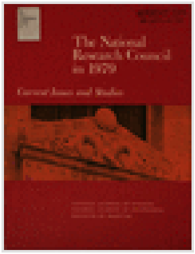

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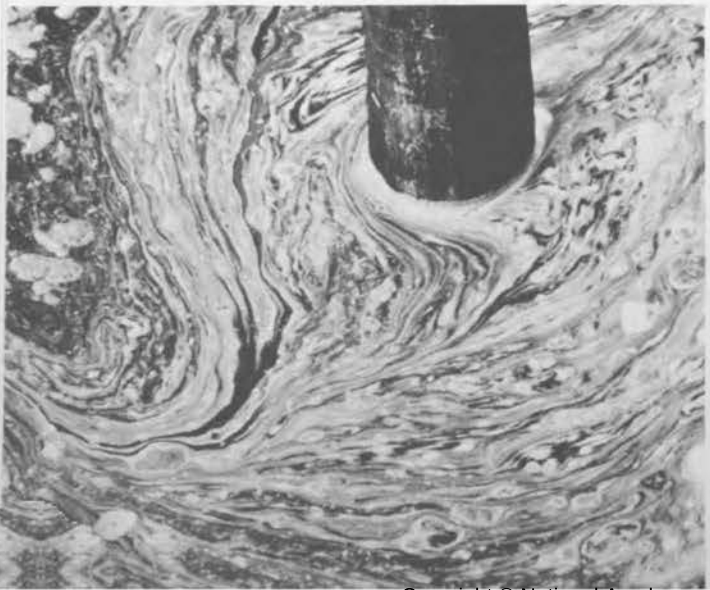

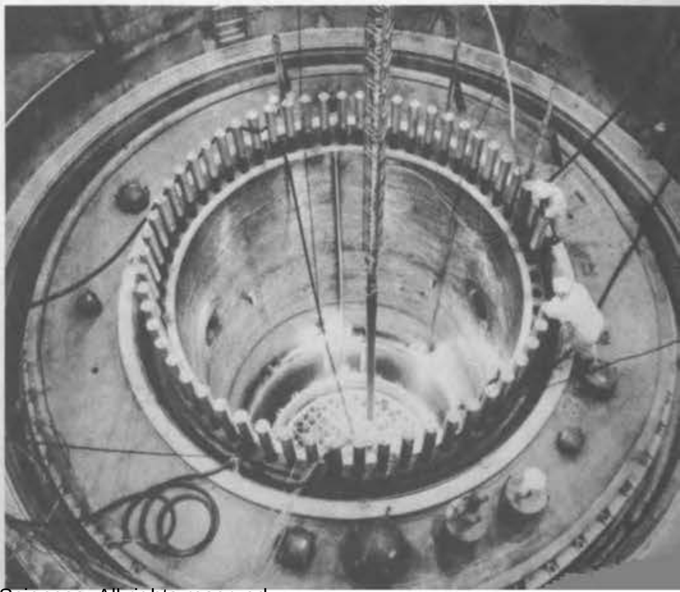

Some Comments on Risk Assessment

PHILIP HANDLER

It has long been a function of government to shield the citizenry from those dangers against which it cannot readily protect itself; hence, police and fire departments, armies and navies. As diverse technologies permeated our civilization and society itself became ever more complex, it came to seem desirable that the state also safeguard the welfare of its citizens from more subtle threats. Government gradually became involved in protection against some of the physical insults of existence in a crowded technological society; for example, it set standards for steam boilers and locomotives, improved the safety of roads and mines, provided reasonably safe drinking water and effective sewers, moved to assure the general sanitary condition of the food supply and restaurants, sponsored immunization against virus diseases, and attempted to minimize accidents in the workplace.

Implementation of these functions flowed from a long legislative history that led to creation of such agencies as state departments of public health, the Food and Drug Administration (FDA), and federal offices devoted to the safety of mines and of roads. These measures

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have gone far to render life for all citizens healthier, safer, and more secure. As Alfred Kahn recently noted, "No one in his or her right mind could argue that the competitive market system takes care of protecting the environment—it doesn't." Yet, even when the nature and scale of the threat was self-evident, establishment of safeguards was accomplished only over significant opposition. In every case, the new measure was put in place only when there had been achieved political consensus that it was a proper function of government and that the nation could afford it, a history particularly poignant with respect to legislation protective of women and children at work.

In the economic sphere, acceptance grew during the great depression that it is insufficient to depend upon the operation of Adam Smith's "invisible hand" for protection. Another group of governmentally sponsored programs evolved: social security, unemployment compensation, disability benefits, federal deposit insurance, federal disaster assistance, to name but a few.

A new era dawned following World War II; as new technologies proliferated, consciousness heightened with respect to eyesores that constituted the public price of older, unregulated technologies. The environmental movement began with alarm for the despoliation of the countryside by the carcasses of discarded vehicles, for the gashed hillsides remaining after strip mining, for acid seeping from mines and waste piles, for artificial rechannelization of streams, for disappearance of the organisms that previously were at the top of the food chains in lakes and streams, as well as for smog, first in the Los Angeles basin and then over almost every major conurbation. Public response, always, to be sure, in the face of some opposition, was relatively rapid.

Although consideration of safety had long been intrinsic in engineering practice, the scale of some new technologies forced assessment of their attendant risks; for example, those of aircraft, high rise buildings, dams, highways, automobiles, industrial installations, and household electrical appliances. Attention was first directed at the likelihood of accidents and their prevention. Later, the more subtle consequences of such technologies, such as air pollution, began to receive examination. (Elsewhere in this volume, H. Guyford Stever and Brian MacMahon discuss, respectively, the role of engineers in risk assessments and of epidemiology in tracing the often tenuous links of causes and effects in diseases.)

Meanwhile, the American dinner table was enriched by a cornucopia of diverse prepared foods and of foodstuffs made independent of local growing seasons or of climate by safe transportation over long distances. In some part, this dramatic transformation was made possible by introduction into the food supply of a battery of chemicals intended, variously, to enhance keeping quality, texture, flavor, aroma, color or stability. Each had been assayed by the classical techniques of toxicology, and there was reasonable assurance that none would occasion acute adverse effects on health. Growing knowledge of the biology of cancer and of the diversity of chemical structures capable of eliciting a neoplastic response in laboratory animals—together with the thalidomide episode, which demonstrated that a substance which successfully passed the screen of assays for acute toxicity could, nevertheless, have disastrous long-term effects—gave rise to concern for possible consequences of chronic exposure to low levels of diverse materials. Although no food additive since Butter Yellow had been noted to occasion cancer in humans—nor is there such evidence at this time—concern grew for the possible long-term effects of food additives as well as for possible effects of trace quantities of materials inadvertently introduced into the food supply by the practices of agriculture or of animal husbandry.

Meanwhile, thousands of new synthetic chemicals were being introduced into the economy for an extraordinary variety of industrial and end uses. Again, whereas the acute toxicity of these chemicals had been more or less adequately assessed, their chronic effects were rarely tested. Uneasiness concerning these matters was brought into focus by repeated references to the epidemiological conclusion that seventy to ninety percent of all cancers are occasioned by "environmental factors."

Consciousness of potential hazard was heightened by a number of tragic experiences, such as those with vinyl chloride, asbestos, Kepone, and the organophosphate pesticides, and rendered yet more acute by the remarkable toxicity of extraordinarily low doses of dioxin, a contaminant in one herbicide that is also generated in minute amounts in a variety of industrial and household processes. Concomitantly, appreciation grew that ionizing radiation could not only induce genetic effects by mutations in the germ line but also cause cancer in somatic cells.

Thus, the environmental and consumer movements came together and out of these diverse concerns were born the Environmental Protection Agency (EPA), the Council on Environmental Quality (CEQ), and the Occupational Safety and Health Administration (OSHA), while the regulatory concerns of FDA and the research programs of the National Institutes of Health (NIH) were given new direction.

RISK ASSESSMENTS AND THE NRC

Called into question within a relatively brief span were materials such as diverse drugs, DDT and various other pesticides, the PCB's used in dielectrics and other electrical devices, diethylstilbestrol (DES) used in "finishing" cattle, antibiotics used in feeds for pork and poultry, various food colorings, cyclamate and saccharin, oxides of sulfur and nitrogen as well as sulfates and particulates from mobile and stationary power sources, chlorinated organic compounds formed during chlorination of communal water supplies, and freons. In each case, some element of the public which demanded that public exposure to the material in question should be reduced or eliminated was opposed by others. In each case, the available evidence was insufficient to compel conclusion by simple inspection; yet, in each case, the question having been called, decision was unavoidable. To reduce or clarify the uncertainties of such circumstances, federal agencies and the Congress have frequently referred such matters to the National Research Council. In consequence, risk assessment concerned with possible health effects has become a major aspect of the work of the NRC. Indeed, about one-quarter of all NRC studies in recent times is concerned with some form of risk assessment, while an equal volume of work has been devoted to the management of known hazards. (A selection of works pertaining to risk assessments completed and under way within the NRC is given at the end of this article.)

Recognizing the centrality of risk assessment in the work of the NRC—and the considerable variation in methodologies and formats applied by NRC committees—the NRC Governing Board has commissioned an exploratory study of the risk assessment function. A special *ad hoc* committee will survey the extent and content of risk assessment activities within the NRC. It will identify generic problems of risk estimation, such as extrapolation from animal experimentation to possible effects in humans, as well as predictions of the behavior of physical systems based on simulated mathematical models. The committee will consider the processes used by various NRC panels to assess and rank risks, the manner of communicating the use of probability statistics to non-scientists, modes of quantification and comparison of risks, appraisal of the costs of accepting or reducing risk, and comparison of risks with the benefits of the engendering technology. It is hoped that this exercise will lead to guidelines to assist future NRC committees and to more standardized methods of conducting risk assessments.

Early in 1980, the Assembly of Behavioral and Social Sciences will conduct a workshop on Risk Assessment and Decision-Making seeking understanding that will lead to "reasearchable questions." The areas to be probed include: the adequacy of data bases required to assess risks; the processes by which such information is used by decision-makers; institutional and organizational factors influencing decision-making; identification of decision-making tools or alternative courses of action available to decision-makers.

Meanwhile, risk assessment and decision-making proceeds apace under many auspices. The large body of law and regulation already in place is evident in the ever-increasing dimensions of the *Federal Register*. A recent Presidential statement indicated that ninety distinct regulatory agencies issued about 7,000 rules last year. One must assume that each is well intended, but each has a cost that should be justified by hard evidence, not by ideological belief. In the absence of persuasive data on the magnitude of the relevant risks, the economic and social costs of their abatement, and the economic and social value of the benefits to be foregone or gained, the sum of this welter of regulation can engender public cynicism, ensnarl life in the workplace, and slow the economic life of the nation, growth of which is the principal means of enhancing the quality of life for those as yet economically deprived.

A SENSIBLE GUIDE

The relevant question, then, is not whether regulation mandating pollution abatement or otherwise enhancing the prospects for health and safety has reduced national productivity—apparently it has—but whether the benefits are commensurate. It has become a function of government to determine whether a given technological benefit is worth the attendant risk where such exists; it also assesses whether the costs of mitigating or eliminating such risks are justified by the latter's nature and magnitude. A sensible guide would surely be to reduce exposure to hazard whenever possible, to accept substantial hazard only for great benefit, minor hazard for modest benefit, and no hazard at all when the benefit seems relatively trivial.

Rarely, however, have reliable quantitative assessments of costs, risks, and benefits been available. All too frequently, these are separated in time, accrue to different population groups, and, generally, appear to be incommensurable. Typically, costs are reckoned in dollars, benefits in esthetic or material values, risks in human lives. Data concerning risk are usually sparse at best, sometimes anecdotal, frequently descriptive only of small numbers of animals exposed to large doses of a suspect material. Not infrequently direct estimation of benefits, in economic terms, has been infeasible—as in the case of abatement of air pollution. Such appraisals have occasionally been conducted mathematically by multiple regression analysis. Valid use of this technique has been the subject of an NRC seminar and a paper on this subject is currently in preparation.

Meanwhile, it is clear that, whereas the analysis of risks and benefits can inform the decision-maker, the intrinsic incommensurability of these parameters renders it inevitable that decision must turn on a value judgment. Indeed, frequently the nonquantifiable nature of "benefit" defeats such an analysis and the wise decision-maker will do better simply to compare the risks of available alternatives. The *estimation* of risk is a scientific question—and, therefore, a legitimate activity of scientists in federal agencies, in universities and in the National Research Council. The *acceptability* of a given level of risk, however, is a political question, to be determined in the political arena. Consider, for example, the following: Do the alleged risks to public health and to ecosystems from the emissions of coal-fired electric power plants warrant the increase in the price of energy necessitated by scrubbers to reduce those emissions? Is the risk of cancer from traces of chloroform in drinking water too great to warrant continuing the chlorination of that water—otherwise, the most satisfactory method for controlling offending microorganisms? Are the psychological benefits of artificial sweeteners to dieters and to diabetics sufficient to warrant unrestricted use of such sweeteners as food additives? Or, in general, are the risks to be avoided by banning the use of a given substance less acceptable than those associated with the use of its most likely substitute?

Are the estimated risks of nuclear power plants too great to be acceptable; are they more or less acceptable than those associated with coal combustion? Is a very small probability of a large catastrophe more or less acceptable than a much larger probability, indeed, almost a guarantee of a small number of casualties annually? Are the penalties for failing to enlarge the supply of electrical energy more or less acceptable than the risks of generating electricity by nuclear power or coal combustion?

BELIEFS

Such questions might be decided simply by agreeing to take no avoidable risks. The decision-maker would then have only to acknowledge the existence of risk and act accordingly. But that could occur only in a world both unreal and unlikely. In the real world, the decision-maker must somehow weigh costs, risks, and benefits and come to a value judgment; in so doing, society is subjected to his or her religious, social, economic, political, and philosophic beliefs. That is, indeed, the nature of the political process.

When scientists enter these lists and debate such questions as if they were entirely scientific, unspoken ideological or political beliefs much too easily enter the argument; conversely, such beliefs have frequently beclouded seemingly scientific debate concerning the nature and magnitude of the risk itself. It is for this reason that the rigorous procedures of the National Research Council are critical to its role in this arena. Committee appointments must be carefully screened for introduction of bias; known protagonists of a given viewpoint may be chosen for their technical expertise only when the contrary view is equally represented; and the report review process must be conducted so as to assure that the committee's findings, conclusions, and recommendations flow from a valid and adequate data base, not from inadvertently introduced ideological biases or unnoted conflicts of interest which occasion avoidance of discrepant observations. Indeed, it is the rigorous adherence to these procedures, in addition to the willingness of highly qualified scientists to so serve, that gives the National Research Council a special place of public confidence in matters of risk assessment.

SOME NOTES CONCERNING PUBLIC DECISIONS BASED ON RISK ASSESSMENT

Numerous regulations, seeking to limit exposure, have called for absence of "traces" of one or another material from drinking water, air, or the food supply, for example. Most were written in an earlier day when the limits of certainty for analytical procedures were measured in micromoles (10^{-6} mole); current techniques frequently permit certainty of identification at the level of picomoles (10^{-12} mole), a level at which adverse physiological effects for most—not all—pollutants are extremely unlikely. The wisdom of such regulations requires reexamination. Indeed, some compounds have been called into question precisely because their widespread distribution has been ascertained by modern ultrasensitive analytical techniques. Rational decision-making should rest on relating such minute concentrations to the possibility of adverse health effects, not on mere ubiquity.

Banning diethylstilbestrol (DES), a synthetic estrogen, for use in cattle, may be a case in point. Detection of DES in cattle liver (not muscle) was possible only with the sensitivity provided by measurements of radioactivity after DES labeled with tritium had been administered.

The maximum possible exposure to pregnant women, the population of concern, from the ingestion of beef from such cattle is but a small fraction of estrogens synthesized daily in women; to be more specific, a pregnant woman eating beef from DES-fed cattle would daily ingest the equivalent of five nanograms (10^{-9} grams), but would at the same time metabolize 200 times that amount of her own estrogen. The carcinogenic effect of DES was manifest in the daughters of women who, when pregnant, had been given extraordinarily heavy doses of DES to prevent spontaneous abortion. That exposure was 10 million times as great as possible exposure from beef. Using such data, one can calculate that the feeding of DES to beef cattle might cause one cancer in the American population every 100 years. The potential cost to consumers resulting from the higher fat content of beef is certain to be enormous, with some estimates putting it at several hundred million dollars annually.

HOW SAFE?

Another body of law and regulations demands that the product or process in question be shown to be "safe" beyond reasonable doubt or to be "essentially without hazard." Experience makes it clear that almost nothing is without some risk. Henceforth, the political and regulatory process must, instead, indicate in some manner the absolute level of risk that should become the operational equivalent of "safe" or "without hazard." That will demand a relatively easy familiarity with mathematical statements of probability, for example, "10^{-6}," recognizing that (a) if 2×10^8 Americans are exposed to a material that has a probability of 10^{-6} of causing an undesired outcome, 200 persons may be so affected, and (b) only in unusual circumstances can data be collected that will permit unequivocal determination that the probability is 10^{-6} and not 10^{-5}, for example. Such decisions, accepting a specified level of risk, may seem "coldblooded" but they are far less so than many other decisions taken by government as a matter of course.

RISKS AND SYMBOLS

In some instances, assertions of danger appear to be offered as surrogates for concern about the nature of society itself. This has seemed most evident in public discussion of nuclear power and of the experimental use of recombinant DNA. There are, indeed, serious technical issues that require full public evaluation, understanding and acceptance before the country will readily return to a course in which nuclear power would supply a markedly increasing fraction of electrical energy; these include, for example, radiation leakage, long-term waste disposal, security against terrorism, weapons proliferation, and the chance of a large-scale accident. However, some of the most vigorous opponents of nuclear energy appear, in fact, to be arguing principally for the decentralization of American society. For them, objection to nuclear power symbolizes their disaffection with an urbanized, materialistic society managed by a bureaucracy—government or corporate—that to them seems not democratically accountable. Indeed, beneath the surface, a substantial fraction of the consumer and environmental movements may be an expression of anomie, a cry of protest against a growing sense of social and political impotence. These are genuine and legitimate issues, particularly noteworthy for the fact that they arise among the most educated segment of our society. Clearly, they warrant the most serious attention. But in the continuing debate concerning nuclear energy and other environmental and consumer concerns, such views must not be allowed to distort dispassionate, objective evaluation of risk, economics, or technical performance.

CANCER

Concern for the possibility of environmentally induced cancer has become the predominant theme of much risk assessment. Accordingly, it seems worthwhile to attempt to place that subject in some perspective. There are three principal axioms of environmental cancer biology: (a) that seventy to ninety percent of all cancer is the result of environmental factors; (b) that the neoplastic transformation is the result of a somatic mutation; and (c) that there is no threshold level to a chemical carcinogen, or radiation, below which exposure to it is "safe." Let us examine the implications of these axioms.

The assertion that virtually all cancer derives from environmental factors was made in consequence of the disparate geographic distribution of diverse forms of cancer combined with the absence of any evidence that predisposition to a locally frequent form of cancer is associated with a specific ethnic group. The prevalence of gastric carcinoma in Japan, and the low rate of this disorder in Americans of Japanese origin is the case in point usually offered. When first the disparate geographic patterns of different cancers were noted, it was logical to conclude that they might be occasioned by differential distribution of primary carcinogens, usually termed "initiators," either natural or man-made. But after two decades of seeking naturally occurring, primary causative agents, only a handful are known, such as the aflatoxins found in molds on peanuts and some cereal grains; these can account for only a trivial fraction of worldwide carcinogenesis. Accordingly, one begins to suspect that such agents are not found because, in fact, they do not exist.

EPIDEMIC OF LIFE

The environmental postulate has been confused with the possibility of carcinogenesis due to the thousands of man-made chemicals recently introduced into the economy and hence into the environment. It is, perhaps, conceivable that a "cancer time-bomb" has been implanted into human affairs. But if so, it has not yet erupted.

On the evidence, the environmental postulate must refer to the natural, not to the man-made, world. Only a very tiny fraction of all current deaths due to cancer, in the United States or elsewhere, could be due to man-made chemicals. Moreover, only one or two percent of cancers can be traced to occupational exposure in such workplaces as coal mines, asbestos mines, and factories; "pollutants" of all sorts may contribute to—rather than cause—perhaps five percent of all cancers. Radiation exposure, principally medical use of X-ray, occasions no more than one percent of all cancers. Indeed, the United States is not suffering an "epidemic of cancer," it is experiencing an "epidemic of life"—in that an ever greater fraction of the population survives to the advanced ages at which cancer has always been prevalent. The age-corrected incidences of only two forms of cancer have changed significantly in the last half-century: The incidence of cancer of the lung has increased markedly due to cigarette smoking, which has less dramatically contributed to cancer of other organs. Meanwhile, the incidence of cancer of the stomach, formerly as prevalent in the United

States as today in Japan, has declined dramatically for reasons that are quite unknown. (We've been doing something right and don't know what it is!) The overall, age-corrected incidence of cancer has not been increasing; it has been declining slowly for some years.

Those who first directed attention to the role of "environmental factors" in influencing the geographic distribution of the various forms of cancer—notably John Higginson of the International Agency for Research on Cancer in Lyons, France—are well aware of these circumstances. However, they associate that varied distribution with neither man-made chemicals, radiation, industrial pollutants, nor natural "initiators" but, rather, with differences in regional "life-styles"—for example, the relative consumption of such items as tobacco, coffee, alcohol, dietary fat, and fiber,[1] or voluntary exposure to the sun. Indeed, neither any specific cancer nor total cancer incidence is correlated with the degree of industrialization or energy consumption per capita of different world regions. Nevertheless, regulatory policy in the United States has heavily emphasized measures to minimize exposure to man-made chemicals which laboratory tests have proved carcinogenic in rodents. Quite apart from the social and economic costs of such measures, they are addressed to a relatively minor fraction of the current mortality rate from cancer of all sorts. To quote Higginson, "There is no justification for ignoring minor hazard because a greater evil exists, but, conversely, there is no justification for overemphasizing a minor risk to the detriment of control of a major hazard." It should be clear that man-made chemicals and radiation are, in this sense, a relatively minor hazard that must not distract the scientific community from the task of understanding fundamental cancer biology and addressing the difficult, complex problem of the influence of "life-style" factors on the incidence and tissue site distribution of cancer.

IONIZING RADIATION

Almost one-quarter of all Americans die of some form of cancer. If the bulk of these casualties were due to insult by specific chemicals, one can ask, as John R. Totter of the Oak Ridge Associated Universities has done, what magnitude of insult is required to elicit this end point? The carcinogen for which there exists the most reliable quantitative dose-response curve is ionizing radiation. These data are available for man as well as for experimental animals, thanks to the careful studies made of the irradiated survivors of Hiroshima and Nagasaki. To induce twenty-five percent excess cancer fatalities would require daily whole body exposure for a lifetime to about 200 times normal background at sea level—sufficient to create one or two defects in the DNA of every cell of the body every day throughout life! Presumably this means that the vast bulk of such defects are either repaired or silent. This calculation can only suggest the considerable magnitude of external chemical insult that would be required to account for our present circumstances. Even if cancer can be occasioned by the cumulative effects of several different carcinogens or cocarcinogens, how could the responsible natural chemical carcinogens (initiators) have so successfully eluded us? The single dose of ionizing radiation required to achieve the same end point is of the order of 1–2,000 rads—about the LD_{50} for acute radiation disease. And that makes the environmental carcinogen hypothesis yet more difficult to sustain. If these radiation dosages are any guide to dose relationships for chemical carcinogens—admittedly, a debatable notion—they make evident the likelihood that no man-made chemical carcinogen identified to date will become a statistically meaningful cause of cancer; the effects of such compounds, if any, will probably be observed with certainty only in unusually heavily dosed individuals, for example, those, like vinyl chloride workers, exposed in the workplace.

Accordingly, explanations of the considerable variation in the incidences of different forms of cancer among different populations must be sought in phenomena more subtle than discrete chemical carcinogens, or initiators, in the environment, presumably those associated with life-style.

CANCERS AND MUTATIONS

A growing mass of observations equates carcinogenesis with somatic mutagenesis. For a long time, it seemed difficult to reconcile the idea of a single mutational event with the numerous physical and metabolic differences between a normal and transformed cell. That puzzle has been resolved somewhat with the observation that several oncogenic viruses function by introducing into the host genome a single gene that is expressed as an enzyme, a nonspecific protein kinase that phosphorylates numerous unrelated cell proteins having diverse functions, thereby potentially accounting for many if not all the morphological and biochemical changes observed during "transformation." At this writing, it is not known whether human tumors similarly contain an excess of such a protein kinase. But how would a chemical carcinogen or radiation accomplish similar change?

Is there a cancer gene locus which is derepressed in carcinogenesis? The great diversity of structures of carcinogens would seem almost to preclude the possibility that all attack the same locus. Do they occasion genuine mutations, permanent changes in the structure of DNA? That has not yet been demonstrated even for a *Salmonella* genome that has undergone "mutation" in the presence of a putative carcinogen. One observation may suggest otherwise, viz., the fact that cancerous cells—from a growing mouse teratoma—can be transplanted to a mouse embryo at the blastula stage, take their place in that embryo, and go on to become a normal liver or other organ. Why should a mutationally transformed cell back mutate in the presence of normal cells? Tumors always arise from cells that are surrounded by normal, like cells. Perhaps relevant is the puzzle concerning the lag between exposure to a carcinogen and the eventual appearance of a tumor—twenty to thirty years later—in humans. Why is the "mutation" silent for so long? Or perhaps the term "somatic mutation" is misleading, suggesting as it does a permanent alteration in the DNA in cells other than those of the germ line, when some other sort of mitotically transmitted alteration actually may be involved. Until demonstrated otherwise, perhaps it would be well to reserve the term "mutation" in eukaryotic species to those events transmissible via meiosis.

The concept of environmental carcinogenesis takes as given a requirement for some external agent as "initiator," an agent whose effects can be potentiated or enhanced by "cocarcinogens" or "promoters." But is this necessarily so? We have already noted the general failure to identify such materials. Are there, then, endogenous "initiators," the effects of which can be potentiated or promoted by "life-style"?

AN HYPOTHESIS

One possibility has been suggested by a number of investigators. The immediate mutational agents created by ionizing radiation passing through living cells are the superoxide and hydroxyl radicals (O_2^- and OH). In the absence of supervening events, the former degrades by a path that generates the latter, which is presumed to be the agent that directly attacks DNA, if that is what it does. However, it has been known for fifteen years that living cells constantly generate superoxide radicals by their own metabolism. Normally, they are rendered innocuous by the enzyme superoxide dismutase which catalyzes:

$$2O_2^- + 2H^+ \rightarrow O_2 + H_2O_2.$$

Any circumstance that might increase the rate of cellular superoxide formation or inhibit the action of the dismutase would increase the flux of superoxide, thereby mimicking ionizing radiation. A few observations are compatible with this very tentative hypothesis: for example, the burst of superoxide formation due to oxidation of the unsaturated fatty acids of disrupted liver cell membranes when chloroform affects the liver; significantly diminished levels of superoxide dismutase found in human tumors; increased incidence of lung tumors when animals dosed with carcinogens are exposed to high oxygen tensions; and the mutagenic effects of oxygen in the standard bacterial assay for mutagenesis. This hypothesis is here presented in some detail not out of confidence in its validity but as a model of a possible metabolic arrangement that would obviate the need for an external "initiator" but whose operation could, conceivably, be modified quantitatively and site-selectively by the "life-style factors" that now seem so significant in the etiology of cancer.

No theory exists to guide thinking concerning the possiblity of a "threshold" for environmental carcinogenesis. Certainly none has been seen experimentally, but even for radiation no data are available for the relevant segment of the dose-response curve, viz., the entire region of low doses in which one might be interested. However, even accepting the no-threshold premise, it is at least debatable whether the entire dose-response curve is linear to the origin or somewhat sigmoid so that low doses might have much less carcinogenic effect than predicted by the simple linear extrapolation of data at high dose levels. This would be of significance in setting exposure standards for carcinogens, including radiation, which are of sufficient benefit that the challenge is to minimize rather than eliminate risk. Under current law, this matter is less consequential for food additives for which zero exposure to added carcinogens has been mandated, thereby, presumably, placing a value of minus infinity on any possibility whatever of cancer. In any case, one looks forward to the publication of reliable dose-response curves for a few chemical carcinogens obtained with the necessarily very large numbers of animals over a wide dose range. The number of reported instances, for example, saccharin, in which nonlethal tumors have appeared only in those animals receiving the highest test dose is disturbing. Acceptance of the view that such demonstrations suffice should be conditioned on a few examples showing that the premise of extrapolation of the dose-response curve to very low doses is valid.

For the nonce, one must accept the premise that demonstration of "carcinogenicity" in rodents indicates potential for carcinogenicity in humans while remembering that, to date, all substances actually known to be carcinogenic in humans were first discovered by their effects in humans. But there are riddles: arsenate which seems surely carcinogenic in humans has shown no such effect in the laboratory; millions of humans have been exposed to penicillin G and DDT, which elicit tumorlike lesions in rodents, yet without any evidence of carcinogenicity. This may be due to low exposure dosages—but, in that case, there would indeed appear to be a "safe dose" or threshold.

Easy extrapolation even of the notion of qualitative carcinogenicity, thus, is of uncertain validity. Increased interest is being shown in the use of "transformation" of cells as an assay. It is certainly true that "carcinogens" can so affect mouse cells that they will divide indefinitely in cultures and give rise to a tumor when reimplanted in a host mouse. But human tumor cells will not grow readily in such cultures and the same "carcinogens" seem unable equivalently to "transform" normal human cells. This is not to argue that evidence of carcinogenicity in rodents is invalid for man, but to suggest caution in interpreting such data. Patently, assessment of the quantitative risk to man from scanty data gathered with rodents is extremely tentative at best, giving additional support to the proposal of the Committee on Saccharin and Food Safety Policy[2] that there would be much regulatory merit in classifying carcinogens as high, medium, or low risks. In the end, the question of a threshold will become irrelevant; what is required is a credible estimate of risk at the dose levels actually likely to be experienced by exposed human individuals so as to inform the inescapable political judgment.

Carcinogenesis is but one risk the possibility of which concerns committees of the NRC. Listed in the next several pages is a sample of reports entailing risk assessment that have been published in the last two years as well as some of the risk assessments currently in progress. Such tasks will continue to confront us for years to come.

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Weissburger, J. H. "Environmental Cancer: On the Causes of the Main Human Cancers." *Texas Reports on Biology and Medicine* 37, 1–18 (1978).

2. "Saccharin: Technical Assessment of Risks and Benefits." Institute of Medicine and National Research Council. National Academy of Sciences, Washington, D.C. (1978).

NRC RISK ASSESSMENT STUDIES IN PROGRESS

Biological Effects of Non-Ionizing Radiation will examine the health effects of microwaves and assess ill effects, if any, of this form of radiation. (Assembly of Life Sciences)

The Committee on Criteria to Set Priorities for Research and Regulation of Agents Hazardous to Human Health will analyze methodologies best suited to determine which of the thousands of potentially hazardous chemicals in common use to evaluate. (Assembly of Life Sciences)

The Committee on the Evaluation of DOE (U.S. Department of Energy) Research on Health Effects of Ionizing Radiation will assess the objectives and quality of DOE's research program and the relationship of science management to the breadth and quality of the research. (Assembly of Life Sciences)

The Committee on Hazardous Substances in the Laboratory will appraise the character and extent of laboratory hazards, identify risk minimizing procedures, and prepare a guide for use in research, teaching, and other laboratories. (Assembly of Mathematical and Physical Sciences)

An Exploratory Study of Risk Assessment in the NRC will survey the extent and content of risk assessment activity within the NRC and identify generic problems of risk estimation including the extrapolation of animal experiment results to humans and the prediction of physical systems on the basis of simulation. (National Research Council)

The Human Health Effects of Subtherapeutic Antibiotic Use in Animal Feeds will analyze existing epidemiological data on this subject, assess the scientific feasibility of additional studies, and, if warranted, suggest other research to resolve the risk-benefit questions posed. (Assembly of Life Sciences)

Nitrites (a study as yet untitled) will examine the health hazards and advantages of the use of nitrites and nitrates in meat. (Assembly of Life Sciences)

Nuclear and Alternative Energy Systems includes a chapter on risk pertaining to the safety and environmental and health effects of the use of various energy forms, then comments on the adequacy of some current standards and regulations. Also a panel report will examine the risks and impacts associated with different energy sources and technologies. (Assembly of Engineering)

The Research and Policy Implications of the Substitution of Diesel Engines in Future Light Duty Vehicles will examine and report upon the state of experimental and theoretical research on possible health hazards from diesel emissions, describe the range of technological options to make diesel engines safer and more efficient, and analyze comparative risks and benefits associated with the increased use of diesels. (Assembly of Engineering)

Wild Horses and Burros: Alternative Management Strategies will outline a research program to examine wild horse and burro population dynamics and methods of achieving sound rangeland management. (Committee on Natural Resources)

Workshop on Risk and Decision Making will identify public policy concerns on risk issues and suggest those that can be developed into researchable questions. Areas to be examined are: the adequacy of the data bases available for determining risks; processes by which such information is utilized by decision-makers; institutional and organizational factors influencing decision-making processes; and the identification of decision-making tools or alternative courses of action decision-makers can use. (Assembly of Behavioral and Social Sciences)

RECENT NRC REPORTS THAT INVOLVED RISK ASSESSMENTS*

Aquaculture in the United States: Constraints and Opportunities surveys the current state of aquaculture, the technological and political problems inhibiting further development, and indicates areas for further research. (Commission on Natural Resources)

Assessment of Low- and Intermediate-Btu Gasification of Coal, and *Assessment of Technology for the Liquefaction of Coal: Summary* call for long-range environmental research and hazard assessment of the technologies under consideration. (Commission on Sociotechnical Systems)

Biological Effects of Electric and Magnetic Fields Associated with Proposed Project Seafarer reviews knowledge of effects on the environment of radiation from Seafarer, evaluates the adequacy of existing data, and suggests additional research. (Assembly of Life Sciences)

The Chemistry of Disinfectants in Water: Reactions and Products, *The Disinfection of Drinking Water*, and *Toxicity of Selected Drinking Water Contaminants* review the effects of disinfectants and other drinking water contaminants on health, and means of control. (Assembly of Life Sciences)

Copper, *Nitrogen Oxides*, *Air Borne Particles*, *Carbon Monoxide*, *Platinum Group Metals*, *Ammonia*, *Hydrogen Sulfide*, *Iron*, and *Zinc* (a series on *Medical and Biological Effects of Environmental Pollutants*) review the effects of these substances on humans, plants, materials, and the environment and summarize possible harmful effects. (Assembly of Life Sciences)

Critical Issues in Coal Transportation Systems: Proceedings of a Symposium initiates discussion on these issues. A subsequent study will be published. (Commission on Sociotechnical Systems)

Decision Making for Regulating Chemicals in the Environment examines U.S. government decision-making processes regulating release of chemicals into the environment and makes recommendations applicable to the regulation of industrial organic chemicals, gross pollutants, and other types of chemicals. (Commission on Natural Resources)

Energy and Climate assesses the possibility of profound changes in the world's climate resulting from an atmospheric buildup of carbon dioxide caused by use of fossil fuels and suggests a program of interdisciplinary research to focus on the scientific, technological, social, and political implications of drastic climatic change. (Assembly of Mathematical and Physical Sciences)

Epidemiological Studies of Cancer Frequency and Certain Organic Constituents of Drinking Water—A Review of Recent Literature, Published and Unpublished reviews studies in which nonspecific measures of exposure to putative carcinogens in water were examined and also in which water quality was characterized by measurements of trihalomethane concentrations. (Assembly of Life Sciences)

*For much information in this section I am indebted to the Academy's *News Report.*

Estuaries, Geophysics, and the Environment deals with estuarine science with emphasis on the role of geophysics and the basic chemical and biological phenomena, especially those related to water quality. (Assembly of Mathematical and Physical Sciences)

Flammability, Smoke Toxicity, and Corrosive Gases of Electric Cable Materials includes recommendations on these topics made at a workshop. (Commission on Sociotechnical Systems)

Interactions of Mycotoxins in Animal Production: proceedings of a symposium. (Commission on Natural Resources)

Kepone/Mirex/Hexachlorocyclopentadiene: An Environmental Assessment evaluates summaries prepared for the EPA on the environmental effects and potential health hazards of Kepone and mirex and the substance from which they and other pesticides derive, hexachlorocyclopentadiene. (Commission on Natural Resources)

Late Mortality and Morbidity Effects of Occupational Exposure to Microwave Radiation examines occupational health epidemiology relating to microwave radiation. (Assembly of Life Sciences)

Maintenance Decision Making and Energy Use, Roadside and Pavement Management, and *Preferential Bridge Icing* are papers on aspects of the subject. (Commission on Sociotechnical Systems)

Medical Technology and the Health Care System: A Study of the Diffusion of Equipment-Embodied Technology examines cost and effectiveness of processes by which new medical equipment and related technologies are adopted and used in health care. (Assembly of Engineering and Institute of Medicine)

Nitrates: An Environmental Assessment examines several environmental effects and health hazards from nitrates in food and drinking water. (Commission on Natural Resources)

Polychlorinated Biphenyls uses what is known about PCB's to assess the effectiveness of current and proposed guidelines for evaluating potential hazards of other chemicals with a view to preventing future problems similar to those resulting from widespread release of PCB's in the environment. (Commission on Natural Resources)

Radiation Intensity of the PAVE PAWS (Phased-Array Warning System) Radar System examines expectations of the PAVE PAWS radiation intensity and field and describes what is known of the effects of the type of radiation to be expected from PAVE PAWS. (Assembly of Engineering)

Radioactive Wastes at the Hanford Reservation: A Technical Review surveys current methods for managing high- and low-level radioactive wastes at Hanford and evaluates plans for their permanent disposal. (Commission on Natural Resources)

Recommendations on Quarantine Policy for Mars, Jupiter, Saturn, Uranus, Neptune and Titan reviews past studies and current contamination-control policies in light of findings from the *Viking* mission to Mars and the *Pioneer* probes to the farther planets. (Assembly of Mathematical and Physical Sciences)

Response to the Ozone Protection Sections of the Clean Air Act Amendments of 1977: An Interim Report examines the state of knowledge and adequacy of research efforts to understand possible inadvertent modification of the stratosphere, probable consequences, and ways to control inadvertent stratospheric change. (Assembly of Mathematical and Physical Sciences)

A Review of the Role of Health Sciences in the Consumer Product Safety Commission examines the Commission's Bureau of Biomedical Sciences and its successor and surveys the use of health sciences in regulating products subject to the commission's jurisdiction. (Assembly of Life Sciences)

A Review of the Use of Ionizing Radiation for the Treatment of Benign Diseases. Vol 1 reviews radiation therapy to provide a rational base for the application of risk-benefit analyses to the use of such therapy for benign conditions. (Assembly of Life Sciences)

Risks Associated with Nuclear Power: A Critical Review of the Literature. The summary and synthesis chapter presents a critical review of the frequently conflicting technical literature on risks from nuclear power and the implications of that literature. (Committee on Science and Public Policy, NAS)

Saccharin: Technical Assessment of Risks and Benefits and *Food Safety Policy: Scientific and Societal Considerations* analyze and appraise current information bearing on the problem of when and when not to ban additives that provide purported benefits to consumers. The saccharin study indicates the present unsatisfactory state of knowledge concerning both the dangerous and salutary aspects of saccharin use. (Assembly of Life Sciences and Institute of Medicine)

Safety of Dams: A Review of the Program of the U.S. Bureau of Reclamation for the Safety of Existing Dams surveys certain dam safety practices. (Assembly of Engineering)

Science and Technology: A Five-Year Outlook, mandated by Congress, anticipates prospective scientific and technological problems and opportunities. Chapters on "Energy" and "Toxic Substances in the Environment" contain material on risk assessment. (National Academy of Sciences)

The Shallow Land Burial of Low-Level Radioactively Contaminated Solid Waste surveys present disposal methods and estimates their future safety. The study indicates the need for guidelines for site selection and radioactive waste management and a "standardized system of definition, nomenclature, and classification of radioactive wastes. . . . " (Commission on Natural Resources)

Sleeping Pills, Insomnia, and Medical Practice examines current scientific and educational issues associated with sleeping pills and evaluates the risks and benefits of various types of sleep-inducing drugs. (Institute of Medicine)

Soil as a Resource in Relation to Surface Mining for Coal and *Ground Water Resources in Relation to Surface Mining for Coal* examine costs of erosion damage and soil impairment caused by mining and assess impacts of surface mining on groundwater. (Commission on Natural Resources)

Statement of the Committee on Military Environmental Research on the Status of Research into Biological Effects of Environmental Contaminants at Rocky Mountain Arsenal reports on the committee's investigation of the handling of contamination problems from nerve gas and pesticide wastes. (Assembly of Life Sciences)

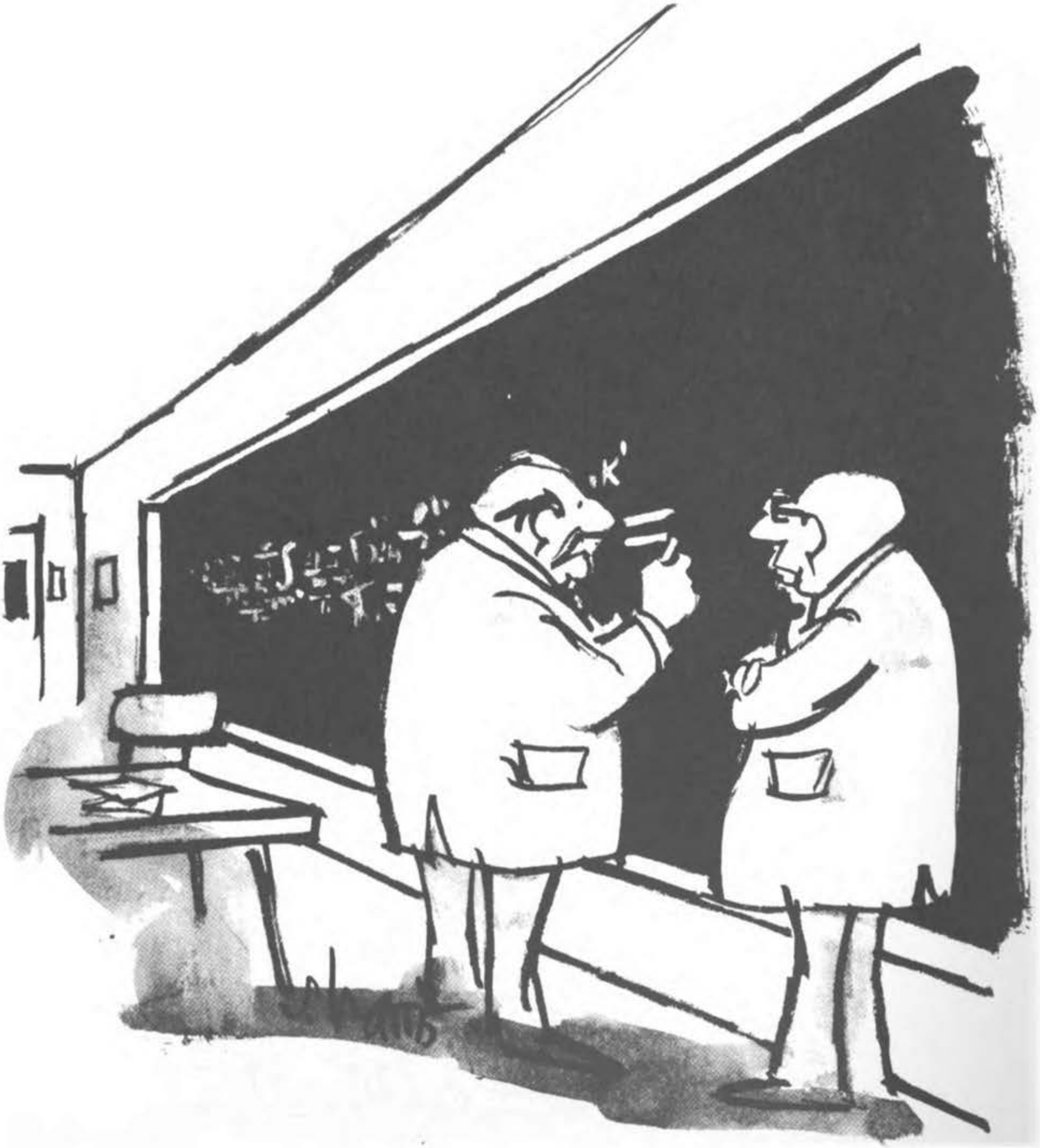
Sulfur Oxides evaluates environmental impact of emitted sulfur oxides and raises policy questions requiring political, not technological, solutions. (Assembly of Life Sciences)

Summary Report: Drinking Water and Health assesses possible adverse effects that impurities in drinking water may have on health and considers problems associated with chlorination. (Assembly of Life Sciences)

Symposium on Perspectives on Food Safety: Proceedings of the 1978 Annual Meeting of the Food and Nutrition Board. (Assembly of Life Sciences)

An untitled report provides the federal Office of Science and Technology Policy with a framework for determining needs and priorities for federally supported environmental research and development. (Commission on Natural Resources)

Assembly of Behavioral and Social Sciences



Drawing by S. Harris

"On the other hand, my responsibility to society makes me want to stop right here."

Science, Politics and Mrs. Gruenberg

JAMES G. MARCH

Not long ago, I spent a few hours with some colleagues, a small cluster of friends stranded in Washington. The occasion was indolent; the talk more Stoppard than Shaw; and the main topic the merits of passing on first down. Intruding on this quiet sonata of acquaintance, however, was a minor serious theme—complaints about the incompetence of scientists in politics, elaborated with vivid tales of exceptional foolishness. It was innocuous, and our pleasant sense of superiority was moderated only slightly by an awareness that the level of discourse was not quite the Vienna Circle and a small suspicion that somewhere else in Washington we ourselves were featured in someone else's favorite illustration of political infancy. It was not the kind of occasion that generates precise memory or clear conclusions, but most of my friends seemed to agree that the political innocence of scientists was unfortunate, that scientific advice related to public policy profits from political consciousness. The discussion elicited sentiments that were

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not unique to this group of friends. They were sentiments that have an impressive ancestry, are reflected in the attitudes of many smart people, and can easily be defended; but I think they are wrong.

