense, can be altered by altering external conditions. Genetic factors, including inherited susceptibility to a particular

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the percentage of technically preventable mortality. In doing so, we recognize that externally caused or exogenous mortality sets an upper limit on technologically caused mortality, but that exogenous mortality can result from social, cultural ("life style"), and environmental factors

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disease, can easily be active in this context. One need only think of the initiation of disease in an individual case as a combination of genetic predisposition and external factors.

as well as technological ones. This division of exogenous mortality (illustrated in Table 3) is not a clear-cut one. In an interrelated and mutually dependent society such as ours, most deaths have multiple causes.

Exogenous Mortality

What fraction of mortality is exogenous, that is, preventable at least in principle? To answer this question, we first divide all of mortality into acute and chronic causes of death (Tables 4 and 5). Among acute causes of death we include all those cases in which death is sudden and not preceded by a long period of illness. Among chronic causes of death we include all those cases where death results from a long period of prior illness due to deterioration of one or more body functions. The division into acute and chronic causes is made because the analysis of the two cases is fundamentally different.

Acute Causes of Death. Except for congenital malformations leading to sudden death, a small percentage of infectious disease, and a percentage of accidents, suicides, and homicides associated with inherited deficiencies and psychotic illness, all acute causes of death are *prima facie* exogenous. Assignment of the exogenous percentage is therefore made at or near unity in most cases, as shown in Table 6.

Chronic Causes of Death. For chronic causes of death we obtain the exogenous percentage by a comparison of the mortality statistics reported by thirty-six nations to the World Health Organization.[4] The nations selected are believed to have sufficiently reliable statistics for our purposes; all have mortality rates for "unknown causes" amounting to less than ten percent of total mortality. From the thirty-six nation data the lowest age-specific mortality rate was chosen and used as the "base case." Exogenous mortality for each nation was then defined operationally as the excess mortality observed in each relative to base-case mortality.

There are several problems with this definition which make it necessary to re-

gard it as only an approximate estimate of true exogenous mortality. Thus, use of the definition implicitly assumes that the genetic disposition toward mortality of various populations is identical. This is not always the case. Some cancers, for example, appear to have a genetic basis. On the other hand, when populations migrate, they usually take on the mortality patterns of their new home, thus indicating the predominance of external factors.

In addition, our method for obtaining the exogenous mortality rate is critically dependent on the validity of the base case. Our definition will tend to underestimate true exogenous mortality if some base-case mortality is preventable in principle; and it will tend to overestimate true exogenous mortality if the base case involves serious under-recording of certain chronic causes of death. Fortunately these latter effects, both of which are surely present, will at least partially cancel each other out.

Figure 1 (p. 12) illustrates the kind of data used: age-specific cardiovascular and cancer mortality for males and females in selected countries, including the lowest and highest mortality cases. Male and female exogenous percentages deduced from this data were eighty and sixty percent for cardiovascular disease, and sixty and forty-five percent for cancer, respectively. Exogenous percentages for all causes of death are summarized in Table 6.

Technological Mortality

What percentage of exogenous mortality is associated primarily with technology, rather than with environment and culture? This is a much more difficult question, with a considerably more uncertain answer than in the case of exogenous mortality per se. There is no simple argument that allows approximate separation of the technological percentage. Our present best estimate must therefore be something of a guess, though hopefully a good one. In order to make this guess, we again treat acute and chronic causes of death separately, as before.

Acute Mortality. Infectious disease, though influenced by the level of tech-

Table 3

CLASSIFICATION OF MORBIDITY AND MORTALITY

ENDOGENOUS: causes reside predominantly within the individual	Aging; genetic defects arising from inherited genetic load.
EXOGENOUS: causes reside predominantly outside the individual	
Natural Environmental	Infection; background radiation-induced cancer; latitudinal skin cancer effects; natural catastrophes.
Social and Cultural	Diet-based disease such as cancer from betel nuts, cirrhosis of liver from alcohol, heart disease from overweight; smoking-related disease, some urban-related mortality, some violence, war death.
Technological	
diffuse effects	Pollution-related disease; some urban-related mortality.
specific technology	Transportation accidents; cancers from specific industrial chemicals such as benzene, asbestos, and vinyl chloride; gun accidents.

Table 4
ACUTE MORTALITY IN THE UNITED STATES, 1972

CAUSE OF DEATH	Mortality deaths/100,000		Mortality (percent of total)	
	male	female	male	female
Infectious Disease	*45.7*	*35.3*	*4.2*	*4.3*
influenza	2.4	2.4		
pneumonia	31.9	23.7		
infection of the kidney	3.0	3.6		
enteritis	1.0	1.1		
infectious hepatitis	0.3	0.4		
other	4.4	3.4		
Deaths in Early Infancy	*27.2*	*19.6*	*2.5*	*2.4*
diseases of early childhood	19.5	13.2		
congenital abnormalities	7.7	6.4		
Transportation Accidents	*43.1*	*15.7*	*4.0*	*1.9*
automobile	39.6	15.1		
other	3.5	0.6		
Other Accidents	*38.9*	*19.3*	*3.5*	*2.4*
poisoning	3.7	1.6		
falls	8.4	7.7		
fire	4.0	2.5		
drowning	5.0	1.0		
firearms	2.1	0.3		
industrial machinery	5.1	0.5		
others	7.2	4.1		
Violence	*32.9*	*10.5*	*3.0*	*1.2*
suicide	17.5	6.8		
homicide	15.4	3.7		
Other Acute Causes	*11.8*	*9.0*	*1.0*	*1.0*
TOTAL ACUTE CAUSES	*199.6*	*109.4*	*18.4*	*13.5*
MALE-FEMALE AVERAGE			*16.3*	

Source: World Health Statistics Annual, Volume I, 1973-76. World Health Organization, Geneva, 1976.