On balance, I think political scientists and others who know about politics place too much emphasis on increasing the political sophistication of scientists involved in policy questions. We simultaneously underestimate the knowledge scientists already have about political life and overestimate the significance of it. By criticizing the naivete of scientific advisors, we encourage behavior that reduces the usefulness of science in policymaking. Capitals are the natural habitat of political voyeurs, people who enjoy the vicarious pleasures of contemplating politics and imagining their importance to it. They are harmlessly clever, like experienced pornographers, and contribute to the sweet ornamentation of life; but I do not think we should make them models for scientists who come to Washington. There is still room for specialization in life.

Science is a collection of ignorances. We want to know everything and count the lack of time, skill, and money that stand in our way as regrettable limitations. Nevertheless, we are specialists; and the illusions we have about our competences are mostly specific to small corners of the library. We have a vague sense of the appropriate balance between specialized and more general knowledge, as wary of those who would goad us into extradisciplinary embarrassment as of those who would confine us too much. We accept our ignorance while trying to reduce it. This comfortable sense of balance is lost when we turn to questions of public policy. Policy questions seem to confound ideas about scientific specialization that we have developed around the canons of more basic research. The contrast is manifest in the differences between the spirit and organization of the National Academy of Sciences as an honorific and scientific society and the spirit and organization of the National Research Council as a consultant on scientific aspects of public policy. The council is littered with multidisciplinary committees, the academy with disciplinary ones. When we work in the policy area, we seem to change our notions of what is tolerable ignorance.

Even more conspicuously, policy questions draw scientists near to politics, where most of them are not specialists at all. People active in political life commonly report that scientists are badly informed about the political system, and that, as a result, they frequently give advice that is irrelevant in a policy context or has perverse consequences. The belief is, as might be expected, persistent among political scientists; it is also frequent among policymakers, particularly experienced bureaucrats and politicians. The picture is plausible. Even for most behavioral and social scientists, the political process is an alien domain, distant in spirit despite its temptations. Although science politicians and agencies have prospered impressively in political systems around the world, many scientists find the rules of politics uncomfortable.

At the base of much of this discomfort is a conspicuous disparity between the rhetoric of science and the rhetoric of politics. Science presumes a process by which alternative theories are evaluated systematically against available data within a framework shared by "reasonable" (i.e., well-trained) people in order to rank ideas in terms of their plausibility. Politics presumes a process by which alternative policies are compared on the basis of the power of the people supporting them in order to rank programs in terms of their acceptability. On the surface, one process attempts to reduce subjectivity through standardized procedures designed to assure verifiable knowledge; the other attempts to organize subjectivity through a set of bargains designed to assure social stability. One process seeks data; the other seeks allies. The prototypic scientist engages in an experiment; the prototypic politician engages in a logroll.

Clearly, the differences can easily be overdrawn; and few observers of either science or politics would accept any simple formulation; but politics has a different logic and a different style. Because of the complications of creating coalitions of supporters, public policy is often ambiguous and intendedly inconsistent. Because of limitations on the attention of political institutions, "good" ideas that are not timely are largely ignored; and timeliness is a matter of political agendas, not scientific ones. Because of the importance of ideology and belief in politics, the symbols of governmental actions are sometimes more important than their substance. Because the constituencies active in shaping a policy in a legislature are often different from the constituencies active during its implementation by a governmental agency, policies seem to change in the course of their execution.

Political leaders calculate the costs and benefits of policy alternatives in terms of their consequences for popular support in the next few months or years. Technical expertise is often vital to such calculations, but it must fit a political frame. Policymakers frequently ask for scientific advice, but they also often seem to use scientific advice as an excuse for doing what they want to do on other grounds, or as a scapegoat for doing what is unpopular with some groups. They often seem to be inattentive to the cautions and fine details of scientific studies, and seem to have an inordinate confidence in the quality of scientific advice given by scientists living in their own districts compared to advice given by others. When scientists disagree, policymakers often seem to view the disagreement as justification for accepting whatever advice is convenient. Agreement among scientists, on the other hand, is likely to be treated as a symptom of conspiracy.

These features of the political process are elementary, familiar, and intriguing; but they can also be disconcerting. When scientists complain, politicians grumble something about getting out of the kitchen if you can't stand the heat, and political scientists give lectures on the nature of politics. Neither response is entirely foolish. It probably is sensible for people who are deeply offended, or bewildered, by the logic of politics to stay in their laboratories most of the time. It probably is sensible for almost anyone to know the rudiments of political analysis. Ignorance is not bliss. It would help if policymakers were better informed about science and scientists about politics.

However, few scientists are quite as ignorant of politics, or as antagonistic, as they are portrayed. They generally believe that it is responsible to obtain the best possible scientific and technical advice before making a public policy decision, and they think that one reason policymakers turn to scientists is to obtain information. They are aware, however, of other reasons for seeking advice and not overly surprised or offended by them. They know that agencies sometimes hold political hot potatoes in their hands and want to share or avoid responsibility for dropping them; that sometimes an agency knows exactly what it wants to do but needs a report from an outside consultant as an excuse, or basis, for action; that sometimes an agency does not want to do anything and hopes that a study will provide a delay adequate for burying a problem or proposal; that sometimes an agency wants the minor accolades that come from association with a distinguished, but undemanding, set of advisors; that sometimes some groups within an agency need allies in internal agency politics and hope they can recruit some scientists to their side; and that sometimes scientists and scientific organizations pursue contracts in order to sustain employment or permit growth, and give advice in order to lay the basis for subsequent favors.

Characteristically, the motivations are intricately intertwined. Personal ambition, interagency warfare, pressure tactics, and creative bureaucratic obfuscation are well-integrated parts of the political process. Congress, the White House, government agencies, and the National Academy of Sciences seek to pursue their visions of public interest in such a way that they prosper as institutions and the individuals within them thrive. They give and take advice; and if the giving and taking seems naturally to generate not only benefits to the nation through improved public decisions, but also increased wealth and the perquisites of power for themselves, they are not surprised.

Most scientists who are involved in advising policymakers know these basic facts of life. They do not suffer from unusual political myopia. They know that trades are made and promises kept in politics, that legislators want rewards for their constituents, that some people count more than others, that bureaus leak information, and that White House and congressional assistants inexorably become insufferable. Moreover, I think most of them are impressed with the general good sense of politics, of the way it reconciles claims, develops alternatives, explores consequences, and manages change. They concede that politicians have useful skills, and the political process a curious intelligence. Scientists, indeed, easily become actively infatuated with politics, enjoying the sense of involvement in vital decisions that attends even a minor role in the political scene. What is distinctive about many scientists is not that they are ignorant about politics, or alienated from it, but that they do not naturally act or think politically or strategically. And what is distinctive about many of the proposals for change is not that they urge scientists to learn more about politics,

Drawing by Stevenson; © 1977 The New Yorker Magazine, Inc.

"It's a task force of the best brains in the country, but so far it hasn't jelled."

but that they advocate a greater explicit political consciousness on the part of scientists, greater sophistication, and less innocence.

Ignorance is not knowing the way life is; innocence is not attending to the way life is. It is possible that scientists should not be ignorant, that they should know something about politics, if they are involved in policy issues. It is also possible that scientists should not be innocent, that they should be more sophisticated in their tactics, less naive in their advice. But the two ideas are not equally compelling; the first seems unexceptionable; the second more doubtful. Indeed, innocence without ignorance is often a feature of wisdom. The case for abandoning innocence usually rests on two arguments: First, it is argued that science, as a distinct social institution with special interests, suffers in the politial arena by not being organized properly to influence political decisions. Second, it is argued that politically naive scientific advice is bad advice, unlikely to be persuasive in policymaking. I think there is some sense in the first argument. Insofar as science and scientists have shared interests and wish to contend with other groups for resources and recognition, effective action probably requires political organization and conscious political tactics. The second argument, however, seems misleading to me. I think there are good reasons for urging scientists to stick to science.

A sharp distinction between science (the traditional realm of the scientist) and policy (the traditional realm of the politician) is impossible to sustain, either conceptually or behaviorally. Scientific knowledge clearly rests on values that regulate the way knowledge is organized and validated. The structures of theories are partly arbitrary and do not necessarily lead to the right questions, nor to the right answers. Like other people, scientists seem to find facts consistent with their policy preferences and to forget facts inconvenient for their hopes. Scientific judgments are not magically shielded from personal commitments and professional biases. In general, scientific purity, like other kinds, is a remote vision far from reasonable hope for attainment. The issue is not whether it is possible, or wise, to be a virgin scientist, for such simplicity is beyond our capabilities. Rather, we ask whether the effort to be sophisticated improves our collective lives more than a commitment to ordinary innocence. And that is a more difficult question.

Some years ago, there was a well-known child psychologist who talked to California parents on strategies for child-rearing. I never heard her, but I am told that at the end of each talk, someone in the audience would invariably ask: "Mrs. Gruenberg, do you really mean that we should never spank our children?" And Mrs. Gruenberg would reply: "Well, I suppose, if you keep reminding yourself every moment that you should never ever spank your children, you will end up spanking them just about the right amount." Mrs. Gruenberg reminds us that precepts are not made inappropriate simply by their impossibility. They are part of the process, not its outcome; and a strategic commitment to innocence is not made foolish by the fact we cannot achieve it.

Giving scientific advice usefully is inseparable from the problem of taking advice intelligently, and the central dilemma in taking advice is the simultaneous need for information and the danger of being victimized by dependence on it. Both as a society and as individuals, we alternate between ingenuousness and stubbornness, sometimes allowing considerable diminution of our independence in order to gain the advantages of expertise, sometimes refusing to listen to advice in order to retain our autonomy. Knowledge and information are sources of power with which a policymaker contends uneasily, and scientific advisors must accept the reality and legitimacy of that unease.

It is possible to argue that society is best served by scientists who self-consciously announce their personal prejudices and try to marshall evidence for them, that politics is the art of making judgments when everyone is probably lying. Consider, for example, the complications of securing scientific assessments in such areas as population control, ethnic or gender bases of behavior, nuclear energy, or family stability and structure. Scientists with strong feelings organize other scientists to assure that "truth" is told, and they confront other scientists with other strong feelings and other "truths." It is a feasible procedure with important elements of beauty in it. Much of the time, however, the giving and taking of advice depends on trust. Neither the fact that it is possible, and sometimes necessary, to function without much trust, nor the fact that trust is fragile destroys its general importance as a basis for exchange of information where some people know significant things that other people need to know.

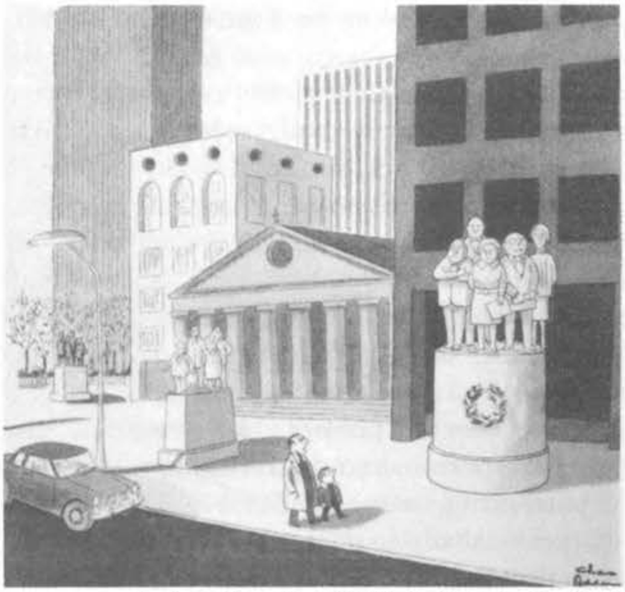
Despite the difficulties, trust is often established and maintained in relations between scientific experts and policymakers. The process is too complicated for short description, but I would note three attributes of scientists that I suspect affect the trust extended to a scientific advisor by most policymakers: competence, reliability, and irrelevance. By competence I mean what any scientist would mean about technical competence in the field. Determining competence is not always easy, but there are clues, informants, and past experiences. You trust someone who is properly respected in the field. By reliability I mean the degree of congruence between the values and personal style of the scientist and the values and personal style of the policymaker. You trust an advisor whose values are close enough to yours that the motivation to mislead you is modest and whose personal style is familiar enough to allow you to understand one another. By irrelevance I mean the extent to which the advisor is politically unambitious, and avoids basing advice on guessing what the policymaker will do with the advice, what is wanted, or what others are thinking. You trust an advisor who leaves the politics to you, who yearns for neither influence nor martyrdom.

The implications are not complicated. Without question, the most competent scientists possible must be available to policymakers. But competence alone, however exquisite, is unlikely to be enough. On the one hand, we need to make science reliable, not in the sense of politicizing it, but in the sense of having a distribution of values and styles among competent scientists that encourages a pairing of competent scientists with policymakers who trust them. In a relatively homogeneous, relatively stable society, this is not a serious problem. In a heterogeneous society, however, it is possible that politically important groups (most conspicuously lower-status groups and nonestablishment social movements) will have difficulty obtaining scientific advice from competent advisors they trust.

At the same time, we need to innoculate scientists against the temptations of political awareness. It is possible for a knowledgeable scientist to give advice with consciousness of the nuances of its political meaning. To do so, however, is to enter a game of political maneuver in which the other players are unusually suspicious and exceptionally adroit. Policymakers, for whom the threats of manipulation through information are clear, are more likely to see political maneuver when it does not exist than to fail to see it when it does. As a result, they may often have unwarranted suspicions; but they rarely mistake cleverness for naivete. And they are unlikely to be fooled for long. The chance that a politically ambitious scientist will maintain trust as a scientist is modest. Moreover, from the point of view of society and science, success is no better than failure. Scientists unfortunate enough to be successful in political maneuver come to think of their role not as someone giving advice but as someone who has influence over policy. It is a tempting shift, by no means dishonorable; but by changing the frame of reference, it tends to compromise the quality of scientific information in the political process.

Innocence in politics, like innocence elsewhere, has its costs. There are personal costs, the embarrassment of naivete amplified by the patronizing amusement of friends. There are social costs, scientific and technical advice ignored because it is given at a bad time, or in an incomprehensible way, or so that it offends a key political or bureaucratic actor or belief. The greatest cost of innocence, however, is the awareness that not everyone is innocent. Politics is filled with sophistication, with people who know what is going on. For the most part, they do what sophisticated people do, look for hidden meanings, lay subtle traps, develop codes for distinguishing insiders, cover their flanks, and happily pull the feathers of any innocents who land in their garden. It is not a style unknown to ordinary life; and most of us, most of the time, would rather be the pluckers than the plucked. Knowledge, pride, and annoyance conspire against innocence, and we try to be clever. But cleverness is its own trap, and never more conspicuously than when scientists play politics.

Quixote said that all knights have their parts to play. We have ours, and we can try to play them. Not in ignorance of politics, for ignorance has no virtue; but in innocence. And when our friends say that the pursuit of innocence is futile, that there are exceptions, complications, and corruptions, and that obviously it would be better to find the optimal balance between innocence and sophistication, we may want to remember Mrs. Gruenberg and reply that, if scientists keep reminding themselves every moment that they should never ever think politically, they will think politically just about the right amount.



"There are no great men, my boy—only great committees."

Study Projects

ASSEMBLY OF BEHAVIORAL AND SOCIAL SCIENCES

ABILITY TESTING

Standardized ability tests have in recent years been the object of widespread public controversy, frequent judicial scrutiny, federal and state regulation, and innumerable scholarly articles and conferences. Against this background of concern about the role of testing in American life, the Committee on Ability Testing was established within the Assembly of Behavioral and Social Sciences to explore the basic patterns of test use in American society and to clarify the policy alternatives available to government, industry, educational institutions, and other interested groups.

BACKGROUND

Societies have developed a variety of mechanisms for apportioning places, honors, duties, and material benefits. These have included selection by birth, occupation, physical prowess, virtue, gender, and, in the twentieth century, the ubiquitous standardized test. Tests seem ideally suited to the needs of modern society for they can be used to screen large numbers of individuals efficiently for specific employment and educational purposes; at the same time, they have tended to satisfy contemporary notions of fairness because they are rational, objective, disinterested—in a word, scientific.

Early expectations for standardized tests were, perhaps, immoderately high. In an address delivered to his colleagues in Section H (Education) of the American Association for the Advancement of Science in 1912, E. L. Thorndike predicted:

> It will not be long before the members of this section will remember with amusement the time when education waited for the expensive test of actual trial to tell how well a boy or girl would succeed with a given trade, with the work of college and professional school, or with the general task of leading a decent, law-abiding, humane life.[1]

Little seemed beyond the natural province of psychometrics; scientific assessment of man's nature seemed to promise power over his fate. Mental measurement, Thorndike assured his audience, is not the tedious and trivial exercise outsiders might think:

> Tables of correlations seem dull, dry, unimpressive things beside the insights of poets and proverb makers—but only to those who miss their meaning. In the end they will contribute tenfold more to man's mastery of himself. History records no career, war, or revolution that can compare in significance with the fact that the correlation between intellect and morality is approximately .3, a fact to which perhaps a fourth of the world's progress is due.[2]

If the claims for mental measurement are no longer so ambitious, still the sheer size of the present-day testing industry—the number and variety of tests sold annually; the number of people involved in the development, administration, and evaluation of tests; the number of institutions that use tests to make decisions about people—would surely astonish even the most enthusiastic of the early promoters.

From the beginning, there have been critics who questioned both the technical and the social assumptions of psychological measurement. In a heated exchange between Lewis Terman, author of the Stanford-Binet, and Walter Lippmann, who had read widely in the behavioral sciences, Lippmann expressed deep misgivings about the claims and assumptions of psychometricians. He disparaged the facile assumption, frequently seen in the testing literature of the period, of a happy congruence of intelligence and high moral character in the right sort of people.

Lippmann also objected to the claim of leading testers that their instruments were capable of measuring intelligence when, in fact, there existed neither an accepted definition of what constitutes intelligence nor reliable evidence of the nature of the abilities that tests measure. "What their foot rule does not measure soon ceases to exist for them . . . ,"[3] he complained, and summed up his discomfort with the psychometric vision of man in replying to Terman's charge that he had an "emotional complex" about intelligence tests:

> I admit it. I hate the impudence of a claim that in fifty minutes you can judge and classify a human being's predestined fitness in life. I hate the pretentiousness of that claim. I hate the abuse of scientific method which it involves. I hate the sense of superiority which it creates, and the sense of inferiority which it imposes.[4]

The testers and their new technology won the day in the 1920's. Tests became a widely accepted and increasingly influential feature of American life. It is now a commonplace that many of the most important decisions made about a person, among them special placement in primary and secondary schools, admission to higher education and professional training, selection for apprenticeship, employment, and military assignment, are made, at least in part, on the basis of test scores.

For all this success, the criticism of testing has not been stilled. What has become evident in the last fifteen years is that the sorting process that is the outcome of standardized testing, regardless of its inherent validity, does not appear neutral or fair in a period when test results contradict social priorities. There was little outcry against the Army's use of tests in World War I and World War II; jokes about cooks being made mechanics and mechanics cooks were the standard response. But in the 1960's and 1970's tests have been charged with frustrating the national commitment to ending discrimination against minorities in employment. They have become the unhappy reminders that expanding aspirations are ill suited to a world where expectations exceed opportunities, as many an applicant to professional school—and many a harried admissions committee—can testify. And they have, in reports of declining scores, become the bearer of bad news to parents, teachers, principals, students, and taxpayers.

No longer protected by the reputation of dispassionate, scientific inquiry, tests have become in various quarters a symbol of social injustice, racial discrimination, cruelty to youth, and wasteful spending (though it is indicative of the ascendancy of testing that complainants frequently suggest new tests or different tests to solve the problem at hand).

OLD ISSUES IN NEW CONTEXTS

The questions currently raised by widespread use of standardized tests in business, industry, government, and various educational settings are, in their essentials, those delineated in the 1920's and 1930's. They fall into two broad categories: technical issues, and social, or perhaps human, issues. On the technical level one finds, then and now, heated

criticism of the Intelligence Quotient, both as a concept and as a measure. The validation process remains an issue of professional and public concern. The adequacy of particular test items is certainly questioned by everyone who has taken a standardized examination. Professionals are aware of the much more fundamental question of the adequacy of a system of item selection that is based on a desire to produce statistically satisfying differentiation rather than focusing on the substantive content of the questions, the particular capacities of the test-taker, or the specific kinds of talent or behavior one hopes to select. Oscar Burros first criticized this approach to item validation, which is used for most standardized achievement tests, in a book review in 1934; he found need to continue to make the point in 1977, when he wrote, "These statistical methods of item validation confuse differentiation with measurement and exaggerate differences among individuals and between grades."[5]

Another matter that continues to be of interest to professional and lay audiences concerns the nature of the abilities measured by various kinds of instruments, and the related issues of test-wiseness, coaching, and the comparability of instruments. And, finally, questions of test abuse, from the selection of inappropriate instruments, through improper test administration, to misuse of test results, continue to quicken debate.

The social dimensions of testing go beyond questions of the adequacy of the instrument. The tremendous volume of testing in this country is quite clearly a response to a widely felt need for a simple, fast, efficient mechanism for selecting, classifying, or grouping people. Tests strip away the extraneous and simplify the complex, to provide the decision-maker with a clean, numerical result. Perhaps this quality is enough to explain their popularity, as the frequent use of employment tests that are not job-related would seem to indicate. Often the predictive capabilities of tests, even if extremely limited, are what satisfy the expectations of users, as seems to be the case with tests used for admissions purposes by universities and professional schools. In any case, advocates of testing have long emphasized their value in identifying talent and in promoting the rationalization of the work-force or the student body.

Critics, for their part, have elaborated upon Lippmann's early concern about the elitist—others would go so far as to say authoritarian—impulses in the testing movement. Several recent works discussed the affinities between the mental measurement movement and social Darwinism, nativism, eugenics, and similar social currents in the early part of the century. They suggest that these affinities are again visible in the recent work linking genetic make-up with performance on tests of cognitive functioning. On the practical level, critics suspect that there is widespread use of tests in industry and schools today for the purpose of continuing by other means the racial discrimination outlawed by the Civil Rights Act of 1964. Those who are not convinced of any systematic and conscious use of tests for the purpose of discriminating are, nevertheless, very concerned about cultural bias and about the effects of labeling. One of the most talked-about recent developments in the field—domain-referenced testing—is, at least in part, a response to the adverse impact of norm-referenced testing on racial and cultural minorities. There are those who would go further and eliminate testing; the search for alternatives will probably attract far more attention in the next decade.

Although the issues perceived have tended to remain much the same over the last fifty years, there is a novel element in the current controversy over testing; the context of debate is now increasingly the product of governmental, particularly federal, interventions. Federal interest in testing has become a matter of importance since the passage of the Civil Rights Act of 1964. Title VII of that Act, the cornerstone of employment discrimination law, specifically allowed the use of professionally developed ability tests provided that such tests are not used to discriminate, on the basis of enumerated classifications, among them race, sex, and national origin. A growing body of case law is establishing the juridical meaning of that proviso. In addition, several federal agencies, most prominently the Equal Employment Opportunity Commission, the Department of Justice, the Civil Service Commission, and the Department of Labor, are involved in implementing the Act through the promulgation and enforcement of regulations that specify its intent.

A major consequence of this federal interest in tests as employee selection devices is that test validity is no longer merely a psychometric quality, but also a legal requirement. Scientist and judge are not, however, likely to ask the same things of tests, nor to find the same kinds of evidence satisfying.

The ramifications of governmental involvement are different, but no less significant, in the area of educational testing. States have long been involved in educational testing for various purposes. Most recently interest has focused on minimal competency testing. On the federal level, the availability of financial assistance to improve the education of disadvantaged children under Title I of the Elementary and Secondary Education Act of 1965 was made conditional upon the submission by the state educational agency of periodic reports evaluating the effectiveness of the payments in improving the educational attainments of educationally deprived children. At the present time, 14,000 of the 16,000 school districts in the country receive Title I funds, which means widespread testing for the purpose of evaluating the effectiveness of the programs; the 1978 amendments to the Act call for still more and better measurement.

The overall federal posture on testing is dichotomous. Some policies in the realm of employee selection procedures would seem to have the effect of making the use of tests unattractive for all but the very large companies because of the expense of the validation procedures required in the face of adverse impact; federal education policy, including the recent legislation concerning the education of all handicapped children, on the other hand, has the overall effect of promoting testing for such purposes as program evaluation and the placement of pupils in the programs most appropriate to their needs. But, of course, the fundamental interest of government is in promoting certain social policies, such as stamping out racial discrimination or breaking down the barriers to equality of opportunity imposed by poverty. Tests are of importance only as they affect or can be used to effect these policies.

COMMITTEE TASKS

The Committee on Ability Testing is presently following two major lines of inquiry: First, in order to establish the facts of test use in the United States, it is compiling data on the nature, incidence, and impact of testing; second, to identify the fundamental policy questions presented by widespread use of standardized tests, it is examining the status of testing technology as well as the legal, political, social, and economic contexts within which testing takes place.

The committee has developed a number of strategies for investigating the basic patterns of test use. In the realm of educational testing, for example, it has solicited from every state commission of education information on statewide testing and assessment programs, including the increasingly popular minimal competency programs. Attention is also being directed to the school district and the individual school, with the object of developing a general picture of how testing programs are devised, how the particular instruments are chosen and administered, and how test scores are used by teachers, counselors, principals, and others.

A parallel study is being made of common testing practices for employment purposes, with particular reference to the requirements of government regulations and case law, and to the recognized professional standards. Through a combination of literature review, interviews, hearings, site visits, and questionnaires, the committee will gather sufficient information to make informed estimates of the strengths and weaknesses of common testing programs, the kinds of benefits accruing to the various parties, typical abuses or ill-considered uses of tests and test results, and the usefulness of assessment practices intended to supplement or replace traditional standardized testing.

In the course of its study, the committee has consulted widely with those who use tests, those who take tests, those who develop tests, and those who regulate testing. It has, for example, conducted public hearings in order to extend to representatives of each group the opportunity to express their point of view and describe their experience with testing. The information gained during two days of testimony was supplemented by written statements solicited from a much larger audience. At present, the committee is considering a series of smaller meetings on specific subjects as another way of tapping the insights and perspectives of the wide range of people involved with establishing testing policies.

This particular point of emphasis reflects the committee's recognition of the importance—quite aside from objective data on test use—of people's perceptions of tests and testing. It is quite likely, for example, that there is a sizeable gap between an industrial psychologist's definition of an appropriate validation process and that of a judge. It is also probable that the judge's requirements will tend to have the greater impact on employment selection procedures so long as they remain the object of frequent litigation. The committee proposes to describe the important differences in the perceptions of the major actors in such cases and to suggest possible links or bridges between them.

The major product of the committee's deliberations will be a report discussing current testing practices, together with the laws, regulations, and professional standards that surround them and makes recommendations for alleviating some of the problems currently giving cause for dissatisfaction. The committee's conclusions will be addressed to those who make decisions with or about testing, including policymakers, educators, employers, unions with apprenticeship programs, the testing industry, and the professional community.

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RESEARCH FOR, AND ON, PUBLIC POLICYMAKING

How can social research more effectively meet the needs of society? Public officials, researchers, and social critics have often raised this question in recent years. United States Senator William Proxmire's approach to it is to spoof the research community by the periodic award of a "Golden Fleece" to a researcher who to him is doing something wrong-headed or silly. In contrast, the Assembly of Behavioral and Social Sciences Study Project on Social Research and Development recently completed a thoughtful study, *The Federal Investment in Knowledge of Social Problems,* that focused on how federally supported social research can better relate to the solving of social problems by government.

Contributors to that study repeatedly called attention to the diverse and largely unexplored ways that knowledge affects human action "as it flows through underground rivers, which branch and rejoin one another in complex ways. . . . "[1] They warned against endorsing narrow tests for assessing the contributions of social research to individual and social well-being. Nothing in what follows is meant to question that view. Nevertheless, I want to discuss but one of the channels through which knowledge flows into ameliorative social action.

We often address social needs by government action. Among the ways that social research can meet social needs, then, is by informing the actions of government. If we view the actions of government as expressions of what we may term "public policy," our concern becomes, how can social research be more useful in the making of public policy? To address this question, we need to understand how public policy is made and, within the framework of that understanding, how knowledge derived from research can be influential.

CHILDREN, FAMILIES, AND PUBLIC POLICY

The problem comes to life when defined in terms of the social needs of children and families, which to an increasing extent are being addressed through government programs. Growing criticism is directed at these programs, however, by those who believe that government-supported efforts are inefficient and inadequate. Many advocates for children fear, moreover, that children will lose out in the increasingly taut struggle for scarce budgetary resources. Old people, the defense establishment, producers and consumers of energy, and cities, all highly organized, are after the same resources. At the same time, taxpayers are after relief from their tax burdens. How, advocates for children ask, can policies be redirected or otherwise influenced to improve children's welfare in the face of this competition? Can research help?

It will certainly be more difficult to influence policy on behalf of children if those who seek to accomplish this fail to understand how and why decisions concerning programs and budgets are made. Contributing to such understanding, and thus to effective public action on behalf of children, is an objective of the Assembly of Behavioral and Social Sciences Committee on Child Development Research and Public Policy. As one of its several activities, the committee has established a panel to study the process of policy formation in selected federal program areas exerting a major influence on families with young children.

KNOWLEDGE ABOUT POLICYMAKING

The study of policy is not an uncharted frontier. The writings of classical theorists of the state—Marxists, functionalists, and neo-classical economists—are all sources of ideas on why governments do what they do. Moreover, by all indicators, policy studies are experiencing vigorous growth as various disciplines and professions become interested in the content of public policies. Many researchers and policy analysts have been concerned with designing policies and with assessing their effects. Others have been concerned with the processes by which policies are determined. Some of the latter have investigated the extent to which socioeconomic or political system variables explain the content of policies. Others have stressed conflict resolution through bargaining among coalitions and groups organized around shared interests, the domination of policy by elites, or the importance to policy determination of distinctive patterns of political relationships.

This body of scholarship suggests that, to understand policymaking, we should identify key political actors, the rules and practices governing the formal and informal relationships among them, the sources of their influence, the factors shaping their interests, and the ways in which they acquire knowledge.

Yet for all the efforts to date, it is still hard to articulate compelling ways of thinking about the policymaking process and explaining what goes on. Hage and Hollingsworth suggest that:

> There is no end of various studies about public policy, with the concerns and objectives of policy makers clearly in mind; yet, few substantial sets of findings have emerged from the plethora of policy studies. The Baconian hope of the inductive approach has not worked. Instead we are left with a bewildering array of specific studies, seemingly unconnected with one another. . . . Regrettably, there has been little systematic building of the general knowledge so essential for the solution of social problems, . . . [2]

or, it should be added, for the study of policy determination.

An important reason for this state of affairs is that studies of policy determination have lacked focus and rigor. One need only survey the definitions of policy used in policy studies to gain this impression.

> There exists in the literature a rather astounding number and variety of suggested boundaries (or lack thereof) about the concept "policy": all government action; . . . a program of goals; . . . general rules to subsume future behavioral instances; . . . the consequences of action and inaction; . . . important government decisions; . . . and "a particular object or set of objects which are intended to be affected . . . [together with] a desired course of events . . . a selected line of action . . . a declaration of intent. . . . "[3]

Policy is an analytic construct, however, not an observable datum. We can observe appropriations and expenditures, the language of statutes, and what particular actors say and do. To call such observations "policy" is to incorporate them in an analytic framework. Hence definitions of policy already incorporate theoretical propositions linking the concept to observable phenomena. These propositions are often unspecified, however, so that policy definitions tend to conceal a variety of assumptions concerning the behavior of participants and the role of institutions and other social structures in policymaking. Definitions that relate "policy" to other unobservable or undefined concepts such as "intent" or "outcome" add to the confusion.

One way to proceed in studying policy determination is to "work forward" from definitions of policy that have intuitive or explicit theoretical appeal to the types of observations they imply. The definitions of policy surveyed earlier have quite different implications for the choice of observations. For example, perhaps the simplest definition is "all government action." Use of this definition would require a researcher to specify *the* actions of government to be observed. That sounds easy. But the "actions" of government include a virtually limitless number of activities, each with different meanings and significance. Further, it does not help much to narrow the list to "actions affecting children": the process of "affecting children" would then have to be defined in observable terms.

A slightly different formulation of the definition introduces new complexities. One popular definition—whatever governments choose to do or not to do—implies the need to observe government in the act of choosing and not choosing to do something. When is government choosing? When votes are taken? When funds are appropriated and expended? When a child is accepted at or turned away from a clinic? When a Cabinet officer declares his or her intent to advocate a certain course of action?

Thus an apparently simple definition of policy—whatever governments choose to do or not to do that affects children—requires further specifications of the concepts "choosing" and "affecting" as well as a precise definition of "whatever governments do."

More sophisticated definitions of policy incorporating "related activities," "consequences," "intent," "goals," "rational selections," and similar concepts introduce new, and formidable, conceptual and operational problems. If it is difficult to determine when government is choosing, for example, it is much harder to know when the choice is rational.

An alternative approach is to work "backward" from observable phenomena instead of "forward" toward their identification. One possible argument relating to children's policy goes as follows. Interest in the determination of federal policy affecting the well-being of children can be translated into an interest in certain observable actions of the federal government: the enactment of statutes, the adoption of agency budgets, the promulgation of regulations and guidelines, the selection of administrative arrangements, and the interpretation of law by federal courts. These actions are interesting because they more-or-less directly affect the well-being of children. Whereas we might well be interested in the expressions or results of many other acts of government—declarations of support or opposition, vetoes, committee recommendations, appointments to office—they relate much less directly to children's well-being. Call the proximate results or creations of these observable acts—statutes, budgets, regulations, organizational structures, and court decisions—"concrete expressions of policy."

Once we are reasonably clear on what we are trying to explain and why, what next? Clearly, a framework or approach to explanation is needed. But here we encounter further intellectual difficulties. The number of behavioral relationships of potential relevance to policy determination is seemingly limitless, especially if one is seeking nontrivial explanations applicable to a wide range of government actions and policy contexts.

To cope with such complexity, many researchers have turned to structured case studies. The popularity of case studies as a methodology for policy studies has its origins in the academic conflict between pluralists and elitists in the late 1950's and early 1960's. Case studies permit the researcher to encompass a wider range of evidence and to examine a variety of interactions among actors and institutions in making inferences as to why policy outcomes occurred. The contexts can be rich and dynamic and incorporate consideration of the kinds of subtleties that every practitioner knows can be decisive in particular situations. A variety of competing views can be investigated in a case.

In the flexibility of case studies lies a notable drawback, however. Despite yielding a variety of plausible explanations, a detailed case study of policymaking may be *sui generis.* The researcher may be unable to isolate the influence of circumstances, factors, or interactions that change over time and vary from context to context. Hence, generalization to other times and situations may be impossible.

There are other difficulties. Case studies can be self-validating; researchers may find what they are consciously or unconsciously looking for because they are guided by their beliefs to the discovery of phenomena they believe on *a priori* grounds to be important. The researcher is restricted to accessible information, which may lead to erroneous inferences. Methods for introducing rigor into the assessment of a diverse array of mostly qualitative information about policymaking do not really exist.

POLICY TOWARD CHILDREN

Despite these problems, scholars of policymaking agree that careful case studies are of major value and that means exist for introducing more conceptual coherence and rigor into them. The NRC Panel to Study the Federal Policy Formation Process, Committee on Child Development Research and Public Policy, decided to conduct three case studies of federal policy developments: the special supplemental food program for women, infants, and children (WIC), the child-care provisions of federal individual income tax law, and the evaluation of the Federal Interagency Day Care Requirements (FIDCR). The broadly interdisciplinary structure of the panel is well suited to introduce such rigor, and to assure that latent assumptions are made explicit.

In designing the analytic framework for its three case studies, the panel has decided that interest in the determination of federal policy affecting the well-being of children can be translated into an interest in certain observable actions of the federal government: the enactment of statutes, the adoption of agency budgets, the promulgation of regulations and guidelines, the selection of administrative arrangements, and the interpretation of law by federal courts. These are the subjects of a considerable and growing body of literature, which furnishes useful insights into the working of governmental institutions and processes that cut across substantive policy areas. Studies have been done on incrementalism as a characterization of budget making,

the general preference for prohibitions and enforcement as opposed to incentives in achieving regulatory objectives, the use of organization as a means of allocating political power, and reorganization as a means of reallocating it. Case studies can incorporate these insights into the investigation of policy outcomes. The objective is generalizations concerning policymaking affecting children and families that will hold up in contexts and times other than those studied.

From analyses of policies and policymaking affecting children and families, a few generalizations are now possible. We know that legislators are reluctant to authorize the government to intervene in child-rearing; they are less reluctant to authorize government action to meet specific needs or problems. The numerous advocates for children find it difficult to unite behind a general policy agenda. Because the welfare of children is a subordinate concern of federal departments, advocacy for children by the federal government is weak. Such observations are of limited help in addressing basic issues, however.

The pertinent questions are many and basic. Why has the totality of the federal effort on behalf of children evolved in the way it has? (Why is it "fragmented" and not "comprehensive"?) Why do we have these programs and not others? (Why do we have means-tested welfare programs instead of universal children's allowances?) Why aren't budgets smaller or larger? (Why have budgets for the women, infants, and children's program grown faster than child-welfare budgets?) What are the prospects for the future? (What is the likelihood that Congress will enact a program to provide universal, quality day care?) Specifically, how can participants in policymaking be more effective on behalf of children? (What strategy should advocates for children adopt in the face of the growing budgetary claims of the older population?) Can research affect future policy direction? (Would more knowledge concerning nutrition and child development lead to different policies concerning child nutrition?)

If one wants to increase social benefits or protection for children, for example, is it better to call attention to or emphasize: (a) children as an age-group; (b) the specific categorizable needs and problems of children; (c) the status of children as an indicator of family functioning, or of the adequacy of child-care services, or of our social values and priorities; (d) children as consumers of professional services; (e) children as victims, e.g., of adult behavior, a malfunctioning economy, or discrimination; children as inherently independent members of society; (f) children as potential delinquents or welfare recipients; (g) children as "human capital"; or (h) children as some combination of the above categories? On what bases might we make this choice? Is it because: (a) a constituency that is organized, economically self-interested, and politically powerful must be mobilized; (b) favorable action is more likely to occur if problems are defined so that ambiguity or value conflicts are minimized; (c) traditional value orientations, e.g., toward healthy children and well-functioning families, must be appealed to; (d) the self-interest of care-givers must be engaged; (e) the conservative committees and coalitions of Congress must be bypassed; (f) the public must be shocked or frightened?

BEYOND CASE STUDIES

Will these case studies, or would a great many more case studies patterned after them, produce insights that will give us confidence in answering those questions raised above? Will the totality of the effort now going on under the heading of policy-determination studies produce them? Are we in the process of achieving sufficient understanding of policymaking, and the role of knowledge within it, so that the research community can better relate knowledge-production activities to ameliorating social problems?

Several observations by Daniel Bell can serve as the background for an answer. We must recognize, he argues, the centrality of "the public household" in the modern state. "[The] public household is not just 'the government,' or a public economic sector alongside the market economy and the domestic household; it is now prior to both and directive of each." That is, the public household:

> not only has to provide for *public needs* in the conventional sense, but it has become, inescapably, the arena for the fulfillment of *private and group wants*. . . . Yet we do not have any theoretical underpinning for this state of affairs—a political economy of the public household that joins the economic and the political dimensions, or a political philosophy of the public household that provides decision rules for the normative resolution of conflicting claims and a philosophical justification of the outcomes . . . .[4]

The answer is, then, that the partial, "technocratic," understanding that policy studies may yield will fall far short of the fundamental understanding that is needed. That understanding will come only with sustained theoretical and philosophical effort that produces both ideas and the nourishment of empirical inquiry. That effort, moreover, must be founded on a recognition of its practical implications, of the need for useful explanations and answers to questions concerning actual political behavior and choice. I doubt that the current effort, the responsibility for which lies with the social sciences and the humanities, is enough, especially when viewed in the light of the pervasiveness of government in human affairs. I suspect that much that currently goes on under the heading of policy studies is busywork related to the internal needs of the research community and to political self-interest. Policymaking must come to be understood less as "politics" and more as a manifestation of social structures, processes, and values. Better efforts are needed to achieve that level of understanding.

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NATIONAL STATISTICS

Are there many more serious crimes committed than are reported to the police? How well are we measuring the results of efforts to clean up polluted rivers and streams? What increases in skin cancer would be caused by changes in ozone in the stratosphere? Are people becoming more reluctant to participate in surveys? Can we tell from our statistics whether the rate of growth in productivity has really declined? These are some of the many questions investigated by the Committee on National Statistics and its panels.

The committee was organized* following a recommendation in 1971 of the President's Commission on Federal Statistics that there be a continuing outside review of federal statistical activities. The commission's report[1] said that:

> a need exists for continuous review of federal statistical activities, on a selective basis, by a group of broadly representative professionals without direct relationships with the federal government.
>
> Such a body could monitor the implementation of commission recommendations and, even more important, conduct special studies on statistical questions it deemed important because their favorable resolution would contribute to the continuing effectiveness of the federal system. The body would need to have the independence that is a prerequisite to completely objective review. With independence, with a policy of publishing its findings, and with the leadership and resources required for the active, continuing review we have in mind, it is our opinion that the purely advisory services of this group would make a critically important contribution to the continued success and vitality of the federal statistical system.[1]

The committee has a broad charter: it selects and studies statistical issues important to the public—important in the sense that public decisions or understanding of issues may be affected by the

*Initial two-year support for the committee came from the Russell Sage Foundation; the Charles E. Merrill Trust provided a helpful later grant. Separate panel activities have been separately funded by federal agencies seeking solutions for specific problems. Other activities of the committee itself—program development and occasional short- term studies—are being supported by a consortium of federal agencies. The committee's first chairman and executive director were, respectively, William H. Kruskal, of the University of Chicago, and Margaret E. Martin.

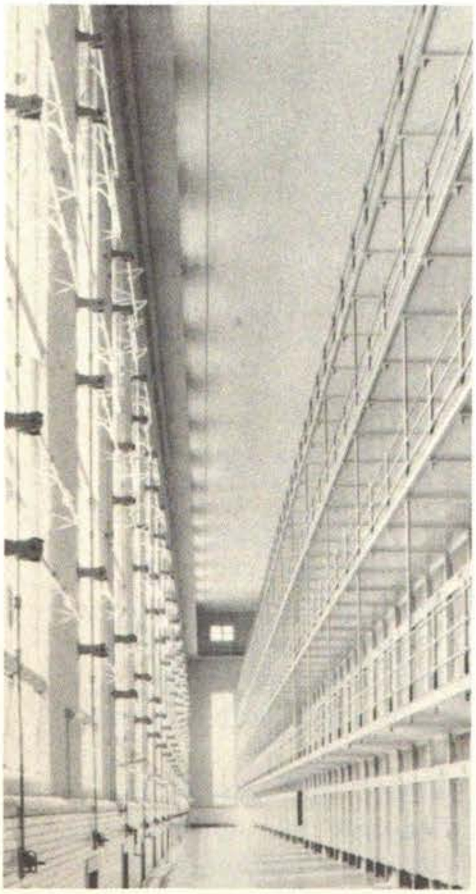
need for good statistical methodology. Thus the committee is concerned not only with statistical activities of government, but also with the application of statistics elsewhere in public affairs, in science, and in private decision-making.

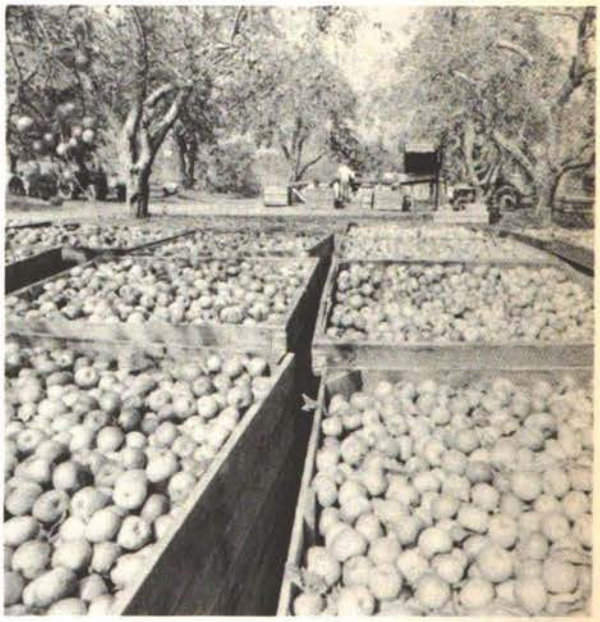
The committee operates mainly by selecting topics of current concern for study in depth by panels of experts. Committee members and staff are largely statisticians with special interests in applications across many scientific disciplines and many issues of public policy. In contrast, the committee's study panels comprise many relevant disciplines and typically include only a few statisticians. The panels have studied a wide range of substantive topics, including ozone and skin cancer, productivity of the economy, environmental monitoring, government paperwork, incomplete census and survey data, and crime statistics. Statistical issues pervade science and government, and therefore a large part of the work of the National Research Council. For that reason, the committee may be expected to have increasingly wide relationships with many segments of the NRC.

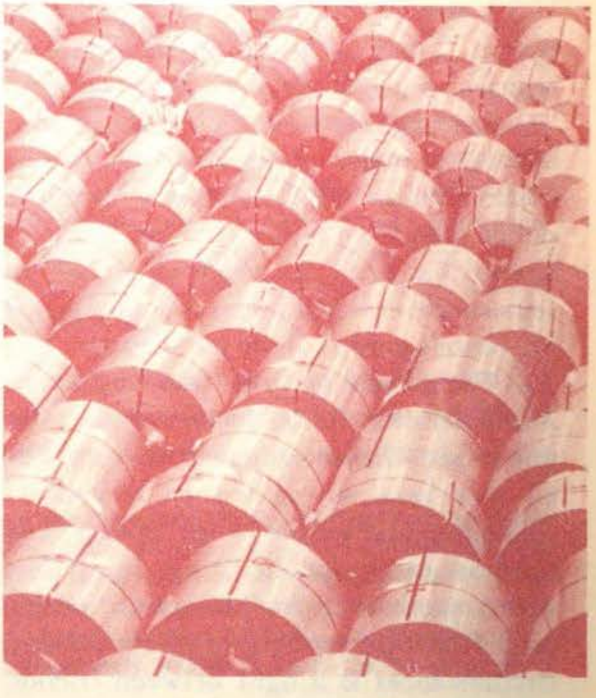
A similar breadth is shown by the functional roles of committee studies. Some of those studies are evaluative and contain praise, criticism, and constructive suggestions.

Surveying Crime,[2] for example, is a study of the National Crime Survey, a major continuing survey begun in 1972 that provides information on crimes obtained from households and their members, rather than from police records. Not only is information obtained on crimes that were not reported to the police, but additional circumstances are described, and it is possible to develop victimization rates for various groups of the population.

The committee was asked by the Law Enforcement Assistance Administration (LEAA) to review both the methodology and utility of this series. The expert panel sponsored by the committee recommended that LEAA strengthen its analytical resources, streamline data collection, and exploit those aspects of information on crime that can be most easily obtained from the public, as opposed to official law enforcement records. Surveys of households can obtain information on different perceptions of what constitutes crime, such as under what circumstances is a fight between friends or relatives perceived as a crime? Surveys of victims might also provide information on vulnera-







bility and risk, on the relationship between the incidence of crime and the use of protective devices and practices, and on similar questions useful to law enforcement agencies.

Productivity Statistics is a study of the meaning, accuracy, uses, and misuses of estimates of productivity of the economy. Current measures of productivity have indicated a depressed rate of U.S. productivity growth for more than a decade. Experts have differed over the causes, some ascribing slower growth to economic causes, some to social and environmental factors; and others have questioned the incompleteness and other technical problems in the measurements. Judgments on the course of the economy's productivity can affect fiscal policy, wage and price policy, international trade, and other macroeconomic issues. The National Center for Productivity and Quality of Working Life asked the Committee on National Statistics to review the concepts of productivity needed in economic and other analyses, to evaluate the current measures in the light of these needs, and to recommend improvements. The panel appointed to undertake this review has nearly completed its report—a report that will describe the limits as well as the utility of productivity measures and encourage their use with realistic appreciation of both. It will also suggest extensions and improvements in present measurement practices.

Environmental Monitoring[3] is a review of the programs of the U.S. Environmental Protection Agency and other agencies to monitor pollution and its effects. This study was undertaken by the committee in cooperation with two other National Research Council units, the Environmental Studies Board and the Numerical Data Advisory Board, as part of a broader NRC review of decision-making by the Environmental Protection Agency. EPA expressed particular concern about programs to measure pollution sources, amounts, and effects. The major recommendations of the Study Group on Environmental Monitoring were for EPA to better apply scientific principles to the design, operation, and evaluation of its monitoring programs. Improvements were also suggested in the agency's management of scientific data, and also new monitoring programs, including some to anticipate environmental problems or to detect them in early stages.

Skin Cancer Statistics is a study that began as an evaluation of fragmentary and conflicting estimates of the incidence of skin cancer.

It progressed beyond a simple evaluation into an attempt to develop a statistical model of the relationship between changes in the amount of ozone in the stratosphere and the incidence of skin cancer. An interim report, *Estimates of Increases in Skin Cancer Due to Increases in Ultraviolet Radiation Caused by Reducing Stratospheric Ozone,* was published as Appendix C to *Environmental Impact of Stratospheric Flight.*[4] Since that time, interest in the relationship of stratospheric ozone and skin cancer incidence has heightened with awareness of the effect of fluorocarbons on the ozone layer. The panel engaged in the study has continued to accumulate evidence and to refine a number of models to determine if they provide broadly consistent estimates of changes in skin cancer incidence associated with changes in intensity of ultraviolet radiation.

Other studies may include within themselves empirical surveys and even controlled, randomized experiments:

Privacy and Confidentiality as Factors in Survey Response is the major example to date of such a study. Preserving confidentiality of responses to censuses and surveys is a statutory requirement laid on the Bureau of the Census by the Congress, yet it conflicts with other statutory requirements permitting access to records. There was also the problem, experienced by many survey takers, of the apparently growing reluctance of the public to participate in surveys. The Bureau of the Census asked the committee's help in discovering how the public feels and behaves in responding to surveys. The work included two exploratory studies (with fieldwork done by the Bureau of the Census and a university-connected survey institution):

- A sample survey of opinions on privacy and confidentiality.
- A controlled randomized experiment in which five conditions of survey confidentiality (from absolute to none) were compared as to frequency and nature of response to the survey questionnaire.

The report on this study was published in Fall 1979. Despite considerable suspicion evinced in the opinion survey that promises of confidentiality are not to be trusted, the randomized experiment achieved a generally high response rate, although there was a positive relation between the degree of confidentiality promised and the response rate.

Some studies center on aspects of statistical planning and organization:

Counting the People in 1980[5] discusses aspects of plans for the 1980 census with special reference to completeness of coverage. In evaluating its own work in earlier censuses, the Bureau of the Census has estimated not only that it missed a certain percentage of the population—overall, about 2.5 percent—but that the miss rate fell unevenly on certain population groups; for example, young black men, of whom almost twenty percent may have been missed in 1970. Differential undercoverage may affect the distribution of federal and state funds to particular jurisdictions, as well as legislative apportionments, so that undercoverage and ways to reduce it have become important considerations in planning for censuses. The committee was

asked to review the Census Bureau's plans for improving population coverage in the 1980 census, including more intensive field procedures, promoting community cooperation, and the controversial topic of possibly adjusting the census figures for the estimated undercount. Its panel suggested that adjusting census figures for an expected undercount of the U.S. population would lead to a more equitable distribution of federal funds for social programs.

Some committee studies are thoroughgoing technical reviews:

Small-Area Estimates, for example, is a review of the small-area population and per capita income estimates used for allocating revenue-sharing and other funds to states and local jurisdictions. There are some 38,000 local jurisdictions in the United States, half of them with fewer than 1,000 residents. The problem is to estimate current population and per capita income in the years following each census, accounting not only for births and deaths but also for the movements from one jurisdiction to another of a highly mobile population. Following a review of data sources and techniques currently in use, the panel will attempt to develop more accurate and more efficient methods. The prospect of having a population census every five years instead of every ten (the first mid-decade census is scheduled for 1985) may well affect these plans.

Incomplete Data, another technical review under way by a separate panel of the committee, is on a problem that plagues almost all who collect or use data from surveys: how to handle incomplete data. The panel is reviewing and comparing procedures used for such data and it is summarizing—and advancing—the relevant theory and methods for field procedures, data processing, and estimation. The panel will also suggest how results of surveys and descriptions of their errors can be reported to take account of the incompleteness.

Broadly speaking, statistics may be described as the science of collecting and summarizing quantitative data to produce information—possibly new information, more accurate information, or information produced more economically. Since public policy depends on a wide range of quantitative information, the concerns of the committee are broad. Despite the apparent lack of connection among the committee's specific studies, they all deal with aspects of the problems of determining, obtaining, summarizing, or drawing inferences from needed data efficiently and at appropriate levels of accuracy. Examples of fundamental themes that arise in most panel studies are the importance of investigating data accuracy, of understanding the strength of inferences, and of extending the scope of high professional standards in statistics.

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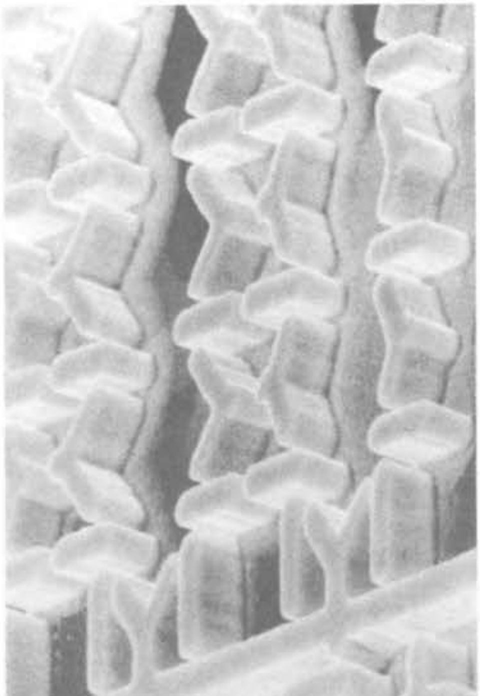
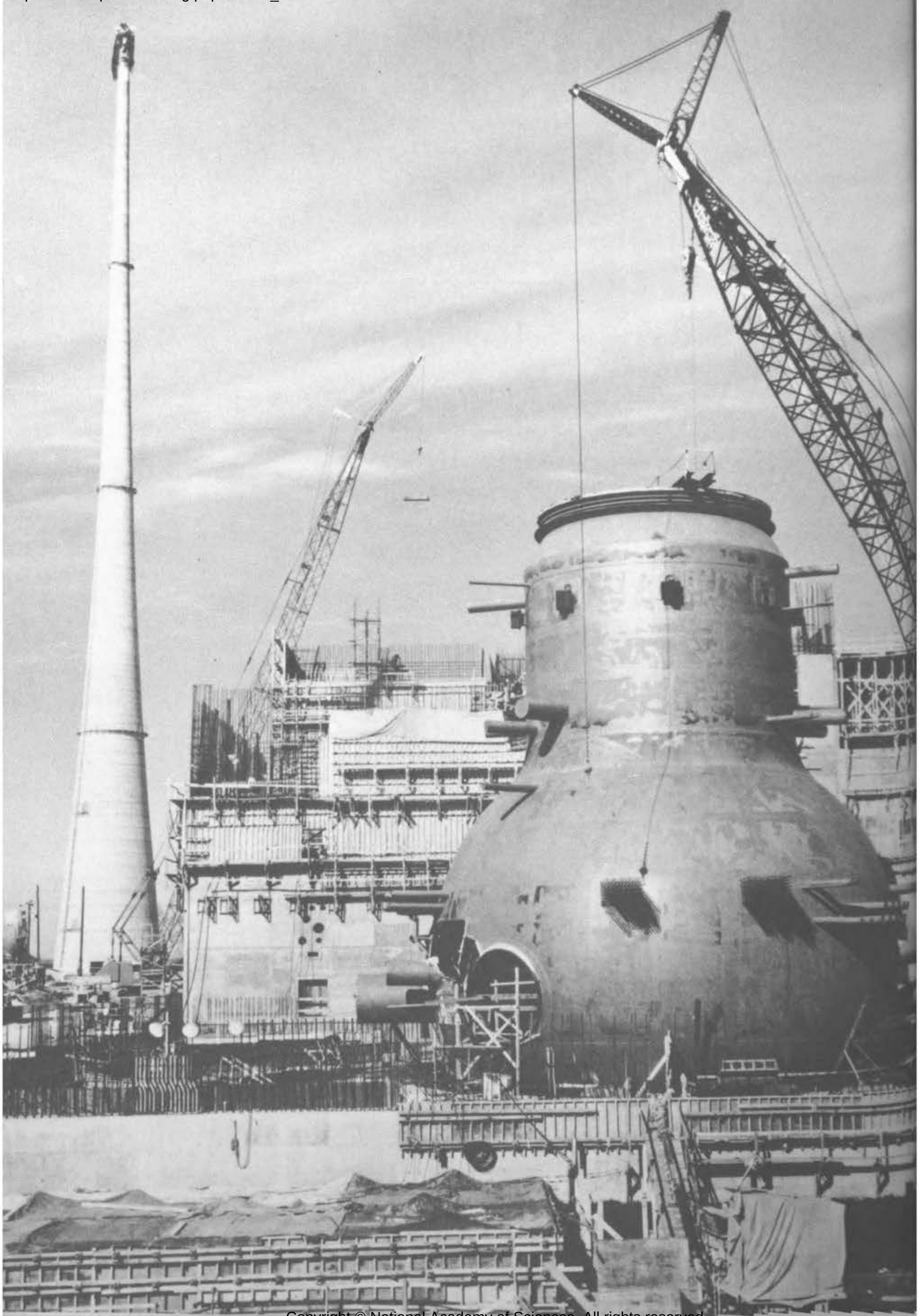
Assembly of Engineering





Deciding on Technology

H. GUYFORD STEVER

The enormous attention now given to the effects of technological change is both welcome and puzzling. It is welcome in assuring that decisions on whether and how to proceed with a given technology involve many parts of our society—the technical, the social, the political, the economic, and the judicial. The puzzle comes in defining the exact role of the various actors in that process, whether it is to decide on the place of nuclear fission power, the use of artificial sweeteners, the construction of supersonic aircraft, the employment of pesticides and herbicides, the mining of coal, or the design of new car engines.

In this essay, I want to outline briefly the role of one of the actors, the engineer, and even more specifically I want to point out his role in the seemingly incommensurable comparison of technological risks and benefits. I won't provide any simple prescriptions, nor do I believe they exist, given the intricate and many-layered structure of American society; but I do want to describe some of the difficulties that accompany any decisions on technological policy and to suggest in

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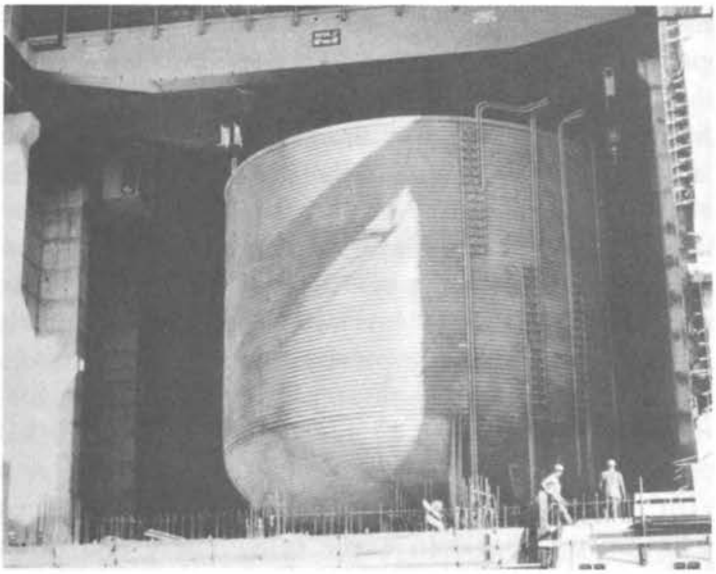
very rough outline some arrangements for making full use of the special talents of engineers in those decisions.

Before going any further, however, I want to make the strong point that the traditional role of the engineer remains paramount—the use of his technological, scientific, mathematical, economic, and business knowledge and skills to create the processes, products, and services that our society needs. This performance from the engineer is necessary to simply staying in place, let alone progress.

Some background may be useful. Widespread national concern with the technology itself—both its efficacy and possible penalties linked to its use and diffusion—is relatively new. In the past, government regulation tended by and large to be economically based, often flowing from obvious and gross inequities, as, for example, the Sherman antitrust legislation was a reaction to unfair financial controls through cartels, market monopolization, and other practices that restrained trade. As regulation widened, it still tended to focus on the manner by which a service was provided, not the service itself. New regulatory bodies, such as the Interstate Commerce Commission, the Federal Power Commission, or the Federal Communications Commission, regulated their cognizant industries not by regulating the technological means but by setting rates, licensing, granting exclusive routes, and so forth. The technology of the jet aircraft was not regulated, but its service and safety precautions were.

That regulatory philosophy has now evolved much more directly to a concern with the nature of the technology itself, while, oddly, we seem to be turning away to a degree from economic regulation, viz., the growing deregulation of the commercial airline industry as opposed to increased interest of the Environmental Protection Agency in developing the "best practicable technology" or the Nuclear Regulatory Commission in providing very exacting specifications for the construction of reactor cores for nuclear power plants.

I mean in no way to imply that these are not proper or desirable events. But the interest in technology *qua* technology does perforce mean that the decision process must incorporate a knowledgeable appraisal of a technology. It also means that engineers can be—and indeed sometimes are—placed in an antithetical position: expected to be expert in a given technology and often its proponent; but also



disinterested witnesses, able to appraise in an unbiased way the benefits and risks associated with that technology. That can be an extremely difficult, if not uncomfortable position, made more so when the engineer must give his judgments in a public arena in which strong beliefs and contrasting views of the world contend and often clash.

OUTLOOK

Pertinent to the engineer's role in technological decision-making is a current running more strongly and deeply than even the present regulatory tide: the very vitality and richness of today's basic science and technology. Our society's strength demonstrably rests in good part on the technology that it has created and used so well, technology that derives in considerable measure from the greatness of fundamental science in America. Coupling that history with today's enormous progress in almost all fields of science and technology, I firmly believe that we as a nation can contemplate a very bright and indeed fascinating future.

Examples of the current ferment in American science and technology were documented in a report by the National Academy of

Sciences, published in 1979, entitled *Science and Technology: A Five-Year Outlook.*[1] That report pointed out that plate tectonics—the idea that the earth's surface is girded by a web of plates—is being applied to understanding the nature of earthquakes and to better ways to predict them, as well as to more sharply focussing the search for new mineral deposits. The already spectacular discoveries that have so transformed biology the last several decades continue, with more attention now given to the structure and functioning of the DNA of organisms more complicated than bacteria. Perhaps less well known but equally portentous are recent advances in the neurosciences. The development of electronic apparatus capable of amplifying, displaying, and analyzing electrical signs generated by individual nerve cells has enabled considerable understanding of how these signals are sent along the axons, or channels, of the nervous system and transmitted across the synaptic junction between nerve cells. These and other fundamental advances in the neurosciences have encouraged a more intensive probing of the neuronal basis of behavior and of the ways in which neural networks form in development—how growing nerves connect properly, how eye and brain are wired correctly.

The heroic efforts to understand the structure of matter are now enriched by simplifying hypotheses: that the structures of the particles within the nucleus of the atom, protons and neutrons, are made not from several hundred particles, a horrendous prospect, but rather of only a few, the quarks; also, that there may be fundamental unities among the four forces governing the behavior of matter, unities in the sense that the properties of the various forces are derivable from common principles.

The fundamental advances in science are mirrored in technological change. The already astounding evolution in the architecture and abilities of computers continues, with profoundly new technologies in the offing, such as Josephson junctions to provide switching capabilities in less than a billionth of a second and magnetic bubbles circuitry to allow new and more dense forms of data storage.

The change in the nature of materials and their processing largely begun in World War II is still with us. Recent examples include progress in significantly raising permissible operating temperatures for nickel- and cobalt-based superalloys and gas turbines, new types of high strength steels, use of directional solidification to give various alloys high-temperature strength, and the start of an effort to exploit commercially a new class of materials—the glassy metals.

Perhaps nowhere is technological progress so graphically evident and so welcome as it is in the continued reduction in the rates of death from diseases of the heart and blood vessels, a decline of more than thirty percent since 1950. The gains come from achievements in both basic science and technology that have enabled new screening methods and monitoring techniques, more effective drugs, new procedures for repairing and replacing diseased blood vessels, surgical repair of the heart, and antibiotics for the prevention of rheumatic heart disease.

NEW CONTEXTS

It would be extremely foolish of me to argue that the changes signaled by these advances will be an unmixed blessing. Change always carries uncertainty in its train, including unforeseen risks and, it must be said, unanticipated benefits. On the latter point, one is reminded of the prediction once made that radio while interesting would have only limited use, such as communicating with ships at sea; or, more contemporaneously, that computers will be of help in doing arithmetic, with few guessing the enormous changes they would force in the way that society handles, transmits, and uses information.

The possibility of harm flowing from ostensibly beneficial progress is hardly new. What has changed is the seemingly intense preoccupation with any risks associated with any technological change. The emphasis has become such as to provoke some rather exasperated writings. Witness:

> The richest, longest-lived, best protected, most resourceful civilization, with the highest degree of insight into its own technology, is on its way to becoming the most frightened. Has there ever been, one wonders, a society that produced more uncertainty more often about everyday life?[2]

That view is an extreme one, but those who have a role in analyzing the relative risks and benefits of a technology are sometimes bemused by the apparently uneven, if not chaotic, way that risks of different technologies are regarded. Thus, there were in 1977 some 50,000 traffic deaths, but there is no serious demand that cars be banned. Cigarettes are indicted as the cause of the climbing rates of lung cancer in this country, but people still smoke.

Even superficially similar technologies are treated differently, as witness the different ways that public regards electrical generation from nuclear fission and the burning of coal: the first intensely scrutinized, even before the Three-Mile Island accident, and the second, linked to certifiable deaths, receiving much less concern.

Another puzzle to engineers and others that must evaluate the putative risks of new technologies is that one can quite reasonably assert that the world has gotten much safer, at least in the industrialized countries. One can talk about better drugs, cleaner foods, improved water supplies and sewage removals, and so forth. But perhaps one illustration will make the point: it is the carnage, and that seems the right word, that accompanied the construction and operation of the railroads in the United States in the latter nineteenth century:

> Between 1890 and 1917, there were 72,000 railroad employees killed and nearly 200,000 injured, and these only on the trains and tracks themselves, not in the railway repair shops and round houses, which counted a total of 237,000 injured and 158,000 killed. These are catastrophic losses, certainly far greater than all the battle casualties of all the Indian wars put together. And passenger deaths and injuries over the same period were roughly as great, with total casualties a good deal over 212,000. There is no doubt that the American railroad system, built with such furious energy, was, by any human standards, unsafe at any price particularly for the crew. . . . [3]

CHANGED SCALES

Why the intense absorption in the possible risks of existing and new technology, and hence the widening regulatory net and added roles for the engineer? A part of the answer must certainly be that the scale of man's activities has increased considerably, especially since World War II and certainly since the time when the frightening accident rates on the railroads described above were apparently regarded simply as a necessary partner to progress. Indubitably, there has been a marked increase in industrial society's production of goods and services and its ability to market them. But, Lord Rothschild, formerly director of the British government's Central Advisory Council for Science and Technology, recently has entered reasons other than simply technological growth. He believes that the more acute sensitivity to risks is not only

> . . . because we are better educated, and because the accelerating increase in scientific and technological knowledge brings with it new and sometimes imperfectly understood risks; but also because the media—particularly radio and television—bring to your notice infinitely more information than was conceivable in the days before Marconi invented radio-telegraphy. . . . It is not the scale of disasters like millions of gallons of oil plastering the beaches of Brittany or 582 people being killed when two jumbo jets collided at Tenerife last year which made a difference. . . . What does make a difference is the speed and ubiquity by which information about such events is now disseminated. We learn about them within minutes or even seconds of their having taken place and are subjected to seemingly endless comments about them—fair, unfair, exact, inexact, scarifying, and reassuring.[4]

Of course, the fact of faster and more ubiquitous communication of information, which in itself is a great technological triumph, has perhaps taught the public that it *ought* to be aware of some of the negative consequences of technology, and to remedy them if possible. And if the public's perception and consequent response to different risks seems illogical, that as a matter of public policy is largely irrelevant.

We ought also to keep in mind that the illogic may be more apparent than real, and that the varying perceptions of risk become more sensible when one considers that benefits and risks of a technology often are unevenly distributed. The worker exposed to vinyl chloride, to take an example, suffers a disproportionate risk to certain cancers than the larger public using polyvinyl chloride plastics; or the aged may be more affected by the pollutants from a fossil-fueled power plant than the general population dependent upon the electricity generated. As Chauncey Starr has pointed out, "technology's contribution to enlarging the range of personal power of the individual unfortunately also provides the individual with the power to damage others. In fact, the usual situation is that the benefits of technology are concentrated on the user, but the penalties are diffusely spread to many."[5] The very fact of public concern demands that we as

engineers work to assure that this concern is properly addressed within the broader framework of productive and beneficial advances in science and technology; that, to be more specific, data be accurately given and correctly analyzed, that hypotheses are labelled as such, and that the unknowns are emphatically stated.

MAKING CHOICES

The explicit analysis of various technologies as to their comparative risks and benefits has already been undertaken by several federal agencies, and at this writing is certainly a growing activity. The analyses take different forms and have been forced by different pressures. Thus, the Environmental Protection Agency, responding to a court's direction, will consider licensing pesticides where it considers benefits to clearly outweigh the risks. The Occupational Safety and Health Administration may enter the game, most notably as a result of a court ruling that it must have some factual basis for expected benefits before it can apply stringent and probably costly standards to benzene. The best-known, if also quite disputed, effort to weigh the risks of a technology, once presuming its benefits, is that done for nuclear power reactors by a group of scientists and engineers chaired by Professor Norman Rasmussen of the Massachusetts Institute of Technology. On an institutional level, there is the establishment in 1975 by the Congress of the Office of Technology Assessment, an effort (whose success is still a discussable point) to consider the future impact of imminent or proposed technological change.

But with all this gathering experience with risk–benefit analyses, we are also gathering a sharper awareness of their inherent problems. One pervasive one is the temptation to invest these analyses with an objectivity that simply is not there. It may be possible, or almost so, for all parties to agree on the facts, but once some weighing of their relative importance is needed, individual values and contention inevitably enter. Thus, one may say on the basis of animal tests that saccharin is indisputably a carcinogen; but it is much harder to find agreement among scientists studying the matter on how worrisome a carcinogen it actually is, whether high or moderate.[6]

Raphael Kasper of the Environmental Studies Board of the National Research Council has argued that:

> Even the objective measurement of risks must, as do all intellectual endeavors, involve some element of subjectivity. The very choice of questions to be asked, issues to be considered, and methods to be used involve judgment. Thus, in examining, let us say, the risk of nuclear power plant accidents, why does the analyst choose to consider a particular chain of events and not others? The choice is subjective and based, at least in part, on the analyst's judgment of what must be the most important modes of failure. In this light, it is difficult, or impossible, to conceive any analysis that is purely objective. Any attempt to reduce risk assessment to a rote, mechanistic application of technique is doomed to failure. . . . [7]

Aside from the probably spurious goal of perfect objectivity, risk–benefit analyses are bedeviled by other problems, as pointed out by Kasper:

> Paucity of carefully-gathered data, difficulties of extrapolating certain effects from one population (often animals) to another (often human), uncertainties in the effects of chemicals or other pollutants in concert, unequal distribution of risks. . . . The important point is that the precise numbers that often result from analyses of risks carry with them a spurious appearance of great accuracy.

How then do we cope? I have no simple answers, and I doubt that anyone does. What is apparent, and perhaps the only real answer, is to acknowledge the realities in any risk–benefit analysis: that we treat different risks differently, that benefits are valued differently depending on who receives them, that facts inevitably are entangled in value judgments, that information will never be sufficient, and that there often will be wide and vigorous disagreement on the sufficiency of the accounting of risks and benefits in any analyses.

The final reality is that we do have a way to resolve the strong disagreements that risk–benefit analyses seem to provoke. It is called politics. What the technically trained person, including the engineer, can contribute to that process is to sort out as objectively and completely as possible the technical pros and cons of whatever technology is being judged. That admittedly is a somewhat Panglossian assertion. Few, if any, of us can always distinguish personal values from our professional judgments. But this is the goal engineers must strive towards, realizing all the while that their evaluations may be severely challenged and debated by other experts often having a quite different view of the world. The task demands practice, understanding, and knowledge. To quote Judge David Bazelon:

> Scientists, regulator, lawyer, and laymen must work together to reconcile the sometimes conflicting values that underlie their respective interests, perspectives, and goals. This cooperation can be achieved only through a greater understanding of the proper roles of the scientific, political and legal communities in addressing the public regulation of risks. Only then can we achieve a program of risk regulation that accommodates the best of scientific learning with the demands of democracy.[8]

But, and to me as an engineer this is the critical point, Judge Bazelon also emphasizes that:

> The starting point . . . is to identify the fact and value questions involved in risk regulation decisions. In determining questions of fact, such as the magnitude of risk from an activity, we as society must rely on those with the appropriate expertise. Judges and politicians have no special insights in this area; conversely, where questions of risk regulation involve value choices such as how much risk is acceptable, we must turn to the political process.

The courts, as Judge Bazelon knows quite well, are a major determinant of the nature and also very much the results of risk–benefit analyses. As he says, "Courts standing outside both the scientific and political debate, can help to make sure that the decision makers articulate the basis for their decisions."

ENERGY

Perhaps the role of the engineer and other technically-trained persons in this process can be illuminated by considering a specific set of technologies where decisions must be made to determine policies, where many facts are known but some are still in dispute, and where the public has a very large interest in the outcome. Energy seems the right example: we are in the throes of considering the relative merits of coal and nuclear energy options and will soon do the same for several incipient energy supply sources, including fusion and various high-technology forms of solar power.

The engineer's job in the forming of decisions about these existing and future forms of energy is to help delineate the known benefits and the known risks they pose, and to clearly distinguish for both categories between the probable and possible. (Again let me emphasize that the first and continuing job of the engineer is to improve the benefit/risk ratio by working to maximize benefit and to minimize risk.) It then behooves the political process, one involving, as stated above, both the legislative and the judicial elements of our society, to consider the information, add its own judgements, and emerge with decisions. We can safely say that these decisions will not be clear cut, in the sense of yielding yes and no answers; rather they will provoke gradual inflections in the eventual paths those technologies take—inflections that in time determine whether they grow robustly or slowly, or whether they die.

Thus, to delve into the energy example a bit deeper,[9] an engineer, if asked to appraise coal from the risk–benefit standpoint, might note the risk to miners during the extraction of coal and include both the ordinary and catastrophic risks, as well as chronic effects from black lung disease and similar problems. The engineer would note the environmental damages that result from unrestored open-pit mines, such as the loss of productive land and the gouging of the earth. There



are also risks associated with transporting coal. There are certainly risks, he would add, in burning coal, including the emissions, controllable to varying degrees, of sulfur dioxide, sulphates, and particulates, as well as accident risks for steam electric plants that exposes both workers and the general population. Against that is set the fact that coal is a far more abundant supply of fossil energy than is petroleum in the United States.

Oil, too, has its problems, an engineer contributing to a risk–benefit analysis of current energy options would be obliged to say. It is produced by on- and off-shore drilling, and accidents occur in those operations. Transportation of crude and refined petroleum can result in fire and spills. There is again air pollution due to emission of sulfur dioxide and sulphates that can at some cost be controlled by using low-sulphur oils and by cleaning stack gases.

The principal difficulties of natural gas are in its transportation and storage, particularly as liquified natural gas, or LNG, where fires and explosions are hazards. Pollution seems to be a negligible problem.

These are all fossil fuels and in common pose the issue of the consequences of the carbon dioxide added to the atmosphere when they are burned. What the effects of that increase will be is uncertain and under study. Yet, the engineer and others who are technically trained must, in providing the technical information for decision, clearly describe possible risks and carefully distinguish what is known (that carbon dioxide is increasing) from what is not (that it will adversely alter climatic patterns).

I have not even described the known and possible risks of nuclear power—my space is limited!—but I think the point is made. Coal, natural gas, and oil are all vitally important and heavily used energy options, and their benefits need little listing. Each has varying amounts of risks, many apparent, but some not.

Thus, we have the classic situation: the risks in many cases have been described and their probable effects identified by technically trained persons, including the engineer; but valuation of these risks is a matter for national decision-making that must consider the benefits of using the various energy sources and the penalties incurred if we do without them or dampen their use. The very agonizing and difficult problems forced by the need to make such decisions on energy strategies has been quite evident the past few years.

PRESENT AND FUTURE

Finally, we ought to keep in mind constantly that we will be surprised by events, sometimes pleasantly and sometimes not; that a given technology may be much more useful than we thought; and that often putative hazards will prove unreal while others will ambush us. We can only attempt to do the best we can and, believing that we have made a wise decision, have faith in future generations to deal with the unforeseen. That, it seems to me, is not an unreasonable position. Aaron Wildavsky put it this way:

> By what right, one may ask, does anyone enrich themselves by endangering future generations? By what right, it may be asked in return, does anyone impoverish a future by denying a choice? What would you have to believe about the future to sacrifice the present to it? It is not necessary to postulate a benevolent social intelligence that is a guarantee of good no matter what happens in order to believe that a capable future would be able to take care of itself. The future can acquire new strengths to compensate for old weaknesses; it can repair breakdowns, dampen oscillations, divert difficulties to productive paths. Not to be able to do this implies that consequences which current actions create are both unique and irreversible, so that acceptable alternatives are no longer available and cannot be created. Without more knowledge than anyone possesses about most natural phenomena, it is difficult to see how this claim could be made with confidence.[10]

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Study Project

ASSEMBLY OF ENGINEERING

DIESELS

Diesel engines, which power about 0.5 percent of the automobiles and lightweight trucks and vans on U.S. roads today, could power as many as ten percent of all such vehicles by 1985. Sales of diesel-equipped cars, mainly makes such as Oldsmobile, Cadillac, Volkswagen Rabbit, and Mercedes Benz, have risen sharply because of advertising campaigns and projected shortages of gasoline. Although the favorable gap in price between diesel fuel and gasoline is rapidly closing, diesel-powered vehicles provide about twenty-five percent greater average fuel savings—only some five percent better in long-distance highway operation, but about forty percent better in city traffic—than cars of comparable size with gasoline engines.

This greater fuel economy is attained by an engine in which the fuel is sprayed into the cylinders after the air charge has been so highly compressed that it has reached a temperature sufficient to ignite the fuel. All other internal combustion engines induct and moderately compress a mixture of air and vaporized or gaseous fuel and then ignite it by an electric spark. The diesel engine can burn a low-grade fuel at a lower rate of consumption per horsepower, principally because of its higher compression ratio; it can contribute, therefore, to meeting the current requirement of the U.S. Department of Transportation that new cars sold in 1985 must average 27.5 miles per gallon.

Diesel engines may face serious problems, however, in meeting the pollution abatement standards under the Clean Air Act Amendments of 1977. While diesel engines meet current HC (hydrocarbon) and CO (carbon monoxide) emission standards, they are at a disadvantage with other pollutant levels, including the 1.0-gram-per-mile standard for NO_x (nitrogen oxides), scheduled to go into effect in 1981. Of more critical concern, the Environmental Protection Agency is proposing new standards for particulates in exhaust emissions of 0.6 gram per mile for 1981 and 1982 models and 0.2 gram per mile thereafter. EPA studies have found that diesel cars emit thirty to seventy times more particulates than do gasoline engines in cars equipped with catalytic converters, which typically emit no more than 0.008 gram per mile.

Attempts in the United States and abroad by automobile manufacturers and research organizations to control particulates and NO_x emissions from diesels have had only limited success. The properties of fuels and fuel additives vary, there is a broad range of combustion products, and these products may be altered by a combination of physical, chemical, and biological processes. The operating characteristics of different engine types also influence the composition of emissions. It turns out, as EPA has found, that the "technology now used to control NO_x relies on techniques that have a tendency to increase particulates."

Indeed, the possibility of new risks to human health is the central issue for the future of diesel engines. One recent study[1] detected 20,000–30,000 different compounds in diesel emissions, most of them not completely characterized, although some—like the polycyclic aromatic compounds—have been identified in animal exposure tests as toxic, mutagenic, or carcinogenic. Of equal concern, some particulates in diesel emissions are small enough to be inhaled and to adsorb other exhaust products. In an ongoing three-year study of experimental animals exposed to diesel exhaust fumes,[2] preliminary findings show alterations in lung protein metabolism, increases in susceptibility to bacterial infection, and reductions in spontaneous locomotor activity. Moreover, mild to severe disorders of the skin or eyes appear from direct contact with irritant emissions.

Many of the consequences of the widespread substitution of the diesel engine for the gasoline engine in light-duty vehicles are still not known. It is possible, for instance, that the complex chain of chemical transformations of diesel pollutants interacts in synergistic ways with constituents in the atmosphere, in water, in materials, and in artifacts of civilization. More must be learned about the diesel engine—its emissions and economic and energy impacts—in order to support the wisest decisions concerning its proper future in the nation's transportation system.

Obviously, the making of public policy in this case will be a formidable task. While several federal agencies are now conducting research on potential health hazards of particulates and certain chemical compounds in diesel exhausts, the existence of carcinogenic effects on humans has not been proved. Such scientific uncertainty about health effects poses a dilemma for the regulator who must assess the risks of diesel engine emissions. It is clear that policy decisions must be based on the best-possible knowledge and on careful, credible evaluation of findings and data.

The National Academy of Sciences proposed, therefore, to conduct an eighteen-month evaluation of the research and public policy issues associated with the prospective widespread use of diesel-powered light-duty vehicles. The technological, biomedical, environmental, energy, and economic aspects of the issues will be examined in a public policy context by a committee established in the Assembly of Engineering of the National Research Council.

The multidisciplinary committee and its panels, which include experts in health, environmental and physical sciences, engineering, economics, and public policy analysis, will work in collaboration with the Board on Toxicology and Environmental Health Hazards of the Assembly of Life Sciences and with the Environmental Studies Board of the Commission on Natural Resources. The committee's study, in support of the three government agencies that ultimately will decide the future of the light-duty diesel engine—the Environmental Protection Agency, the Department of Transportation, and the Department of Energy—will focus mainly on the period 1985–2000. The goals will be, first, to examine the state of experimental and theoretical research in federal agencies and elsewhere on the possible health hazard from diesel emissions, including the limitations and implications of such research in light of the technological feasibility of control. Second, the committee will develop an independent analysis of the comparative risks and benefits associated with the widespread use of diesel engines in automobiles and light trucks. Specifically, in meeting these goals, the committee will examine the state of knowledge and current reseach programs on the biomedical effects of diesel engine emissions; the applicable technologies of diesel engines, fuels, and emission controls; and the environmental impacts of diesel technologies. It will then examine ways of analyzing trade-offs between adverse health and environmental effects and the economic benefits of diesel engine use. Finally, the committee will consider the public policy implications of its findings.

BIOMEDICAL EFFECTS OF ENGINE EMISSIONS

A comprehensive review and assessment will be made of toxicologic and epidemiologic data on the inhalation of diesel engine emissions from both mobile and stationary sources and how they affect human health. The variables that affect human exposure will be an essential element of the committee's analysis. The operating characteristics of different engine types that influence the composition of emissions will also be studied.

Because epidemiological data often do not permit the isolation of one causal factor from others in the environment, the committee will attempt to assess health risks from composite mixtures of diesel exhausts including airborne vapors, gases, and particulates, as well as from purified single components. This is especially relevant because recent data concerning the toxicity of mobile emissions are based on studies of composite mixtures. Thus, in some cases, it may be possible to identify synergistic and antagonistic effects.

Although potential carcinogenicity will be emphasized, the study will encompass all observed and predicted adverse effects related to the structure and function of organs, as well as biological and demographic factors that may affect susceptibility (e.g., genetic disposition, health status, sex, and age). Another consideration will be the role of metabolic and other biologic pathways and their relative rates for the activation and deactivation or removal of compounds that may influence the risk of disease from the inhalation of emissions.

In addition, an attempt will be made to identify and differentiate diseases related to exposure to different types of emissions. Whether or not the condition is reversible is an important concern in the formulation of policy. Throughout the analysis an effort will be made to define dose–response characteristics in order to provide a better understanding of cause–effect relationships. For characteristics such as carcinogenicity, for which there is no universally accepted "safe" level or threshold, attempts will be made to extrapolate the data beyond the experimental observation range to predict the levels of risk at ambient exposure levels. The question of confidence in such extrapolations will also be addressed.

The committee will identify gaps in toxicologic and epidemiologic data in the current research activities of federal agencies, research centers, and industrial organizations as an aid in planning a research agenda that could lead to improved knowledge about biomedical effects of engine emissions.

TECHNOLOGIES OF ENGINES, FUEL, AND EMISSION CONTROLS

This aspect of the study will evaluate the feasibility, cost, fuel economy, and general effectiveness of alternative pollution control devices and technologies, and compare the emissions and fuel economies of diesel engines that have been modified or equipped for pollution abatement with those of alternative automobile and light-truck engines, such as modified spark-ignition and stratified charge engines.

The committee's panels on engine technology and on biomedical effects will work together from the beginning because options for engine design and adjustment, emission controls, and alternative fuels will depend, in large part, on the evaluation of probable biomedical effects, especially the carcinogenicity of exhaust products.

Diesel emissions of particulates and polycyclic aromatics are of special concern because of their carcinogenic properties, but, so far, efforts to control them have had little success, either here or abroad. A full review is needed of such control devices as catalytic converters and traps, as well as the effects of varying the fuel mixture, lubricants, and additives. Available alternatives to the diesel engine should also be examined, including modified combustion-chamber designs for gasoline engines, valve selectors (where the number of cylinders in use may be varied automatically according to the power requirements in transit), and engines with other practical modifications or adjustments in design and operation.

Estimates and comparisons of cost, producibility, price to consumers, fuel economy, and driver satisfaction will narrow the range of feasible control technologies and the specific emission compounds that the committee will consider.

ENVIRONMENTAL IMPACTS

To advance its understanding of the effects of diesel emissions on humans, the committee will look at adverse effects on animals and vegetation near traffic and on economic crops, forests, grasslands, and structures that are at some distance from high concentrations of diesels. The committee will assess weather effects as well, including quantifiable contributions to smog formation and acid rainfall, and damaging effects on materials.

INTEGRATION AND ANALYSIS OF TRADE-OFFS

On the basis of its evaluation of biomedical effects, technologies, and environmental impacts, the committee will analyze the respective risks, benefits, and costs associated with the potential widespread use of the diesel engine in light-duty vehicles—a prerequisite to assessing the range of possible public policy options—and develop a means for collecting and integrating the information and organizing it in such a way to permit the analysis, comparison, and clear presentation of trade-offs.

IMPLICATIONS FOR PUBLIC POLICIES

The prospect of widespread introduction of light-duty diesel vehicles raises public policy issues that will require wise and informed decisions by the Environmental Protection Agency and the Departments of Energy and Transportation. The decisions concerning whether and by what means to regulate additional emissions constitute but one of a variety of policy issues. Governmental responses to identifiable impacts may also include the setting of standards, legislation of economic incentive policies, or even the prohibition or restriction of diesel engines. The appropriate government agencies must also decide upon research strategies on the basis of an assessment of current knowledge, or gaps in knowledge, required for informed decision-making. On the basis of the results of its study, the committee will identify and assess a range of policy alternatives to assist those who must address the future of diesel engines.

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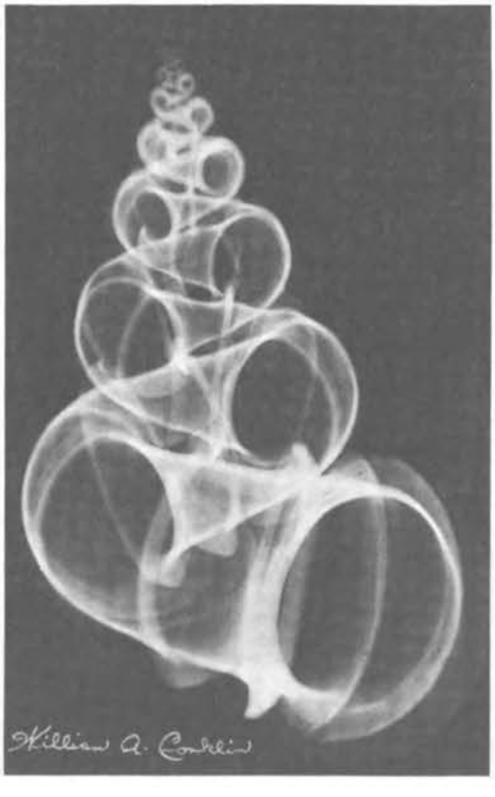

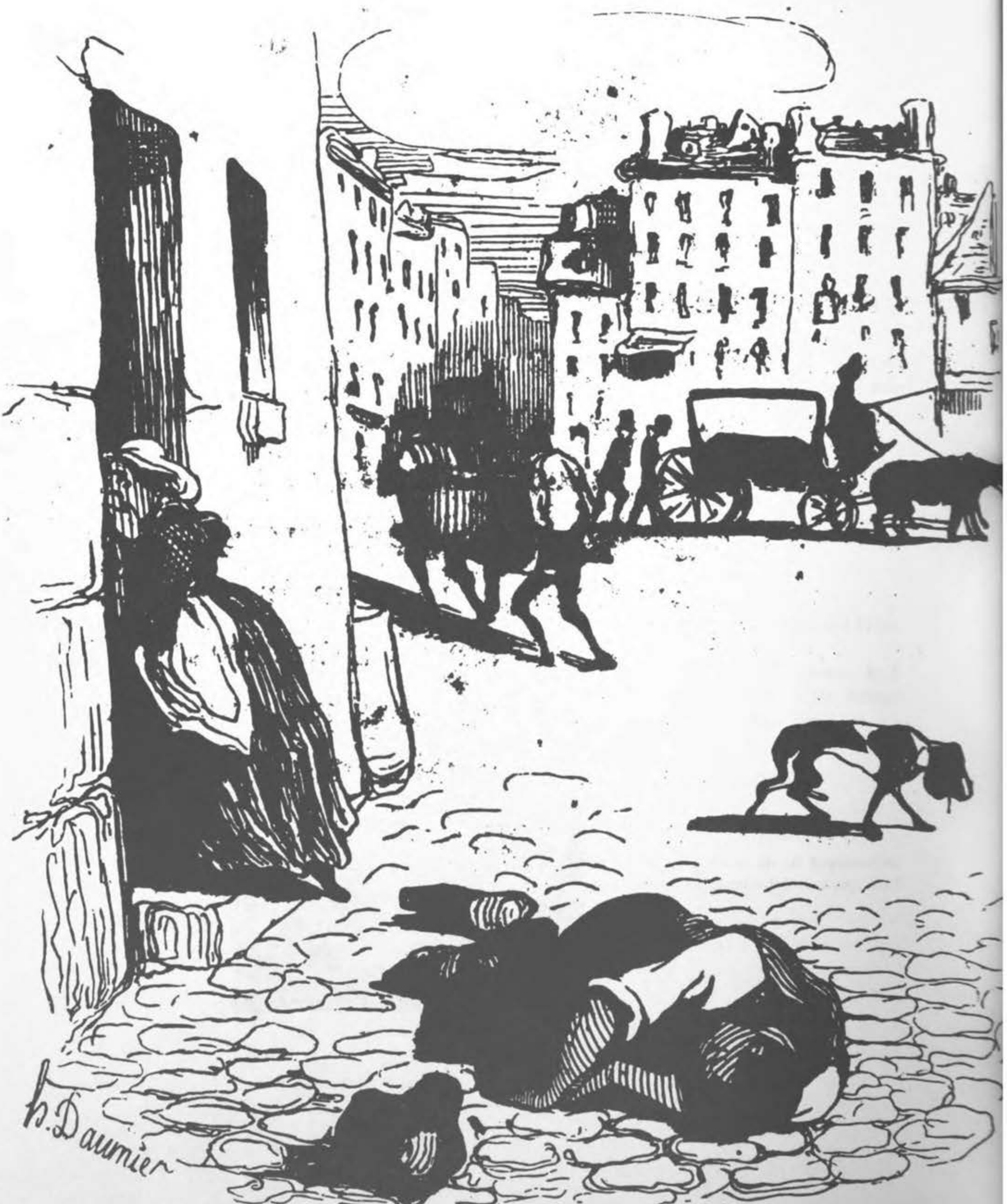
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Strengths and Limitations of Epidemiology

BRIAN MACMAHON

A recurring theme in the work of the Assembly of Life Sciences is an effort to discern patterns in a mass of data, usually incomplete, of variable reliability and susceptible to many interpretations. This is meant not as a complaint, but as a statement of simple reality. Thus, the recent efforts within ALS to identify the effects on humans of low levels of ionizing radiation or of very low doses of saccharin illustrate the difficulties of describing associations, let alone identifying causes and effects, with limited data. Such difficulties infuse the many sciences applied to evaluate the effects of environment on human health. Yet, for planning national research efforts, for recommending priorities in the allocation of resources, and for providing proper guidance to those who must make laws and regulations, it is necessary not only to ascertain meaningful patterns but, to the extent possible, to describe them in quantitative terms. Epidemiology is one of the sciences used to discern and measure patterns in the relationship of environment to human health. In this essay, I will explore briefly some of its strengths and limitations.