Table 5
CHRONIC MORTALITY IN THE UNITED STATES, 1972

CAUSE OF DEATH	Mortality deaths/100,000		Mortality percent of total	
	male	female	male	female
Cardiovascular Disease	*554.5*	*459.3*	*51.3*	*56.5*
hypertension	9.5	10.9		
ischemic heart disease	382.4	277.6		
cerebrovascular disease	94.0	110.5		
arteriosclerosis	29.2	26.7		
other cardiovascular	39.6	33.6		
Cancer	*188.1*	*149.6*	*17.4*	*18.4*
lung, trachea, bronchia	56.8	14.0		
colon	17.4	18.8		
breast	0.3	29.2		
lymphatic tissues	10.5	8.4		
prostate	18.0	—		
stomach	9.2	5.8		
leukemia	8.1	5.8		
uterus	—	6.0		
rectum	5.6	4.2		
mouth-pharynx	5.3	2.0		
other	56.9	55.4		
Chronic Liver Disease	*37.7*	*31.8*	*3.5*	*3.9*
diabetes	15.6	21.4		
cirrhosis	21.1	10.4		
Chronic Respiratory Disease	*25.8*	*7.6*	*2.4*	*0.9*
tuberculosis	2.5	0.9		
bronchitis, emphysema, asthma	23.3	6.7		
Other Chronic Disease	*74.6*	*55.1*	*6.8*	*6.8*
TOTAL CHRONIC DISEASE	*880.7*	*703.4*	*81.6*	*86.5*
MALE-FEMALE AVERAGE			*83.7*	

Source: World Health Statistics Annual, Volume 1, 1973-76, World Health Organization, Geneva, 1976.

nology, is largely environmental and cultural in origin. To the extent that technology is involved, it usually leads to a reduction of disease rather than increased hazard. In contrast, accidents, homocide, and suicide are highly associated with technology and culture and only marginally with the natural environment. Our estimate of the technologically involved percentage of acute mortality thus ranges from zero percent in the case of infectious disease to ninety percent in the case of transportation accidents (see Table 6). For cancer, similar results have been obtained by others.[11-13]

Chronic Mortality. We have already noted in our discussion of exogenous mortality that direct assignment of cause in the case of chronic disease is usually not possible. For estimating the technological component of exogenous mortality we again use an indi-

rect method, based on national and international comparisons. Our approach is to look for correlations of chronic disease mortality with certain indicators of technology, such as per capita GNP, per capita energy consumption, and percent of labor in manufacturing. If chronic disease increases with level of technology, this analysis yields the equivalent of a "dose-effect" relation: it permits the determination of the change in mortality occasioned by a given change in level of technology. Unlike high quality dose-effect relations in the field of toxic substance epidemiology, the exposed populations in this case are poorly controlled for factors other than level of technology. Hence, one must expect a certain amount of scatter in mortality at a given level of technology.

The Case of Cancer. The incidence of cancer can be used as an illustration

of this type of analysis. International "dose-effect" relations for men and women are shown in Figure 2; equivalent relations for the United States, for both blacks and whites, are shown in Figure 3. In each case the mortality in 1972-73 is plotted against percent of the labor force in manufacturing in 1940, thus allowing for the latency of cancer. Our interpretation of the observed relations are as follows:

● Internationally, cancer in males varies widely and shows an average increase of a factor of 2.7 and 1.7 for males and females as the level of technology varies from lowest to highest. Particularly for males the scatter is very large, indicating that there are many other causes at work.

● For whites within the United States, the international pattern is repeated, though with smaller increases and less scatter. Thus mortality increases by an average factor of 1.5 and

Environment, Vol. 20, No. 7

11

Table 6

ESTIMATED EXOGENOUS AND TECHNOLOGICALLY INVOLVED DEATHS IN THE UNITED STATES

CAUSE OF DEATH	Estimated U.S. exogenous percentage of mortality (percent)		Estimated U.S. technological component of mortality			
			(percent)		(annual deaths in thousands)	
	male	female	male	female	male	female
ACUTE MORTALITY						
Infectious disease[a]	90	90	0	0	0	0
Deaths in infancy[b]	50	50	5	5	1	1
Transportation accidents[c]	100	100	90	90	39	15
Other accidents[d]	100	100	70	50	28	11
Violence[e]	100	100	30	30	10	3
Other acute deaths[f]	100	100	70	50	8	5
CHRONIC MORTALITY						
Cardiovascular disease[g]	80	60	0-40	0-40	0-217	0-132
Cancer[h]	60	45	40	25	82	35
Chronic liver disease[i]	80		0	0	0	0
Chronic respiratory disease[j]	60	10	0-20	0-5	0-5	0
Other chronic disease[k]	70	70	25	25	19	15
ALL MORTALITY			17-30	11-21	182-318	85-167

a. Exogenous percentage of 90% is based on the hypothesis that this amount of infectious disease is in principle preventable before genetic factors become dominant. Supportive of the hypothesis is the fact that the declining trend of infectious disease mortality is steep. The technological fraction of zero is based on the fact that infectious disease is usually prevented by technology, not enhanced.

b. Presently the U.S. ranks 17th in infant mortality and, even in the lowest nations, infant mortality is still declining. The estimate for the exogenous percentage is meant to reflect these facts qualitatively. The technological percentage is low because infant deaths are caused largely by disease.

c. Transportation accidents are prima facie 100% externally caused. The technological percentage given includes all deaths except those that are estimated to be predominantly homicidal and suicidal.

d. Other accidents include numerous categories, as shown in Table 4. All are by definition externally caused. Some, like drowning and falls, are primarily rooted in culture and society, not technology, and hence these are excluded in estimating the technological percentage.

e. Although nearly all violence is committed with the help of technological devices, and this suggests 100% exogenous causation, there is little evidence that violence is prevented by modification of technology. Rather, violence is rooted in culture and society. The assignment of a modest technological percentage reflects this fact.

f. Other acute deaths involve many causes but relatively small numbers. The values given represent the average behavior of other acute deaths.

g. The exogenous percentage is based on 36 nation comparisons as illustrated in Fig. 1. The technological percentage is uncertain, yielding 40% based on cross-national plots similar to Fig. 2, the difference between the U.S. rate and some theoretical rate without technology (0%), yet yielding near zero based on state by state comparison within the U.S. similar to Fig. 3. Since much of cardiovascular epidemiology points toward diet and stress, we are inclined to believe the lower technological percentage.

h. The exogenous fraction is based on Fig. 1. The technological fraction on Fig. 2, and the support given this by Fig. 3 as well as the available literature on cancer epidemiology.

i. The exogenous percentage is based on data similar to Fig. 1. The low technological percentage is based on the predominant role of diet and alcohol in liver disease epidemiology.

j. The exogenous percentage is based on analysis similar to Fig. 1. The technological fraction is based on the literature describing the urban-rural difference in epidemiological studies of smoking related disease.

k. Other chronic diseases involve a large variety of causes, but rather small total mortality. Percentages assigned here are guesses based on the average behavior of the chronic diseases which we have analyzed.

1.4 for males and females as the level of technology rises from lowest to highest.

• For blacks within the United States, the pattern is significantly different. For black males the increase in mortality is an average factor of 2.0 as technology varies from lowest to highest. This is a significantly greater increase than that for whites. For females, on the other hand, no significant effect is seen, though scatter is large and average values are higher than for white females.

Thus, although there are some puzzles, a reasonably consistent picture emerges. Cancer mortality, as one would expect from the epidemiological literature,[14] has an appreciable technological component. Using the international data shown in Figure 2, we estimate the difference between the U.S. rate and some theoretical rate without technology (zero percent in manufacturing). This gives a conservative estimate of the technological component of at least forty percent for men and twenty-five percent for women in the United States. Thus, very roughly speaking, about half of exogenous cancer mortality is the result of technology, the rest of social and cultural causes. Similar results are obtained if the per capita energy consumption is used as an indicator of technological development.

We do not wish to claim that energy consumption or industrial employment causes cancer per se. Correlations such as those shown in Figures 2 and 3 are too weak a tool for this purpose (see box). However, when correlations with mortality exist for several indicators across a wide range of populations and cultures, it is likely that the results are not accidental but are evidence of a number of factors that form links in the causal chains leading directly or indirectly to observed chronic disease mortality. Sometimes these links are fairly simple and well-established; for example, coal mining leads to deposit of fine coal dust in deep lung cavities and, through obstruction of these, reduces lung function (black lung disease). In other cases the links are highly complex, such as the incompletely understood connections between diet and heart disease. It is the task of medical science, particularly epidemiology, to identify and describe these specific links, and it is the task of hazard management to control them. Our purpose here is to explore the magnitude of the problem and for this our correlations of disease with general indicators of technology are adequate and appropriate.

Using a method similar to that employed in the cancer illustration above, we have estimated the percentage of mortality for other chronic disease that is technologically related (Table 6). It is necessary to stress that by technologically related percentage we mean mortality which is in principle preventable by adjustments in technology. This does not exclude the involvement of other causative factors such as genetics, cultural milieu, lifestyle, and natural environmental conditions as contributing causes.[15] To compensate, and to be conservative, we exclude smoking and diet as technological causes, even though technologies have figured highly in the consumption of cigarettes (as opposed to the less hazardous tobacco forms) or in the availability of low-cost meat and dairy products (implicated in cardiovascular disease).

The Cost of Technological Mortality

Estimates of mortality and morbidity costs for various causes of death are available in the literature.[16] These estimates indicate the dollar value of medical costs and of the cost of lost productivity. Such estimates do not place any dollar value on life and suffering as such, since this necessarily depends on diverse personal and societal ethical judgments that are widely held to be beyond economic valuation. However, such estimates are important because they define the magnitude of the economic problem of lost life and illness and in this way serve to indicate the savings that can be realized if mortality and illness are prevented.