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CONSIDERINGS

The fundamental objective of epidemiology—to understand the relationship of a population's disease experience to its environment—has remained the same since Hippocrates' dictum of 2,400 years ago:

> Whoever wishes to investigate medicine properly should proceed thus: in the first place to consider the seasons of the year, and what effects each of them produces. Then the winds, the hot and the cold, especially such as are common to all countries, and then such as are peculiar to each locality. In the same manner, when one comes into a city to which he is a stranger, he should consider its situation, how it lies as to the winds and the rising of the sun; for its influence is not the same whether it lies to the north or the south, to the rising or to the setting sun. One should consider most attentively the waters which the inhabitants use, whether they be marshy and soft, or hard and running from elevated and rocky situations, and then if saltish and unfit for cooking; and the ground, whether it be naked and deficient in water, or wooded and well watered, and whether it lies in a hollow, confined situation, or is elevated and cold; and the mode in which the inhabitants live, and what are their pursuits, whether they are fond of drinking and eating to excess, and given to indolence, or are fond of exercise and labor.[1]

In light of such a clear statement from such an influential teacher, it is remarkable that for more than 2,000 years virtually nothing was discovered about the specific characteristics of environments that led to disease. The British epidemiologist Greenwood, writing some forty years ago, attributed this to the fact that the operative word in Hippocrates' statement is *consider*—not *count.* Greenwood believed that, however full of insight an investigator's "considerings" may be, they are unlikely to form a basis for the considerings of future generations of investigators if they are not supported by observations objectively recorded in quantitative terms.[2]

The first serious attempt to count health-related events was undertaken in the middle of the seventeenth century by John Graunt, a Gentleman of London and a Founding Fellow of the Royal Philosophical Society. Graunt chanced on the weekly Bills of Mortality published by the parish clerks of the City of London episodically since about 1600, principally to monitor the comings and goings of the plague. He collected as many of the bills as he could find and analyzed them to show that more males were born than females, and that more males also died though females were more frequently sick, that mortality was high among infants, that there were seasonal fluctuations in mortality, that more people died of the plague than were so recorded (as with influenza today), and, more parochially, that "not one in two thousand are murthered in London" and that "the Stone decreases, and is wearing away," "The Gowt stands at a stay" but "the Scurvie encreases."[3] Graunt was the first to attempt two basic statistical procedures—the estimation of the size of the population of a large city (London) and the construction of a life table showing the age distribution of the population. Even more importantly, he demonstrated "the uniformity and predictability of . . . biological phenomena taken in the mass"[4]—the cornerstone of biostatistics and of quantitative epidemiology.

THIS GRAND EXPERIMENT

In the middle of the nineteenth century, epidemiology received methodologic inspiration from the work of John Snow, a London anaesthesiologist. Snow is known for his dogged documentation of the case-to-case transmission of cholera and in particular for his linking of several hundred cases of the disease in an epidemic of 1845 to a single contaminated water pump. His broader contribution, however, stemmed from his refusal to limit himself to previously recorded information. He did not ask, as did Graunt, "What use can I make of this information?" but "What information do I need to solve this problem?" Having observed a geographic association between risk of cholera and the source of water supply to several districts of London, he perceived a way of testing the hypothesis that the water source was responsible for the spread of the disease. In his own words:[5]

> the intermixing of the water supply of the Southwark and Vauxhall Company with that of the Lambeth Company, over an extensive part of London, admitted of the subject being sifted in such a way as to yield the most incontrovertible proof on one side or the other. In the sub-districts . . . supplied by both Companies, the mixing of the supply is of the most intimate kind. The pipes of each Company go down all the streets, and into nearly all the courts and alleys. A few houses are supplied by one Company and a few by the other, according to the decision of the owner or

A LONDON BOARD OF HEALTH HUNTING AFTER CASES LIKE CHOLERA

occupier at that time when the Water Companies were in active competition. In many cases a single house has a supply different from that on either side. Each company supplies both rich and poor, both large houses and small; there is no difference either in the condition of occupation of the persons receiving the water of the different Companies. Now it must be evident that, if the diminution of cholera, in the districts partly supplied with the improved water, depended on this supply the houses receiving it would be the houses enjoying the whole benefit of the diminution of the malady, whilst the houses supplied with the water from Battersea Fields would suffer the same mortality as they would if the improved supply did not exist at all . . . it is obvious that no experiment could have been devised which would more thoroughly test the effect of water supply on the progress of cholera than this, which circumstances placed ready made before the observer.

The experiment, too, was on the grandest scale. No fewer than three hundred thousand people of both sexes, of every age and occupation, and of every rank and station, from gentlefolks down to the very poor, were divided into two groups without their choice, and, in most cases, without their knowledge; one group being supplied with water containing the sewage of London, and, amongst it, whatever might have come from the cholera patients, the other group having water quite free from such impurity.

To turn this grand experiment to account, all that was required was to learn the supply of water to each individual house where a fatal attack of cholera might occur.

This Snow proceeded to do, demonstrating unequivocally the insalubrious nature of the sewage-water mixture distributed by the Southward and Vauxhall Company.

Much of the epidemiology since Snow has consisted of attempts to identify and exploit other "natural experiments" to elucidate the etiology of human disease.

NEW QUESTIONS

A little more than a century after Snow, epidemiology is experiencing another revival. The stimuli for this revival include a change in the patterns of the major diseases affecting technologically developed nations—with a corresponding need to understand the causes of the new diseases—and recognition of the fact that epidemiologic studies have an enviable record in contributing to our understanding of the relationship of environment to human health. While the laboratory produced the means for control of infectious disease, epidemiology first told the microscopists where to look and what to look for. Most dramatic has been the identification through epidemiologic studies of the cigarette as the cause of this century's epidemic of lung cancer. There are few exceptions to the generalization that the agents known to cause cancer in man have first been identified as carcinogens in studies of humans, rather than of animals. A similar statement could be made for congenital defects. Laboratory studies on other species have yielded understanding of mechanisms and principles of carcinogenesis and teratogenesis, but knowledge of the specific agents responsible for human disease has come predominantly from studies in humans. One of epidemiology's great strengths is its record, one of undoubted and practical accomplishment that is accumulating exponentially.

New dimensions have been added to the expectations of epidemiology in this latest revival. First, in addition to asking "What are the causes of this disease?", questions such as the following are being raised: "Given that substance *x* occurs in the human environment, what, if anything, is it doing to human health?" Although the first type of question is difficult to answer, the second is much more so. When the focus of investigation is a disease, one knows at least that the disease exists and that it must have causes: If we cannot discern the causes, that can only be because of our own limitations. However, when investigating an exposure, one does not know whether or not a problem exists and may be faced with the statistical impossibility of "proving" absence of an association. Further, we may be searching for a rare effect against a background of similar effects due to other causes.

Second, knowing or suspecting that a given substance causes ill-health at some level of exposure we need to know what its effects are, if any, at the lowest levels to which humans are being or may be exposed. The problems of measuring the usually rare effects of low-level exposures and of distinguishing them from "no-effect" levels are, of course, vastly greater than those of identifying common outcomes of heavier exposures.

The strengths and limitations of epidemiology in these contexts stem from the two principal characteristics of the science—it is concerned with studies in humans and it is predominantly observational, rather than experimental.

PEOPLE AND ANIMALS

The fact that the science deals with observations in humans is predominantly a source of strengths. The obvious advantage is that this is the species of concern and the necessity to extrapolate inferences across species is avoided. A less widely recognized advantage is that people are numerous and they expose themselves to hazardous substances with abandon. The typical toxicological experiment in laboratory animals for economic reasons uses the smallest possible number of animals—usually fewer than a hundred for a given exposure—and the largest doses of toxin that can be administered, without killing too many of the animals, to maximize the chances of achieving an effect. Inferences from such studies that are useful, for example to the regulator, therefore involve not only the extrapolation across species, but also from enormously high to very low doses.

Humans, on the other hand, not only are available in very large numbers—many think too large—but also house and feed themselves and keep themselves clean at no expense to the investigator. They choose a broad range of dosages of a variety of potentially toxic substances. Consider the cigarette habit to which hundreds of millions of persons have exposed themselves at levels ranging from almost zero (for those exposed only through smoking by others) to the addict's three or four cigarettes per waking hour, and the consequent two million or more deaths from lung cancer in the last half century in this country alone. Consider the fact that fewer than half of American women pass through the menopause without either having their uterus surgically removed, being liberally dosed with hormones that are known to increase cancer risk in animals, or both. Consider the implications of the fact that more than fifty million women worldwide take regularly for contraceptive purposes a combination of hormones that essentially cuts off the function of their own ovaries. Such figures must make the tinkerers in the animal laboratory green with envy. Numbers such as these have permitted the identification of innumerable hazards never suspected from laboratory experiments—the unravelling of the cause of the lung cancer epidemic, ascertainment of the high risk of uterine cancer associated with estrogen use, the variety of cancers associated with exposure to ionizing radiation, the role of rubella and certain therapeutic drugs in the causation of congenital defects, and literally hundreds of causes of ill-health attributable to high-level exposures in the workplace.

The oral contraceptive story is instructive. Laboratory work led us to believe that use of these compounds might be associated with increases in risk of cancer, particularly cancer of the breast. No such increases have yet been observed. On the other hand, substantially increased risk of death from cardiovascular disease associated with these contraceptives is now well established, particularly for women who are over thirty-five years of age and who have other risk factors for cardiovascular disease. This risk of cardiovascular disease was totally unexpected. It demonstrates clearly the danger of any surveillance or regulatory system that depends solely on inferences from animal experiments. On the other hand, were our ultimate concern with the health of guinea pigs rather than humans, it would be unwise to proscribe, on the basis of the cardiovascular effects in humans, the use of oral contraceptives by guinea pigs. Guinea pigs do not get this particular disease.

TIME

One limitation of epidemiologic studies that stems from the fact that the object of study is man is that the lifetime of the subject approximates that of the investigator. This becomes a serious problem when the disease or diseases of concern develop only after periods of time that represent substantial fractions of the individual's lifetime. In such a circumstance the experimentalist may be able to turn to a species with a shorter lifespan and, with luck, a speeded up disease induction time. The epidemiologist may be able to overcome this handicap only if he is able to capitalize on records accumulated in the past—as the Medical Follow-up Agency of the National Research Council has capitalized on the personnel and medical records accumulated by the Armed Services and the Veterans Administration—or if over several decades a succession of investigators is attracted to the study of a particular experience (see, for example, the account in this volume of the work of the Radiation Effects Research Foundation, p. 105).

OBSERVATIONS AND CAUSES

The most serious limitations of epidemiology stem from its observational nature. Some epidemiology is experimental—that is, it involves the deliberate manipulation of a suspected cause in order to measure the change in a supposed effect. When in the experimental mode, subjects can be selected, randomized, and measured in standard ways, making it likely that any observed differences between exposed and unexposed, or between treated and untreated, subjects result from the variable that was manipulated. Such methodology in humans, however, is virtually limited to circumstances in which something that is presumed to be beneficial—a therapy or a preventive measure such as a vaccine or water fluoridation—is being evaluated.

Most epidemiology is not experimental. It depends on observations of association between ill-health and exposures that were accidental or inadvertent and that are distributed capriciously and in biased and often unknown ways through the population. It is rare that the observation of association between a particular disease and a particular exposure in any one study can be said with confidence to indicate a causal connection between the two. Nearly always, the observation must be repeated under different circumstances and using different methods of study until a whole body of information has been assembled to make alternative explanations of the association in any one data set unlikely.

When a single study is convincing, it is usually because the disease involved is uncommon and the experience shared by the afflicted persons is unusual. For example, the associations of vinyl chloride with angiosarcoma of the liver, of exposure of a fetus *in utero* to diethylstilbestrol with vaginal cancer in young girls, of maternal rubella with cataract and deafness, and of thalidomide with a set of previously extremely rare malformations of the limbs were accepted as causal almost immediately.

Much more difficult is the evaluation of increases in a disease that is fairly common even in the absence of the exposure of immediate concern—in other words, when one is attempting to evaluate a fluctuation in disease incidence against a background of "natural" incidence that itself fluctuates with time, geography, socioeconomic status, and other factors that can affect the findings in any particular study. Thus, the cigarette–lung cancer association had been observed in more than fifty studies before the Surgeon General saw fit to announce that cigarette smoking *may* be dangerous to your health. Now, knowing that heavy cigarette smoking is associated with a fortyfold increase in lung cancer rates and that smoking habits vary considerably by age, sex, socioeconomic status, occupation, and other factors, we must be cautious in interpreting observations in small increases in lung cancer rates in a particular occupational or other subgroup of the population—even if the observation is soundly based—since a quite small difference between that subgroup and the general population in smoking habits will result in a substantial difference in lung cancer rates. The same is true for other common disorders—such as fetal death—that have multiple causes that, again, vary by time, geography, socioeconomic status, and other personal characteristics.

POSITIVE AND NEGATIVE LIMITS

The limitations of epidemiologic data that appear to show an association between an exposure and a disease—in addition to those having to do with study design and quality of measurement, which affect all studies—stem primarily from lack of knowledge of the distribution in the population of other factors that affect the disease frequency. Negative epidemiologic studies also have their limitations. They may be wrongly interpreted as indicating lack of effect on health of a particular exposure, because of inadequacies of design or measurement, because a meaningful effect is occurring but too infrequently to be detected in a study of the given size, because the population was not studied at an appropriate interval after the exposure so that the effects had already occurred and disappeared or had not yet occurred, or because this particular study involved a subpopulation that was not susceptible to the exposure.

All these are limitations that are real and of great practical significance. They may be so real as to be insuperable. Thus, if one defines as "meaningful" *any* effect, then one can never assemble a study group large enough to declare that there was *no* effect. One can only define the probability with which a particular data set suggests that there is unlikely to be an effect greater than *y*. If one assumes that the latent period between exposure and appearance of health effects is fifty years, it may not be possible to study the association at all. If one decides that a substance must be regulated down to a level that would be safe for the most susceptible members of the population, one may never be able to identify that level since the susceptible individuals may be too few to study.

Not all these limitations are likely to apply to all studies—or even to any one study—so it may be that, as with the interpretation of positive associations, the accumulation of a series of negative studies using different populations and different methods will lead to an overall pattern that must be taken seriously in, for example, the regulatory process. Unfortunately, investigators are reluctant to spend their efforts and resources for studies that they judge likely to be negative. It may therefore be difficult to assemble sufficient evidence to arrive at a convincing negative conclusion from epidemiologic studies alone.

PEOPLE AND RECORDS

Not all of the limitations of epidemiology are intrinsic to the method itself. It is also constrained by lack of manpower, lack of resources, and lack in some parts of the population of understanding of its purposes and uses, leading to proposals regarding permissible and impermissible uses of information that are antithetical to an effective effort in the field.

The present lack of epidemiologic manpower—to which many government and private agencies will attest—has historical roots. Until the last decade the great majority of persons working in epidemiology were physicians. Since epidemiology rarely involves the treatment of ill persons, which most physicians went to medical school to learn to do, it is not surprising that recruits into epidemiology from that source have never amounted to more than a trickle—perhaps one or two, at most, from a typical medical school class. That trickle sufficed to keep the discipline alive but not to meet the demands now being made on it for the study of environmental health, the evaluation of medical services, and the investigation of toxic substances. The deficit is being met by training programs that train epidemiologists per se—providing the necessary background in human biology and medicine as well as in quantitative methods. These programs are new, however, and their graduates just beginning to appear. The manpower limitation in epidemiology is likely to be much less serious a decade from now.

Resource limitation is not primarily financial, although money is needed to develop the types of resources epidemiology uses. The principal limitation is of records in forms that are accessible and linkable to other records relating to the same individuals. This country has a superb file—or rather files—of death certificates giving basic demographic characteristics of the decedent and the certifying physician's notion as to the cause or causes of death, but until this year (1979) there was no index to that file. The records are maintained by more than fifty registration areas (mostly states and some large cities), and, while indexes may be available in the individual registration areas for their own files, to locate a death certificate one must know in which area and in approximately what year to look. To rule out the possibility that an individual is dead, it would be necessary to search in all the registration areas—clearly an impossible task. Beginning in 1979, the National Center for Health Statistics has established a central National Death Index, which will facilitate the identification of deaths among any subgroup of the population that is of research interest. It will be some years before this index has accumulated to a point where it will be of maximum value, and the lack of such an index in the past has limited the work that might have been done. Retroactive indexing, though tremendously valuable, would be a very expensive undertaking and seems unlikely to be attempted in the near future.

The files of the Social Security System, containing, for most individuals, a lifelong record of employment and of current vital status (living or dead) are seriously underutilized for research purposes. While their use for linking occupational exposures to mortality is increasing, there are many ways—which are too technical or detailed to elaborate on here—in which the value of this resource could be greatly enhanced and the resource more effectively used. The utility of this system is not limited to the study of the effects of occupational exposures.

Absence of a unique identifying number that would facilitate "linkage" of information from different sources—say occupational history with cancer registry, or pharmacy prescription with congenital defect—is another current resource limitation that is slowly becoming less of a limitation. The idea of a unique identifying number has until recently been politically unacceptable precisely *because* it enables linkage of records. Nevertheless, such a number is coming into being. Contrary to avowed intent when it was first introduced, the Social Security number is now used on virtually all payments monitored by the Internal Revenue Service, as the military service number, as the drivers' license number in many states, on insurance policies and credit cards, and in many other circumstances. This widespread use of the Social Security number should be accepted in medical, as it is in financial, circles and used as the unit hospital record number, on drug prescriptions, and on other health records.

At least partially responsible for the slow progress in the development of record resources for epidemiologic purposes—and indeed for some setbacks—is the undoubted fact that these developments impinge adversely on other values that are held as dearly by some as the desire for knowledge of the causes of disease; these are the rights of privacy and confidentiality of personal and medical information. There is little problem in situations in which the individual can be asked whether his or her record or information can be utilized. The difficulty comes from proposals in which such permission is required for *any* use of individual records. Here there is a conflict between what would be desirable for confidentiality and the fact that this requirement makes impractical, and sometimes impossible, many uses of records for research purposes—as, for example, when very large samples are required or when the records relate to past events and the individuals are no longer available to give their permission. The Privacy Protection Study Commission, established under the Privacy Act of 1974, has published recommendations and guidelines for use of medical records in research that, if implemented, would assure the continued availability of such records under procedural safeguards that protect confidentiality.[6] Implementation of these recommendations would be a considerable step in the development of record resources for epidemiologic and other health research.

As I have already noted, the range of human exposure to potential agents of disease in the environment is enormous. It is unfortunate that only a small proportion of this experience is observed, recorded, and analyzed to build our knowledge of the relationship between environment and health. With the availability of computers to record, store, and process information on an unprecedented scale, and the widespread recognition of the potential benefits to be derived from epidemiologic research, an enlightened attitude towards the use of personal records for research should lead to a far greater proportion of our experience being used to provide information of practical value to our own and future generations.

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Study Project

ASSEMBLY OF LIFE SCIENCES

HIROSHIMA, NAGASAKI, AND RERF

At 1:45 a.m. on Monday, August 6, 1945, two planes took off from an airfield on Tinian Island in the Marianas. Their orders were to head for Hiroshima. If it was cloudy there they were to continue on to Kokura and, if again weather was bad, make for Nagasaki. Hiroshima, with a population of 300,000, was first on the list because it had not been previously bombed, was constructed on a large, flat delta surrounded by mountains, served as the headquarters of the Second Army, and was a major military staging area for Southeast Asia. Shortly before 8:00 a.m. the planes were spotted at Hiroshima and air raid warnings sounded. As the weather scouts passed over and continued on, the all-clear signal was given. The weather was perfect, with almost unlimited visibility. At about 8:14 a.m. the *Enola Gay,* carrying the atomic bomb, appeared. Since there was obviously no squadron of bombers and since the first planes had passed on, no air raid warning was sounded. At 8:15 a.m. the bomb was dropped and exploded at 1,800 feet with power equivalent to 12,500 tons of TNT. Forty thousand buildings (eighty percent of the total) were destroyed. The number of casualties at Hiroshima is not known because detailed records of the large number of military personnel were not kept. Among the civilians, approximately 64,600 died within the first few months, of burns, concussion, and radiation. It has been estimated that chances of survival were zero at ground zero, twenty-five percent at 3,000 feet, fifty percent at 4,000 feet, and ninety-five percent at 6,000 feet (over one mile). The second bomb, delivered three days later, was destined for Kokura, but, because of cloudy weather there, was dropped on Nagasaki instead. Some 39,000 people were killed. Despite the fact that the second bomb was more powerful, mortality in Nagasaki was less because the mountainous terrain protected parts of the city from direct exposure. The first bomb had released considerable amounts of neutrons, while the radiation from the second bomb was largely composed of gamma rays, which travel farther (up to 2,500 meters) and penetrate more deeply.

EFFECTS

The three principal impacts of an atomic bomb explosion above ground are air blast, thermal radiation, and ionizing radiation. While this account will focus on the long-term effects of the latter, the other two impacts are immense. These were bombs that were very small indeed by present-day standards. The figure on page 107 shows a two-story, steel-frame building with seven-inch, reinforced concrete walls. It stood 0.4 mile from ground zero at Hiroshima. With the buckling of the walls, the entire second story dropped to the ground. The effect of such an air blast on wooden frame houses was obviously more catastrophic, even at far greater distances.

Paper, cloth, and dry wood were set afire at distances up to 3,500 feet from ground zero. A fire storm completed the devastation. This phenomenon, not confined to nuclear bombs but also encountered in saturation incendiary bombing of Tokyo and several German cities, notably Dresden, is caused by the countless scattered, individual fires. Their updraft produces a strong wind moving from the periphery to the center of the city. This is greatly accentuated in the case of the atomic bomb by the mushrooming phenomenon with its accompanying updraft. Virtually the entire city of Hiroshima became an

enormous bonfire almost immediately after the bomb exploded. (In the museum at Hiroshima many of the exhibits such as melted glass, melted metal pots, and fused bunches of nails were caused not by thermal radiation, as the exhibit implies, but by the fire storm.) In the first few weeks after the explosion, air blast, fire and nuclear radiation probably accounted about equally for the casualties. It is not widely known that the sudden updraft of hot, moist air to the cooler heights resulted in condensation and the black rain that poured down on both cities later in the day. The raindrops contained much smoke and dust, hence black, and were radioactive. There are no mortality figures specific for this fallout.

Regarding fallout, a very large number of substances are rendered radioactive in the dust drawn up from the earth by the mushroom effect of the explosion. In the Nevada tests, for example, some three hundred different isotopes have been identified. Many of these, while occurring widely in nature, have short half-lives and thus are active only for brief periods after the explosion. Examples are iodine-131 (8 days), sodium-24 (15 hours), manganese-56 (2.6 hours), and silicon-31 (2.6 hours). At the other end of the scale is carbon-14 with a half-life of 5,730 years. In between these extremes are strontium-90 (27.7 years) and cesium-137 (30 years). Iodine and strontium deserve special mention. The former is concentrated in the thryoid gland and may be ingested by drinking milk from cows eating foliage contaminated by iodine-131. Strontium localizes in bone and constitutes a large fraction of the fission product. For every 1,000 atoms undergoing fission, 30–40 atoms of strontium-90 are formed. When all the above is averaged out in terms of total fallout at or near the bomb site and if the radiation dose rate at one hour is the reference point, then at seven hours the rate will have decreased to $^1/_{10}$ of the reference value, at two days to $^1/_{100}$, and at fourteen days to $^1/_{1,000}$. These factors, of course, will vary widely depending on the type and height of the bomb as well as the wind velocity. Of interest in this connection is that there has not been an increase in the incidence of cancer among persons who moved into Hiroshima and Nagasaki in the months and years following the explosions.

For meaningful radiation studies, it was essential to determine extent of exposure. The Air Force normally kept records of bombing altitude, wind speed, approach direction, and air speed for every bombing mission. But in the case of the atomic bombings, as John Auxier of the Oak Ridge National Laboratory has so succinctly stated, "The records for the two most important bombing missions in history are incomplete and inaccurate to a degree beyond comprehension." So the information had to be assembled from later discussions with the plane crews, from Japanese eye witnesses and, perhaps most importantly, from ground studies of the shadow angles cast by thermal radiation and of residual radiation. The difficulties are illustrated by an episode cited by Auxier. One of the most active radiation experts at the site was Dr. Sakae Shimizu of Kyoto University, who, learning of the disaster, made his way as quickly as possible to Hiroshima with a crude but workable Geiger counter and recorded innumerable measurements. He also collected photographic film from camera shops and sulfur from insulators on telegraph poles to determine intensity of radiation at different distances from ground zero. Unfortunately, to the U.S. military occupation forces, Dr. Shimizu looked pretty suspicious creeping around and jotting mysterious symbols in notebooks. An officer therefore confiscated all his notebooks, giving the doctor a signed receipt. Through this, the officer was identified twelve years later in civilian life. He told his interviewers, however, that when he left Japan, he had given the notebooks to another officer whose name he could not remember. The notebooks have not been located to this day.

There were, of course, other scientists, both Japanese and American, recording similar data. Through such studies, the height and location of the bomb, and some estimates of the intensities of air blast as well as of thermal and nuclear radiation, could be made. But reasonably accurate calculations of nuclear radiation, upon which the significance of medical effects would directly depend, were lacking. This was particularly true for the civilians exposed within houses destroyed by the bomb.

The Army of Occupation established a Joint Commission of Japanese and American Scientists to gather initial data to determine the immediate medical effects of radiation. It soon became evident, however, that a more integrated effort over a considerable period of time would be necessary. On November 18, 1946, in a letter to President Truman, James Forrestal noted that "a conference group of the Division of Medical Sciences of the National Research Council convened to discuss the problem." He then quotes their recommendation to the effect that the President should direct the National Academy of Sciences to "undertake a long-range, continuing study of the biological and medical effects of the atomic bomb on man." Across the bottom of this letter is handwritten the word "approved" beneath which are the President's signature and the date, November 26, 1946. With funds provided by the U.S. Atomic Energy Commission, the Atomic Bomb Casualty Commission (ABCC) was established. This had the advantages of drawing upon the reputation and scientific expertise of the NAS and of avoiding charges of bias, which might arise if the military or any federal agency were conducting the research.

Concerning those early years, R. Keith Cannan, a former Chairman of the Division of Medical Sciences, noted:

> The task facing the ABCC in the early years was formidable. To establish operations in two devastated cities, it had to locate housing as well as clinical and laboratory facilities, and mobilize American and Japanese physicians, nurses, statisticians, technicians, interpreters, and field workers. The local national machinery for administering community affairs had to be learned. But above all, it was necessary to secure the good will of the survivors—people who spoke an unfamiliar tongue and followed an alien culture, who had lost members of their families, relatives, and friends, their homes and their accustomed occupations—people with little left to them but their memories.

The problem of securing "the good will of the survivors" was compounded by building the facility in the midst of a cemetery in a city park on a high hill looking down on Hiroshima. This site it still occupies, despite the objections of the citizenry.

To continue to quote Dr. Cannan:

> The early years of ABCC were spent building up resources and groping toward a coherent program. Not knowing the kinds of delayed effects that might be encountered, a broad strategy was followed. Searches were initiated for new diseases uniquely associated with radiation, altered incidences of known diseases, and changes in physiological status without overt disease. . . . Growth and development of individuals exposed in childhood were studied. In addition, the incidence of cataracts and of leukemia and other blood dyscrasias in children and adults were surveyed.

In 1955, an academy committee examined the program and recommended a unified study focused on a fixed population and using systematized epidemiological follow-up studies. This became the basis for most of the subsequent work.

As the research continued, it became increasingly apparent to many participants, not the least of whom was George Darling, appointed director in 1957, that a binational foundation should be established with equal governance, staffing, and funding by the United States and Japan. Accordingly, the Radiation Effects Research Foundation (RERF) was established in 1974 with financial support from the two governments. There is a board of directors and a science council of equal numbers by nationality.

So much for this brief history. What of the information acquired since 1950? The only way in which adequate data concerning radiation dosage could be obtained was to build several typical Japanese houses, containing monitors, locate them at varying distances from ground zero, and measure the attenuation of radiations during explosion of bombs of approximately similar size and at equivalent heights. Fortunately, for this study, it turned out that, within a three-foot horizontal deviation, a large two-story house, a middle-sized one-story house, and a small one-story house represented ninety percent of all Japanese houses in both Nagasaki and Hiroshima. In 1957 and again in 1958, radiation was monitored within these reproduced houses at the test sites and the results applied house-by-house and person-by-person to the cohort under study. (See photograph below.)

People with different amounts of radiation exposure, as well as matched, nonradiated controls, are being studied. The original cohorts were obtained from the 1950 national census. Medical data on deaths derive largely from death certificates and to a lesser extent from autopsy information. A group of some 20,000 people is followed closely by biennial medical examinations at the Radiation Effects Research Foundation. It should be emphasized here that the epidemiologic studies were begun in 1950 and hence do not include data on the first five years following exposure, which would include the acute and semiacute effects. Another significant point is that the studies concern a single exposure and may or may not be applicable to multiple exposures resulting in cumulative dosages.

SOME FINDINGS

In the case of those directly radiated *in utero,* there was reduction of head size with accompanying mental retardation in a statistically significant percentage. This was directly proportional to the amount of radiation and most marked when exposure occurred in the first trimester. In children exposed after birth, growth, as measured by average height, was diminished if the radiation was experienced before the age of twelve.

Leukemia is of particular interest, since it is one of the most striking effects of ionizing radiation and its incidence increases in direct proportion to the amount of radiation received. Although acute lymphocytic, as well as acute and chronic myelogenous, leukemias were significantly increased among the exposed population, there was no increase in chronic lymphocytic leukemia. The latent period from exposure to the appearance of the acute leukemias lengthens as the age at which exposure occurred increases. In chronic myelogenous leukemias, on the other hand, this difference is not so manifest. It should also be noted that the risk declines with the passage of time. The extent of this decline is age-related, particularly in the case of acute leukemia. In other words, incidence in the younger population returns to nearer the baseline over time than in the older. The incidence of leukemia, especially the acute form, continues to the present well above the incidence among the control population. The rates are higher at Hiroshima, presumably reflecting the neutron component of the bomb. For those under fifteen years of age, who were exposed to doses of 100 rads or more, the incidence is twenty times that of the control population.

Concerning solid tumors, children exposed to radiation have shown a latent period of about ten to fifteen years. Since then, the incidence has climbed and continues to do so to the present. Cancer of the thyroid is especially prominent in females exposed under ten years of age. Breast cancer continues to increase, and the relative risk is highest for females between ten and nineteen years of age at the time of radiation. The incidence of stomach cancer, which is surprisingly common in Japan generally, increased at moderate radiation doses in Hiroshima, but only at very high levels of radiation in Nagasaki. Oddly enough, the incidence of lung cancer increased most noticeably if radiation occurred at the age of fifty or over. Other cancers, which are beginning to emerge after a fifteen- to twenty-year latent period, are those of the urinary tract (especially bladder), salivary glands, and esophagus. Lymphomas are also on the increase. Other tumors, such as those of bone or liver, have not appeared in sufficient numbers to project clearly above the levels among the control populations, nor have increased deaths from cardiovascular or infectious diseases been detected.

In other words, if one excludes the tumors cited, radiation, if survived through the acute phase, has not to date resulted in decreased life expectancy. Finally, deaths from tumors, while statistically significant, are not overwhelming in actual numbers. When last calculated in 1974 among the population of 54,000 being followed, the norm was exceeded by eighty-five leukemia deaths and one hundred deaths from the other forms of cancer discussed above.

Studies of the F-1 population, i.e., 45,000 children conceived by mothers and/or fathers following exposure to radiation, have not shown chromosomal aberrations, such as translocations and dicentrics, which do occur and persist in the survivors themselves; nor has there been an increase in traditional congenital abnormalities, congenital metabolic diseases, detectable blood protein dyscrasias, or infant mortality. The sex ratio is not altered.

There are three critical areas demanding continued study as time recedes from the instant of exposure. The first concerns the solid tumors—their types and incidence—as more of the younger survivors approach ages at which those tumors generally become more prevalent. A second problem of special interest is whether suppression of the immune mechanism is reflected by subtle abnormalities later in life. So far, all attempts to uncover such conditions have been unsuccessful. The third concerns the F-1 generation, which needs to be followed longer and with increasingly refined methods of analysis to detect any defects that may still be masked by a latent period.

Having contemplated the above, and, in particular, the statement that the absolute number of tumors is not overwhelming, one cannot but be drawn back inevitably to individuals and their families. More moving than the Peace Park in Hiroshima, or the ruined building left as a monument, or the museum built as a reminder of the horror, is a very simple monument within the Peace Park. Standing alone and somewhat off to one side is the statue of a young girl standing on the dome of a simple oval-shaped monument supported by columns. Inside the monument are hung from her arms and hands innumerable strings of origami—small, white cranes folded from paper and strung in long rows. It seems that a little girl, who had been exposed to the bomb at Hiroshima, developed leukemia. With the realization that she was dying, she was determined to fold a thousand paper cranes. She died before completing all thousand but classmates finished them for her. The memorial was built and the string of cranes hung there. To this day, not only from Hiroshima and Nagasaki, but from other parts of Japan as well, children with leukemia fold similar cranes, which are here assembled in tribute.

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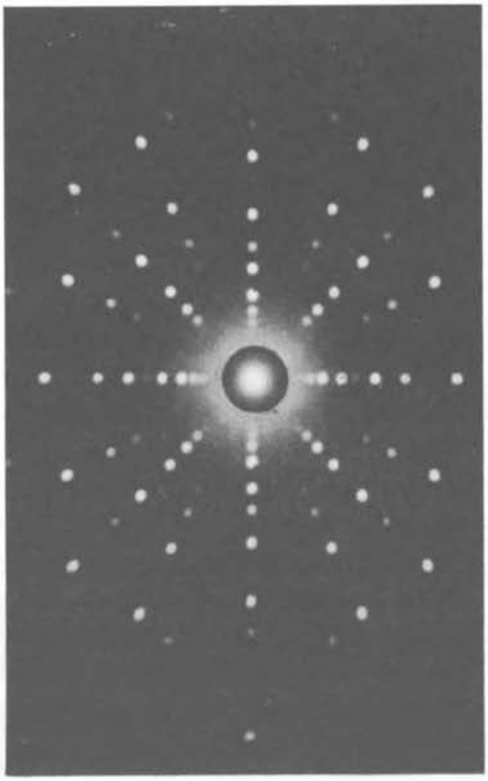
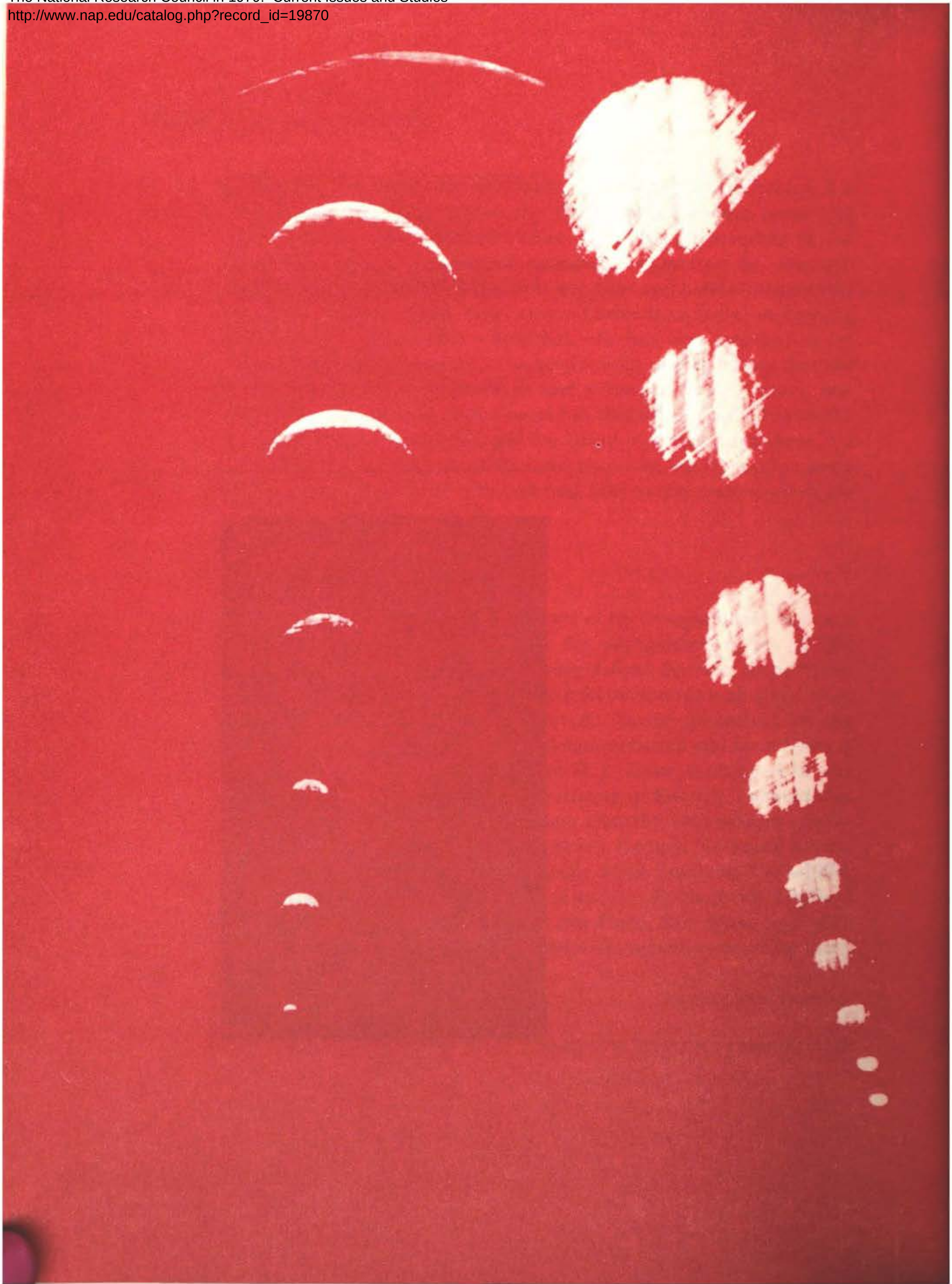
COUNCILMAN MORGAN

Councilman Morgan is the Executive Director of the Assembly of Life Sciences.

Assembly of Mathematical and Physical Sciences





◀Pioneer views of Jupiter

The Science of Planetary Exploration

EUGENE H. LEVY
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Scientific interest in solar-system bodies and the motivation to explore and study them are driven by a number of expectations. We expect that, by determining the composition, structure, and distribution of planets and of smaller objects orbiting the Sun, we will take major steps toward understanding conditions in the early solar nebula and the processes that controlled formation of the planets. We expect to discover important clues about the evolution of the planets to their present states and about the chemical and physical conditions that led to the appearance of life. We believe that intensive study of other planets will strengthen our grasp of the general rules by which planets behave and ultimately will enable us to decipher the Earth's history and to understand the nature and stability of planetary environments. This last goal may take on increasing significance as perturbations of

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the Earth's atmosphere and ocean resulting from human activities grow in magnitude.

Scientific exploration of the solar system and its bodies is one of the ways that we extend our direct experience of the laws of nature and their manifestations. Many natural phenomena are governed by processes only discernible in objects of extremely large physical scale and over times of long duration. These processes are not readily amenable to controlled laboratory investigation and often are not even potentially susceptible to that approach. We expect that, by extending our direct experience to the diverse but accessible bodies in which these processes may occur naturally, we will improve our understanding of the behavior of the world in which we live. These exotic phenomena range over broad areas of science; they include, for example, the tectonic processes that shape the surfaces of terrestrial planets, the escape and evolution of planetary atmospheres, and the energetic plasma processes that seem to accelerate particles in objects as diverse as planetary magnetospheres, the solar corona, and astrophysical radio sources.

GOALS AND CONSTRAINTS IN PLANETARY EXPLORATION

Direct exploration and study of the solar system demand a dedication of effort and resources only possible through a significant national commitment. The return, however, is comparably significant. The level of intellectual and scientific inquiry is not only an important measure of a people's vigor, but also a stimulus to progress in modern societies.

Nevertheless, realistic constraints limit the level at which such activities can or should be conducted. These constraints are especially apparent in the exploration of planets and other, similar deep-space adventures. By their very nature, these activities involve many people, large amounts of time, and large expenditures. Spacecraft missions are limited in number and frequency, so that the empirical basis of solar-system science depends, to a large extent, on the technical and intellectual success of a relatively small number of measurement opportunities. It is important, therefore, to make optimum use of these limited opportunities, to ensure that exploration programs elucidate significant questions and that the quality of returned data makes a substantial contribution to our knowledge and understanding.

In practice, the planning and execution of a planetary exploration mission takes five to ten years. This inhibits the normal conduct of scientific investigation, which relies on the ability to interact with experiments and to devise new measurements in response to the results. Planetary exploration inevitably reveals unanticipated and surprising facts that cause us to rethink our assumptions and that promote enthusiasm for a new generation of studies. It is important that exploration strategies chart a balanced course between responsiveness to new discoveries, continuous attention to major scientific questions, and coherence in planning on the roughly ten-year time scale necessary for designing and carrying out many of the exploratory missions. Generally, the ability to strike a balance in this kind of scientific exploration is enhanced by setting long-term goals for study. Substantial progress toward realization of these goals requires specific strategies of investigation that should rest securely on our current knowledge of solar-system bodies and should aim at testing our ideas about their behavior, origin, and evolution.

PRESENT KNOWLEDGE OF THE SOLAR SYSTEM

The planets divide naturally into two classes on the basis of size, density, and position in the solar system. The major planets—Jupiter, Saturn, Uranus, and Neptune—contain most of the mass and angular momentum of the solar system, are of low mean density (1–2 $g cm^{3}$), and range from 5 to 30 AU (Astronomical Units) in distance from the Sun. (An Astronomical Unit is the mean distance from the Earth to the Sun, approximately 93 million miles.) These large outer planets are rich in volatiles, especially hydrogen and helium, have low surface temperatures, and have well-developed satellite systems that mirror, in a fashion, the solar system itself. The inner planets—Mercury, Venus, Earth, and Mars—are by contrast smaller in diameter, higher in density (4–5 $g cm^{3}$), and range from 0.4 to 1.5 AU in distance from the Sun. The inner planets are composed chiefly of rock and metal, are comparatively poor in volatiles, and have few satellites. The ninth planet, Pluto, which is 40 AU from the Sun, is clearly different from the other outer planets with its small mass and radius and the unusually large satellite-to-planet mass ratio of its single known moon.

In addition to the planets and their satellites, the solar system contains numerous small bodies with a wide range of sizes and characteristics. The asteroids are dominantly rocky and metallic objects up to 1,000 kilometers in diameter and are chiefly confined between the orbits of Jupiter and Mars. Comets are volatile-rich bodies; many have highly eccentric orbits and pass close enough to the Sun to give rise to spectacular comas (nebulous mass surrounding the nucleus of the comet) and tails.

Comets are thought to have spent most of their lifetimes in cold storage in a large cloud surrounding the solar system and extending to about 50,000 AU. Occasionally, a comet is deflected by gravitational disturbances produced by nearby stars and is sent into the inner solar system where it can be observed. Meteorites were probably originally derived from either asteroids or comets.

Origin of the Solar System

All these solar-system bodies—planets, satellites, asteroids, and comets, as well as the Sun—are believed to have originated in the expanse of gas and dust that constituted the proto-solar nebula. The mechanism of collapse of this nebular cloud into the proto-Sun and proto-planets is not known. One theory, stimulated by the recent discovery of distinctive isotopic anomalies in certain primitive inclusions in carbonaceous chondrite meteorites, suggests that star formation in the proto-solar nebula was triggered by a supernova shock wave. Matter injected into the nebula from the supernova, according to this view, would be rich in such nuclides as ^{16}O and ^{26}Al and would not likely be homogeneously mixed throughout the nebula. Isotopic anomalies dating from this event might be expected to be preserved in portions of those primitive objects distant from the Sun and never subjected to substantial heating and isotopic reequilibration.

The chemistry and mineralogy of chondritic meteorites and the bulk composition of the inner planets and the planetary satellites are crudely consistent with the idea that these characteristics were shaped by chemical equilibrium in a medium of roughly solar composition. According to this theory, pressure and temperature decreased with distance from the center of the early solar nebula, and equilibrium thermodynamics dictated which materials condensed as solids and which remained gaseous at varying distances from the Sun. At some point, much of the uncondensed material must have been dissipated, perhaps by an unusually strong solar wind. Whether proto-planets with massive atmospheres formed prior to the dissipation of nebular gases is not certain. In any case, this sweeping out of gas is called upon to leave the inner solar system volatile-poor while preserving the gaseous material now in the atmospheres of the outer planets.

This chemical equilibrium model for the formation of planetary material leads to the prediction that the planets should range in composition from Mercury as the most refractory to the volatile-rich objects in the outer solar system. Equilibrium at 600°K can account for the characteristic assemblage of metallic iron, ferromagnesian silicates, and ferrous sulfide in the ordinary chondrites. Equilibrium at still lower temperatures, below 150°K, yields the ices of H_2O, NH_3, and CH_4 as major components of the condensed phase, which are characteristic of planets far from the Sun.