Using the percentages of technologically involved deaths given in Table 6 and the estimated values of life shortening applicable to each cause of death, we find that the total annual loss due to technological hazard mortality is approximately seven to ten million person-years, about two-thirds of which is attributable to males. Using the methodology developed by Rice, Feldman, and White for translating this into medical and lost productivity costs, we find that an annual loss of $50 to

FIGURE 1. Age-specific cancer and heart disease mortality in selected countries for males and females for 1972-73. The countries were selected because they are believed to have reliable statistics and because they represent the full range of recorded mortality, from lowest to highest. The difference between the lowest and U.S. mortality was used to estimate the exogenous fraction of mortality for the U.S., as indicated in Table 6. Note that the plots shown here utilize a logarithmic scale for mortality. This is a convenient device for numbers that vary over a very large range and has the effect of giving equal intervals to each factor of ten. The source for the data is referenced in note 4.
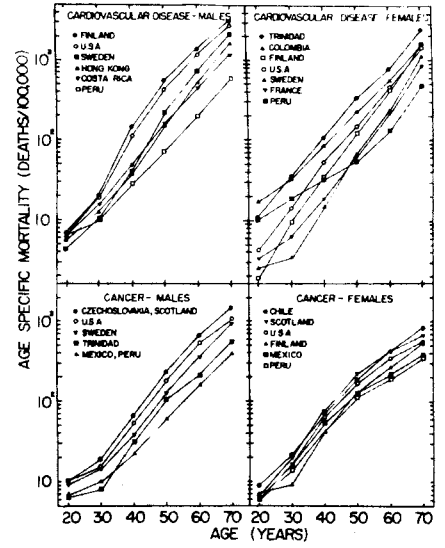
FIGURE 2. Correlation between age-specific 1972-73 cancer mortality and percent labor in manufacturing in 1940 for nations believed to have reliable statistics. Though the data exhibit wide scatter among nations, both males (top) and females (bottom) show increasing cancer mortality with increasing industrialization. The scatter indicates that there are causes for cancer other than industrialization. The consistent increase with industrialization of cancer mortality indicates that the latter is probably one of the causes of cancer (see box on cause and correlation). The choice of 1940 to measure the level of industrialization allows for the known, approximately 30-year lag between exposure to carcinogens and the occurrence of cancer. Note that, consistent with their greater participation in industry, males show a bigger increase than females. These data were used to estimate the fraction of technologically involved mortality given in Table 6. The source of the mortality data is note 4, the source of the percent labor in manufacturing is W. S. Woytinksy and E. S. Woytinsky, *World Population and Production* (The Twentieth Century Fund, New York, 1953).
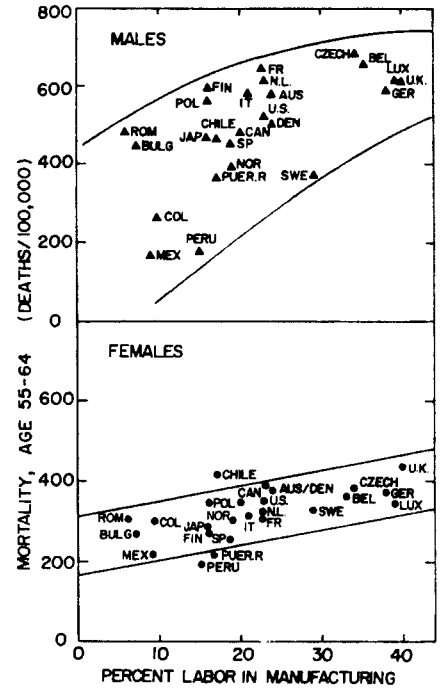
FIGURE 3. Correlation between average 1950-1969 age-adjusted cancer mortality and percent labor in manufacturing in 1940 for states within the United States. As might be expected from the greater homogeneity of the U.S., the scatter is considerably reduced relative to international data shown in Fig. 2. At the same time, the pattern of increasing mortality with increasing industrial exposure is repeated. Again men show a more pronounced increase than women and, in addition, black men show a bigger increase than white men. The only surprising aspect of the data is the fact that black females show no apparent increase. The source of the data is *U.S. Cancer Mortality by County; 1950-69.*
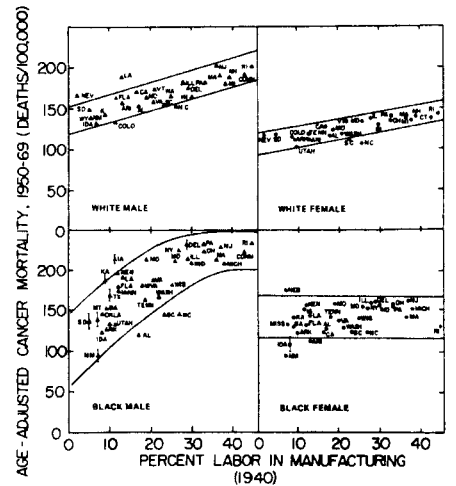
$75 billion is due to technologically involved mortality and related morbidity. Interestingly, accidents and violence, though they constitute only ten and six percent of male and female mortality, respectively, account for forty to sixty percent of the costs. This is because of the relatively higher technological percentages and larger life shortening effects in the case of accidents and violence.

Technological Impacts on Ecosystems

In contrast to human mortality, the ecosystem impacts on biological communities, while perhaps the most important of the dimensions of technological hazard in the long run, are also the most difficult to quantify. Here there are no world-wide, nearly all-inclusive accounting systems such as death certificates. And instead of dealing with one dominant species, we are dealing with literally millions of species related by a complex and often fragile system of interdependence. How can the impacts of technology on this system be defined? Two possible measures of ecosystem impacts by technological hazards (recall Table 2) are species extinction and ecosystem productivity. Both of these measures are in principle quantifiable. Yet each has less specific meaning to humans and what they value than does human mortality. Each is separately considered below.

Species Extinction

Species extinction is the most drastic and inclusive form of wildlife mortality. Like human mortality this can occur naturally, independently of any technological effects. As in the case of human mortality, we are interested here in the percentage of species extinction that is of technological origin. As before, we divide the problem by asking two questions:

(1) What is the rate of *exogenous* species extinction, that is, the percentage of cases for which the underlying causes are not of predominantly natural origin?
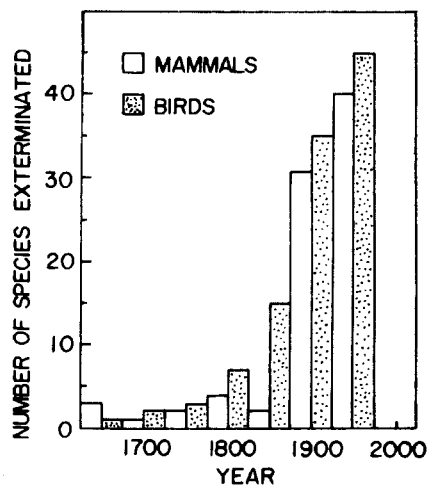

FIGURE 4. The number of exterminated mammal forms (white bars) and bird forms (shaded bars) eliminated over the last three hundred years. Each bar represents a 50-year period. Source of the data is referenced in note 9.

(2) What is the rate of *technologically involved* extinction, that is, the percentage of exogenous extinction that is predominantly related to technological causes?

One approach to the first question is through the historical record. As shown in Figure 4, the world-wide rate of vertebrate extinction has speeded up considerably during the last hundred years, culminating in a current rate that is at least ten times

the "baseline" or evolutionary rate observed 300 years ago.[17] As shown in Table 7, one in ten species of native, higher plants in the United States is currently endangered, threatened with becoming endangered, or recently extinct; in Hawaii nearly half of the total diversity of native vegetation is similarly involved.[18-21]

Another approach to estimating the rate of exogenous extinction is through direct classification of species extinction according to cause. Using available data[17] on extinction and rarity for birds and mammals since 1800, we have obtained the division into exogenous and natural causes shown in Table 8. Thus, for the period studied, more than two-thirds of extinction and rarity has specifically non-natural causes.

How much of exogenous extinction is of distinctly technological origin? This question is unfortunately unanswerable in terms of any well defined analytical approach. Technology certainly plays an important role in hunting and in much of physical habitat modification but we do not have the data for a case-by-case review of recorded extinction. In the absence of such detailed data, we conservatively estimate the technological percentage of exogenous species extinction at

Table 7

ENDANGERED, THREATENED AND EXTINCT SPECIES OF NATIVE HIGHER PLANTS IN THE U.S.

STATUS	Continental United States (including Alaska)		Hawaii	
	species, sub-species and varieties	percent	species, sub-species and varieties	percent
Total native higher plants	20,000	100.0	2,200	100.0
Endangered[a]	761	3.8	639	29.0
Threatened[b]	1,238	6.1	194	8.8
Extinct[c]	100	0.5	255	11.6
Total	2,099	10.4	1,088	48.9

Source: Smithsonian Institution, "Report on Endangered and Threatened Plant Species in the United States" (U.S. Government Printing Office, Washington, 1975).

a. "Endangered" is defined as in danger of becoming extinct throughout all or a significant portion of their natural range.
b. "Threatened" is defined as likely to become endangered in the foreseeable future.
c. "Extinct" is defined as limited to recently (or possibly) extinct species only: they cannot be found after repeated searches in the localities where they were formerly observed or other likely places. Some of the latter appear to be extinct in the wild but are still preserved in cultivation.

14

approximately one-half, with the remainder being largely of cultural character.

Whatever the division between technological and cultural causes may be, it is clear that the rates of exogenous extinction currently being observed are much faster than the normal evolutionary process of replacement. Nor is it possible to insure adequately against such loss in zoos, botanical gardens, and other protected environments.[17] Ecological theory, furthermore, suggests that wildlife mortality of the magnitude currently being observed can lead to significant diminution and loss of ecosystem productivity and resilience, with occasionally catastrophic consequences.

We wish to emphasize that counting species by itself is inadequate for defining the impact of technology on ecosystems. It is not enough to have a catalog of characters to predict the outcome of an evolutionary play. What is needed is some measure of the effectiveness with which ecosystems use energy and how well an ecosystem is able to recover from a stressed condition (resilience). Important new concepts related to ecosystem energy analysis[22] and ecosystem resilience[23] are currently undergoing intensive study in the scientific community. Until these provide well defined indicators, however, it seems prudent to use crude indicators like species extinction as warning signals of potential hazard.