The Inner Planets

Among the objects in the solar system, the inner planets and their satellites are the best known. Though broadly similar in composition, the inner planets vary in mean density from 5.5 $g\,cm^3$ for Mercury to 3.9 $g\,cm^3$ for Mars. The variation in planetary mean density with solar distance can generally be explained by the equilibrium condensation model for proto-planetary material. The moons of Earth and Mars, substantially lower in uncompressed density than the planets they orbit, are less easily explained by the simple nebular condensation model.

All the inner planets, including the Earth's Moon, have undergone significant internal heating and differentiation. The oldest preserved rocks on the Earth are about 3.7 billion years old, and most of the Earth's surface—the ocean floor—is less than 0.1 billion years in age. In contrast, the Moon has preserved some rocks dating back to its early episode of melting and crust formation 4.5 billion years ago and contains no rocks younger than the period of volcanic flooding of the lunar maria from 3.9 to about 3.0 billion years ago. The Moon has also recorded a period of intense meteor bombardment that ended about 3.9 billion years ago, a bombardment that produced many of the large impact basins on the Moon and presumably also occurred on all the inner planets at about the same time. This assumed heavy bombardment of the inner solar system has provided a chronological reference marker that has been the basis for constructing the geologic history of Mars and Mercury and may serve a similar purpose for Venus.

The inner planets differ substantially in the characters of their atmospheres. Both Mercury and the Moon are devoid of any stable atmosphere. The dominantly CO_2-rich atmosphere of Venus is nearly one hundred times more massive than the Earth's, while the CO_2-rich atmosphere of Mars is one hundred times less dense than that of the Earth. The noble-gas abundances in these three respective atmospheres roughly correlate with their atmospheric density. Venus and Earth have similar abundances of nitrogen with respect to planetary mass, while Mars is relatively depleted. Venus is covered by a dense global blanket of clouds composed in part of sulfuric acid droplets. Cloud motions indicate a global wind pattern with a substantial height-dependence to mean wind speed. Mars is known to have episodes of high-velocity winds that give rise to global dust storms. Mars also has climatological seasons, with cycling of CO_2 between the polar caps providing a major component of atmospheric circulation.

The Earth

The Earth is unique among the planets in the large quantities of free water on its surface and in its atmosphere. Water is present in the atmospheres of Mars and Venus, but is substantially less abundant. Water ice is also the chief component of the small residual polar caps on Mars. Mars shows evidence on its surface, however, of ancient large-scale flooding and fluvial erosion, suggesting both a denser atmosphere and abundant liquid water at some time in the Martian past. The present fate of that water is a major mystery; that substantial quantities of volatiles are held in a "permafrost" layer at some depth beneath the Martian surface is currently the most favored hypothesis. The Earth also stands alone among the planets, so far as is known, in that its surface, atmosphere, and hydrosphere have provided an environment conducive to the development of life and the evolution of complex living organisms. Because the surface of Venus is so hot (750°K), Mars has long been thought to be the planet next to Earth most likely to harbor life. The absence of detectable organic molecules on the Martian surface and the apparently hostile surface chemical and physical environment suggest that living organisms are not present on Mars. Whether Mars was less hostile to the development of life during earlier times, when it may have had a denser atmosphere and flowing surface water, is an important but open question.

The Earth's surface is now known to be in a state of continuing dynamic evolution. Crustal material is continually created at mid-ocean ridges and destroyed beneath the deep-sea trenches, as the plates that make up the Earth's surface move in more or less steady relative motion. The creation of huge mountain belts, the development of chains of volcanoes, and the driving force behind many large earthquakes are all linked to these plate motions. Neither the Moon, nor Mercury, nor Mars show evidence for global tectonics of such vigor or for the wholesale recycling of the surface into the interior. The surfaces of the Moon and Mercury preserve a clear record of early heavy meteor bombardment and of limited ancient volcanism and tectonic features associated with that volcanism or with tidal spindown and global cooling. The surface of Mars also shows a record of heavy meteor bombardment, slightly softened by subsequent wind erosion, but demonstrates a more extended and extensive history of volcanism and tectonics, though still less than on the Earth. The Venusian surface, hidden by permanent clouds, is largely an enigma. Limited low-resolution Earth-based radar images suggest a surface with both craters and large volcanoes, as on Mars, together with mountain belts as on Earth. Many of these are currently being mapped at low resolution by the Pioneer–Venus radar altimeter and imager.

The Earth's interior is known to be layered, a product of global differentiation. At the Earth's center is a metallic core, largely fluid and in convective motion, but with a small solid inner core. The core is surrounded by a mantle of ferromagnesian silicates, mostly solid and in very slow convective motion. The mantle is capped by a thin crust of igneous and metamorphic silicate rocks, generally overlain by a veneer of sedimentary material. Each of the other inner planets is thought to be similarly layered, but the evidence for this varies. The Moon is known to have distinct crust and mantle layers, and is covered by a regolith layer that is continually "gardened" by repeated meteor impacts. Mars is thought to have a core because of its low moment of inertia factor and a crust because of the isostatic compensation of its surface topography. Mercury has a lunarlike regolith, but global-scale structural information is lacking. That Venus likely has a crust is revealed by long-wavelength topographic and gravity information and by the density and radioactivity measurements by Venera landers.

The Earth has a substantial magnetic field of internal origin, evidently produced by the action of a hydromagnetic dynamo sustained by the interaction of convective motions in the fluid core with the Earth's rotation. The field is dominantly dipolar, with a polarity that reverses at apparently random times, and has nondipole terms that tend to show a systematic westward drift. The Earth's field extends through a volume of space many times larger than the planetary volume, forming an umbrella that shields the Earth from the flowing interplanetary plasma. Of the other inner planets, only Mercury has a magnetosphere comparable in character, though much reduced in size. The Moon shows evidence for a past magnetic field of substantial magnitude, now recorded in the remnant magnetism of lunar rocks and of large segments of the lunar crust. The origin of the ancient magnetic field of the Moon is not known. Venus apparently has no internal magnetic field. The existence of a magnetic field in Mars is currently a matter of debate; if any field exists, it is small.

The Outer Planets

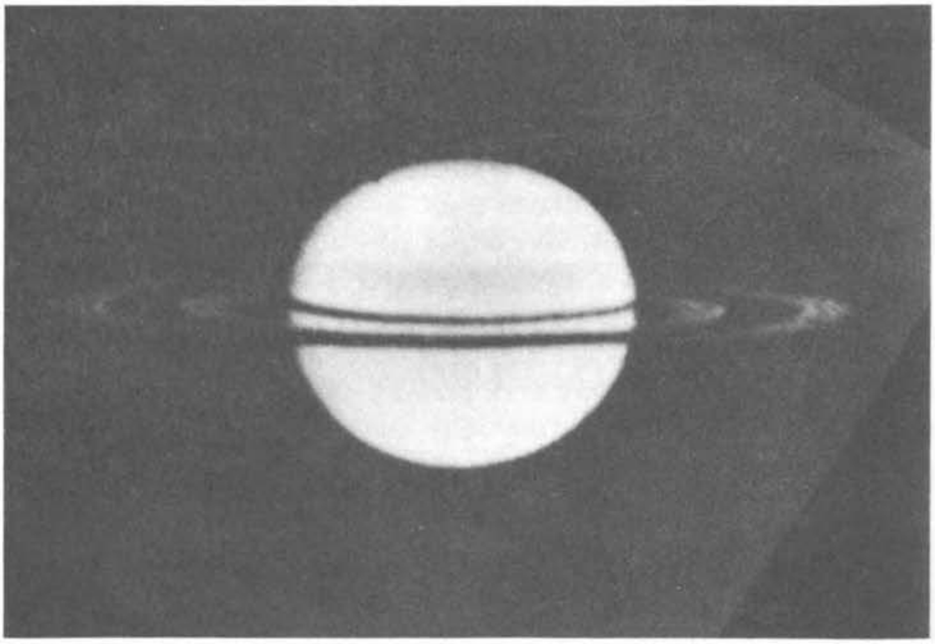
Information on the outer planets is much sketchier; so far, only Jupiter has been visited by spacecraft. On the basis of mean density, the major planets fall into two gross compositional groups. Jupiter and Saturn, the two largest bodies and the two with the lowest mean density, appear to have roughly the same composition as the Sun. Uranus and Neptune, in contrast, contain proportionately larger fractions of ice and rock. For Pluto, our present understanding is so meager that not even the mean density is well known. Even for Jupiter, about which the most is known among the outer planets, compositional information is very sketchy. The abundance of helium, the second most abundant species, has been inferred only indirectly and, though other molecular species have been identified, their precise abundances are not established. The compositions of the several cloud layers on Jupiter are not definitely known. Even less chemical information is available on the other outer planets.

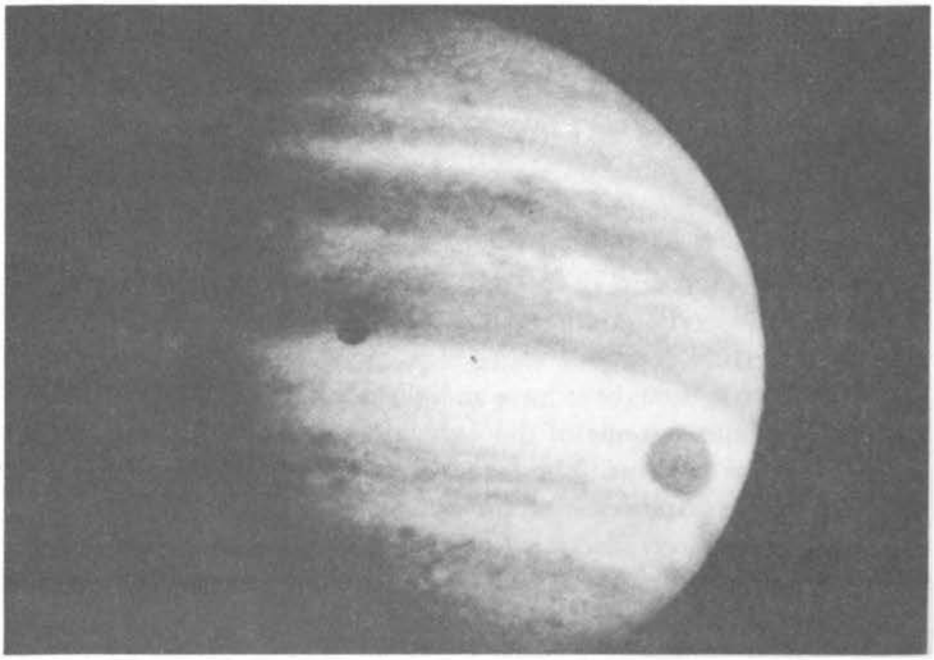
The net energy balance and large-scale atmospheric dynamics of the major planets are of interest, both for their own sake and for the information they carry on the state and dynamics of the interior. Jupiter, Saturn, and Neptune each appear to radiate substantially more energy than they receive from the Sun, indicating an internal energy source, perhaps gravitational in origin. Much is known about the atmospheric circulation on Jupiter from cloud observations and radiation measurements, but the vertical atmospheric structure is not well established. Even less information is available about Saturn's atmospheric dynamics, and almost nothing is known of atmospheric dynamics for more distant bodies.

Jupiter has an internal magnetic field and a large magnetosphere that accelerates energetic particles. The origin of the field—as for the Earth—is ascribed to dynamo action in an electrically conducting fluid interior, but the conductor is thought to be metallic hydrogen in Jupiter, rather than iron–nickel as in the terrestrial planets. The magnetospheres, if any, of the other outer planets are uncharted. On the basis of observed nonthermal radio-frequency emissions, presumably produced by energetic charged particles trapped in a magnetosphere, Saturn is thought to have an internal magnetic field.

The satellite systems of the outer planets might be regarded as miniature solar systems. The larger satellites are presumed to have formed at large distances from the Sun. At least three planets, Saturn, Uranus, and Jupiter, also have rings of small particles orbiting at distances within the range at which large satellites would be disrupted by tidal stresses. The rings of Saturn may be largely water ice.

The larger satellites of the outer planets are of planetary size, and include objects with their own atmospheres and ionospheres. Compo-





Pioneer pictures of Saturn and Jupiter

sitional and structural information on these bodies is very scanty. The four largest satellites of Jupiter decrease in mean density with distance from the planet, from 3.6 to 1.8 $g cm^3$. These densities suggest compositions ranging from rock to roughly equal mixtures of rock and ice. The variation in density with distance from Jupiter has been ascribed to a decreasing temperature with distance from the proto-planet during its formation and evolution, much as the variation in density of the planets has been ascribed to heliocentric temperature and pressure gradients.

The recent Voyager mission revealed that some of Jupiter's moons are active planetary bodies. For example, Io may be one of the most volcanically active bodies in the solar system. Moreover, Io is unusual in that the energy source for its volcanism may be its tidal interaction with bodies in the Jovian system. Europa shows evidence for global tectonic processes, perhaps in an outer shell consisting of water and ice.

Comets and Asteroids

Comets and asteroids are objects that may have escaped most of the internal heating and differentiation to which the planets have been subjected. Although these objects have been studied only remotely from Earth to date, they may have sent samples to us in the form of meteorites. Though much intensive work has been performed in laboratories on the chemistry, mineralogy, and detailed chronology of meteorites, a definite link between any meteorite and any individual or class of asteroid or comet has not been established.

Asteroids and comets differ in their sources of origin in the solar system, in their abundances of volatiles, and in their orbits and interaction with the Sun. Asteroids are largely rocky or metallic and most likely were formed approximately at their present solar distances. There is a similarity—on the basis of spectral-photometric comparisons—between asteroid surfaces and those of a variety of meteorite classes. The significance of this similarity is not now understood. There is evidence that some asteroids, and the parent bodies of some meteorites, have undergone some heating, metamorphism, and, in some cases, differentiation since their formation. Other asteroids are thought to be composed of material that has undergone no significant change since accretion. The asteroids are extremely heterogeneous in size and surface composition. There is some indication that the average composition of asteroidal material varies significantly with solar distances.

Comets are thought to be mixtures of ice, dust, and rock that remain from solar nebula condensation in the outermost regions of the solar system. Stored for most of their lifetimes in orbits at great distances from the Sun, the comets with which we are familiar were perturbed into eccentric and often highly inclined orbits around the Sun and with perihelion distances within several Astronomical Units. The interaction of a comet with the solar heat and wind near perihelion (the point of its closest orbital approach to the Sun), through a process not well understood in detail, gives rise to the cometary coma, or atmosphere, and to the often spectacular cometary tail. The nucleus of a comet is thought to be a solid mixture of ice and less-volatile silicates. However, no nucleus has ever been seen as other than an unresolved point of light. Like asteroids, the population of comets is extremely diverse in orbits and in remaining volatile content. Many of our ideas about comets are untested. Both the testing of these ideas and the establishment of a link between comets and the basic building blocks of the outer solar system require *in situ* study.

TECHNOLOGY FOR SOLAR-SYSTEM EXPLORATION

Strategies for exploring the solar system require not only a strong scientific foundation, but also an awareness of technical capabilities and restrictions. These restrictions take many forms but are, of course, clearly related to the level of available financial support. Strategies must also incorporate new developments and constantly changing technical capabilities.

So far, all solar-system exploration has relied on spacecraft that travel along nearly ballistic trajectories. Spacecraft journeys are spent mostly in free, unpowered flight after a relatively short interval of thrust following launch and are possibly terminated by another short thrust to produce orbital capture about the target planet. This mode of operation leaves many bodies relatively inaccessible. Trips to the outer solar system require long flight times and large expenditures of fuel even for the delivery of modest scientific payloads. Not only are the requirements for doing scientific research taxed, but so also is the long-term reliability of spacecraft components during extended travel times. An unfamiliar dynamics governs the motion of objects that move in orbits rather than in straight lines. In terms of the propulsion needed to reach and achieve orbit, even some objects that seem to be nearby are relatively inaccessible. For example, Mercury's orbit, at four-tenths of an Astronomical Unit from the Sun, is only six-tenths of an Astronomical Unit removed from the orbit of the Earth. Getting to Mercury and orbiting it is comparable in difficulty, however, to getting to and orbiting planets of the outer solar system, which are ten times, or more, farther from Earth. Other objects are similarly inaccessible to traditional ballistic launch capabilities. For example, most young and middle-aged comets travel on highly inclined orbits and at high velocities when in the inner solar system, making it difficult to achieve the low-velocity, sustained encounters needed to address many of the fundamental scientific questions we wish to ask of these interesting objects. The ability of spacecraft to reach difficult targets with significant payloads can, in some cases, be augmented by maneuvering past planets and taking advantage of deflection in their gravitational fields. This depends on fortuitous planetary alignments and, even when possible, often exacts a penalty by extending travel times. An exploration strategy and its pace must take into account what is possible and practical in terms of spacecraft propulsion. At present, this is a real limitation.

Freedom from this limitation requires new approaches to propulsion. There is now under development a continuously thrusting propulsion system—the so-called ion drive—that operates on electricity and produces a high specific impulse thrust. This should provide us with a new measure of capability, beyond that currently available, in addressing significant scientific questions of difficult-to-reach objects such as Mercury, Saturn, and comets. The continuously thrusting propulsion system should relieve our dependence on relatively rare launch windows, allow the delivery of greater scientific payloads, and, in some cases, shorten trip times.

Aside from the problems of accessibility, other technological limitations also hamper our ability to carry out scientific measurements. An important example occurs in the case of Venus, where extremely high surface temperatures curtail the useful life of scientific instruments. The longest operational interval—two hours—was accomplished by a recent Soviet vehicle. Using present technology, measurements taken on Venus are restricted to those that can be made quickly; long-term monitoring of the planet's seismicity, for example, is not technologically feasible. Much of the surface of Mercury presents similar barriers. Development of a capability to operate scientific instruments for extended times in such hostile surroundings will enable us to address important questions that are now beyond our reach.

So far as we know, the technological difficulties inherent in planetary exploration are not insurmountable; adequate planning and research should overcome them. In some cases, there are advantages to carrying out measurements in laboratories, rather than with instruments aboard spacecraft. For the detailed chemical and isotopic analyses needed to read the ages and histories of solar-system materials, for instance, there are great advantages to analyses by the full panoply of laboratory techniques. Return of extraterrestrial samples for analysis, therefore, is an important component in the study of many solar-system objects, and sample-return techniques should be planned as an integral part of an overall exploration strategy that should also include *in situ* measurements. The two kinds of investigations should be structured so as to take advantage of their mutually supportive aspects in a continuing program of solar-system studies.

ADVISING ON SCIENTIFIC GOALS

The Space Science Board Committee on Planetary and Lunar Exploration has developed a new approach to advising on solar-system exploration. Traditionally, a set of specific missions was recommended, which implied that exploration of the solar system was defined by a sequence of missions, rather than by a set of scientific goals. A strategy identified in terms of missions rather than expected accomplishments is extremely vulnerable to the vagaries of fiscal and programmatic decisions. But a strategy based upon expected accomplishments remains valid and useful independently of the missions that may be chosen to carry it out.

When formulating a strong, coherent science strategy, a line must be drawn between those areas of the scientific endeavor that should be very strongly influenced by a concerted advisory process and those areas that are not well served by such a process. Much of the empirical basis of solar-system science depends on the intellectual success of a very few deep-space ventures. A strong advisory component is important, therefore, to ensure taking maximum scientific advantage of exploration opportunities. However, most of the scientific endeavor depends on the efforts of individuals in laboratories and offices—areas that do not lend themselves to a strong advisory process. In these cases, centrally controlled planning and allocation of resources is likely to result in stifling the creativity of the investigators to the detriment of the scientific enterprise.

EXPLORATION STRATEGIES

Planetary exploration can proceed on many levels. To organize and keep track, at least in a crude way, of the progress of our investigations, it is useful to define several levels of study. This provides a convenient framework within which to construct our plans for exploration of any object. Such an organizational framework is particularly useful to the effort to understand basic aspects of the origin and evolution of solar-system bodies. This scientific thrust requires emphasis on comparative studies and enhances the value of a broad-based exploration program with a balance of attention to relevant and accessible objects. Cataloging the progress of our investigations of various bodies according to a carefully thought out set of levels helps to maintain a reasonable balance. There are important reasons for achieving balance in the exploration of solar-system bodies. Science is characterized by the application of a small set of ideas to the elucidation of a large set of phenomena. Unless we have comparable information about a class of objects, we have no way to judge the generality and correctness of our ideas, and it is then easy to be seduced by *ad hoc* explanations that appear successful when applied to only one or two bodies, but that collapse when examined in a broader context. However, the definition of levels of investigation should not be allowed to dominate and restrict our thinking. The desire for a balanced approach to planetary exploration should not be allowed to destroy the flexibility of our programs and our responsiveness to new information. For many reasons it is natural to expect that planetary studies, especially at the more intensive levels, will concentrate on some bodies more than on others. This will come about for reasons of easier accessibility as well as the relationship of questions that may be asked to the concerns of Earth-bound man.

Levels of Investigation

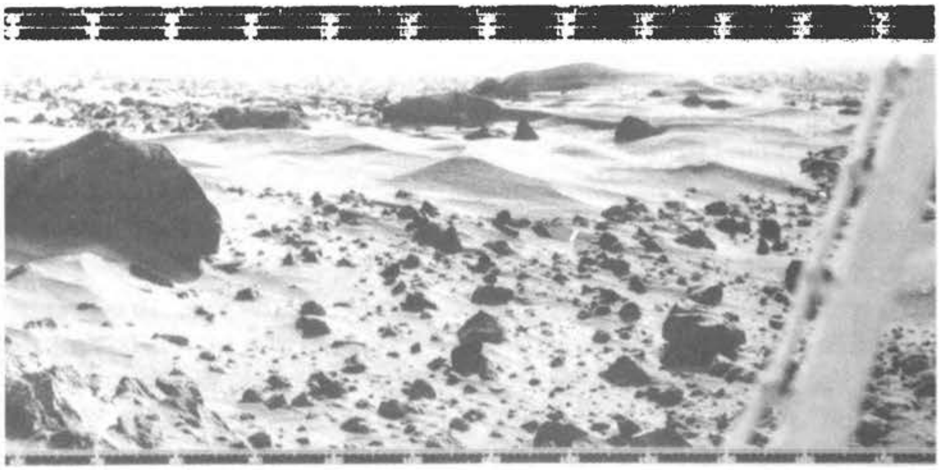
The Committee on Planetary and Lunar Exploration (COMPLEX) has defined three levels of investigation applied to planets: reconnaissance, exploration, and intensive study. These levels are arranged hierarchically, proceeding at one end from measurements aimed at grossly characterizing a body's properties and environment to performing experiments designed to answer specific and well-defined questions. This hierarchical sequence of investigation levels corresponds closely to the sequence in which planetary exploration will normally be carried out, experiments designed for the later phases coming in response to questions posed by earlier, less-intensive investigations. Generally speaking, as defined by COMPLEX, the objectives of planetary reconnaissance are met in the first brief encounters by spacecraft, usually as they fly by the planet. The next level of study—exploration—which begins to aim at understanding important aspects of a planet's present state as well as the processes involved—requires more intimate association and generally involves orbiting spacecraft and probes that enter the atmosphere and land on the surface. The most intensive study proceeds to active experimentation, including the possibility of return of samples for laboratory analysis.

Not all solar-system objects fit smoothly into one level of investigation. Knowledge derived from Earth-based telescopic observations varies in magnitude and character from one class of objects to another. Thus, for some objects, we may conclude that spacecraft investigation is justified only if the initial science return is at a more advanced level than could be expected from, say, an exploratory fly-by. As an example, exploration strategy for the small, primitive bodies of the solar system—comets and asteroids—is now under consideration. The burdens placed on a program to explore these objects are different from those placed on much of planetary exploration. To begin with, meteorites recovered on Earth provide us with samples of solar-system debris, which are surely related to asteroidal and cometary material, even if in an unknown way. Also, these objects are numerous and are interesting as members of classes that may represent different degrees of primitive evolution. Further, as mentioned earlier, asteroids reveal a range of spectral characteristics to telescope observations; these spectral characteristics bear a loose relationship to the properties of meterorites. We also know that some meteor showers are associated with orbits of comets, suggesting the possibility of a relationship between some recovered meteorite samples and some component of the nonvolatile comet material. These facts raise questions, even at our present level of knowledge, that cannot be addressed by the usual fly-by reconnaissance investigation. A judgment must be made about what kind and level of investigation is necessary to return information that will address these questions and provide a significant increment in our knowledge. Thus, for example, since we already have established, from telescopic observations, the existence of wide variation in the types of asteroidal material, we may conclude that to justify exploration with spacecraft requires chemical and mineralogical measurements of a quality sufficient to distinguish among the major known meteorite types.

A Strategy for the Next Decade

COMPLEX has formulated a stragegy to guide solar-system exploration over approximately the next decade. It has been convenient and conceptually useful to divide the recommendations into three parts: the planets of the inner solar system (Mercury, Venus, Earth and its Moon, and Mars); the outer solar system (Jupiter, Saturn, Uranus, Neptune, and Pluto); and comets and asteroids. One reason for the utility of this division can be seen by summarizing the salient characteristics of these three classes of objects, which were described earlier. Most of the outer solar-system planets apparently formed at low temperatures and trapped large quantities of volatile material from the preplanetary nebula. The four rock and metal planets of the inner solar system consist primarily of minerals that condense at relatively high temperatures and that apparently accreted to form planetary bodies without carrying along large quantities of highly volatile substances. The planets of both the inner and outer solar system have in common the qualities of being large and formed with enough internal energy to drive continuing planetary evolution, which has erased evidence of the formation processes and altered the character of planetary material since the time of formation. By contrast, the smaller solar-system objects—especially comets and asteroids—did not contain enough internal energy to drive continuing planetary evolution. Thus, in these bodies, the character of solar-system material at the time of formation is relatively well preserved; also, evidence of early energy sources and metamorphic processes, which has been obliterated on planets, is apparently preserved in some of these primitive bodies.

For the decade running through 1985, COMPLEX has recommended that outer solar-system exploration not extend beyond Uranus. The targets for investigation in this time period are Jupiter, Saturn, and

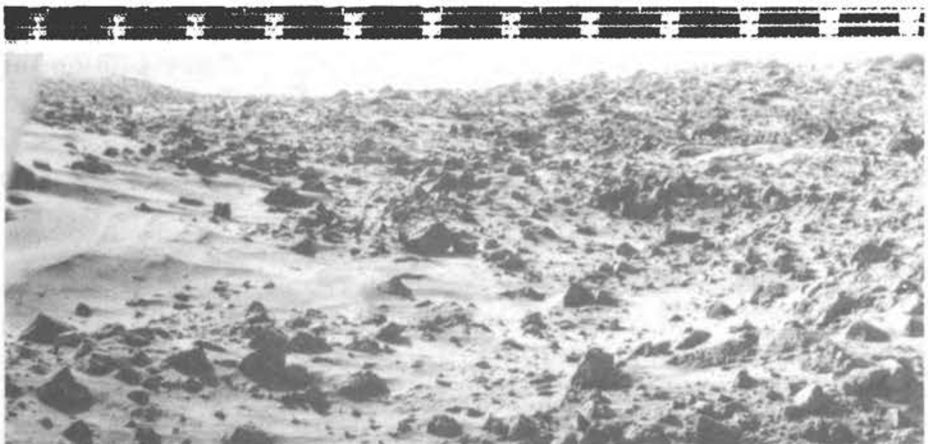


Martian landscape

Uranus, along with their satellite systems. A reconnaissance of Jupiter was accomplished by the Pioneer and Voyager spacecraft and the committee recommended that a major undertaking during the decade be an exploratory investigation of Jupiter, its satellite system, and magnetosphere. The primary recommended objectives are to determine the chemical composition and physical state of Jupiter's atmosphere and satellites and to explore the planet's magnetic field and energetic particle fluxes. The Galileo mission, being developed to accomplish these goals, will employ an atmospheric entry probe as well as a Jupiter orbiter that will explore the magnetosphere and make numerous close passes to several satellites, enabling investigations through remote-sensing techniques.

The committee has also recommended that reconnaissance-level investigations of both Saturn and Uranus be accomplished during the decade. Aspects of these recommendations are expected to be satisfied through planetary fly-bys involving the Pioneer and Voyager spacecraft. Looking forward, COMPLEX regards exploratory investigation of Saturn as the next step in continuing study of outer solar-system bodies beyond 1985.

For the inner solar system, reconnaissance-level investigations are completed, and COMPLEX has recommended that the decadal strategy



have as its major focus the triad of planets—Venus, Earth, and Mars. This choice is based on the belief that these three bodies pose a fundamental and well-defined challenge to our understanding of planets. As noted earlier, the atmospheres of these bodies span a factor of 10^4 in density; Mars' atmosphere is about one percent of Earth's; Venus' atmosphere is about one hundred times that of Earth. These differences are very apparent from our anthropocentric viewpoint and are very large in comparison with other variations in the planetary properties as we currently perceive them. The "air"-less bodies of the inner solar system are relegated to a lower priority for the decade. This recommendation also takes into account anticipated propulsion capabilities.

At this time, Venus is being subjected to investigations of its atmosphere and solar-wind interaction by the Pioneer–Venus mission, which employs several atmospheric probes and an orbiting spacecraft. The major science objectives recommended to carry Venus investigations through the decade to 1987 are to ascertain the composition of the planet's surface material and its interaction with the atmosphere and to explore important photochemical processes in the atmosphere that are analogous to processes in the Earth's atmosphere.

Maps of planetary surfaces have had a profound impact on our understanding; they contain records of the dominant processes that have shaped the terrestrial bodies. For example, maps of Mars reveal the earlier episodes of erosional processes that are not understood in terms of the current Martian climate. This suggests that conditions on Mars may have been very different in the past and raises important questions about the stability of planetary environments. Venus is shrouded in a dense layer of clouds, its surface hidden from us except for a few coarse, but tantalizing, sketches drawn by Earth-based radar; these vaguely show a number of large features spread on the planet's surface. An important goal for the next decade of studies on the inner

solar system is construction of a detailed map of Venus' surface. It appears that techniques employing radar from an orbiting satellite are applicable to this task.

Since the Viking mission to Mars, studies of that body have advanced to a more intensive level than have studies of any other planetary object save the Earth and Moon. Our investigations of Mars have posed new questions that challenge our understanding in important ways. Approaching the answers will involve major scientific efforts. The recommended primary objectives include establishing the composition and chemical and physical character of the surface in its diverse domains, determining the nature and chronology of surface-forming processes and the inventory and distribution of volatile substances, exploring the structure and circulation of the atmosphere, exploring the structure and dynamics of the interior, and establishing the planet's state of magnetization and its solar-wind interaction.

CONCLUSION

The Committee on Planetary and Lunar Exploration has designed a decadal strategy for scientific exploration of the planetary system and is now formulating a strategy for exploring the small, primitive, and relatively unevolved solar-system bodies—the comets and asteroids. This will complete a task begun some five years ago and will provide the framework for a coherent approach to solar-system exploration through most of the 1980's.

The recommended program of exploration is vigorous within the confines of an anticipated restricted budget for these activities, is conservatively paced, and, for the most part, reflects a level of activity near the minimum that is perceived necessary to keep the research efforts viable and healthy.

When the explorations are completed, we will have reached all the known planets of the solar system save two—Neptune and Pluto. We will have achieved a gross understanding of the morphologies and environments of Uranus and Saturn and their satellite systems. We will have plunged into Jupiter to test its composition directly, and we will have explored its satellites. In the inner solar system, we will have begun to unravel the profound mysteries that will be the legacy of our earlier exploration of the terrestrial planets. We will have focused on the triad of close sister planets—Venus, Earth, and Mars. Disentangling their similarities and differences will provoke and test our ideas about planetary evolution and the behavior of terrestrial environments. And we will have undertaken to study the primitive bodies of the solar system, which, we expect, have most faithfully recorded conditions during the early years of the solar system.

Study Project

ASSEMBLY OF MATHEMATICAL AND PHYSICAL SCIENCES

CHEMICAL SCIENCES

The truism that chemistry in its concern with the transformation of materials is a central science is apt. An understanding of the changes in the structure and properties of molecules with varying conditions is intimate to the progress of many sciences: whether molecular biology, relating molecular properties to genetic effects; condensed-matter physics, in which the behavior of liquids and solids is in part a function of the atoms and molecules that compose them; or oceanography, in which, to take one example, the abilities of the ocean surface to absorb and release carbon dioxide depend directly on the carbonate chemistry that occurs.

And just as chemistry is central to other fundamental sciences, so it is to applied science and to technology. Chemical principles and facts weave through the efforts to create new energy sources or to improve existing ones; a host of environmental problems, from controlling automobile emissions to identifying hazardous materials in water; or the search for new materials.

The evident pervasiveness of chemistry is not invariably mirrored in the management and support of programs relating to fundamental or applied science or to technology. Chemistry as a science per se is strong, but its wider role is not always explicitly acknowledged nor always understood. In part for that reason, the National Research Council brought into being the Committee on Chemical Sciences, within the Assembly of Mathematical and Physical Sciences, to "assist federal agencies responsible for funding basic research in chemical sciences in developing long-range plans, identifying potential problems, and [to] call attention to emerging fields of chemical science that could contribute to the solution of national problems such as energy, environment, and the availability of materials." The intent of the committee is to provide advice on the broad potential of chemistry as a science and the conditions of management and support that best nurture it.

The committee in its first year dealt with chemical research in the Department of Energy (DOE). In its coming year of work the committee will survey the opportunities for chemistry on a broader basis and will, with the support of the National Science Foundation, the Department of Energy, and other federal agencies, examine a number of specific concerns, both scientific and institutional, of multiple-agency interest. The latter may include the funding and use of large, invariably costly, scientific instrumentation, improved methods for information storage and retrieval, and collaborative arrangements between university and industrial chemical research laboratories. Scientific concerns that the committee may consider are needs and opportunities in polymer science and engineering, advanced methods of organic synthesis, surface chemistry, and laser photochemistry. In research relating specifically to energy, the committee's agenda may include chemical investigations pertinent to solar, geothermal, and biomass energy.

The committee's probable approach to these fields is foreshadowed by its first report, issued April 1979, *The Department of Energy: Some Aspects of Basic Research in the Chemical Sciences.* The topics treated in that report include combustion science, coal chemistry, research related to reprocessing of reactor fuel and disposal of radioactive wastes, and analytical chemistry. The report also deals with some aspects of the management and structure within which DOE-supported chemical research is done, including the review and funding procedures of DOE's Division of Chemical Sciences, the use of the facilities of national laboratories by university chemists, and a mechanism for the support of an urgently needed data-evaluation program.

Obviously, the issues considered in that report—and those in its second effort—are wide-ranging, but in common can be appraised chemically: What insights and opportunities does a better knowledge of reactions and properties of materials offer?

COAL IGNORANCE

The committee's analysis of the role of chemistry in advancing coal technology is illustrative. Simply put, the committee found that new and better ways to manipulate coal may result from a better understanding of its chemical nature. Coal is the nation's principal energy supply. But it is also often dangerous to mine, messy to burn, and challenging in its conversion into a liquid or gaseous fuel.

Coal has a long history. But remarkably little is known of the chemical and physical properties of different coals, chars, and liquids. Characterization of coal is complicated by its origins, and the chemical and physical structure of coal may vary no less from millimeter to millimeter in the same seam than between coals formed from different plants in swamps hundreds or thousands of miles apart.

This great variance demands better tools for analyzing coal structures, and also their more artful use. To give just one example, better ways are needed for determining the chemical forms of oxygen, nitrogen, and sulfur in coals. Such knowledge may ease both the removal of these elements and the selection of the best ways to change coal into other products. More reliable methods are also needed for determining the physical structure of coals and coal products, particularly as it affects the access of gases and liquids to the interior of the coals.

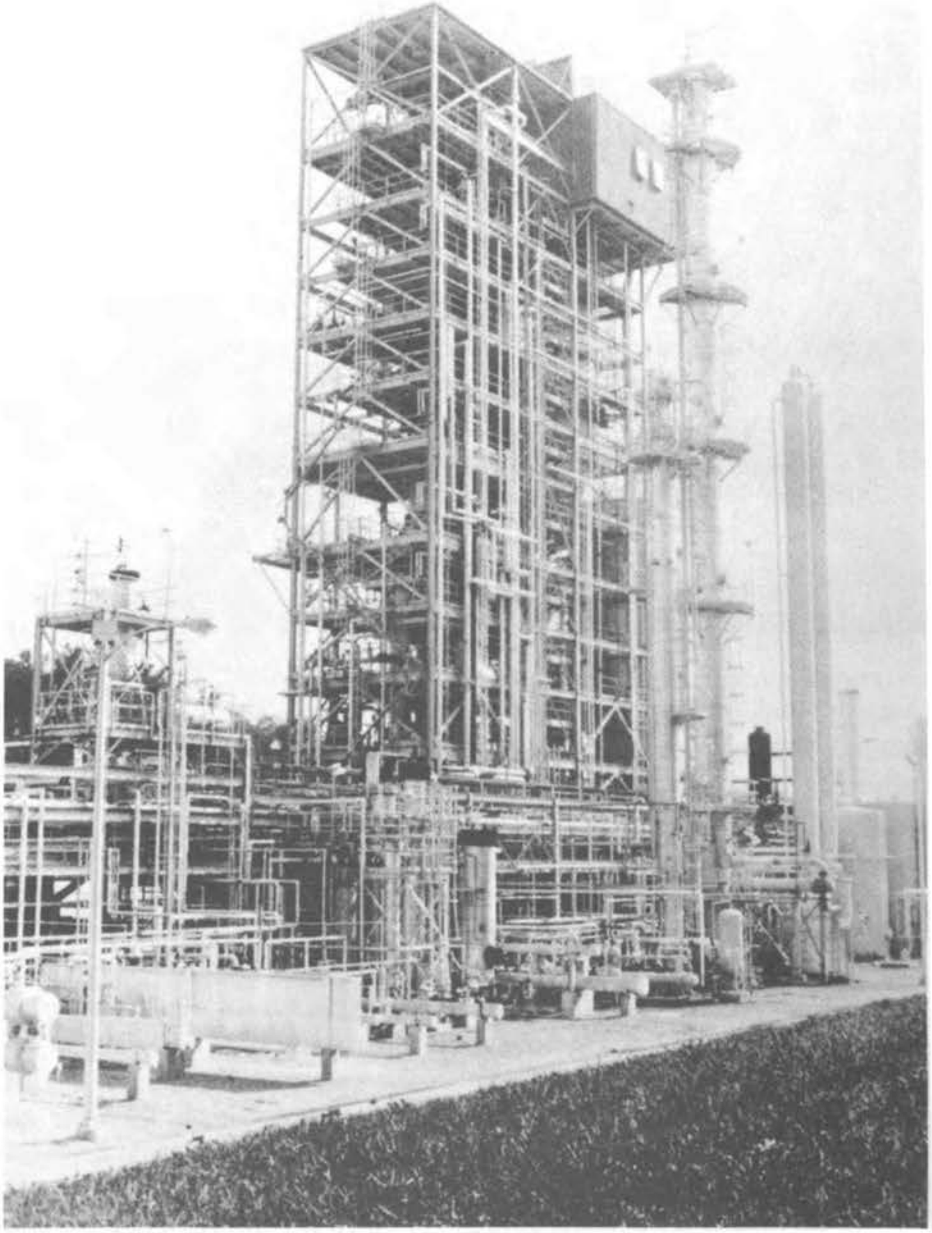
COAL COMBUSTION

Coal costs more to burn than oil and gas, in part because of the need to deal with the ash. While ash is not avoidable, some of the associated problems, such as slagging and fouling, are. Both the ash and its

slagging and fouling characteristics result from inorganic reactions that are not fully understood. It would be useful to burn coal in gas turbines, but that would require the technology to remove the corrosive, erosive ash from the combustion gases before they reach the turbine blades.

Coal when burned emits many pollutants—predominantly, the familiar particles and oxides of sulfur and nitrogen, but also smaller amounts of substances such as organic compounds, hydrogen cyanide, and hydrogen chloride. It is not known to what extent these emissions are unavoidable in coal combustion or are merely an accident of current coal technology. For example, the amounts of nitrogen oxides emitted depend on how the coal is burned; whether there is an unavoidable minimum production is not clear.

Particles emitted by coal-fired boilers are collected very efficiently by electrostatic precipitators, except for those smaller than one micron in diameter. These, unfortunately, are the particles collected most



Pilot plant for coal gasification

efficiently by the lung. Submicron particles also tend to contain a disproportionately large share of the toxic trace constituents in coal. Given the mechanisms that appear to be involved, the formation of these submicron particles likely is sensitive to the manner of combustion. Here, as with slagging and fouling, a better grasp of the inorganic reactions that produce the ash would help solve the problem.

GASES FROM COAL

The possibilities of basic chemical research on coal are further illustrated by coal gasification. Coal can be gasified in several ways, depending on the desired fuel value of the gas produced. A key goal today is production of gas high in methane to replace natural gas, itself mainly methane. This synthetic natural gas (SNG), or pipeline gas, would be made in enormous amounts, making process costs and efficiency critical.

Many bituminous coals must be pretreated, usually by oxidation, to prevent agglomeration during gasification. Five to twenty percent of the coal is lost during pretreatment. It is important, therefore, to learn to gasify raw or less-pretreated coal or how to better prevent agglomeration.

Coal is gasified in four steps. It is first pyrolyzed, or heated without burning, to produce methane, tars, liquids, carbon monoxide and dioxide, and, the major product, char. The char is reacted with steam to give carbon monoxide and hydrogen, with the mixture further reacted with steam to raise the proportion of hydrogen. In the fourth step, carbon monoxide and hydrogen are reacted to give more methane. In practice, the four steps are combined in various ways.

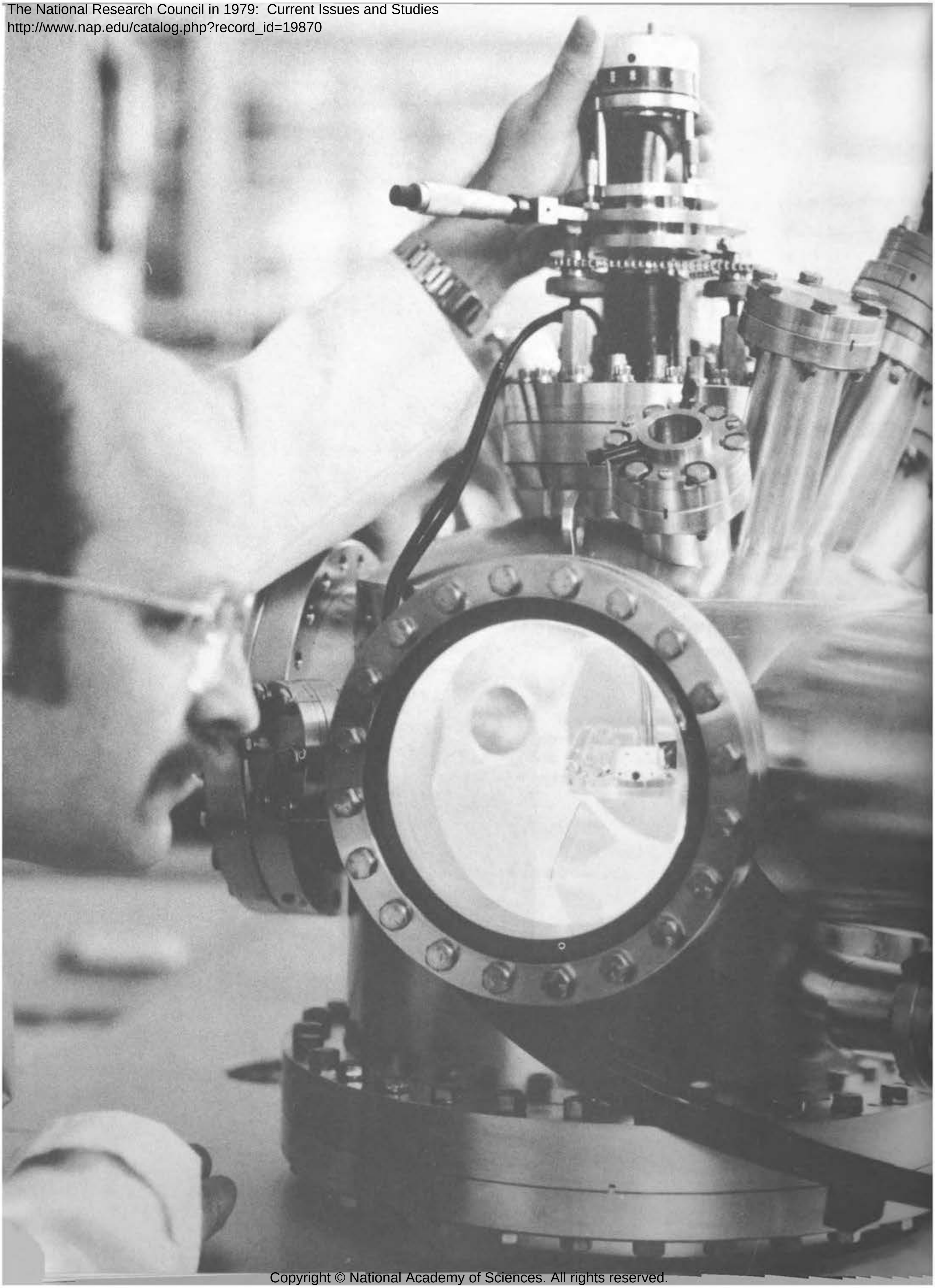
Methane is made by pyrolysis at about twenty-five percent of the cost of making it from char. Efficiency demands that the char be gasified, but the more methane obtained from pyrolysis, the lower the overall cost. Certain compounds increase gas yield and minimize coking during pyrolysis, and rapid heating and high temperature produce more methane. But ways to maximize methane output await deeper understanding of the chemical and physical processes that occur during pyrolysis, especially at high pressure.

As much as one-third of the cost of making methane from char can be accounted for by the heat requirement of the char-steam reaction. The subsequent reactions produce about as much heat as the char-steam reaction absorbs, but at a much lower temperature—600°–650°K, as opposed to 1,250°K—so this heat cannot be used to meet the thermal demand of the char-steam step. This thermal imbalance could be corrected, and costs reduced, by gasifying the char at 600°–650°K. The process is thermodynamically possible, but it requires a catalyst that is not at hand.