Ecosystem Productivity

As a second measure of ecosystem impacts we consider productivity, or the ability of ecosystems to produce organic material from inorganic substrate and sunlight. In so doing, we limit ourselves to the changing magnitude of the land biomass—that is, the organic material of biological origin found on land. Land biomass is subject to natural variability arising from such factors as weather and disease; it also responds to the expansion of timbering, agriculture, urbanization, and similar pressures from humans. The question of biomass impacts can

Table 8

CLASSIFICATION OF CAUSES OF EXTINCTION AND RARITY FOR BIRDS AND MAMMALS SINCE 1800 ON A WORLDWIDE SCALE.[a]

CAUSE OF EXTINCTION	Birds (%)	Mammals (%)
NATURAL CAUSES	24	25
EXOGENOUS CAUSES		
Acute (hunting)	42	33
Chronic		
habitat disruption (physical)	15	19
habitat modification (biological and chemical)	19	23
TOTAL	100	100

CAUSE OF RARITY	Birds (%)	Mammals (%)
NATURAL CAUSES	32	14
EXOGENOUS CAUSES		
Acute (hunting)	24	43
Chronic		
habitat disruption (physical)	30	29
habitat modification (biological and chemical)	14	14
TOTAL	100	100

Source: Recalculated from Wildlife in Danger, note 21.

America's best known endangered species.   USDA

therefore, as before, be divided into natural and exogenous effects.

Global changes in land biomass have recently been explored in connection with studies of the world carbon cycle.[24-25] These studies show a net annual decline in global land biomass (albeit with great uncertainty) amounting to 0.2 to 2 percent. The causes of change are largely exogenous and, as seen in Table 9, involve decline and destruction of major land plant communities in areas of maximum population pressure. Among the communities destroyed, tropical forests are of particular concern because it is not clear that reforestation can take place in some lateritic soils. A detailed study of tropical forests estimates that 0.3 to 0.6 percent of the total is being destroyed each year.[26]

In addition to direct losses in ecosystem productivity from deforestation, indirect impacts on drainage basins, resulting from major changes in hydrologic and chemical cycles, can also diminish long term productivity of the total ecosystem. For example, replacing biomass and nutrients lost in harvesting northern hardwoods may take sixty to eighty years.[27]

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Table 9

ESTIMATES OF CURRENT NET LOSS OF MAJOR LAND PLANT BIOMASS, AS REFLECTED BY THE RELEASE OF CARBON INTO THE ATMOSPHERE

Plant community	Carbon released (billion tons/yr)	
	average	range
Tropical forests	3.5	1-7
Temperate forests	1.4	0.5-3
Boreal forests	0.8	0-2
Other vegetation	0.2	0-1
Detritus and humus	2.0	0.5-5

Source: Modified from data given in G. M. Woodwell et al., note 25.

As with the case of species extinction, exogenous decline of land biomass is of specifically technological as well as cultural origin. Because the bulk of the large changes now being seen, particularly in tropical forests, involve the application of high technology, we believe the technological component of biomass decline to be as high as seventy-five percent of the total.

Technological Hazards in Historical Perspective

Our discussion so far has focused on present technological hazard impacts. Except in the case of species extinction, we have made no effort to look at the historical record. Industrial development in the West is now 300 to 400 years old, and much of what has occurred in the past fifty years has been termed "post-industrial." Historical experience with technology is therefore extensive, and it is thus interesting to ask whether the problem of technological hazards is getting worse.

Human Mortality

In regard to human mortality, the benefits of technology appear to have been large and dramatic. As already noted, they include the near elimination of the worst of natural hazards—infectious disease. This development is largely responsible for the fact that, since 1850, when the United States had a highly dispersed agricultural population, life expectancy has shown a

near doubling at birth, a thirty to fifty percent increase at midlife, and a modes, increase at age sixty. Technology has also led to a food supply system that is so productive that few in the industrialized world need fear even slight deprivation in relation to this basic need.

In addition, hazards of technology were undoubtedly higher in earlier, less fully managed stages of industrial development. Thus occupational mortality, at least of the acute variety, has shown a continuing and steady decline, as shown in Figure 5; and large technological disasters apparently peaked during 1900-1925.[28] If evidence from literature is desired, one need only recall the novels of Charles Dickens and D. H. Lawrence, which contain accounts of industrial pollution and human exploitation in an industrial setting that find few parallels in the modern age.

Thus, at worst the present problem may be that the positive effects of technology have for some time now reached their maximum effect on human mortality, while the hazards of technology continue partially unchecked, affecting particularly the chronic causes of death that currently account for eighty-five

FIGURE 5. Historical variation of occupational death and injury rates in the United States for 1930-1976. Injury data are considered to be only roughly correct due to varying recording practices. Source of the data is note 28.
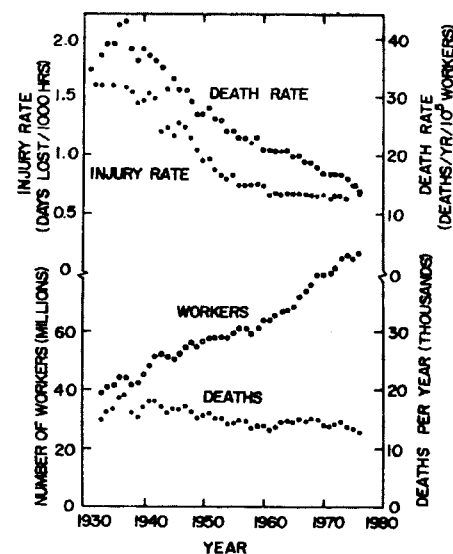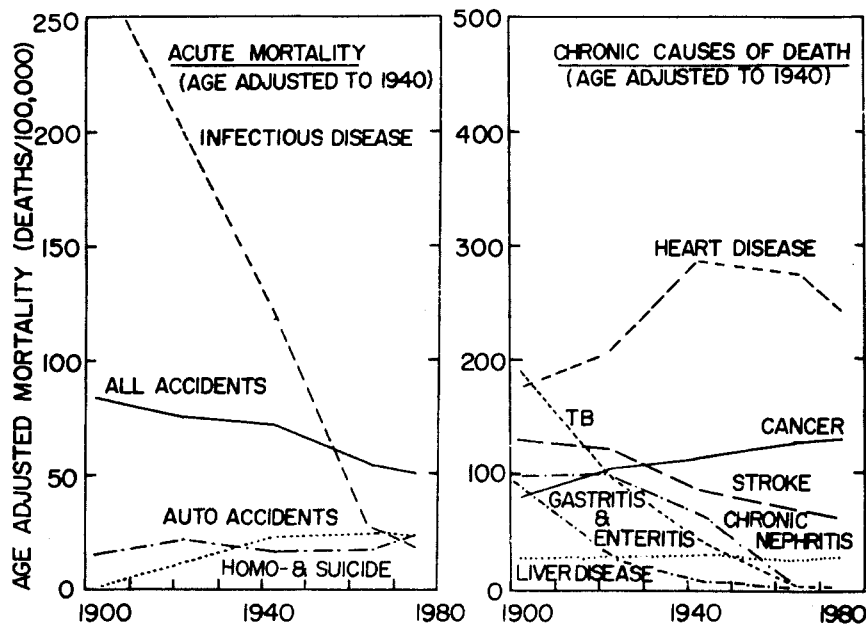
FIGURE 6. Historical variation of age-adjusted causes of death in the United States from 1900 to present. Among acute causes of death, note the sharp decline of infectious disease and the rise in auto-accident mortality; among chronic causes of death, note the decline of most causes except for cancer and cardiovascular disease. Even the latter shows a peaking in 1940, followed by a subsequent decline. Source of the data is Spiegelmann and Erhardt, *Mortality and Morbidity in the United States* (Harvard University Press, Cambridge, 1974).

percent of mortality in the United States. Supportive of this view is the fact that male life expectancy has not increased since 1950 and has even shown a slight decline.

But this view may be too pessimistic. Even the apparent increase in chronic disease, which forms the principal evidence for unchecked technological hazard mortality, may be erroneously interpreted. Thus, as shown in Figure 6, along with most other causes of death, the age-adjusted mortality from heart disease is declining; and increasing cancer mortality can in large part be explained by the delayed effect of earlier increases in smoking. In addition, there is indirect evidence[10] that certain chronic diseases were seriously under-reported in earlier parts of this century. Therefore, the actual cancer and heart disease mortality rates shown from 1900-1940 were probably higher and the overall increase since 1900 lower than shown in Figure 6.

In summary, we believe the burden of technological hazard mortality is not currently rising. Rather, it is clear that in the United States the last century has brought three things: (1) longer

life through elimination of old ways of death which were largely acute and rooted in natural hazards, (2) an increase in chronic causes of death, which are rooted significantly in technology, providing therefore (3) a continuing burden of death, close to half of which results from accidents and violence and the remainder from various chronic diseases.

Ecosystem Impacts

Beyond species extinction and productivity decline, what are the long-term trends in technological hazard impacts on ecosystems?

On the positive side of the ledger, it is clear that massive, local releases of pollutants to the environment, as exemplified by the London killer smog, Minamata disease, and fish-killing concentrations of pesticides in rivers, are now less frequent. Trends in air and water quality indicate that, after massive investments, environmental quality in the heavily populated and industrialized areas of the United States is generally improving.[29,30] Thus strong control programs for particulates and sulfur dioxide have reduced emissions to the

point that very few urban regions are now experiencing violations of standards for these pollutants. Fish have returned to western Connecticut's Naugatuck River, even in areas where no aquatic life could survive in the 1950s.[6] Interestingly, almost all of the major ecological hazards which have been identified and brought under control share two common attributes which determine the nature of the hazard management process—they originate from an easily identifiable point source and are amenable to control by technological fixes of the source.

On the negative side of the ledger, it is equally clear that widespread release of pollutants in relatively low concentrations are degrading aquatic and terrestrial ecosystems at an unmitigated or even increasing rate. Calculated ratios of man-made to natural fluxes of heavy metals, for example, indicate that natural cycles of mercury, lead, antimony, and selenium are being significantly altered by human activities.[31] The input of mercury to the global atmosphere from industrial and fossil fuel emissions exceeds the natural flux eighty-fold, and the ratio of man-made to natural flux is large for a number of other cases (Table 10). This explains, in part, why toxic metal pollution was cited by thirty-five of forty-one states

Table 10

GLOBAL AVERAGE RATIOS BETWEEN MAN-MADE AND NATURAL FLUX OF SELECTED HEAVY METALS IN THE ENVIRONMENT

Element	Ratio of man-made to natural flux
Nickel	0.9
Vanadium	1.3
Copper	2.3
Arsenic	3.3
Tin	3.5
Zinc	4.6
Cadmium	5.2
Selenium	14
Antimony	28
Molybdenum	29
Lead	70
Mercury	80

Source: Modified from Mackenzie et al., note 4.