The basic chemistry of coal gasification is poorly understood, but help might be had from other fields. For example, graphite is a semiconductor, so its behavior may be affected by metal atoms. This may explain why pure graphite is much more sensitive to catalysts than less well-ordered carbons. What is known in solid-state physics about the behavior of semiconductors doped with foreign atoms might prove applicable to problems in coal gasification. Similarly, gasification in some ways resembles catalyst regeneration—the removal of carbonaceous deposits from the surface of solid catalysts by steam and/or air. Much is known of catalyst regeneration, and this knowledge might help to clarify the gasification process.

Committee on Chemical Sciences, Assembly of Mathematical and Physical Sciences. Committee Cochairmen, Robert E. Connick, of the University of California at Berkeley, and Alan Schriesheim, of the Exxon Research and Engineering Company; Staff Officer, William Spindel.

Commission on Human Resources



Institutional Dimensions of Human Resources

HARRISON SHULL

For more than half a century, the work of the National Research Council has reflected its recognition that the intellectual capabilities of our people are one of the nation's most important renewable resources. This work has been concerned with the education, training, quality, and supply of scientists and engineers. In 1919, the National Research Council Fellowship Program was launched; later, the Council undertook the screening of candidates and administration of fellowship programs on behalf of a number of federal agencies. In 1941, the Office of Scientific Personnel—now the Commission on Human Resources—was created to carry out studies related to scientific and engineering manpower.

Traditionally, the Commission on Human Resources has been heavily involved in building and maintaining files of scientific and engineering manpower data. Although these files represent an extraordinary national resource and should continue to be maintained,

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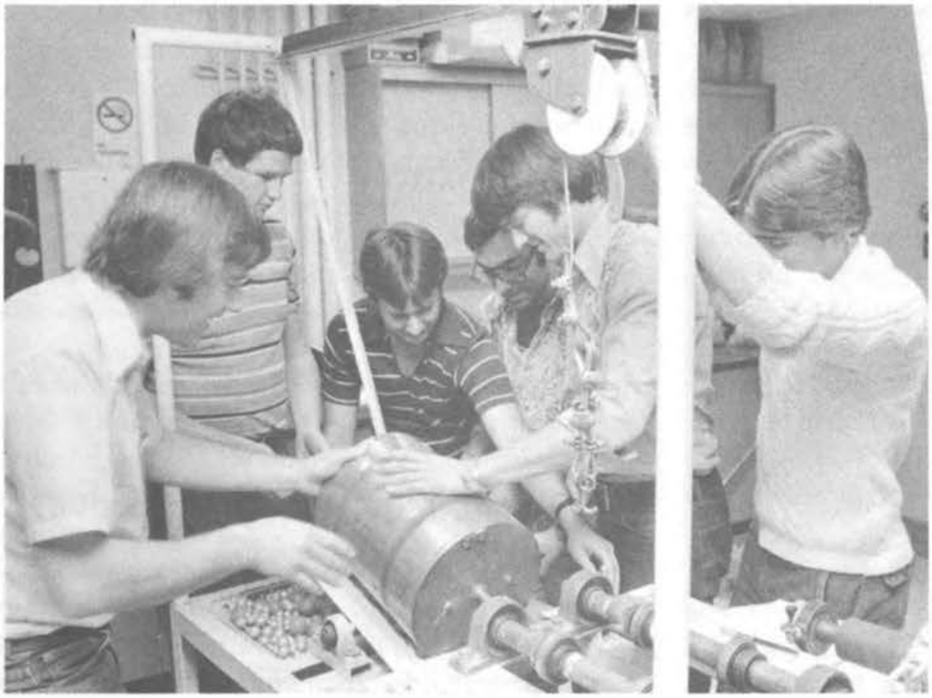
there are still gaps in our knowledge and in our understanding of many other dimensions of the problems of human resources.

For example, we have no reason to believe that there are basic innate differences between the potential capabilities of individuals elsewhere and in the United States of America. Yet, in some societies, many human resources fail to be developed at all. We cannot sort out what portions of this failure to develop come from inherent genetic differences, from differences in nutrition, from different social patterns in nurturing the young, from differing social attitudes, and from different institutional settings for the education of the young. All of these undoubtedly are contributors to the lack of full development of human capabilities.

Many of these questions are under study by other groups in the National Research Council—nutrition, social patterns, genetic characteristics, and the like—but none has the primary assignment to worry about the health of the institutional framework, which is so essential in the identification, encouragement, and education of our very brightest citizens. None has an overarching mandate to analyze the ability of institutions in our society to produce an electorate sufficiently educated to be able to make sound decisions for the future. Nor do we have studies that make clear what "sufficiently educated" really means. If our democracy is going to survive and prosper in this technological age, it is important that we do not lose sight of this need.

In this regard, the Commission on Human Resources is addressing a series of questions about the health of our educational institutions, how that can be measured, and how it can be improved. A crucially important side of the whole human resource potential of the nation is the quality of that resource—the intellectual capacity not only of individuals, but of the institutions in which these individuals are educated, and the effectiveness of the educational programs themselves. We have been concerned with what factors determine the effectiveness and the quality of a research university and graduate education. We have been concerned about the effective allocation of resources to graduate education. We worry about the state of the scientific curriculum in our universities and colleges. We deplore the lack of scientific insight of our lawyers and our business graduates. We wonder what the institutional barriers are to the full participation of



minority groups in the more intellectual reaches of our society. We ponder the great inertia of our institutions in picking up the potentially revolutionary technological opportunities in education.

Much remains to be done at every level of education, not least of all in our primary and secondary schools. We believe these can be and must be improved significantly. We were grateful, therefore, when the National Science Foundation recently asked the National Research Council to comment on the current status of school science. The panel we gathered under the chairmanship of Dael Wolfle has made thoughtful inroads into a vast area of problems in the formal education of the young. Dr. Wolfle has been good enough to summarize much of the work of that panel in the following article. This represents only the "foot in the door," the very beginning of what should be a developing and continuing concern of the National Research Council with these problems and their solutions. We welcome the interest and support of the entire scientific community in our future efforts in these directions.

Study Project

COMMISSION ON HUMAN RESOURCES

THE STATE OF SCHOOL SCIENCE

Beginning in the 1950's, several groups of scientists and mathematicians set out to achieve major improvements in the teaching of science and mathematics in the nation's schools. Congress and the National Science Foundation (NSF) responded by providing financial support through the foundation's Course Content Improvement Program and by supporting many institutes to enhance the knowledge and teaching effectiveness of thousands of teachers.

The program was a success; some major and permanent improvements resulted. Yet within twenty years of its start, the whole effort was in trouble. Some aspects of the course implementation efforts had been attacked as unfair competition for commercial publishers. Some of the materials were said to be destructive of values held dear by some segments of the population; some to be insufficiently related to real-life problems. Federal funding was reduced or eliminated.

Acutely sensitive to these charges and changes, and aware of the declining use of the innovative new courses and teaching materials that had been developed under its Course Content Improvement Program, NSF commissioned three national studies of the status of the teaching of mathematics, natural science, and social studies in the nation's schools. One of these studies is a three-volume review of the literature of the field.[1] The second surveyed national samples of school administrators, science and mathematics coordinators, and classroom teachers, as well as some students and parents.[2] The third consisted of case studies of eleven quite different and widely scattered high schools of the United States, and of the elementary and junior high schools associated with each.[3]

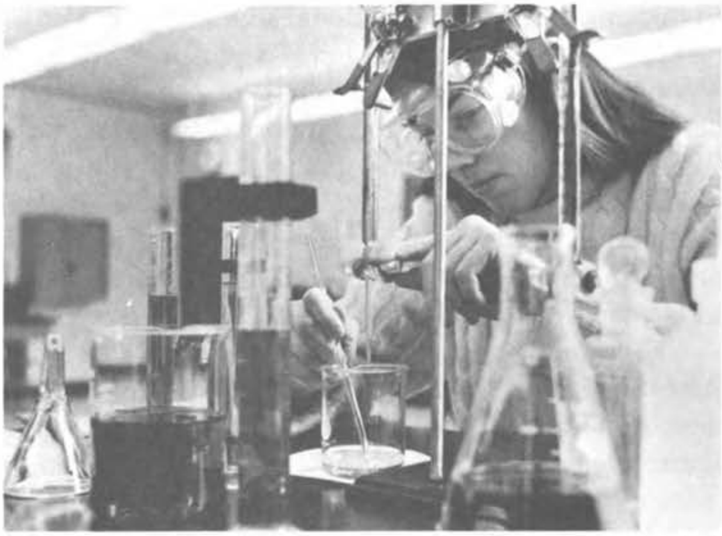
Following receipt of the three reports, NSF asked the National Research Council (NRC) to review and analyze the reports, to compare their findings with other evidence concerning the status of school science and mathematics, and to make such recommendations as seemed desirable from the standpoint of the constituency of the academy complex.

Concurrently, NSF arranged for similar reviews and appraisals by the American Association for the Advancement of Science, American Association of School Administrators, Association for Supervision in Curriculum Development, National Congress of Parents and Teachers, National Council for Social Studies, National Council for Teachers of Mathematics, and National Science Teachers Association.

Responsibility for the NRC review was assigned to an ad hoc Panel on School Science appointed by the Commission on Human Resources.[4] Working with the assistance of Dr. Douglas Lapp, Science Coordinator for the Fairfax County, Virginia, school system, the panel members reviewed the three reports, met twice, wrote summarizing statements and recommendations on specified topics, and prepared a report to the NSF. A tight schedule compressed these activities into the period between appointment of the panel in the autumn of 1978 and submission of the report to NSF early in the summer of 1979. That report and the companion reports of the other reviewing organizations are to be published by NSF in 1979.

THE THREE STUDIES

The findings and conclusions of the three studies are in general agreement. However, they were planned independently and so were



not designed to check on the detailed findings of each other. As a result, there are points on which figures do not agree closely, and there are sometimes gaps when it would have been well to have planned overlap. Even so, the three studies provide a comprehensive review of the teaching of the natural sciences, mathematics, and social studies from kindergarten through grade twelve.

A general conclusion from the three studies, and an important one to stress before looking at details, is that there is great diversity among the nation's schools. Whether a general finding be critical or complimentary of what is going on in those schools, the schools themselves are widely different. Diversity is in itself an important characteristic of American schools; but the following summary will give some general trends and characteristics emphasized in the three studies.

THE TEACHERS

The teacher decides what is taught in the classroom. Curricular outlines and instructional guides are usually prepared by school districts, or by state departments of education, and it is the state or the district that usually selects the textbooks. But when the class meets, the individual teacher is in charge. The guidelines may call for thirty minutes for the teaching of science, but it is the teacher who decides whether there will actually be thirty minutes, and whether the time will be devoted to a question and answer drill on assigned pages of the text, to an inquiry approach to a challenging question, or to reading stories about science or scientists.

On the average, the teachers who exercise this day-by-day and class-by-class responsibility have been teaching for twelve years, with only small differences among those responsible for different subjects or different grade levels. Custom and union pressures have been successful in protecting seniority, so it is the younger teacher who has been dropped when enrollments have declined or cuts have become necessary. The more experienced teachers have been retained, sometimes by transferring them to new subjects or different grade levels.

At the elementary level, forty-nine percent of the teachers feel themselves to be "very well qualified" to teach mathematics, and most of the rest feel "adequately qualified." The figures for "very well qualified" are thirty-nine percent in social studies, only twenty-two percent in science, and a high of sixty-three percent in reading. At the other extreme, sixteen percent feel themselves "not well qualified" to teach science, with smaller percentages giving this answer in the other areas.

Teachers of the junior high school grades generally feel themselves less well prepared for work with their age-group and subjects than are teachers of younger or older pupils.

High school teachers are generally better prepared in their own fields of teaching than are junior high school teachers. Half of those teaching in grades seven through twelve have earned degrees beyond the bachelor's level, as have nearly a third of those teaching through grade six. Almost half of the science teachers working in grades ten through twelve have attended one or more institutes, workshops, or conferences sponsored by NSF, and so have forty percent of the mathematics teachers at this level. In both science and mathematics, attendance rates were substantially lower for teachers of grades seven to nine, and still lower for teachers of kindergarten through six. Only a few social science teachers attended such meetings, largely because

NSF sponsored many fewer in the social sciences than in mathematics or the natural sciences.

At the elementary level, one of the studies concluded that there were so few teachers really interested in and qualified to teach science that fewer than half "of the nation's youngsters would have a single elementary school year in which their teacher would give science a substantial share of the curriculum and do a good job of teaching it."[5] For students who are still interested when they enter high school, the prospects of finding interested and qualified teachers become brighter.

WHAT IS TAUGHT

Science typically receives about fifteen to twenty minutes a day in grades kindergarten through three, and around half an hour a day in grades four through six. Social studies is given a little more time, arithmetic still more, and language arts much more. The time allotments generally fulfill requirements set by state or district guidelines, but in science they are sometimes fulfilled in a quite perfunctory way. It is probably no accident that the amounts of time devoted to the four areas parallel the teachers' self ratings of their qualifications to teach in these areas.

In grades seven and eight, students typically have one course in science (usually general science or biology) and one in mathematics (usually general math or algebra). In grades nine to twelve the elective system allows much variability. In most senior high schools there are enough courses in mathematics, natural science, and social studies to enable interested students to take one course—or sometimes more—in each area each year. Minimum requirements are much lower, however. Only a third of the school districts of the United States require more than one year of mathematics in grades nine through twelve, and only a third require more than one year of science, while three-fourths require more than one year of social studies.

More interesting and important than the time allocations are the questions of what is taught. Here there is a continuing conflict between emphasis on learning ideas and concepts versus learning facts that can be reproduced accurately in question and answer drills or on examinations. Scientists, mathematicians, and like-minded teachers who worked together in the Course Content Improvement Program were critical of the whole approach of the typical textbooks of the time and the procedures under which facts were presented, learned, and repeated in class and on examinations. Instead, they wanted to develop new courses and teaching materials that would foster better understanding of ideas and principles. Thus they placed emphasis on what is called the inquiry approach, on learning by a "hands-on" method, on discovering relationships and generalizations.

For a time, the inquiry approach, with its emphasis on ideas, gained ground, as appropriate new teaching materials became available. But some of that change was only temporary. Some of the new programs were never used by more than a tiny fraction of American schools. Others were adopted more widely, but are less used now than formerly.

Use of the new mathematics programs has declined to the extent that the "new math" in its originally introduced form has been largely abandoned. However, this statement partially misrepresents the situation, for the authors of some of those programs hoped the ideas and concepts they were advancing would be adopted by commercial textbook authors and publishers, and, to a slight extent, that has happened. Nevertheless, most of the school districts and individual teachers who tried the new math have gone back to more traditional texts, content, and methods.

New programs in the social studies were faring somewhat better in 1976–1977, although some of those programs had never been widely used, and "Man: A Course of Study" (MACOS)—the program whose innovative content was considered by some members of Congress as inappropriate and objectionable—was being used in only three percent of all school districts, and had never been more widely adopted.

It was in the natural sciences, and at the high school level, that the Course Content Improvement Program had its largest and most lasting impact. Even so, most of those courses are not being used as extensively as they were earlier. And along with that change there appears to be less use of the discovery or inquiry approach to learning, and less use of laboratory work based on that approach. Instead, the three studies agree, there is more straight didactic instruction, using commercial textbooks, some of which have been influenced by the work of the Course Content Improvement Program.

WHAT OF FUTURE CHANGES?

Still, there are some teachers, especially in grades nine through twelve, who continue to use materials and approaches of the Course Content Improvement Program. And there is a larger group who would welcome help in using the inquiry approach, who want better teaching and laboratory materials, and who oppose the current "back to the basics" movement. The case studies include a number of concrete examples, and the national survey tells us that nearly half of the science, mathematics, and social studies teachers want assistance in implementing the discovery or inquiry approach and as many want help in using manipulative or "hands-on" materials. They also want more institutes for the improvement of teaching, and they want more resource people available to help them with teaching problems.

It is difficult to know how strong their motivation is and how many would actually make use of these resources. For teachers who express these wishes are looking toward a remote ideal, while all of the daily pressures make that path an increasingly difficult one to follow. The whole climate under which they are working is less favorable for the fulfillment of these wishes than it was in the latter part of the 1950's and most of the 1960's. Science has lower priority in the thinking of school administrators. The case studies found much apathy among students, and described many of the schools as not being intellectually stimulating places in which to work. Federal and state governments have assumed so much control over the schools that school administrators have increasingly had to become managers and interpreters of the social bureaucracy rather than educational leaders. Under government mandate or court order, schools are being required to keep together the well motivated, the slow learner, the psychologically impaired, the apathetic, and the violent troublemaker. No child should be denied the opportunity to learn, but the laudable effort to provide that opportunity equitably to all, and the effort to use the schools to attain desirable social goals, create situations in which the students disturb each other, and few, if any, learn as well as they might.

Not surprisingly, "bad news" has become a frequent theme of reports concerning the nation's schools. Average scores of high school seniors on the Scholastic Aptitude Test have declined progressively since 1963. Complaints are frequent that students do not read, write, spell, or compute as well as their predecessors. Inability to read and write to expected standards is the most pervasive criticism of student performance from the upper elementary level through college. In many city schools absenteeism is high, and violence and vandalism are frequent. Whether teachers will be in their classrooms on opening day depends on whether their strike has been settled.

In this troubled climate, the prevailing goal is no longer excellence nor the mood optimistic. The schools are beset by pressures from a public grown resentful of ever-rising costs; from parents distressed by what their children do not learn in school, and sometimes by what they do learn; and from government agencies that expect detailed accountability for quantitatively measurable performance under a variety of pressures, programs, and funding arrangements.

A defensive reaction is to be expected. And the back to the basics movement is partly a defensive reaction, one that is easy to defend and justify. Reading is a basic skill, essential for later work in science, social studies, history, and every other field. If children are unable to make change accurately or to keep track of amounts and costs, further drill on the basic numerical operations seems called for. Thus the one movement that seems to be most widely supported by administrators, parents, and many teachers is to increase emphasis on reading, writing, and computation. Whether this regime will mean that high school graduates are better prepared to enter jobs or college remains to be seen. But for the time being the movement has much support, and it calls for a program that has little room for science in the elementary grades and little room for ideas, concepts, or general understanding of the principles of mathematics, science, or other fields, until some unspecified later time, after basic facts have been learned and basic skills developed.

Surely this is not the set of conditions one would choose as the environment in which to start a new course content improvement program. But continuing effort is essential, and there may be other and more promising ways of cooperating with that nucleus of teachers who retain the spirit of the Course Content Improvement Program. Many teachers would take advantage of a revived program of NSF institutes. Many said they wanted access to knowledgeable resource people who could help them with their teaching problems in science and math. Are more frequent and more cooperative school–college relationships feasible? Are there ways of augmenting the services of the science and mathematics coordinators who now provide excellent help in a few school districts? Could better use be made of science centers, museums, and similar nonschool agencies? Television has never attained its potential; is it a reasonable hope?

Whether these or other possibilities seem most promising, the three studies of current status, and now the series of reviews of those studies, constitute an invitation to think critically about precollege education and how it could be improved. The reports by the NRC Panel on School Science and the other reviewing organizations represent different points of view, but all are addressed to a set of problems of long-range importance to all scientific associations, problems that call for attention by scientists in all fields.

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4. Members of the panel were: Dr. Leallyn B. Clapp, Department of Chemistry, Brown University; Dr. Johns W. Hopkins III, Department of Biology, Washington University; Captain Grace M. Hopper, United States Navy; Dr. Gordon Millar, Vice President, Engineering, Deere and Company; Dr. John A.

Moore, Department of Biology, University of California, Riverside; Dr. David Page, Departments of Mathematics and Education, University of Illinois, Chicago Circle; Dr. James Perkins, Department of Chemistry, Jackson State University, Jackson, Mississippi; Mr. Gerard Piel, Publisher, *Scientific American;* Mrs. Sylvia D. Roberts, The Spence School, New York City; Dr. David Z. Robinson, Carnegie Corporation; Dr. John G. Truxal, State University of New York at Stonybrook; Dr. Dael Wolfle (*Chairman*), University of Washington; and Dr. Jerrold R. Zacharias, Education Development Center, Newton, Massachusetts. Captain Hopper and Dr. Millar did not attend either meeting of the panel. Dr. Colin Hudson of Deere and Company attended both meetings as an observer and made helpful suggestions.

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DAEL WOLFLE

Panel on School Science, Commission on Human Resources. Panel Chairman, Dael Wolfle of the University of Washington; Staff Officer, Douglas M. Lapp.

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Commission on International Relations

International Institutions

THOMAS F. MALONE

The twentieth century has seen revolutionary scientific and technological advances—in transportation, space exploration, communications, agriculture, industry, and medicine—that have led to rapid social, economic, and political changes in much of the world. Since World War II, we have seen a virtual end to colonialism; the establishment of new, still developing nations; and urgent demands by these new nations for a fair share of the world's goods. Despite a growth in worldwide nationalism, we have come to realize the global nature of many of man's problems, the interdependence of nations, and the need for intelligent day-to-day judgments on an international scale by both governments and nongovernmental institutions. As Harlan Cleveland[1] has pointed out, the distinction between domestic and foreign issues is increasingly artificial. The rapid growth of interdependence makes it difficult to find a policy question that is not both domestic and international in its impacts and implications. Interna-

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tional institutions in their negotiations must cross these vague boundaries, and they must candidly treat domestic decisions as components of international bargains.

Fashioned in the aftermath of World War II, the United Nations and its specialized agencies have been the principal focus for intergovernmental cooperation, while those international scientific and technical organizations without governmental or political labels have been free to organize dialogues across national frontiers on issues not yet ripe for official negotiation. These latter apolitical institutions have been able to use an interdisciplinary approach free from conceptual confines, to write adventurously and speak freely about alternative futures and their implications for today's public policy, to generate discussion among people from contending groups and different professional fields, and to fashion the institutional instruments capable of generating new insights that may be required to link together diverse disciplines, ideologies, and cultures.

INTERGOVERNMENTAL COOPERATION

Speculation about the role of the United Nations as an influence on scientific and technological development is as futile as speculation about whether the United Nations could exist or be sustained without scientific research and development. It is clear, however, that the UN-sponsored "town meetings of the world" on human environment, population, food, water, desertification, and the status of women, and the meetings on climate and on science and technology for development stimulate thinking whose impact cannot be evaluated for another decade. Yet, the perception of growing politicization and the problems of coordination among the UN agencies raise serious questions about their ability to mount effective new programs for international cooperation in science and technology. The strength of the UN specialized agencies rests in their given mission not in their cross-disciplinary creativity.

Several years ago, speaking of twentieth century institutions in general, John Gardner[2] warned that institutions can be "caught in a savage crossfire between uncritical lovers and unloving critics." On the one side, he said, "those who loved their institutions tended to smother them in an embrace of death, loving their rigidities more than their promise, shielding them from life-giving criticism." On the other side, the unloving critics are skilled in the techniques of demolition, but untutored in the arts of innovation and renewal.

A telling and more direct criticism of the total UN system was leveled by the *ad hoc* Working Group on Policy for Science and Technology.[3] According to the Working Group, "the System is composed of a wide spectrum of activities in science and technology under widely different systems of planning and implementation, and with insufficient coordination among the parts." There is also need, the group said, "to ensure that greater harmonization, compatibility, and complementarity be achieved between policies in the field of science and technology at the national level and those at the level of the UN system at large. In the absence of clear consensual definition regarding what constitutes a 'science and technology' category, no detailed quantitative assessment can now be made of the utilization of the currently available resources for science and technology in the United Nations system."

NONGOVERNMENTAL COOPERATION

As early as the mid-nineteenth century, the needs of scientists from different nations to communicate and cooperate resulted in international nongovernmental associations of astronomers, geodesists, and geomagneticians. In 1900, the International Association of Academies was formed, but the first truly global association of scientists from many disciplines was the International Research Council, founded in Brussels in 1919. It brought together representatives of twelve academies and twelve international scientific unions. Because of political restrictions on membership, the council was dissolved and the International Council of Scientific Unions (ICSU) was created in 1931. The strongest of the nongovernmental organizations, ICSU now includes seventeen autonomous international scientific unions, each embracing a major discipline, and more than sixty national members (academies of sciences, research councils, or similar scientific institutions). International collaborative research programs, frequently of an interdisciplinary nature, are coordinated by twenty scientific and special committees and commissions.[4] Discussed below are examples of ICSU activities.

The International Geophysical Year (IGY)

Conducted between July 1, 1957, and December 31, 1958, the IGY was the most ambitious venture in international scientific cooperation ever undertaken. Its purpose was to observe geophysical phenomena on a global scale. Tens of thousands of scientists and observers from sixty-seven nations worked at some eight thousand stations around the world. Planned and run by scientists for scientific, not political, purposes, it contributed importantly to the 1961 Antarctic Treaty, the 1963 Test Ban Treaty, the 1967 Space Treaty, and the initiation of the Space Age.

The Global Atmospheric Research Program (GARP)

This program was first suggested by ICSU's Committee on Atmospheric Sciences and is now a joint enterprise of ICSU and the World Meteorological Organization (WMO), a specialized agency of the UN. GARP was established in recognition of the fact that scientific and technological developments in meteorology and related fields presented an opportunity for unprecedented progress in man's understanding of atmospheric processes and for applying such knowledge to societal objectives, such as improved weather predictions and insight into natural and man-made climatic change. The Global Weather Experiment is a recent GARP venture. Its institutional arrangements are novel. The "central nervous system" for program planning and direction is a Joint Organizing Committee appointed by agreement between WMO and ICSU. The array of five geosynchronous meteorological satellites, several polar orbiters, hundreds of ocean buoys, aircraft, ships, land stations, radiosondes, and very large-scale computers are operated by national governments. In progress for one year, beginning in December 1978, it dwarfs in sheer magnitude, complexity, and coordination any international experiment yet conceived.

The Scientific Committee on Problems of the Environment (SCOPE)

This interdisciplinary committee, established in 1969, combines the talents of national groups and scientific unions to advance knowledge about the influence of human activities on the environment and to serve as a source of international advice on environmental problems—assessing gaps in knowledge, recommending needed research, specifying alternative courses of action, and proposing steps for the more effective management of the human environment. (The essay by Gilbert White, beginning on page 189 of this report, provides a more detailed description of this program.)

ICSU—*Its Strengths and Weaknesses*

The two chief sources of ICSU's strength are its support for the health of the scientific disciplines and the activities of its scientific and special committees. ICSU-sponsored congresses, symposia, and workshops, which involve thousands of scientists from many nations, promote scientific communication and the well-being of the disciplines. The scientific and special committees address interdisciplinary and societal problems through collaborative research programs, such as the IGY, GARP, and SCOPE, described above. ICSU's major weakness is its organizational fragility, which is largely due to its extreme financial austerity and its high dependence on voluntary intellectual resources. Similar constraints under which it operates have prevented the World Federation of Engineering Organizations from assuming its appropriate role in international affairs.

INNOVATIVE PROGRAMS

A hopeful example of a new kind of international collaboration can be found in the network of International Centers for Agricultural Research, sponsored by a consortium of donor foundations, national governments, and international agencies. Under the guidance of a perceptive Technical Advisory Committee, the centers are achieving a balance between basic and applied research of unquestioned excellence. What has been done with agriculture might be done, with appropriate modifications, with many other transnational problems.

Great organizational flexibility is possible; a single senior investigator, with a demonstrated capacity for excellence and creativity, assisted by postdoctoral assistants and linked to related centers of inquiry, is all that is required for a start. Larger, multidisciplinary centers with a broad range of talents can also be employed. Close and supportive ties to the university community, to national governments, to regional intergovernmental institutions, and to the UN agencies are not only desirable, but necessary, even as care is taken to insulate these centers from political conflicts.

Other examples come to mind. The International Institute for Applied Systems Analysis (IIASA) in Vienna, for instance, has been successfully launched by an *ad hoc* consortium of scientific bodies, supported by public funds, to bring together scientists from different disciplines, cultures, and nationalities to work on such problems as energy, food, water, the environment, and urbanization. IIASA's goals are to create a network of research institutions for the initiation, dissemination, and critique of the findings and concepts of systems analysis; to improve analytical techniques and their usefulness in decision-making; to bridge the gap between scientists and decision-makers; to contribute to the education of the expert as well as the interested layman; and to inform the objective layman of the results of its studies of international problems. Special emphasis is given to the problems of industrial societies.

The Stockholm Institute for Peace Research in Stockholm and The Institute of Strategic Studies in London are modest, but scholarly and productive efforts to address the problems of conflict. Despite the highly political and controversial nature of the issues with which they deal, their objective and scientific approach has earned both organizations a high degree of respect and authority.

The International Federation of Institutes of Advanced Study is a network of research institutes that deal with problems common to many nations, as well as problems that transcend national and disciplinary boundaries. The federation also seeks more effective communication between decision-makers and the world scientific community.

Another institutional innovation, founded in 1972, is the International Foundation for Science (IFS)—a nongovernmental organization sponsored by scientific academies and research councils of forty-two countries, two-thirds in developing countries and one-third in industrialized areas. The foundation provides grants to young scientists from developing countries for research, carried out in their home institutions, that is relevant to their countries' needs. These grants are normally limited to $10,000 a year, for not more than four years; the grantees' home institutions contribute salaries and basic support. Although still modest in size, the program warrants expansion and could grow to have major impact. At present, ten countries contribute to the foundation's budget (for 1978, $1.4 million), largely through government grants administered by academies or research councils.

The International Development Research Centre (IDRC), established by the Parliament of Canada in 1970, is another excellent example of an innovative approach. The centre's goals are to initiate, encourage, support, and conduct research on the problems of developing regions of the world and on how to apply and adapt scientific, technical, and other knowledge to the economic and social advancement of those regions. To accomplish these goals, the centre enlists the talents of natural and social scientists and technologists of Canada and other countries, assists the developing regions to build up their research capabilities and innovative skills and the institutions required to solve their problems, encourages the coordination of international development research, and fosters cooperation in research on development problems between the developed and developing regions for their mutual benefit.

To develop the most effective application of research results to the needs of the people, high priority is given to programs that assist the developing countries in building their own scientific and technological capabilities so that they may be contributors in their own right to the solutions of their own problems. IDRC is the first organization set up specifically to support research projects that are identified, designed, conducted, and managed by developing country researchers in their own countries, in terms of their own priorities. It has helped to create research networks through which developing countries can share common experiences, conduct studies with a common design in areas of mutual concern, and learn from each other as they work toward common goals. The centre does not carry out any "in-house" research, and it engages scientists from the industrialized countries only when needed to assist in the establishment of research teams in the developing countries and to provide the appropriate scientific framework for their studies or when it is necessary to support basic research, particularly sophisticated research, that is beyond the present capabilities or facilities of the developing countries.

The IDRC receives financial support from Parliament and reports to it annually but is guided by an international and autonomous Board of Governors. Since its inception, over $100 million of IDRC support has been provided for 550 research projects, of which more than two-thirds were in science and technology.

In recent years, the United States and other nations have experimented with multinational technical assistance organizations and with bilateral science and technology agreements, joint commissions, and the like. The results of these experiments are still not fully known, but there is no question that, while both multilateral and bilateral approaches are needed, they must be well designed, well funded, and well staffed if they are to succeed. We have learned from sad experience that throwing science and technology at political problems does not solve problems, but it does debase the science and technology so used.

The "networking" of research institutions and the sharing of information and mutual recognition of priorities in scientific research can be extended to a number of economic and development efforts. Some experiments in regional collaboration are getting under way and more should be encouraged, as should new forms of disciplinary collaboration and cooperative research. Although it doubtless will be more difficult to extend these ventures into technological fields where profits and power enter the picture, sheer societal need may provide the motive force.

It is clear that American managerial talent and American institutions face great challenges over the next five years if this country is to help confront two problems that will attract increasing worldwide attention—(a) economic development to meet basic human needs in the developing countries and (b) the arms race.

As to the first problem, suffice it to say that we are currently observing the fissioning of the world into two megacultures—the rich and the poor. The resultant imbalance is so pronounced that the total disappearance of the two-thirds of the world's population that constitute the poor countries would decrease world resource consumption by only ten percent. Yet, if present trends continue, the two-thirds of the world's population that is "poor" today will grow to nine-tenths within a generation or so.

The second problem is manifestly out of control. The global competition for arms consumes more than $1 billion per day of public funds. After allowance for price inflation, yearly outlays had risen by 1978 to fifteen percent above the 1970 level, and exports of arms over this period tripled. Nuclear bomb inventories, already sufficient to destroy every city in the world seven times over, are still growing at the rate of three bombs per day. Clearly, a will to reestablish control and reorder priorities is overdue. Where there should be an international network of funding agencies, nothing exists. Where there should be a network of knowledge-generating and knowledge-assembling agencies at the international level, we find only the Stockholm Institute for Peace Research, The Institute of Strategic Studies, and a handful of more narrowly based institutions. Success will require international institutional innovation.

Thoughtful consideration should be given to the simultaneous development of an array of three kinds of interacting international institutions: (a) a donor network, (b) a knowledge-generating network, and (c) an implementation network. The first suggests the need for a coalition of institutions, patterned on the IDRC model, in at least a dozen countries. The new Institute for Scientific and Technological Cooperation (ISTC) in the United States begins to approximate this need.

A CLIMATE OF CHANGE

Other factors may influence U.S. thinking in regard to international activities. The United States is being increasingly challenged by the numbers of foreign students in the U.S. educational system. Their needs and the obvious importance they assume in a declining population of American college-age youth are forcing U.S. colleges and universities to reevaluate their roles. The Western ethos of science and technology, in particular, is being questioned in the context of the wave of "new international orders." There is a return to traditional values linked to the search for international equity and domestic justice. Thus, the new international economic order has spawned demands for change in the world order of science and technology; the purely rational approach is under fire and, in some ways, for good cause.

For many members of the scientific and technical community, new societal issues have assumed singular importance—human rights, the privilege of universal participation regardless of internal political conflict, repression and freedom of inquiry, restraints on travel, immigration, dissemination of research results, and obstacles to free circulation of scientists and ideas. While none of these issues is truly new, the current perception of their importance and the hope for uniform acceptance of an international "code" for scientists have increased the clamor for reform and have disrupted scientific exchange to an as-yet-undetermined degree. To the extent that these issues continue to divide communities of scientists and engineers, they will affect the ways in which the global community of science and technology interacts. The implications are difficult to discern, but the need to examine them with care and to assess the effects of governmental policies and activites cannot be ignored.

If these heightened perceptions of human rights are channeled toward international institutions that can control the threat of war and help relieve the misery of poverty for most of the world's population, we may yet enter a new era of freedom from fear and freedom from want.

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Study Project

COMMISSION ON INTERNATIONAL RELATIONS

CHINA'S SCIENCE AND TECHNOLOGY: A REVIEW

All his life Mao Zedong (Tse-tung) had a love–hate relationship with China's intellectuals—and scientists were not excluded from this sentiment. On the one hand, he clearly recognized that if China was to achieve the dreams he dreamed and the goals he set, major reliance would have to be placed on intellectuals—and especially on the so-called higher intellectuals. On the other hand, Mao was never able to overcome his conviction that higher intellectuals, most of them from capitalist families, were basically bourgeois and elitist and therefore would have to be thoroughly remolded before they could become both red and expert and be integrated into his vision of an egalitarian China. In language characteristic of the Cultural Revolution, the *Beijing (Peking) Daily* commented on the problem by explaining that not all intellectuals smell bad because "if one is a bourgeois intellectual, he is very stinking; if one is a proletarian intellectual, he is very fragrant."

The country had few uncontaminated proletarian intellectuals, however, so that in a very real sense the sporadic, thirty-year struggle to transform "stinking intellectuals" into "fragrant intellectuals" not only typified China's factional strife, but accurately reflected her policies toward science, where so many of the intellectuals were concentrated. Drawing inspiration by interpreting Mao's printed thoughts to suit their own leanings, the pragmatists and the radicals (convenient, but only approximate, designations) led China through a series of developmental cycles that in no sense bypassed science and technology. For better or for worse, politics have been in command.

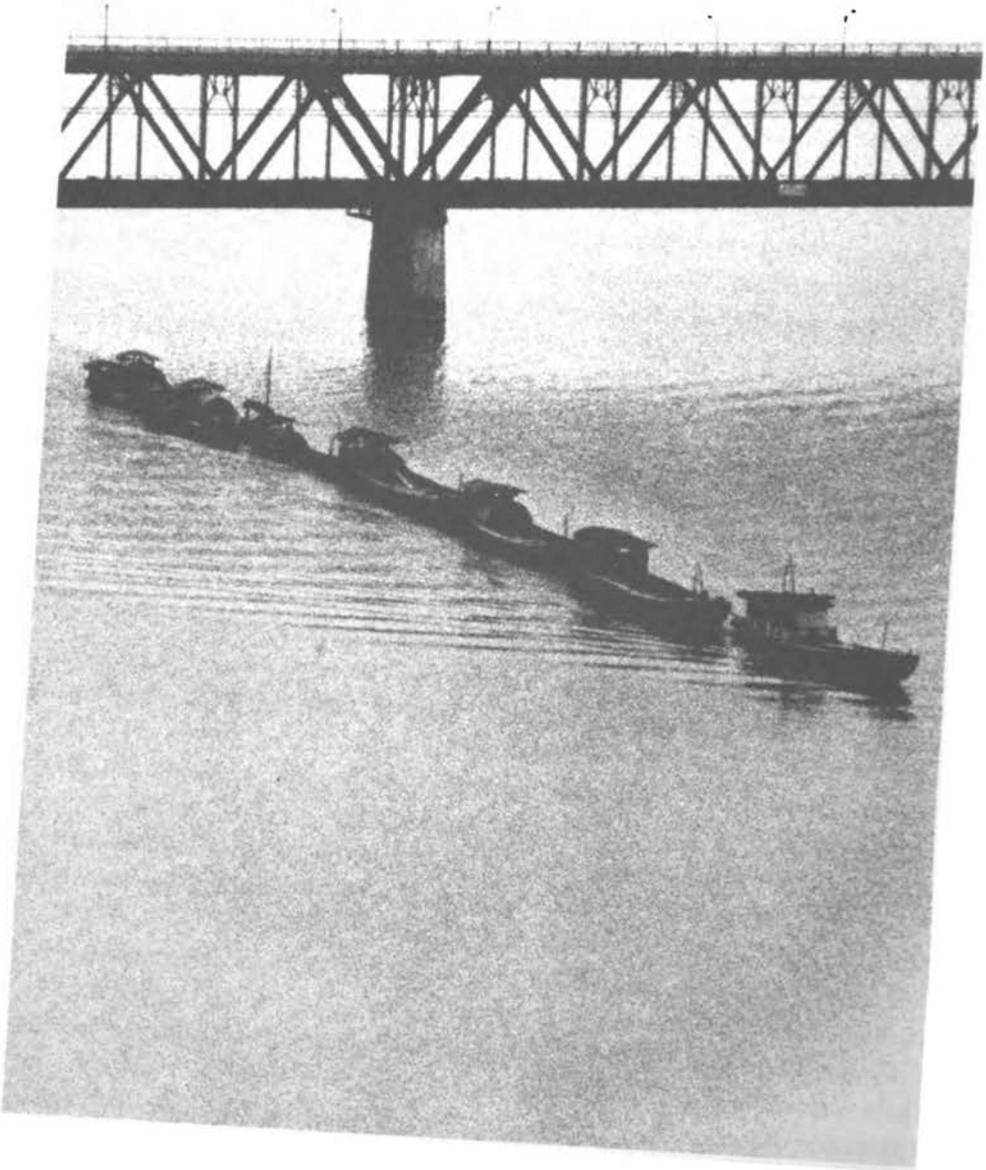
China is once again in a stage of transition. The death of Mao, quickly followed by the purge of the notorious "gang of four," set the People's Republic of China on a course that only a few years earlier would have been termed revisionist. The emphasis on rapid economic development and the designation of science and technology as leading factors in the projected modernization of agriculture, industry, and national defense has once again boosted scientists to elite positions within the society. But while the new direction of science and technology has been clearly proclaimed to the world and to the 6,000 delegates who attended the National Science Conference in Beijing in the spring of 1978, the drastic changes must be silhouetted against the recent past in order to fully appreciate the new goals and values for science and technology expressed by China's leaders.

There were basically two periods in which Mao's idealist concepts of mass line and mass initiative dominated the Chinese scene: The Great Leap Forward (1958–59) and the Great Proletarian Cultural Revolution (1966–69). Both periods had an adverse effect on scientific development, proving once again that, given their chemistry, politics and science should not be mixed. What is often missed, however, is that China moved in and out of these periods of extremes over a period of time—a fact that becomes especially obvious through hindsight. In other words, since the mid-1950's there has never been a time when the influence of the faction temporarily out of power was not making itself heard or felt through "the two line struggle"—a polemic that Mao considered inevitable and invaluable in achieving the wise consensus. This struggle and the attendant policy twists were most overtly displayed between 1970 and 1977, when the more pragmatic leadership was attempting to pull China out of the morass of the Cultural Revolution, while other forces ("gang of four" and their followers) were resisting any drastic departure from the policy of subordinating science and education to politics and practice. Thus, while a brief review of China's science policies must deal essentially in blacks and whites, the reader should appreciate that some of the grays are missing from the discussion.

SCIENTIFIC GOALS

In the most general sense the demands that China has been making on science have not changed for thirty years. Science must make China a competitive world power and science must pull the hundreds of millions of Chinese people into the second half of the twentieth century. While it would be easy to conclude from his rhetoric that Mao's prime concern was "science for the people," it is fair to say that he also knew that China could not afford to ignore the development of a modern scientific establishment. But since science was not immune from political vacillations, China leaned during different time periods either toward rapid economic development and the acquisition of modern science and high technology, or toward instilling "the love of science" among the masses and the complete integration of science with production. Undoubtedly, these cycles served to slow down development, but what is surprising is that despite the policy shifts China managed to make significant progress in both areas.

Within the bona fide scientific establishment, the most persistent and heated debate has centered around the conceptual problem of basic versus applied research. Looking in from the outside it is difficult to see why this argument should have persisted for over two decades. Given China's level of development, it is probably quite reasonable that most of the country's scientific, human, and capital resources should go into applied research, development, and the adaptation of existing scientific knowledge and technology to China's needs. Occasional departures from basic research by individual scientists should not have disturbed these broad priorities. Unfortunately, during periods of radical control, reasonable policies tended to be carried to unreasonable extremes. During the Great Leap and the Cultural Revolution, scientists, by definition, became suspect and, with little discrimination, were accused of being elitist, of "living in ivory towers," of wanting to acquire "personal fame and gain," and of



persisting with theoretical research that was unrelated to China's production needs; they all needed reeducation.

Curiously (but not untypically), many of the recent arguments on basic versus applied research centered on how to interpret Mao's statement that: "Class struggle, the struggle for production, and scientific experiment are the three great revolutionary movements for building a mighty socialist country." The leftists, radicals, or, more recently, "the gang of four" contend that Mao meant class struggle ("a locomotive pulling history forward") to have priority over the other two "struggles" and, conversely, that the theory that "science decides everything" was a reactionary policy of those who oppose class struggle and proletarian politics. According to the present leadership, this is a misinterpretation of Mao, who fully appreciated the role of science in revolution and who believed that "the three struggles" were coequal in importance, because without the "struggle for production and scientific experiment" China would not be able to improve the well-being of the people by consolidating the power of the proletariat. In other words, scientific research must lead not only production and construction, but it must even lead class struggle. Those who compare scientific research to "water from afar which cannot quench immediate thirst" do not understand that it is conducted precisely to avoid "digging wells only when feeling thirsty."

In his address to the National Science Conference, Vice-Premier Deng Xiaoping (Teng Hsiao-ping) translated these philosophical wranglings into a concrete new line. "The crux of the four modernizations," he said, "is the mastery of modern science and technology." He went on to point out the close relationship between the laboratory (basic research) and production, because, although there are many theoretical research topics with no practical application in plain sight, "a host of historical facts have proved that once a major breakthrough is scored in theoretical research, it means tremendous progress for production and technology sooner or later." "Backwardness must be perceived before it can be changed," said Deng, and the new goals of science and technology must not be politically determined.

What this seems to mean is that at least for the time being China will attempt to maintain a balanced approach to scientific goals and that, while applied research will undoubtedly continue to dominate the scientific establishment, basic research will no longer have to be disguised. Chinese scientists feel a great relief in knowing that science has been legitimized as a productive force and they undoubtedly derive a certain security from Teng's statement that brain workers who serve socialism are also working people—something that was questioned during the Cultural Revolution.

ORGANIZATION AND LEADERSHIP

It is unnecessary to tire the reader who has a casual interest in China with a detailed discussion of the effects of political fluctuations on the organization and management of China's scientific establishment. Suffice it to say that, at the higher levels, China has patterned her highly structured and bureaucratic science system on the Soviet model. Planning and coordination of science and technology have been the responsibility of a commission placed directly under the ruling State Council, but it is the prestigious Chinese Academy of Sciences, as well as the Chinese Academy of Agricultural Sciences, Chinese Academy of Medical Sciences, and, since mid-1977, the Chinese Academy of Social Sciences, that are the nation's primary research centers. One of the effects of politics on this organization has been the degree of control the academies have been able to maintain over the activities of individual institutes under their jurisdiction. During the Cultural Revolution, for example, not only were many of the institutes closed down, but the emphasis on local needs and production problems placed most of the remaining institutes under regional control. After some years of vacillation that followed, the basic responsibility for research in science and in high technology is definitely reverting to the academies and to the most-qualified scientists. There are some ninety research institutes now under the Chinese Academy of Sciences and their number is growing.

At the same time, the less-sophisticated activities in science and technology have been scattered throughout a patchwork network of subprovincial-level institutions and industrial and agricultural production units. At this level everyone was encouraged to participate in "scientific experiments" and to come up with innovations that would benefit production. To a large extent, politically inspired shifts in organization and leadership were meant to increase or decrease the level of contact between the academician and the worker and peasant "scientist." Mao felt that both sides would profit greatly by this contact. While the effort to force scientists to participate in solving production problems and to urge workers and peasants to be courageous in becoming involved in scientific and technical activities has had some adverse short-term effects on economic growth, on the whole, Beijing has managed to take the complex scientific establishment, with its vertical and horizontal relationships, and somehow ensure a degree of forced rapport between the two groups, which probably has not been entirely detrimental to China's long-term goals.