Technology's impact on the ecosystem has apparently resulted in a net decline in the earth's biomass.

that reported water quality problems to the Environmental Protection Agency in 1976.[6]

Similarly, persistent pesticides consisting of chlorinated hydrocarbons, though banned for some time because of potentially harmful ecosystem impacts, are found with a sixty-eight percent detection rate in water and sediment samples in Houston, Texas.[6] And DDT, while controlled in the U.S., is increasingly being produced for global sale in developing countries.[32]

Finally, acid rain, resulting from regional deterioration of air quality in areas downwind from urban centers is having a number of effects. One of the most remarkable and potentially hazardous of these is the fact that it apparently results in a complete shift in forest floor mineral cycling processes which may eventually lead to problems with nutrient availability and metal toxicity, as well as direct damage to leaf tissue.[33-34]

Thus, for ecosystems, as for human mortality, we observe a change from acute to chronic effects, from easily understood to complex causal structure. Much of what is happening in ecosystems is in fact so incompletely understood that no clearcut directives can flow from scientific work to hazard management. All that science can presently hope to provide are warnings about what may possibly happen.

The Challenge

Hazards arising explicitly or implicitly out of technological practices have, in the industrialized world, significantly surpassed natural hazards in impact, cost, and general importance. At present in the United States, technological hazards account by our estimate for fifteen to twenty-five percent of human mortality, with associated economic costs and losses of $50 to $75 billion annually. About half of these costs and losses are associated with accidents and violence, the remainder with various forms of chronic disease. Ecosystem impacts, though difficult to define fully, are indicated by a number of danger signals, such as significant exogenous species extinction, productivity losses, and high concentrations of manmade toxic chemicals in the environment.

Overall, the burden of risk assessment, hazard management, coping, and adjustment may be as high as $200 to $300 billion per year, or ten to fifteen percent of the Gross National Product. So far, the principal result of this effort has been the elimination of numerous acute effects such as infectious disease and point-source pollution, with little progress in stemming the tide of chronic disease and ecosystem impacts.

We conclude, therefore, that, while the problem of technological hazards is on balance not getting worse, the

main success of hazard management has been with the relatively more accessible part of the problem. And, while this part of the problem is by no means under control, as indicated by the continuing burden of violence and accidents, the principal challenge for the future involves hazards that have indistinct causes and a broad distribution of impacts. Coping with technological hazard is and will continue to be one of the major social issues of our time.

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OVERVIEW

California

Why not? "The people that run it [the Department of Energy]. It starts at the top. Jim Schlesinger's nuclear to the core. . . . There's no one in there that fundamentally has the philosophy that energy conservation makes any difference or that new consumer-oriented demand technologies are important."

Sim Van der Ryn, California's state architect, feels much the same way and says so. Van der Ryn is currently planning three new solar-heated and -cooled state office buildings for Sacramento. He is also chairman of the governor's committee overseeing the state's Office of Appropriate Technology. He and Clark are good friends and I talked to Clark at Van der Ryn's own solar-heated house near the coast north of San Francisco. As it turned out, I talked to Van der Ryn himself in his Sacramento office whose clutter

included a ten-speed bike and a stack of unassigned certificates saying: "In recognition for showing a way to live lightly on the earth, the Office of Appropriate Technology confers this award of merit." Van der Ryn made it clear that he was not planning to send any of the certificates to Washington. "At the federal level," he said, "there's no real commitment to conservation. What the hell are they doing? Nothing's going on."

Clark blamed Schlesinger for what he saw as shortcomings in national energy policy, rather than Carter himself. But Van der Ryn did not make intramural distinctions. When I suggested that the view of Carter as pro-nuclear and Brown as pro-alternative might be overly simplified, he said, "No, I don't think it's too simplified." Then, echoing some of our earlier discussion about appropriate technology, he went on: "I think the reason the whole nuclear issue is so charged and so loaded is that pro-nuclear views [reflect] how people view the role of technology in society and where it's going to take us. . . . In the whole assumption that you have to have nuclear energy is the assumption that we are still on this upward curve, that there's a direct correlation between income, productivity, capitalization per job, energy usage. And the reality is that that discontinued in 1973. The curve leveled off and went downward. To me, the writing is there on the wall. The society is falling apart and choking on too much energy use.

"If all [nuclear safety issues] were solved, I would still be opposed to nuclear power because I think our society is falling apart because of energy addiction per se. That's my basic ideological position."

But is it Brown's? Though he once did, Brown has not had much to say of late about small being beautiful or about the "era of limits." Has he in fact moved away from such thinking, I asked him. "I believe that change occurs over time," he said. "It's evolutionary and so it's not an abrupt jump from one style to another. Society is organized around some very large technologies—automobile manufacturing or power generation or telephone communications. These