Since 1949, China has also experienced an almost perennial strife between the science professionals and the Communist party administrators for control of the scientific institutions and programs. In principle, Chinese scientists have learned to accept and perhaps even understand the ultimate authority of the party in establishing the general direction of scientific research. They have tended to react strongly, however, on occasions when politics came to dominate science and when party administrators attempted to extend their role as "facilitators of research" to become involved in decisions directly affecting research. The level of friction between the scientist and the party fluctuated but it was never entirely absent—a situation that is not conducive to an efficient pursuit of scientific objectives.

Well aware that this condition must be corrected if science and technology are to play a leading role in China's modernization, in his speech to the National Science Conference, Deng Xiaoping carefully circumscribed the role of the party in science. He said that scientific results of the research institute are the only criteria by which the work of the responsible party committee should be judged and that putting politics in command without showing scientific results "will remain mere empty talk." The party leadership must ensure the correct political orientation, must guarantee supporting services and supplies, and should even "get acquainted with the work of the scientists," but the scientific leadership of the research institutes should have "a free hand in the work of science and technology."

It is true that at the same National Science Conference, Chairman Hua Guofeng (Kuo-feng) attempted to provide some balance to

Deng's remarks by warning the assembled scientists that modernization of science and technology should not be "left to a few people in research institutions or universities" and in general stressing the continued importance of politics. Nevertheless, the unmistakable impression one gets from the recent developments in China is that Deng's philosophy of practicality is dominant and that Hua's words of balance constitute little more than what was then still considered to be a necessary show of reverence to Mao's thoughts.

EDUCATION AND SCIENTIFIC MANPOWER

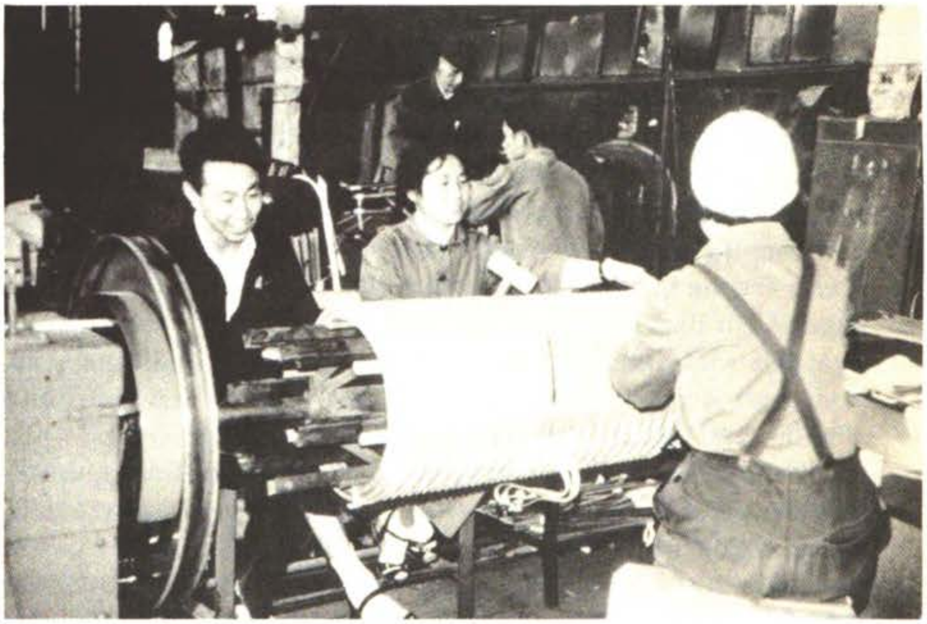
The highly publicized closing of universities for four years during the Cultural Revolution reflected Mao's conviction that China's educational system was too elitist and discriminatory against the children of workers and peasants. In 1970, the institutions of higher education started to reopen, but because debate over the nature and priorities of the educational system continued, the process was slow and cautious. The shortened curriculum integrated with productive labor, the abolition of examinations, and the acceptance of poorly prepared students from worker and peasant families into universities was bound to keep the educational caldron boiling. Political factions found the educational system to be the ideal stage on which to play out their broader ideological beliefs, resulting in continuing instability and considerable insecurity on the part of professional educators.

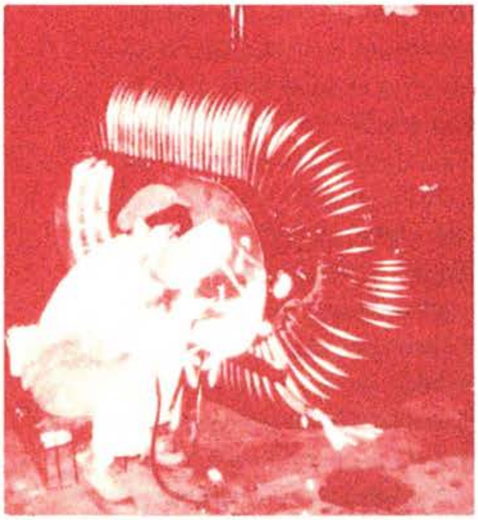
The situation is rapidly improving, but it will take time to correct the damage that has been done. Not only is there a serious shortage of university graduates in the twenty-five- to thirty-five-year age-group, but the quality of education received by the young people who managed to complete their college training after 1970 has been well below the standards that existed before the Cultural Revolution. This is, of course, a basic limiting factor in the current all-out push for modernization and the "high-speed development of science and technology." How far can China go on the expertise of the aged scientists trained in the West prior to 1949 or on those trained in the Soviet Union in the 1950's? Does she have enough competent Chinese-trained scientists and engineers who finished their education before 1966 and who would be capable of leading the new revolution in science and technology? How quickly and how well will China be able to fill the ranks of scientists and engineers with a new generation of experts?

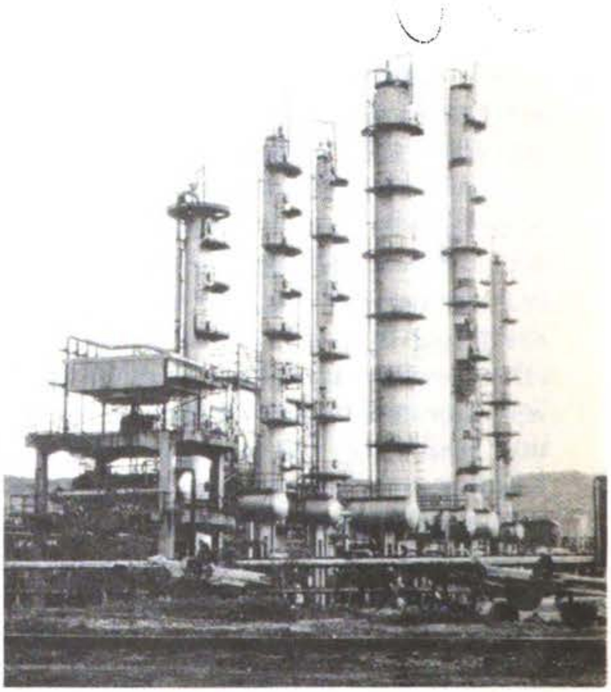
The above questions, so often asked outside China during the past decade, may not receive direct replies from the Chinese, but it is important that the leadership is now very aware of these problems and is beginning to address them directly. As usual, Deng Xiaoping's comments are the most forthright. After the standard references to the sabotage of Lin Biao (Piao) and the "gang of four," he admitted at the National Science Conference that "there is an age-gap in the (scientific and technical) force which makes the training of a younger generation of scientific and technical personnel all the more pressing." On a positive note, however, he pointed out that China has a vast pool of people with great potential who, with careful selection and training, could become first-rate scientists. He urged China's scientists to find satisfaction in uncovering and training scientific talent and proclaimed that "the future of science lies with the youth."

The "National Plan for Development of Science and Technology," presented at the National Science Conference by Fang Yi, vice-premier and minister in charge of the State Scientific and Technological Commission, included the goal to "increase the number of scientific researchers to 800,000" by 1985. The unusual publication of a numerical manpower target received much publicity and it also raised two important questions: What is meant by "scientific researchers" and how many of them are there in China now. While there are no ready answers, it would be wrong to assume (as so many seem to) that the target is to be reached solely through new graduates from the educational system. The Chinese are aware that it will take time to reinvigorate the battered educational system, and therefore they stress that great effort will be made in training and raising the level of the existing contingent of scientific and technical workers to "bring their role into full play." But whatever the composition of the projected "800,000 scientific researchers," it is already clear that Beijing is giving the highest priority to scientific and technical education.

In view of Beijing's past determination to isolate her students from outside influences, the most startling aspect of the current educational plan concerns China's hope to have 10,000 Western-







trained personnel by 1985. Although at present many of the details of this massive student exchange between the People's Republic of China and the technologically advanced nations are still to be worked out, this ideologically risky enterprise clearly indicates the urgency with which Beijing views the need to close the educational gap that was left by the Cultural Revolution.

FOREIGN SCIENTIFIC CONTACT

As a philosopher, Mao avoided discussing issues in terms of "right" and "wrong" and therefore left much leeway in how his followers chose to interpret his thoughts. China's policies in relation to foreign science are yet another example of what his love of contradictions has wrought. In his work "On the Ten Major Relationships," Mao pointed out that China should "learn from the strong points of all nations" but that she mustn't "copy everything indiscriminately and transplant mechanically." He said, "Rely mainly on our own efforts while making external assistance subsidiary." It is easy to see how "the gang of four" and their kind would choose to interpret these statements to mean that China should be completely self-sufficient and self-reliant in science and technology and accuse opponents of subscribing to the "philosophy of servility to things foreign." Their rationale was that the only way for China to achieve an indigenous problem-solving capability in science and technology was to "do it yourself." On the other hand, it was just as predictable that the moderates and the modernizers would insist that obtaining scientific help and advanced technology from abroad was nothing more than "making foreign things serve China"—which is just what Mao ordered. To them, it made little economic sense to duplicate the technology that was already available abroad.

As might be expected, the level of rhetoric about how dependent or independent China should be regarding foreign science fluctuated with the political winds, but in practice the rhetoric was not translated uniformly into policy. Both when politics were in command or when more liberal leadership was dominant in Beijing, China managed to severely restrict any contact between her scientists and their foreign colleagues. Until the post-Cultural Revolution period, China avoided participating in virtually all international scientific conferences and only an occasional Western scientist managed to get into the country to meet his Chinese counterparts. Albeit, during most of these years, foreign scientific literature was readily available in all the major scientific institutions. On the other hand, in an area that obviously had priority, China never completely stopped purchasing significant quantities of technology from Western Europe, Japan, and, after 1972, the United States, even during years when this seemed to cause considerable discomfort to some of the leaders in Beijing.

Since the downfall of the "gang of four" almost all the discomfort that may have been associated with scientific and technological intercourse between China and the technologically advanced nations has disappeared. In his speech to the National Science Conference, Teng proclaimed that "backwardness must be perceived before it can be changed" and "a person must learn from the advanced before he can catch up and surpass them." This the Chinese are intent on doing, as evidenced by the July 1978 invitation to Beijing of the American delegation of senior governmental scientific officers, led by Frank Press, the President's science and technology advisor. The new policy was spelled out by Fang Yi at the farewell banquet. After making the usual brief "bow" to "relying on our own efforts," he went on to say, "We will take an active attitude toward strengthening international scientific and technical exchanges and cooperation and developing both governmental and nongovernmental contacts in these fields on the principles of equality and mutual benefit." In other words, the previous contradictions have been erased: China can now be self-reliant without isolating herself from the world of foreign science and technology.

PROJECTS AND CONSTRAINTS

Accelerating academic exchanges, increasing commercial relations with the concomitant technological contacts, and the resumption of the publication of scientific and technical journals and texts have all made it possible to make some reasonable judgments as to where China stands in the perspective of world science and technology. One of those judgments will be provided by a comprehensive review of China's science and technology, prepared by a group of scientists for the Committee on Scholarly Communications with the People's Republic of China.* It will be published in the spring of 1980 by Stanford University Press, under the title *Science in Contemporary China.*

But while it is possible to make a fairly realistic assessment of where China is now, the future continues to be murky and difficult to forecast even for the Chinese themselves. As is usually the case, the many additional "answers" we now seem to have propagate even more questions. Chinese leaders may be determined to "storm the citadels of science," but citadels are not easily captured and many serious obstacles must first be overcome, of which two seem to stand out above all others.

The first relates to China's ability to purchase the technology she wants and find the necessary funds for capital construction directly related to the acquisition of this technology. It is already evident that China's scarce capital will not stretch to accommodate her original and broad-ranging priorities in agriculture, industry, national defense, and science and technology. The hopes that new oil resources will ease this problem are both problematical and distant. For the time being, most of China's foreign exchange will have to continue to come from agriculture—a precarious platform for a great leap into modernization, especially in view of a population of some 950 million that is increasing by at least 14 million every year.

The other serious constraint has already been alluded to and it concerns the quantitative and qualitative adequacy of China's scientific and technological manpower to absorb, adapt, and manage the world's most advanced knowledge to the country's advantage. Certainly the current reforms in the educational system and the anticipated growth in the number of Chinese students studying abroad are essentially of long-term significance and will have only limited effect on China's immediate problems. Plans to permit senior scientists and engineers to spend extended periods of time studying and doing research abroad would obviously have more direct benefits, but the question of numbers versus goals remains.

Since politics can never be disregarded in China, there is also the question of the permanency of Beijing's current direction. For

* The committee was established in 1966 by the American Council of Learned Societies, the National Academy of Sciences, and the Social Science Research Council.

example, will China's all-out drive for modernization falter with the death of seventy-five-year-old Deng Xiaoping, who is the architect of this policy? Can we anticipate yet another cycle that will shift China's priorities from the pragmatic to the ideological? The veneer of unity in Beijing appears to be thin and we have seen too many unanticipated changes in China not to be cautious in looking at the future. Nevertheless, since China without Mao can never be what China was when Mao was alive, it seems unlikely that shifts in policy could ever be as drastic as they were in the past. As China gains momentum in her economic development and security in her relations with the outside world, it should become much more difficult for any residual forces of radicalism to force a major turnaround in China's policies.

The relaxation evident within China and Beijing's preoccupation with modernization and economic growth are understandably looked on with favor by most of the world. There is a widespread consensus, at least in countries outside the Soviet influence, that a secure China is more likely to be a peaceful China. And, yet, it is possible to feel some regret that her drastic vacillations did not settle on some middle ground. Mao's romantic pronouncements about egalitarianism, his "serve the people" concept, and the sense of idealism he attempted to instill in the people tended to capture their imaginations. Individuals who disagreed with China's politics and policies could identify with the kind of dream world that Mao attempted to create. Unrealistic though it might have been, it set China apart from every other nation. It would be nice if, in their impatient and turbulent drive toward modernization, the current Chinese leaders could see fit to retain "a touch of Mao"—for old times' sake.

LEO A. ORLEANS

Committee on Scholarly Communications with the People's Republic of China, Review of China's Science and Technology. Chairman of the Steering Committee, Walter A. Rosenblith of the Massachusetts Institute of Technology; Study Director, Leo A. Orleans.

Leo A. Orleans is China Specialist, Library of Congress.

Commission on Natural Resources

International Exploration of the Global Environment

GILBERT F. WHITE

Most environmental studies in the United States, as in other countries, are undertaken to answer questions of local, regional, and national import. This will continue to be the case because many of the issues are at the scale of cities, states, and nations. But if the human family is to learn the conditions required for the maintenance and enhancement of the life-supporting capacity of the planet, more concerted attention will have to be paid to international collaboration in environmental inquiries. While most studies will continue to attend to national concerns, some must be at the global scale. It is increasingly evident that the scientific community is entering into a period in which the concept of one earth is matched—though as yet only feebly—by a unified program of research to probe the essential processes of the biosphere. Recognition of the complexity and challenge of that larger exploration gives perspective to national studies and opens up ways of enhancing their contributions to global goals.

In high-income, industrialized countries, as was previously noted

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for the United States,[1] a major portion of the research review and policy studies consider resource-management problems from three standpoints. One is the establishment of baseline information on resource use and quality, which, for example, enlightens our investigations of the environmental influences of toxic substances and of the quantity of mineral resources. A second type of study reviews environmental problems where there is ambiguity or controversy as to the status of scientific knowledge and its policy implications. An example is the appraisal by the Environmental Studies Board of the sources and consequences of lead in urban living places. Another is the Board of Mineral and Energy Resources' examination of the effects of different techniques of surface mining on surrounding areas as a basis for formulating federal regulations of such practices under the Strip Mining Act of 1977. (This study is more fully described in the article that follows this essay.) A third type of study seeks to define problems and conceptual schemes that may shape the approaches of public agencies to policy matters. An example is the study initiated by the Board on Agriculture and Renewable Resources of how more precise information may be gained on the rates of flux of substances between the atmosphere and the biosphere and the resultant long-term effects.

DRAWING UPON THE WORLD STORE OF KNOWLEDGE

To be as useful as possible, most such studies must draw upon the knowledge and experience of scientists in other countries. Although no two landscapes on earth are exactly alike, there are enough similarities in conditions and sufficient commonalities in basic processes that what is learned about one area may well have relevance to a good many others. Estimates of mineral resources employ methods that may have wide applicability in a number of nations. Halogenated hydrocarbons behave much the same in similar physical and biological systems. The problems of integrated pest management for a given crop, such as boll weevil control for cotton, are broadly similar from one country to another.

Ideally, every environmental and resource study undertaken by the National Research Council will command the full body of knowledge and experience that has accumulated around the world insofar as that is applicable to the questions at issue. This aim may seem at first blush to be so obvious as to be indisputable. In all fields of science, it can be argued, the conscientious investigator seeks out relevant findings regardless of their country of origin, without regard for intellectual tariffs or import quotas. However, the international traffic in information and ideas is rarely perfect.

Obstacles occur in a variety of combinations. The burden of searching a proliferating and sprawling literature is heavy. Languages are perennial barriers that can be surmounted only by assiduous abstracting services; research workers have enough trouble keeping up with studies in their own countries. Economic and political constraints on the movement of scientists and their publications slow down the speed of exchange. National funding agencies are reluctant to support travel to and from foreign areas. Overcoming these restraints takes time, persistence, and, oftentimes, extra funds. It is usually easier to review the readily available literature and to convene an advisory group from people well known at home than to reach out to the literature and people of distant places.

In practice, studies on environmental problems are hampered by several conditions that add to these usual obstructions to transnational exchange. The resources and environmental studies field is sufficiently young that it has not fashioned channels of communication similar to those functioning in better-established fields such as physics and botany. Beyond that, there is a widespread tendency to regard resource issues as unique to each nation. This is partly, as already has been noted, because of the unique combinations of natural conditions that nations treasure and partly because different policies of public management create an aura of individuality that obscures common features. The responsibility of individual governments to set permissible levels of smokestack emissions, to specify desirable forest-cutting practices, and to determine the suitability of pesticides encourages emphasis on their own national experience and knowledge. Yet human beings in similar climates react to sulfur dioxide without regard to nationality, trees grow similarly in the same soil and climate wherever they are, and pesticides infiltrate biological systems with complete disregard for political boundaries. The effects of atmospheric lead on children's brains and of methyl mercury on metabolism in fish are not affected by national domain.

NATIONAL RESEARCH COUNCIL INITIATIVES

At least two dozen recent and current National Research Council studies in the environmental field deal with biological and physical phenomena common to other countries. Examples include reviews of methods of estimating the environmental consequences of offshore oil exploration[2] or of the surface mining of coal and other minerals, the methods of estimating the producibility and availability of uranium resources,[3] the research requisites for a viable aquaculture,[4] the effects of feeding antibiotics to cattle, the health consequences of using lead in paint and in automotive fuels, the assessment of the environmental impacts of manufacturing nitrates,[5] and the effects of alternative techniques for disposing of municipal sewage sludge.[6] Indeed, it is easier to point to studies that should draw from international experience than to those that need not.

In investigating these topics, the National Research Council, like other national groups, can try to assure access to experience elsewhere in various ways.

One measure is a canvass of the relevant literature from other nations. But a literature search rarely will be complete in this world of multiplying journals and reports, and it runs the risk of losing time spent on materials that turn out to be irrelevant.

Perhaps most effective are the informal networks of communication among concerned scientists. The meetings arranged by national or international scientific organizations like the International Union of Pure and Applied Chemistry bring together research workers whose inquiries converge and who invent ways of keeping in touch. Worldwide intergovernmental groups—principally the United Nations Environmental Programme, the United Nations Educational, Scientific, and Cultural Organization, the Food and Agriculture Organization, the International Atomic Energy Agency, the World Meteorological Organization, and the World Health Organization—facilitate and supplement that kind of exchange. Regional organizations like the Organization for Economic Co-operation and Development, the

Commission of the European Communities, and the Arab League play similar roles. Bilateral exchanges such as the U.S.–U.S.S.R. program on environmental issues likewise foster communication.

Beyond depending upon U.S. scientists to become familiar with all relevant work elsewhere and to use the appropriate findings, the National Research Council employs other devices. It can invite scientists from other countries to serve as members of workshops or study groups. Or it can join in governmental or nongovernmental groups that span a wide range of national activity.

The first is tried in a relatively small but growing number of investigations. An early venture of this sort was the review of the environmental effects of the application of herbicides in the Vietnam War, in which the suspicions of political bias encouraged the enlistment of biologists from neutral countries.[7] The World Food and Nutrition Study solicited comments from citizens of a number of developing nations.[8]

More recently, with the support of the Andrew W. Mellon Foundation, an express effort was launched to strengthen international cooperation in attacks upon environmental questions of importance to the people of the United States. One example is the examination of the diffusion, storage, and eventual decay of polychlorinated biphenyls in natural systems.[9] The production of these residues, principally from electrical equipment, has been curbed because of their deleterious effects upon aquatic organisms. The residual materials have a long persistence. Problems arise in judging what, if anything, should be done to reduce their damaging effect as they are transported or released in river and estuarine sediments. Such an appraisal is similar to that undertaken in other industrial countries, and it seemed wise to bring in the experience and outlook of Canadian and Swedish scientists familiar with the processes involved.

Much of the investigation of environmental pollution is plagued by a lack of systematic intercalibrated measurements of the volume and changes in foreign substances. Without a network of rigorous sampling and analysis, it is impossible to draw valid comparisons among areas or over time. While examination of water samples by individual laboratories may serve the purposes of local appraisals, a network of sampling and analysis permits broader comparisons. Using

bivalves (*Mytilus*, *Ostrea*, and *Crassostrea*) as sentinel organisms, a program for monitoring heavy metals, transuranic elements, petroleum hydrocarbons, and halogenated hydrocarbons was begun in 1976 with the support of the Environmental Protection Agency and coordination by the Scripps Institution of Oceanography.[10] Initially, this was confined to coastal waters of the United States. In late 1978, steps were taken to extend the network to other areas, including the Mediterranean.

A number of questions arise in connection with the use of accumulator organisms to measure the quantities of substances that these organisms concentrate from low levels in seawater. How accurately do the organisms reflect the prevailing concentrations in seawater? How is this affected by age, by dissolved organic matter, and by other factors? What is the minimum size of an adequate composite sample? What are the effects of differences in species and size? These questions are particularly in controversy in connection with increasing pollutant discharges from continental streams, from ocean pollution, and from disposal of nuclear waste. But if sound judgments are to be reached by monitoring trends in the condition of the earth's oceans, these and other questions must be resolved.

RADIOACTIVE WASTE

No issue concerning the global effects of human intervention in the natural environment has provoked more widespread and emotional controversy than the disposal of radioactive waste from nuclear power and military weapons production. A principal reason for citizen opposition to nuclear energy development is fear that the wastes, particularly high-level wastes such as plutonium, will in time threaten the health of people and ecosystems. This fear is sometimes dismissed as exaggerated, and it often is mingled with concerns for the safety of nuclear power plants, the possibility of political blackmail with stolen materials, and the outbreak of nuclear holocaust. In political reality it is difficult or impossible to sort out these various concerns neatly: all will enter into administrative and electoral decisions on the building and location of plants and the ultimate disposal of the growing volume of waste that is stored at Hanford, Washington, and other installations. Nevertheless, seeking to specify what is known and not known about the environmental consequences of alternative ways of disposing of radioactive waste may help to clarify a debate that ranges from Tokyo to Paris to Washington.

Such an effort should be in the hands of nongovernmental international scientific groups for several reasons. National governmental agencies are suspect as being unduly subject to political influence. Intergovernmental groups are seen as reflecting the confluence and conflict of national policies. The skeptics want assurance of scientific findings in which national government aspirations are excluded or muted. No matter how prescient a report from a Canadian or Swedish scientific group on waste-disposal issues, it is unlikely to be fully convincing until its findings are sifted, weighed, and consolidated in a genuinely nongovernmental transnational exercise. The International Council of Scientific Unions, in response to a suggestion from the presidents of the National Academy of Sciences and the National Academy of Engineering, recently initiated such a review amid fears that the process will be too slow or too weak to complete the task in time. Its handicaps are, indeed, heavy, but without a solid appraisal of this sort, the anxieties and delays attending the current debate will continue.

LIFE SUPPORT SYSTEMS

A larger challenge arises in the case of the life support systems of soil, water, and air. Although the possibility of climate change has attracted more popular attention, the alteration of the elementary cycles of nutrients in the biosphere is basic to understanding some of the projected changes in atmospheric systems and has broader import for the productive capacity of the globe.[11] The discussions in recent years of the possible significance of increases in atmospheric carbon dioxide and of depletion in the ozone layer are concerned with particular distortions of systems that have many other facets. Focusing immediate attention on CO_2 and ozone diverts analysis away from the fundamental characteristics of the cycles of oxygen, carbon, nitrogen, sulfur, and phosphorus upon which the life of the planet depends. These are not well understood; as, for example, our incomplete understanding of the global carbon cycle.[12]

While there are accurate measurements of the average annual and seasonal rises of concentrations of CO_2 in the atmosphere at Mauna Loa, at the poles, and elsewhere and of production of CO_2 from fossil fuel power plants, several links in the cycle cannot be explained adequately. The volume of carbon that is locked in terrestrial vegetation and is released by decay, cutting, and burning is a matter of speculation. The rates at which carbon is exchanged at the ocean surface and particularly in coastal zones are in doubt. There is no fully verified model of how the vegetation, soil, water, and atmospheric components in the system interact.[13]

In these circumstances, any predictions of the long-term consequences of burning fossil fuel or cutting tropical forests or burning semiarid grasslands must be hedged by disclaimers as to whether or not the assumptions about the workings of the cycle are correct. To complicate the picture, it is unlikely that the carbon flow can by itself be appraised with validity since it is affected by the movements of sulfur, nitrogen, phosphorus, and other less common elements.

Every industrial nation has immediate reason to be concerned about the nature of the carbon cycle. Every agricultural nation is interested in the supply and flow of carbon and nitrogen. Major decisions on consumption of fossil fuels, on management of forests, and on applications of fertilizers require understanding of these cycles.

The research necessary to explore these questions in greater depth encompasses a large number of disciplines, including botany, geochemistry, geography, geology, meteorology, microbiology, oceanography, photochemistry, and physics. The data are drawn from marine and terrestrial observations around the world. Analytical and conceptual contributions are made by scientists in several dozen countries. Refined and precise description of the processes involved will come only through cooperation in data collection, analysis, and interpretation on an international scale, and the informal communications networks will need to be supplemented with better organization.

CURRENT INTERNATIONAL STUDIES

Beginnings have been made in that direction. One important building block that was established to advance understanding of the processes basic to improved weather forecasting and climate change is the Global Atmospheric Research Program. This provides an integrated framework for exploring the atmospheric circulation processes involved in nutrient cycling. It is under the direction of a joint committee of the International Council of Scientific Unions (ICSU) and the World Meteorological Organization (WMO) and is responsible for a series of data-gathering and analytical exercises.

ICSU's Scientific Committee on Problems of the Environment (SCOPE) has stimulated a few pioneering efforts in the coordinated study of nutrient systems. Following a preliminary review of the state of knowledge on that subject in 1975, a unit to coordinate new investigations of the nitrogen cycle was set up by SCOPE and the United Nations Environmental Programme three years later. Based at the Swedish Royal Academy of Sciences, the unit assesses data from nitrogen studies, reviews methods of monitoring nitrogen substances, and promotes regional analyses—workshops in West Africa and in Southeast Asia, for example—of the state of the nitrogen cycle and its implications for the human population.

In cooperation with the United Nations Environmental Programme and the Academy of Sciences of the U.S.S.R., a first effort is being made to delineate stocks and movements of sulfur. This includes estimates of the flux processes in atmosphere, ocean, and biosphere.

Based at the University of Hamburg and the University of Stockholm, with auxiliary units at Brussels and Essen, and with the support of the Belgian, Swedish, and West German committees for SCOPE, studies of carbon distribution and flows in marine systems and of atmospheric and ocean-atmosphere exchanges of carbon are being coordinated.

Two current efforts sponsored by SCOPE with support from the Department of Energy illustrate the types of cooperative exploration now under way. Under the chairmanshp of Mohammed Kassas of the University of Cairo and hosted by George Woodwell of the Woods Hole Marine Biological Laboratory, a conference is being held to examine the role of terrestrial vegetation in the global carbon cycle. The basis for estimating standing stocks of carbon and possible assistance of remote sensing in evaluating vegetation changes will be assessed.

A closely related workshop has been organized by Bert Bolin of Stockholm, C. D. Keeling of the Scripps Institution of Oceanogaphy, and Lester Machta of the National Oceanic and Atmospheric Administration. Its purpose is to appraise the adequacy and relative merits and demerits of the available models of the global carbon cycle.

These efforts are fruitful as far as they go, but need to be extended and strengthened. Proper assessment of presently recognized hazards as well as early identification of new threats and promising opportunities are possible only on the basis of refined scientific knowledge of how the life support system of the earth works and of the extent to which it is vulnerable to the effects of human activities. It is time to study causes as related to the physiology of the patient as a whole, instead of concentrating attention on a few symptoms.

We are still unable to describe with confidence the broad outlines of the interlocking systems of carbon, nitrogen, sulfur, and phosphorus as they nourish the life of the planet. We know enough to think it not unduly sanguine to hope that a preliminary blueprint of those systems can be prepared by 1982. Such a blueprint, ten years after the Stockholm Conference of 1972, might show in integrated perspective the principal links among the systems and the chief gaps in knowledge. Much farther down the road we can confidently anticipate a more authoritative understanding of the vital processes. Nothing short of that will provide the solid base on which fateful decisions about global alterations of land, sea, atmosphere, and biota may be appraised.

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Study Project

COMMISSION ON NATURAL RESOURCES

SURFACE MINING AND RECLAMATION: BEYOND COAL

On August 3, 1977, the Ninety-fifth Congress passed Public Law 95–87—"The Surface Mining Control and Reclamation Act of 1977." The focus of the new law was coal; but Section 709 called for a study of surface mining for minerals other than coal to determine whether existing or developing technology for mining minerals other than coal can be used to achieve the performance standards described in the act and to describe alternative regulatory mechanisms to control mining. The legislative implication was that, in the current concern with coal, we must not neglect surface mining operations for other minerals, but we need first to know more about such operations. The law directed the Council on Environmental Quality to contract with the National Academy of Sciences, and other agencies or groups, if appropriate, to conduct the study. In response, the Board on Mineral and Energy Resources of the Academy's Commission on Natural Resources formed the Committee on Surface Mining and Reclamation (COSMAR).

AN OLD CONTROVERSY

A brief look at a controversy that has troubled mining throughout its history may be useful before we examine in greater detail what COSMAR was expected to do. Mining is the removal of a mineral-bearing substance from its natural resting place in the earth. It is man's oldest industry, and its pivotal role has been recognized by terms such as Stone Age, Bronze Age, Iron Age—terms whose sequence also reveals the increasing complexity of society's reliance on mining.

The most obvious debit in mining is that it may alter the landscape, perhaps denying the mined land to agriculture, housing, or other surface uses. Reclamation is the process of restoring land to a beneficial use after mining. To be done soundly, reclamation should be planned as the mining is begun, so that, ideally, mining and reclamation are part of one process.

The ideal, however, is not always achieved, and the controversy, one as old as mining, continues between those whose primary concern is the ore and those whose primary concern is the earth. Georgius Agricola spoke for both sides in 1556 when he wrote, in *De Re Metallica*:

> now I come to those critics who say the fields are devastated by mining operations . . . the woods and groves are cut down, for there is a need for an endless amount of woods for timbers, machines and smelting of metals. And when the woods and groves are felled, then are exterminated the beasts and birds. . . . Further when the ores are washed, the water which has been used poisons the brooks and streams and either destroys the fish or drives them away. . . . Thus, it is said, it is clear to all that there is a greater detriment from mining than the value of metals which mining produces. . . . But man without metals cannot provide those things he needs for food and clothing. For though the produce of the land furnishes the greatest abundance of food for the nourishment of our bodies, no labor can be carried on and completed without tools. The ground itself is turned up with ploughshares and harrows. . . .

MINING IN THE UNITED STATES

The United States first began to construct a mining policy in 1872. Certainly, mining from the early days of the Republic had to compete, as it does today, with farming, grazing, urbanization, and other activities that use the land. While much of the pace of development of the western United States could be attributed to mining, the search for minerals did not become particularly intense until after the Civil War. The result was that before 1872 there was no explicit policy regulating the use of public lands, simply because mining was not a major factor in our industrial development. The Mining Law of 1872 was designed to promote the mining of resources and to encourage settlement and development of the continental interior. The law disposed of land and generated revenue for the federal government. It stipulated that lands managed by the federal government, with exceptions, should be open to prospecting for most metal minerals. If the prospector found evidence of some deposit of metallic ore or other mineral covered by the 1872 law, he could file a claim, move onto the land adjacent to the deposit, and mine it for as long as he liked, taking whatever timber or other surface resources he needed to run his mine. Through a document of title, he could patent the land and gain title not only to its subsurface resources, but to its surface resources as well. And to obtain the patent, he had only to show that there was enough ore to make mining worthwhile, survey the claim area, and pay the required patenting fees.

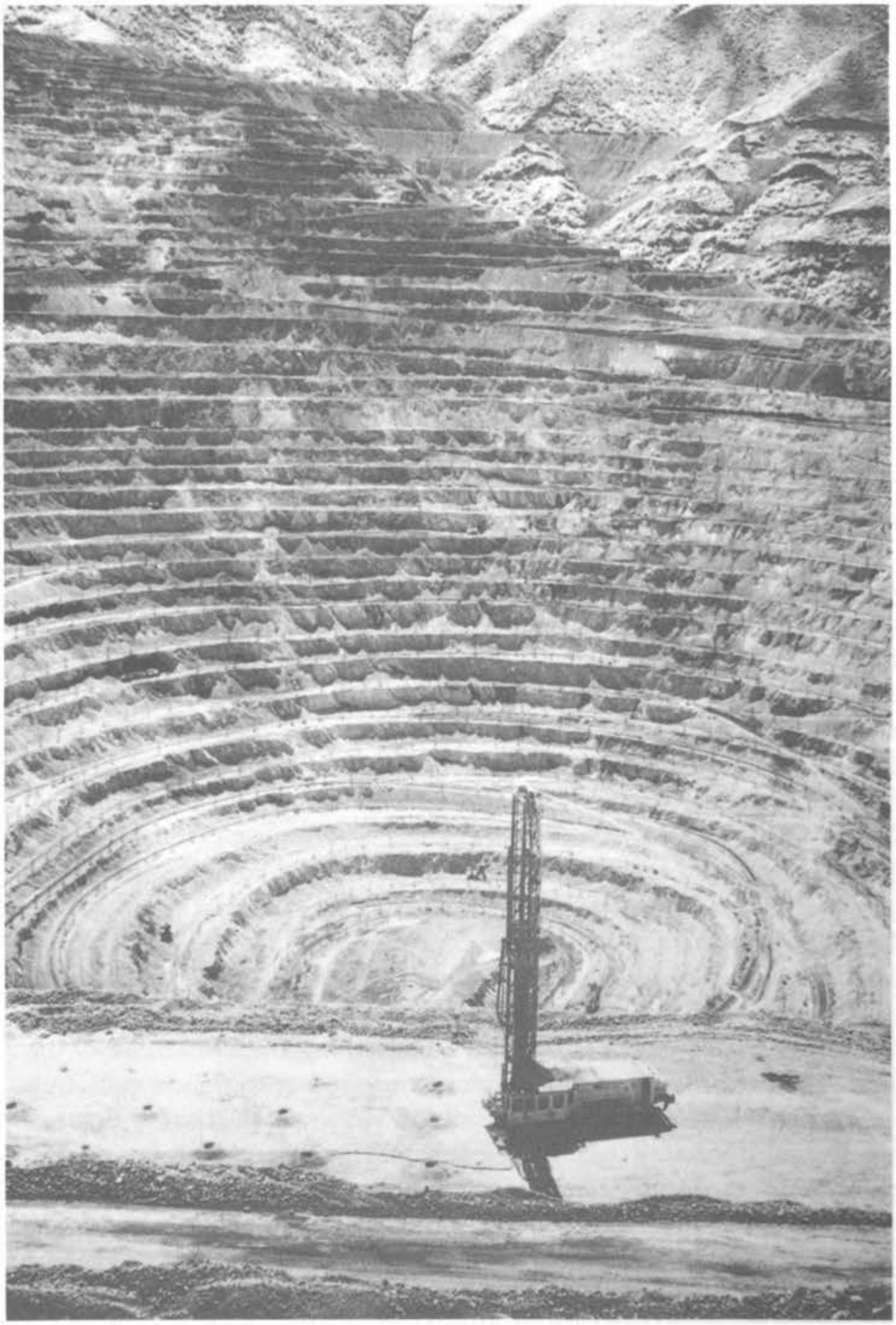
Additional laws were passed after 1872 that affected mining and the management of public lands. Most notable of them were the Pickett Act of 1919, the Mineral Leasing Act of 1920, the Federal Land Management and Policy Act of 1976, and various other special statutes, such as the Wilderness Act, the Endangered Species Act, and the Mining in the Parks Act, all of which restrict mineral development to varying degrees. Nevertheless, the claim-patent system established by the 1872 law still applied to hard rock mineral deposits on public lands.

Despite these various attempts to regulate and manage public lands, however, the conflict between minerals and the land surface that Agricola described remains: Mineral products provide an essential underpinning to our industrial economy, yet, at the same time, mining them can potentially degrade our environment. As our industrial appetite for mineral products intensifies, the potential for environmental damage increases.

The trend toward an increasing scale of operations, brought about by the need to exploit lower-grade ores, is typified by the copper mining industry. About 1800, the largest copper mine in the world was on Parys Mountain, North Wales, producing in excess of nine thousand tons per year of ore containing about six percent copper. By about 1900, the average grade of copper ore was less than five percent. These high-grade ores were rapidly exhausted, and since the 1920's, attention has necessarily turned to disseminated ores of lower grade, usually under two percent and in some cases today under one-half percent recoverable metal. By 1977, the average grade was well below one percent. As a result, a mine today may have to excavate and process about forty times more ore to produce the same amount of metal that a mine did in, say, 1900; yet economics and demand dictate that mining be carried out on an ever grander scale. Thus, more complicated and more costly mines are required, covering larger areas, moving greater tonnages of material, and generating larger quantities of waste from more sophisticated processing. Meanwhile, the need to reconcile mineral development with protection of the environment remains. In March of 1965, the Eighty-ninth Congress enacted Public Law 89–4, the Appalachian Regional Development Act of 1965. Section 205(c) directed the Secretary of the Interior to survey and study strip and surface mining operations and their effects in the United States. The study, completed in 1967, recommended that the federal government establish standards and reclamation requirements for surface mined areas in cooperation with industry, conservation groups, government, and other interested sectors.

In 1968, the Department of the Interior completed a study, *Surface Mining and Our Environment*, which described the wide range of impacts on the environment from surface mining. It said that the impacts, unless controlled, have the potential to adversely affect commerce and the public welfare by destroying or diminishing the usefulness of the land, causing erosion and landslides, contributing to floods, polluting the water, destroying fish and wildlife habitats, impairing natural beauty, and creating hazards to life and property. Certain mining operations constitute a temporary use of land, and costs of reclaiming it should not be deferred to future generations.

The Interior study contained recommendations for a national program that would regulate surface mining to mitigate its adverse



effect on the environment. Legislation regulating mining of all minerals was first introduced in Congress in 1973, but Congress rejected the "all minerals" approach and, instead, passed Public Law 95–87 regulating the surface effects of *coal* mining only. Because this law focused on a single commodity, it was possible to write specific requirements and performance standards based on the mining history and current mining technology of coal alone. Coal, however, accounts for only about forty percent of all the land disturbed by mining, and its distribution is, geologically, relatively simple. The other sixty percent encompasses nearly eighty different commodities, recovered from mines in the widest possible variety of geological and environmental settings.

SOME CONCERNS OF P.L. 95–87

It is the "other sixty percent" then that COSMAR was to deal with in responding to the congressional mandate in Section 709 of the new law. How did COSMAR approach its task, and what, specifically, are the minerals of interest?

The 1977 Surface Mining and Reclamation Act, in attempting to control effects on the environment from mining coal on the surface of the earth, asks a great many questions of the prospective miner: How will you carry out your mining operations? What kind of equipment will you use? How much land will you affect? When will you start mining and when will you stop? What watersheds will you affect and how? Do you have accurate maps, to scale, of the land you will be working on? Do they show the makeup and depth of the overburden that covers the ore? And what is the land like below the ore? What peculiar factors of climate should be considered?

Those questions relate to conditions before the work begins. There are also questions relative to how the land is left and how it will be reclaimed. How useful will the land be after it is mined? What will it be used to produce? What assurances can you give us that the land will be usable in the most appropriate way? How will you protect the quality and amount of water on the surface of the ground and below it? How will you eliminate piles of waste, depressions, and high walls (i.e., huge cutaways, sometimes one hundred feet high, left behind in

hillsides after the ore has been cut out of contoured land)? How will you restore prime farm lands to their most productive use? How will you protect the quality and amount of water above and below the ground, near, but away from, the site of the mining? How will you assure that piles of waste from the mining do not cause hazards or disturbances once your operations have ended? How will you build your access roads so that they do not interfere with fish or wildlife, damage property, or cause erosion, siltation, or pollution? What plans do you have for taking care of spoils and the various problems associated with them? How will you revegetate whatever ground you have disturbed or denuded? What will you do with your abandoned or disabled equipment to prevent its being a hazard or a nuisance? The list of questions is representative of those considered.

THE CHARGE TO COSMAR

In drafting P.L. 95–87, and in directing these questions at coal miners, the legislators knew that the questions should also be put to miners of other minerals. But where the technology of the coal mining industry is at a stage where its practitioners could answer the questions, that may not be the case with the technologies for other minerals. Therefore, COSMAR has been asked: (1) to assess the degree to which the requirements of P.L. 95–87 can be met by current and developing technology for minerals other than coal and the costs involved; (2) to identify areas where the requirements cannot be met by current and developing technology; (3) to describe in those instances requirements most comparable to those of the Act that could be met, the costs involved, and the differences in reclamation results between these requirements and those of the Act; and (4) to discuss alternative regulatory methods for achieving the most beneficial postmining use of land in areas affected by surface and open-pit mining.

In addition to these specific questions, the committee and its panels asked themselves a related series of more general questions about the environment of each mining operation. What is the primary current use of the land involved? Is it rural or urban? Industrial or recreational? If it is open space, is it improved or unimproved? Is it scenic? Is it used for agriculture? Is it used for transportation? Is it in transition? What is the climate: humid, arid, subarctic, subtropical? Is the land's topography hilly, flat, mountainous? Will there in fact be beneficial legacies from the mining? And what are the consequences of the answers to these questions in relation to the regulations of P.L. 95–87?

The committee's panels used expertise ranging across mining engineering, hydrology, agronomy, land use, landscape architecture, ecology, botany, regulatory law, geology, and geochemistry. The panelists were organized in nine groups according to bodies of ore and the mining techniques used to extract them under different climatic conditions. One panel dealt with oil shale and tar sands, another with construction minerals. These panels prepared separate reports as requested in the Act. The other panels studied large open-pit mines in low water-table areas, primarily the copper mines in arid regions; large open-pit mines in more humid regions, like the iron ore pits in the North Central States; coastal plain mining, now primarily used for recovering phosphates in Florida and North Carolina; mining that has impacts on the surface, even though the operations are carried out underground, as with lead–zinc, silver, or gold; quarrying operations from which dimension stone is extracted, leaving behind high vertical walls; discontinuous ore bodies in sedimentary formations, primarily represented by the uranium deposits of Wyoming, Utah, Colorado, and New Mexico; and continuous sedimentary deposits like clays and bauxite.

There are also economic and social costs that can be considered across the board for all mining operations that were studied by a specialized subcommittee. Another subcommittee concentrated on environmental questions to assure that, in studying the technology, adequate attention is paid to effects of the mining methods and procedures on the immediate locality or the ground and surface waters downstream from the operations.

Finally, COSMAR responded to the specific request of P.L. 95–87 that the ways in which the regulations are developed and carried out be studied, some determination made about whether alternative methods would be better, and what form they might take if indeed they are needed. A third subcommittee considered the findings of each of the nine panels and described alternative methods of regulation.

The panels solicited information from federal, state, and local government officials; representatives of industry; conservation and public interest groups; and local citizens. A number of site visits were made to representative mining operations. Case studies and working papers from the panels provided the raw material for COSMAR's final report. Each panel described actual and potential disturbances to the environment caused by the mining methods under its scrutiny, described how best to minimize these disturbances with the technology that is available, predicted effects that will be left behind even after the best technology is applied, and compared these results with the requirements of P.L. 95–87.

COSMAR's report to the Council on Environmental Quality will in part be the basis on which CEQ in turn may recommend to the President and the Congress specific legislation for regulating the conduct and effects of surface mining in this country for minerals other than coal.

GEORGE WHITE

ROBERT C. ROONEY

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Commission on Sociotechnical Systems


TODD

Technology and Innovation

HARVEY BROOKS

If it were possible to choose a single, common theme among the great diversity of studies undertaken by the committees and boards of the Commission on Sociotechnical Systems, that theme would probably be "innovation"—the general climate for innovation and its potential benefits in conservation of energy and materials, in transportation and housing, and in new ways to enhance safety and the quality of life.

Innovation has been the subject of rising political interest during the past year, prompted, in part, by the rapid growth of the U.S. trade deficit, which has continued to grow despite recent improvements in the exchange rate for the dollar. The United States, historically an exporter of technology, is now widely perceived as an importer of technology, and the government's concern is evident in the recent interagency study on innovation, chaired by the Secretary of Commerce.

There is still no general consensus about the reasons for the apparent stagnation of new technology or about the effect that

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decreased federal support of research and development has had on innovation. There are some who attribute the lag to the unfavorable financial and regulatory climate for investments in the deployment of new technology, rather than to any lack of available innovative technology or lack of adequate basic and applied research.

The United States has the lowest savings rate of any industrialized country; in addition, capital investment has increasingly shifted toward technology designed to improve environmental protection, rather than to increase the output of labor. Thus, the growth in productivity per man-hour has lagged behind that of our competitors, even though we still have by far the highest labor productivity of any country in the world. Whether this is good or bad depends on a value judgment concerning the economic growth of a cleaner environment, which is not valued as part of output and, therefore, does not show up fully in the national accounts.

Another development in the U.S. economy is the shift in employment toward services rather than production. The aggregate value of manufacturing output has continued to grow faster than the gross national product as a whole, but since a considerable fraction of services is valued at its input cost, the productivity growth in these sectors is zero by definition and hence lowers the average growth in productivity measured across the economy as a whole. Again, the question arises as to whether that is bad and how much it affects our true competitiveness in international trade.

In any event, there is no question that many industries are in trouble, and very often this trouble has arisen, not because the United States has failed to produce new inventions, but because other countries—notably Japan and West Germany—have commercialized American- and British-originated innovations faster than we have.

These and related problems are occupying many committees and boards of the National Research Council. In the Commission on

Sociotechnical Systems, for example, there are studies of innovation in the steel industry by the National Materials Advisory Board; case studies of maritime innovation by the Maritime Transportation Research Board, including a study of the potential of specific innovations, such as in coal transportation; the work of the Advisory Board on Military Personnel Supplies on infantry helmets and on the reorganization of food services at sea; Building Research Advisory Board studies on innovations in energy conservation in buildings; and studies of transportation energy problems, highway law, and state aviation planning by the Transportation Research Board.

MARITIME TRANSPORTATION

A strong, modern, and competitive merchant marine is recognized as vital to the nation's commercial, diplomatic, military, and national defense interests. Currently, the U.S. maritime industry is undergoing a searching self-examination, as well as the most intense examination by Congress and the Executive Branch that it has experienced in recent history. The ferment within the industry is extensive—on this there is general agreement—but knowledgeable observers remain divided on what this ferment will produce.[1]

Behind the current concern about the economic health and the future competitive position of the nation's waterborne transportation system lies a set of complex and often-interlocking problems that are both national and international in their impact. Foremost among these is the worldwide overcapacity in both shipping and shipbuilding, which has led to competition in government subsidies among the maritime nations. The effects of these subsidies tend to be very costly to each of the nations involved, but each feels compelled to offer traditional subsidies to keep up with those of its competitors. The development of shipyards and merchant-marine fleets by several of the newly industrialized countries—notably South Korea and Brazil—has challenged the traditional seafaring countries and intensified competition. The position of the U.S. merchant marine has begun to slip once again, despite a technological revolution in the last decade that saw this country pioneer, partly with government financial support, such innovations as containerization, satellite communications (MARISAT), and RO/RO (roll-on/roll-off). Also, questions are arising about how the new authority accorded to the states for coastal-zone management will affect maritime activities and the development of port facilities.

The economic health of the nation's merchant marine has traditionaly been treated by Congress as essential to national defense, and there is now increased concern about the capacity of the various elements of the merchant fleet to support the military services in peace and war. Finally, there is the problem of the vulnerability of different segments of American society to various future developments in maritime transportation, such as a greater concentration of port facilities, offshore deep water ports, offshore oil development, and increased movement of coal in international trade.

Maintaining an awareness of the emerging problems and choices confronting the maritime industry, and of the international trends that affect the economic and operational setting in which the industry does business, is an important function of the commission's Maritime Transportation Research Board (MTRB). Its charge includes the assessment of opportunities presented by science and technology for meeting the problems facing the waterborne commerce of the United States. The role of MTRB also requires it to estimate the vulnerability of different segments of society to potential economic, technical, and international political developments in maritime transportation. MTRB recommends programs to improve the economic strength and operational capability of the U.S. waterborne transportation system, including its inland waterways; to strengthen the ability of the U.S. merchant marine to support the military services in peace and war; to improve the safety, caliber, and quality of working life of the labor force; to improve efficiency in the use of resources; and to safeguard the environment.

Coal Transportation

A recent MTRB study[2] dealt with the problems of coal transportation. The growing demand for energy in the United States, the steady depletion of known U.S. and world oil reserves, and the ever-present threat of petroleum shortages resulting from the disruption of production or exports from other countries has focused national attention on coal as one of the most promising and versatile of the nation's short- and medium-term alternative sources of energy. Some time ago, the MTRB identified coal transportation as an area of opportunity and responsibility for the maritime industry. A systematic identification of research and development needs in this field had not previously been carried out.

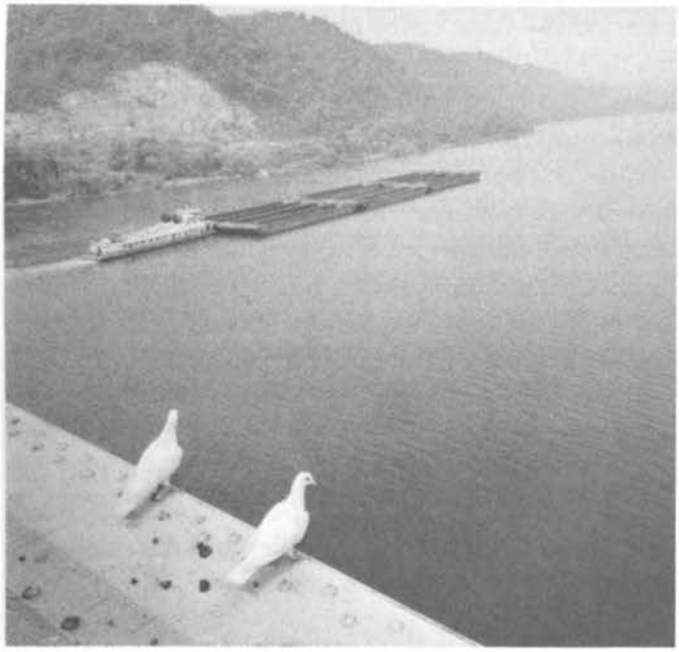
The board's Committee on Critical Issues in Coal Transportation Systems concluded that the nation's transportation system can move whatever coal may be required over its inland waterways and railroads, in intercoastal trade, and in export—not without difficulty, but with no insurmountable problems. Essentially, the need is to smooth and improve the current transportation system, not to undertake a major overhaul, because the lead-time for development of new mines and new coal-consuming plants is longer than that for adding to and modernizing the transportation system. Constant surveillance of the supply and demand for coal is essential so that transporters can stay ahead of demand, and this surveillance includes both domestic and international movements. Several problems must be assessed in regard to supply and demand, including economic regulation, environmental policies, capital formation, and public acceptance.

According to the committee, new technology should be evaluated to ensure solutions for frozen coal and sludge removal problems; constant review of security against sabotage is necessary; and the design of coal movement on an intermodal basis requires a systems approach to ensure the safe, efficient, and most economical movement of coal. Basic to the committee's conclusions and recommendations is the assumption that the various industries comprising the transportation community will continue their involvement in coal-transportation research. If the problems of coal transportation are to be solved and the movement of the needed volume of coal in the long term assured, industry–government cooperation in addressing the problems is essential.

The growing interest in coal is both national and international. Our exports of metallurgical and power-plant coal are expected to increase, not only to the traditional markets of Western Europe and Japan, but to other countries with uncertain access to petroleum. Metallurgical coal currently accounts for eighty-five percent of the nation's coal exports. Forecasts of a fourfold increase in steam-coal exports to Japan, however, appear overly optimistic in light of the anticipated export increases at competitive prices from South Africa and Australia. Nonetheless, the foreign market for U.S. coal appears certain to grow, and special attention should be given to improving the economics of the transoceanic shipment of coal.

Two important factors in effecting economies are ship size and the speed with which coal can be loaded and unloaded. A major limitation to ship size is the draft restrictions imposed by water depths in transit and in port. For example, water depths in Japanese ports of about forty to forty-five feet will constrain U.S. West Coast coal exports in conventional dry-bulk carriers to ships of a maximum deadweight of 60,000 to 80,000 tons. New shallow-draft designs could make possible dry-cargo ships of up to fifty percent greater deadweight. Studies indicate that such ships will allow lower freight rates per ton, their increased productivity more than offsetting the effect of their increased construction cost.

Although coal-loading rates at highly developed terminals, such as Baltimore and Hampton Roads, generally exceed 6,000 tons per hour, unloading remains a problem. Continuous unloaders offer a promising solution to reducing in-port time of ocean-going colliers. Two basic systems, proposed or under development in ports, are continuous chain-bucket unloaders—similar to those used to unload coal barges on inland waterways—and vertically oriented screw conveyors.



An appealing approach to waterborne coal transportation is the use of slurry. Such a system would offer several advantages over the conventional method of transport and handling. For example, it would reduce cargo handling time, eliminate polluting coal dust, and make possible the use of offshore unloading facilities, which would allow the use of larger, more economic vessels. In addition, there is the possibility of converting existing petroleum tankers—of which there is a worldwide surplus—to coal-slurry vessels. On the debit side, coal slurry requires large quantities of fresh water for the initial loading, repulping, and discharge.

The Merchant Marine and National Defense

The importance of the merchant marine to military operations was amply demonstrated during World War II. Even pleasure craft were called into service, or volunteered by their owners, for use in the coastal defense of the United States. Unlike cargo vessels, tankers, or even cruise ships, many craft developed since World War II—and especially in the last ten years—have never been evaluated for possible use by the military in a national emergency.

For example, there have been significant changes in the vessels used in offshore exploration for natural resources, for commercial fishing, and for tug–barge transportation. Oil and natural gas drilling and production require a variety of craft for transporting workers and supplies through stormy and calm weather to rigs far from shore, as well as floating equipment capable of hoisting heavy loads. The fishing industry has seen an increase in large, sophisticated vessels capable of traveling great distances in search of a catch. Increasingly powerful tugs and sophisticated tug–barge systems ply the oceans.

In the interests of preparedness, therefore, the Military Sealift Command asked the MTRB to determine what types of vessels had not been catalogued by the military, to assess the possible military roles and missions for each type, and to match these roles and missions with the vessel characteristics required to perform them.

MILITARY PERSONNEL SUPPLIES

Although the primary mission of the Advisory Board on Military Personnel Supplies (ABMPS) is to advise the U.S. Army Natick Research and Development Command on its programs, the board is also involved in a continuing search for civilian applications of the new products and technologies that emerge from these efforts.

For example, since 1972, an ABMPS committee has been working with the military services to develop a new infantry helmet[3] to replace the standard M-1 helmet that consisted of a Hadfield steel shell and a nylon liner. In July 1978, the Army adopted the new single-piece, polymeric helmet and a new improved ballistic vest made of the same material. The new helmet was extensively tested and, in all cases, proved as good as or better than the M-1. Made of the fiber-reinforced resin, Kevlar, the helmet tested twenty-five percent better in ballistic resistance; it was also found to be more stable, more comfortable, and to have less perceived weight than the M-1 headgear. It will, therefore, probably be worn more and thus be a major factor in reducing casualties. Kevlar is already being used in making armor jackets and vests for law enforcement officers and shows promise in other protective uses, such as safety hats.

A second project with both military and civilian applications is the replacement of visual color assessment in textile fabrics by a practical, economical, objective, quantitative, computerized, instrumented color-inspection system.[4] Each year, the U.S. military buys $500 million worth of dyed fabrics. Disputes over the acceptability of the materials because of off-shade colors cause undesirable delays, extra work, and unfortunate friction between contractors and the government. The goal is a quantitative measurement system of color and color differences based on the latest color-measurement instruments and high-speed microprocessors or minicomputers. Experience with this method in other industries shows that tolerances can be progressively tightened to the satisfaction of both the supplier and the purchaser. Such a system would be of great practical value in the procurement of dyed military fabrics and in other industrial and consumer uses.

Food at Sea

The provision of adequate food services aboard U.S. naval ships at sea[5] is an enormous logistical undertaking. An aircraft carrier, for instance, has approximately 4,000 enlisted men who receive 10,000 meals a day. Yet an assessment of seven Atlantic and Pacific fleet carriers, made by analysts of military systems, revealed a food-service operation that appears to be fifty or sixty years behind times in materials, equipment, and planning.

As a result of recommendations by the ABMPS, a short-term experiment was begun in mid-1978 aboard the U.S.S. *Saratoga*. The experiment consists of a fast-food outlet established in the ship's forward galley to serve hamburgers, French fries, and pizza—both as a morale booster for the men and as a means of evaluating new methods for improving food service. To be evaluated are the expanded use of convenience foods to reduce problems of storage and preparation, the introduction of new processing equipment (e.g., minisystems for hamburgers and French fries), and the fuller use of food-service equipment. The substitution of shelf-stable dehydrated potatoes for frozen French fries resulted in a space saving of sixty-six percent. Introduction of a shelf-stable pizza shell also conserved limited freezer space on the *Saratoga*.

The board's suggestion to investigate and evaluate continuous-processing equipment has resulted in the selection of a commercially available conveyor-broiler for hamburgers and several pieces of bakery equipment to support a hamburger line. The new menu and equipment layout is expected to considerably increase the equipment use rate. Experience with the system to date surpasses expectations. It will serve as the basis for a new food-service system planned for the U.S.S. *Ranger* in the Pacific fleet.

Food Waste

A 1977 report by the General Accounting Office (GAO)[6] found that about one-fifth of all food produced each year in the United States is lost or wasted—three percent in the distribution system, and an estimated seven to fourteen percent in households discarded as inedible. In 1974, according to GAO, some 137 million tons of food valued at $31 million were lost or wasted. The study further concluded that there has been little research aimed at reducing this waste.

Obviously, not all food losses can be eliminated; often the cost of reducing losses exceeds the value of the food saved. Nonetheless, it is imperative—now more than ever before—that attention be devoted to reducing food loss and waste wherever it makes economic sense. The traditional response to a growing demand for food has been to raise production, but since 1974 there has been a leveling off of yield increases in the United States. This has led to higher food prices and the realization that food losses must be controlled. While economic incentives might be expected to reduce waste as food costs increase, ingrained consumer habits and institutional inertia make this a slow process.

With the cooperation of the Board on Agriculture and Renewable Resources of the Commission on Natural Resources and the Food and Nutrition Board of the Assembly of Life Sciences, the Commission on Sociotechnical Systems is proposing a comprehensive systems-analysis study of food losses in the United States from harvest through consumption, using several selected commodities as test cases. A steering committee will include experts in operations research and systems analysis, agricultural economics, home economics, food storage and stability, food processing, food preservation, food distribution, food science and nutrition, food marketing, and so on.

TRANSPORTATION RESEARCH

The introduction of the automobile provided Americans with a personal mobility that most perceive today as a basic right. Efforts to reduce transportation fuel consumption must win public acceptance if they are to succeed. Thus, it seems prudent to look for solutions to our transportation energy dilemma that preserve personal mobility rather than impose controls and limitations possibly seen as infringing personal liberties. Understanding user choice is the key to lowering energy consumption with minimal limitations on the freedom of mobility.

To this end, the commission's Transportation Research Board (TRB) established the Committee on Ride Quality and Acceptance to study the interrelationships between ride quality and passenger comfort and acceptance in all types of passenger transportation systems. The committee's report will be based on the findings of a three-day workshop that sought to identify the technological developments that most probably will contribute to improved energy efficiency in transportation vehicles and system operations, to predict the effects of such technological advances on ride and service quality, to estimate the impact on user acceptance that may result from these changes, to define specific problems or policy issues that require further study, and to suggest possible approaches to the investigation of these problems.

Highway Law

The automobile and its highways involve annual expenditures in the billions of dollars and, not unexpectedly, generate many legal problems. Highway law is a product of mid-twentieth-century jurisprudence, with only the shallowest of roots in the common law. As a result, it is neither taught in law schools nor has it received adequate research coverage in commercial legal publications.

The TRB began work in highway law shortly after the passage in 1956 of the act creating the Interstate Highway System; its "Highway Law Series" were among its first products. The board organized its first national "Workshop on Highway Law" in 1962 to provide a professional forum where attorneys working in this field could gather and exchange ideas and information; last year, the seventeenth annual workshop was held, with representatives attending from most states.

The Highway Law Series concentrated on the organic and statutory law of the various states, deliberately leaving the vast and ever-increasing body of highway case law unexamined. Subsequently, the American Association of State Highway and Transportation Officials asked the TRB to undertake such an examination through its National Cooperative Highway Research Program. This has been done with funds provided by the states and the Federal Highway Administration.

The program began by producing papers on critical problems as they arose. For example, it published the first analyses of the impact of the newly enacted National Environmental Policy Act of 1969 and the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970. Then the program produced analyses of long-standing problems in highway law that had never been adequately researched. As part of this effort, the program published a comprehensive textbook entitled *Selected Studies in Highway Law,* the first of its kind in Americal legal literature.[7]

State Aviation Planning

Since the late 1960's, most of the states have included aviation policy as a component of their overall state transportation plans. The Airport and Airway Development Act of 1970 provides federal planning grants for the development of state aviation systems, and nearly all the states have taken advantage of this program. Moreover, seventeen states have passed legislation requiring that all federal funds for airport development be channeled through their state governments.

The TRB established the Committee on the State Role in Air Transport in 1977 to encourage research and disseminate information about numerous issues confronting state aviation officials and programs. The committee is particularly concerned with air service to small communities; planning, development, and maintenance of general aviation airports within financial constraints; and levels of intergovernmental coordination necessary to meet the demands of air service.

Four areas have been identified for study—problems of airport-system implementation, including multiyear programming and establishing project priorities; airport landside compatibility planning; noncapital or low-capital alternatives to achieve improved service or increased capacity; and innovative methods for financial management for small airports.

MATERIALS

Recently the National Materials Advisory Board (NMAB) has been increasingly involved in the safety of materials (for example, the fire hazards associated with polymeric materials).[8] The board's Committee on Maritime Hazardous Materials was formed to advise the Coast Guard on the safe handling, transportation, and stowage of hazardous materials. This committee has established a panel to evaluate the safety issues associated with liquefied natural gas (LNG). The panel is addressing two broad subjects—one dealing with LNG ship design and

operations, risk assessment, personnel training, and related topics; the other with the spill and burning characteristics of LNG. The panel's report will be concerned with the prevention of spills and will cover the information needed to assess the chain of events leading to spills in order to minimize their consequences.

The Platinum-Group Elements

For several years the NMAB has been studying trends in the use of a series of critically and strategically important materials. Currently under study are the six platinum-group elements. The United States is completely dependent on foreign sources for its supply of platinum, palladium, rhodium, iridium, ruthenium, and osmium, all of which have unique catalytic and electrical properties as well as superb oxidation and corrosion resistance. These six elements are being examined in terms of their geology, chemistry, availability, and commercial applications. The study report will address use trends—citing where substitutions might be possible and what areas will be heavily affected by shortages and price fluctuations—and will analyze conservation and recycling opportunities.

Ceramic Gas Turbines

Another materials problem being evaluated by the NMAB involves the reliability of ceramics in gas-turbine engines. Such ceramic materials as silicon carbide and silicon nitride are being used experimentally for blades and rotors in gas turbines. Their oxidation and corrosion resistance permit use at temperatures well above those of the traditional superalloys. In recent tests, ceramic blades have run for hundreds of hours at temperatures up to 2,500°F, as compared with up to 1,900°F for superalloys without cooling. This higher working temperature could increase engine efficiency up to forty percent.

Ceramic turbine parts are also much lighter in weight and are, therefore, particularly attractive for both automotive and aircraft use where weight reduction results in increased fuel efficiencies. Moreover, these ceramics are made from materials widely available domestically, and thus they are not vulnerable to a supply interruption as are such critical constituents of superalloys as cobalt, chromium, and nickel. Ceramics are inherently brittle, however, and their toughness and reliability must be greatly improved if they are to be used routinely as replacements for superalloys. A major problem today is the difficulty of predicting how long any individual ceramic part will function in a gas turbine.[9]

Steel Industry Study[10]

Recently, the Academy was requested by the Office of Science and Technology Policy to conduct a rapid study of the status of research and development in and for the domestic steel industry. The NMAB was assigned the task and began work, under a proposed seven-week contract, to assess the state of research and technology for the steel industry and to recommend alternative uses for abandoned steel plants. The report was delivered in eight weeks.

The report briefly assesses the current state of technology in the domestic steel industry, emphasizing research and development on energy conservation and pollution abatement and the role of the federal government in support of research and development. It reviews the causes of the present economic distress of the industry and the reasons for the highly competitive position established by some foreign steel producers, notably Japan.

A principal conclusion is that any comprehensive federal program for improving the technological capability of the domestic steel industry must address the related problem of the industry's financial condition. Although research is an important component in the industry's technological base, an expanded research and development effort would have little immediate effect in improving the current economic status of the industry. Federal support is justified, however, for long-term basic research and for large, high-risk technology demonstration programs. Several specific research and development projects in process development, energy conservation, and pollution abatement are identified and recommended for government support, preferably under some cooperative industry–government arrangement. These projects include the direct reduction of iron ore using a solid reductant, continuous coke-making, high-temperature heat recuperation, direct coal firing for process heat, control of fugitive emissions, and recycling waste-water systems.

On the question of alternative uses of abandoned steel plants, the study concluded that no general solution exists. Because of the complex and site-specific nature of plant abandonment, it will be necessary to conduct a more comprehensive study, involving specific sites, to develop recommendations for an appropriate federal program.

Housing Cost and Quality

The Building Research Advisory Board (BRAB) points out that recently there has been a great deal of media attention focused on rising housing costs, and, in particular, on the median cost of a new house in relation to median family income. BRAB warns that statistics can be misleading. For one thing, several recent studies have been distorted because the base year chosen—1970—was a year in which an unusually large portion of new construction was publicly subsidized, thus artificially depressing the average price for the year. From 1966 to 1976, the median sales prices for new homes, relative to the consumer price index (CPI), increased 2.2 percent annually, while that for existing homes increased 3.1 percent annually. Relative to personal income, the rise has been between 0.8 percent and 1.7 percent annually.[11] Thus, some deterioration in buying power has occurred, but not so much as popularly believed. Moreover, most families buying new homes do so by selling an old home whose value has increased since purchase. The main burden of home prices falls on families buying new homes for the first time. This is an increasingly serious problem as first-time buyers struggle to assemble the cash for down payments. The extent of this aspect of the problem has not been fully assessed. Once a family gets into the housing market, the fraction of its income going into housing tends to decline with time, since most of the cost of home ownership consists of mortgage payments. Thus, in a limited sense, long-time homeowners are beneficiaries of inflation because salaries rise with inflation, while mortgage payments do not, and those who move benefit from the rising sales prices. Indeed, most American families could not afford to buy the homes they live in today if they were entering the housing market for the first time. The real losers are renters, who experience increased costs, but do not build equity.

Another fallacy is that the escalation of labor and materials costs is largely responsible for pricing housing out of the range of the middle-income family. In fact, during the last decade the price index for building materials, on the average, has closely followed the CPI. In one rather typical, but high-cost area, Montgomery County, Maryland, the average annual increase in the cost of houses between 1969 and 1976 was 7.6 percent, compared with 6.8 percent for the CPI, but for land and site development, the annual increase was 17.3 percent. Between 1949 and 1977, according to Sumichrast,[11] the fraction of the price of a new house attributed to the structure itself dropped from 69 percent to 46.7 percent, whereas the cost of land, site development, financing, and overhead increased from 31 percent in 1949 to 53.3 percent in 1977. The costs of land and financing more than doubled during the period. Most of these costs result, directly or indirectly, from land-use controls, environmental regulations, and new standards for site preparation by developers. The rise in the cost of the house relative to the CPI is largely due to improved building standards, rather than to higher per-square-foot costs.

Indeed, the increase in average housing standards has been surprising. The percentage of families with more than one person per room dropped from more than twenty percent in 1940 to less than five percent in the mid-1970's, and many of the five percent were in rural areas. The percentage of housing units with all plumbing (private bath, flush toilet, hot running water) increased from 55.4 percent in 1940 to 96.9 percent in 1974.[12]

When U.S. housing standards are compared with other industrial countries, we again stand out. Only Sweden and the United Kingdom are comparable, and they still have more crowding and less plumbing. Of course, these statistical averages conceal large variations with respect to geography and income level, as well as among individual families with the same socioeconomic characteristics.

Solid Waste Resource Recovery

The Building Research Advisory Board is conducting a study for the Environmental Protection Agency to establish research priorities for the recovery of materials and energy from solid wastes. The board is considering current knowledge about applicable technologies, the administrative and institutional constraints affecting solid waste collection and processing, and the potential economic effects of federal intervention in research and development applicable to resource recovery. The study will evaluate and analyze such conventional disposal methods as landfill, composting, and incineration, as well as newer recovery techniques. In addition to meeting the specific needs of the Environmental Protection Agency, the study should help municipalities in devising ways to dispose of solid waste and, to some extent, lessen the national dependence on fossil fuels.

Liability in the Construction Trade

Sponsored by the Department of Transportation, the Bureau of Reclamation, and the Department of Energy, a BRAB committee has completed a study of the responsibility, liability, and accountability for risks in construction. The committee's exploratory efforts established that the problems involved are intimately related to the escalating cost of construction and the increasing delays in delivery of vitally needed facilities. It concluded that there is neither a "clear understanding and recognition on the part of all parties to the construction process that risks are inherent in construction" nor is there any "adequate system or mechanism in general application at the present time for clearly and equitably assigning reponsibility and liability for risks in construction."

The committee recommended that the dialogue initiated with its study be continued "so that its conclusions and recommendations can be adequately criticized and debated and positive courses of remedial action developed." Specifically, it suggested that a way be found so that the various parties in the construction industry—owner, designer, contractor, laborer, manufacturer and supplier, insurer and bonder, the legal professions, all levels of government, and the general public—can be brought together in developing courses of action that will produce consensus solutions to the various problems.

The committee listed seven areas that should be investigated to facilitate the implementation of sound risk-analysis and risk-management programs: (1) the potential for the application of risk-analysis and risk-management procedures to the construction process, (2) the requirements for trained specialists to perform risk-analysis and management functions in construction, (3) improved techniques for the identification and analysis of risks, (4) construction-hazard analysis as it relates to safety for everyone involved in construction, (5) the delineation of responsibilities in construction (including government and the public), (6) an equitable allocation of risks and liabilities considering the respective capabilities of parties to control the risks and to bear the liabilities, and (7) the extent to which insurance and bonding are available and applicable to construction risks.

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Study Projects

COMMISSION ON SOCIOTECHNICAL SYSTEMS

TRANSPORTATION TECHNOLOGY SUPPORT FOR DEVELOPING COUNTRIES

Agriculture, distribution of food, availability of health services, and access to educational services and other forms of communication in rural regions of developing countries are all heavily dependent upon transport facilities. Although rail and water are important in many areas, a dominant and universal need is for roads that provide an assured yet inexpensive way to move people and goods. This need is mostly met by low-volume roads that generally carry only five to ten vehicles and seldom as many as four hundred vehicles each day.

The planning, design, construction, and maintenance of low-volume roads for rural regions of developing countries can be greatly improved in their economics, quality, and performance by the use of low-volume road technology that is already available in many parts of the world. Much of this technology was produced during the earlier stages of what are now the more developed countries, and some continues to be produced by the entire spectrum of developing countries.

Some of this technology has been documented in papers, articles, and reports written by experts in the field. But much of it is undocumented and exists mainly in the minds of those who by necessity developed and applied the technology. In either case, existing knowledge about low-volume road technology is widely dispersed geographically, is varied in its language and the form in which it exists, and is not readily available for application to the needs of developing countries.

Throughout its history of more than fifty years, the Transportation Research Board of the Commission on Sociotechnical Systems has provided a meeting ground for transportation technologists; it has developed techniques and resources for generating, compiling, and disseminating technical information in response to both the specific and the general needs of the transportation research community. In effect, the Transportation Research Board (TRB) is a center and agent for the transfer of transportation technology as technical information.

Because of its concern for the effective use of existing information in the economic development of transportation infrastructure, and because of its resources and capabilities for information transfer, the TRB was asked by the U.S. Agency for International Development in mid-1976 to propose a project that would provide developing countries with improved access to basic information on usable transportation technology.

The Transportation Research Board in response proposed a three-year project that would incorporate methods that have been used successfully by TRB to develop and transfer technical information throughout the U.S. transportation research community. The proposal was accepted and the project began on October 1, 1977.

Although the project has much narrower subject scope and a quite different clientele than the overall TRB activity, it is a microcosm of TRB with respect to project activities, products, and organization. The project provides an opportunity for TRB to use its experience in the United States in meeting special technical needs of developing countries.

Major functions of the project are to produce publications; to arrange meetings among those concerned with the substance, quality, and performance of the project work; and to communicate personally and systematically with those who will use the information in their own countries. Of the project's budget of $700,000 for three years, about one-half is allocated to publications production, about one-quarter to group interactions, and about one-quarter to personal communications.

PUBLICATIONS

Three types of publications are produced: compendiums of selected material published previously, syntheses of information from a mixture of published and unpublished documents, and reports on the meetings and conferences arranged as part of the project. Compendium production is scheduled at the rate of six books per year. Syntheses will be prepared at the rate of about two per year, and at least two conference reports will be produced over the three-year period. Thus in three years, each developing country correspondent will have received about twenty-six books constituting a mini-library of low-volume road technology. The project goal is to provide a select yet comprehensive collection of basic and applied information that will be useful for many years.

Compendiums

Compendiums begin with the selection of relatively narrow topics that are known to be basic to the provision and improvement of rural roads in developing countries. Each topic represents a singular contribution to technical information needs; collectively, the topics will embrace the entire scope of the project. Another selection criterion is that basic information on each topic, while documented, is scattered. There would be no need for a compendium whose topic is well covered by one or two existing documents. Topics for the first eleven compendiums have been selected by the project steering committee. Titles and scopes for the topics are as follows:

1. *Geometric design standards for low-volume roads.* Evolution of separate design standards for low-volume rural roads. Suggestions for further modifications of standards for economic reasons.

2. *Drainage and geological considerations in highway location.* Drainage and types of soil and rock in proposed roadway corridor. Simple tests for soil and rock classification. Use of air photos in route location and the identification of landslide-prone areas.

3. *Small drainage structures.* Requirements for proper roadway drainage. The role of the small drainage structure in the overall roadway drainage system. Guidelines for the hydraulic design of culverts, control of debris at culvert entrances, control of erosion of culvert exits, and the structural considerations of culvert design.

4. *Low-cost water crossings.* Various types of low-cost water crossings including fords, paved dips, submersible causeways, timber bridges, Bailey bridges, floating bridges, and ferries. Economic analysis of each type of crossing to assist in proper selection of crossing for a specific stream or river.

5. *Maintenance practices for roadside drainage.* Problems of maintaining roadside ditches. Erosion problems in ditches and other open channels. Design data for open channels. Reconstruction of eroding ditches as the most economical maintenance procedure.

6. *Inventory and development of materials resources.* Location and evaluation of sources for highway construction materials. Examples to show economy of locating low-volume roads near material sources.

7. *Properties of surface gravels.* Gravel requirements for surfaces that need water-retaining fine material for durable riding surfaces. Gravel requirements for roads that are to receive a surface treatment and are apt to fail if the gravel retains water under the surface. Blending of local materials to produce a proper gravel surface.

8. *Inexpensive soil modification with local materials.* Methods of soils stabilization with local materials such as clay, lime, cement, asphalt, and other less-used local materials. Problems that can be encountered if proper control of the stabilization procedure is not exercised.

9. *Control of erosion.* Erosion problems frequently encountered on the road surface, on slope faces, and around bridge piers. Suggested solutions for each problem.

10. *Quality control of low-volume roads materials.* Simple methods for controlling the materials that are used in low-volume road construction. Field tests and proper methods of handling and stockpiling of materials.

11. *Decision methodology for maintenance and upgrading.* Criteria for use by administrators and supervisors to determine the amount of effort and the types of equipment and material necessary to maintain low-volume roads. Procedures for determining when a road needs to be upgraded rather than routinely maintained.

Compendiums on the first eight topics have already been published. It takes about six months to produce one compendium. Thus at a given time work should be in progress on about three compendiums in order to maintain a production rate of six per year.

The project steering committee annually revises and extends the list of compendium topics according to two criteria: parts of the project scope not yet covered and needs reported by project correspondents in developing countries.

Compendium production for a given topic begins with references obtained from various libraries and information services that include the TRB Highway Research Information Service (HRIS), the OECD International Road Research Documentation (IRRD) network of which HRIS is an element, and the catalog files of the U.S. Department of Transportation Library. (The DOT Library was for many years the U.S. Bureau of Public Roads Library and holds a very high proportion of all documents that have been published on low-volume roads technology.)

The acquired references are screened by the staff engineer, familiar not only with the theory and practice of highway engineering but also with technology needs and applications in developing countries.

Experience to date is that 500 to 800 references are acquired for a compendium topic, and that 50 to 100 of these survive the initial screening; full-text documents are obtained for the latter references. The staff engineer examines and evaluates each document for its potential contribution to the compendium. The end result is that from eight to twelve documents or parts thereof are selected for their complementarity and completeness in covering the compendium topic. Other considerations are the readability of each text and a total page limit of about three hundred pages.

An additional ten to fifteen references are selected for inclusion in the compendium bibliography. These references are for documents that are relevant to the topic and might have been included in the absence of a page limit. It is by intention that each bibliography is limited to a small number of references, since acquisition of the referenced documents can be quite difficult, even in the United States. References do not include documents that are considered not basic to the compendium topic or that contain only a small proportion of relevant material.

After each topic is selected, a corresponding subcommittee of the steering committee is named to provide advice and review as the compendium develops. After the initial selection of papers to be included, the staff engineer prepares an eight- to twelve-page overview that gives the background and scope for the subject addressed, describes the rationale used in text selection, and points out the general and specific contributions of each text included.

The staff engineer then discusses the draft overview, selected texts, and bibliography with each subcommittee member. When all have agreed on the contents of one compendium, the overview is translated into Spanish and French, and an index is prepared for overview and text. Concurrently, a request is made to the original publisher of each text for permission to reproduce and publish the selected information. All permissions have been granted to date, provided proper acknowledgments are made to the source.

These concepts and methods for compendium production are new in TRB publications; they could be adapted readily to other technologies wherein selection and compression of existing literature is desirable.

Syntheses

Either a synthesis or compendium could be produced for any topic, but some topics can be treated more effectively in a synthesis than in a compendium. In terms of the project as a whole, it is intended that the coverage of compendiums and syntheses be complementary rather than overlapping. A synthesis is preferable when existing documentation on the topic is so fragmented that text selection is virtually impossible. More telling is when considerable technical knowledge on the topic exists in the minds and notes of practicing engineers and technicians but has never been published. In this case a compendium based on published materials would have serious gaps. Finally, there are some topics for which a fresh treatment is needed to bring coherence and uniform depth of treatment to existing information.

The Steering Committee for the project constructs and revises topic lists for compendiums and syntheses on an annual basis, and decides which topics go to synthesis publications. Three topics have been selected for the first syntheses:

1. *Maintenance operations for unpaved roads.* Operations required to maintain gravel roads. Proper techniques for each operation and the proper location and composition of maintenance camps.

2. *Labor-intensive intermediate technology for construction and maintenance of low-volume roads.* Current practices in developing countries throughout the world. Constraints that affect the economic competitiveness of labor-intensive construction and maintenance. Circumstances under which various mixes of labor and equipment-intensive operations are most effective or economical.

3. *Stage construction methodology.* Stage construction of a low-volume rural road from a track of graded *in-situ* material with low-cost water crossings through improvement by means of various spot alignment corrections, the application of all-weather surfacing and all-weather water crossings.

Whether compendiums or syntheses, all but two topics are on engineering and operational aspects of low-volume roads. The last topic in each list deals primarily with planning and administrative concerns. It is expected that this ratio of about six to one will prevail throughout the project history and that it represents the actual proportions of concerns among road specialists in developing countries.

A subcommittee of the steering committee is appointed and a consultant is employed for each synthesis topic. Criteria for consultant selection include a working knowledge of the subject, firsthand experience with relevant technical problems that exist within developing countries, and demonstrated ability to organize and present technical information.

The starting point for each synthesis is a meeting of the subcommittee, consultant, and staff to develop scope, outline, timetable, and guidelines for the work.

At this initial meeting proposals are made for the types of undocumented information on the synthesis topic that should be thus acquired and for the types of individuals who should be interviewed to acquire it. Documented information on the topic is obtained just as for compendiums. From these documents and the interview information, the consultant then prepares an initial draft for review, which is discussed at a second meeting. The consultant's work is complete when a final draft has been approved by the subcommittee and by the steering committee. Front matter, bibliography, and index are produced for each synthesis as for the compendiums.

In terms of page count, the average size of a synthesis is only twenty to thirty percent of the average compendium size. Feedback from users and cost analyses will be used to determine the relative advantages of the two types of publications for those topics that might be treated in either way.

Conference Reports

The project is a cosponsor of conferences on low-volume roads and does not have primary responsibility for conference reports that are produced. Nevertheless, the conference reports are considered to be project publications in that each conference report will contain project information and will be distributed to those developing country correspondents who receive compendiums and syntheses.

Each conference report will contain individual papers that were presented and summaries of group discussions that were held. At least one session of each conference will be devoted to a discussion of the work of the project.

The reports will provide project correspondents with up-dated information on many topics for which basic information has been provided in compendiums and syntheses. In effect, compendiums and syntheses represent an encyclopedia on transportation technology and the conference reports represent yearbooks on current thinking, including new and prospective technology.

GROUP INTERACTIONS

Three types of group interactions are included in the project design: meetings of the project steering committee and its various subcommittees, international and in-country conferences involving the project, and student colloquiums organized by the project on an annual basis.

Steering Committee

The project steering committee is responsible for (a) general overview of the project activities, (b) liaison between project activities and related activities that may be internal or external to TRB, (c) identification of publication topics, (d) assessment of feedback on project activities and products, (e) correspondent network development, and (f) definition and review of individual products. The first four of these responsibilities are carried out by the whole committee. One standing subcommittee has responsibility for development and overview of the correspondent network, and one subcommittee is appointed for each compendium and synthesis topic. In keeping with the scope of subject matter of the project, steering committee responsibilities require it to include experts on all major aspects of low-volume roads, people who have firsthand experience with the application of road technology in developing countries, and individuals who can speak for project-related activities in TRB and other organizations throughout the world. The present steering committee meets these requirements quite well in that about ninety-five percent of the members have special knowledge of road technology and about sixty percent also have firsthand knowledge of developing countries. Internal liaison is provided by overlaps between membership on the steering committee and membership on the TRB Standing Committee for Low-Volume Roads, and through staff representation of other TRB and NRC units. The committee includes members who can speak for four major U.S. organizations whose work is related to the project: the Federal Highway Administration, the Office of International Coopera-

tion of the U.S. Department of Transportation, the U.S. Agency for International Development, and the National Association of County Officials. Liaison members are provided for five international organizations that have direct interest in transportation technology for developing countries: the International Bank for Reconstruction and Development (World Bank), the International Road Federation, the Permanent International Association of Road Congresses, the International Labor Organization, and the Road Research Program of the Organization for Economic Cooperation and Development. It is expected that steering committee membership will be modified as new needs become apparent throughout the work of the project.

Steering committee meetings are held two or three times a year. Compendium subcommittees do not meet as a group, since their work is accomplished through correspondence and personal interviews with staff. Each synthesis subcommittee meets twice—once to define the work and once to review the initial draft that has been produced by the consultant.

At any time, each member of the steering committee is also a member of two or three subcommittees and therefore contributes to the project work on a continuing, though intermittent, basis.

Conferences

The project plan includes partial support of two international conferences on low-volume road technology. One is the "Second International Conference on Low-Volume Roads," held at Ames, Iowa, August 20 to 23, 1979. This conference and its predecessor were organized by TRB, and the conference report will be a TRB publication. The project has responsibility as a cosponsor for organizing one session within the overall conference and for contributing a report on the session to the overall publication.

The project will also participate in the IVth African Highway Conference, to be held in Nairobi, Kenya, in January 1980. Again the project will be a cosponsor, will assume responsibility for a forum on the project work, and will contribute to the conference report.

Finally, the project plan provides for staff cooperation in the planning and conduct of within-country conferences that may be organized by one or another of the developing countries. Although not yet done, this project activity might be labeled "conference technology" transfer. Thus the project would be a channel for sharing TRB conference experience and know-how with organizations in developing countries.

Colloquiums

The third type of planned group interaction is an annual colloquium of students from developing countries who are currently enrolled in undergraduate or graduate transportation courses at U.S. academic institutions. The first colloquium was held in January 1979.

University representatives for TRB in about one hundred and fifty U.S. institutions provide the project with names, present addresses, and home countries of appropriate students in the respective schools. Each student is invited to attend the colloquium, but since the project budget does not provide for travel assistance, only about ten percent of the invited students are able to attend.

The colloquium format is a panel discussion followed by general discussion. The agenda includes scenarios for low-volume road situations in specific countries, associated needs for technology support, and ways in which the project can have beneficial impact on the needs.

A summary report on each colloquium is prepared for publication in *Transportation Research News.*

PERSONAL COMMUNICATIONS

In developing personal communications between project personnel and the developing country constituency, a preliminary step is to identify the constituency, then create and maintain a machine-readable file that contains necessary and sufficient data for communicating with each correspondent. For example, TRB maintains an administrative file that contains about twenty thousand names and addresses for organizations and individuals that are associated with TRB activities and services in specified ways. Several hundred of these individuals are TRB representatives for their respective organizations, e.g., state departments of highways and transportation, transit authorities, universities, and organizational members of TRB. Each TRB representative has agreed to be a focal point for many types of communications between his organization and TRB, acting both as a central receiver and distributor of communications to and from the Transportation Research Board. The project has adapted this successful TRB representative scheme to the development of a correspondent network in developing countries. Also, an important part of the overall TRB activity is its field visit program, through which all representatives and major elements of the TRB constituency are visited by TRB staff on a regular and continuing basis. This TRB function is also an essential element of the project design.

Correspondent Network

Developing country correspondents for this project are people who upon invitation have accepted certain responsibilities for personal communications with project staff and with fellow countrymen on behalf of the projects.

With advice from AID missions in developing countries, and from its individual knowledge and resources, the subcommittee for network development has identified more than two hundred correspondents in a total of sixty-six developing countries. The number of correspondents per country varies from one to five, but at least three people have been named in all but seventeen countries. Personal messages to correspondents are in English for thirty-four countries, in Spanish for fifteen countries, and in French for seventeen countries.

The primary responsibility of each correspondent is to receive all the project publications and to make them available to the right people, leaving it to his best judgment as to how this should be done. A second responsibility is to respond to questions transmitted semiannually by the project that will probe into what methods are being used to make the books available, who has been using the books, how useful they appear to be, and what suggestions or comments have been made.

In twelve countries, one correspondent has been invited to be a review correspondent, that is, to have each publication reviewed by an appropriate person and to respond to questions that are specific to the book. In the case of a compendium these questions will be specific to each part of the book, but with particular emphasis on the texts selected. The general feedback should reflect how the publications are being used and with what impact; review feedback should provide guidance for changes in publication characteristics.

In addition to the publications, correspondents receive news about the project activities and plans, are listed in a special section of the annual TRB *Directory*, and receive a certificate that acknowledges their special and valuable contribution to the project work. It is expected that the correspondent file will be current with respect to countries and individuals.

Field Visits

Field visits by project staff are semiannual and rotate among Latin American countries, African countries, and Asian countries. Visits will average about two weeks and will generally include three or four countries. The first visit was made to Liberia, Ivory Coast, and Kenya in late June and early July of 1978. The second visit was scheduled for selected Asian countries in late 1979.

The aims of each visit are to (a) meet with project correspondents, (b) extend local knowledge and understanding of the project, (c) obtain firsthand reactions to project publications and procedures, and (d) acquire knowledge about the country's needs for transportation technology.

A secondary but important consequence of the field visits is that the staff visitor can discuss specific technical problems with local people. Some of these discussions may lead to immediate and useful advice. Other questions may be brought back for later consideration by the project.

Distribution of Publications

Individual users receive the project publications through any of several delivery systems: (a) the correspondent network, (b) distribution by the U.S. Agency for International Development, (c) preprinting agreements for group delivery, and (d) postprinting orders for individual mailings.

Publications that are mailed through the correspondent network will include project news articles that have been released, semiannual requests for general feedback, and requests to review correspondents for feedback on each publication.

Several hundred copies of each publication are distributed by the U.S. Agency for International Development to personnel in AID missions throughout the developing countries.

The third system provides a way for any organization in the United States or abroad to purchase and distribute (or have distributed) specified quantities of any publication to designated individuals. Since these agreements are reached before the printing order is placed, a relatively large discount is provided. In the United States, group deliveries will generally be used by the Federal Highway Administration, the state highway and transportation departments, the U.S. Forest Service, and perhaps other organizations whose employees or constituents use technology that is related to the publication. It may also be that some developing countries will place group orders for publications beyond those received by the project correspondents.

Finally, several hundred copies of each publication are held for individual orders that are received as a result of announcements in TRB news releases and publication catalogs.

PAUL IRICK

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RESEARCH PRIORITIES FOR ENERGY CONSERVATION IN BUILDINGS AND RELATED COMMUNITY SYSTEMS

Buildings—ranging from residential housing to such large complexes as office and apartment buildings, shopping centers, and hospitals—are major targets for energy conservation because, by most estimates, they consume at least one-third of the total energy used in the United States, and much of that energy is wasted. Before the Arab oil embargo in 1973, little thought was given to energy efficiency or conservation in building design and construction. While there was considerable research on building systems and products that affect energy consumption, energy economy, as such, was subordinated to other considerations, such as comfort, low first cost, esthetics, efficiency of space use, low maintenance, and high reliability.

Since the oil embargo, both the government and private organizations have undertaken a number of research and development projects on energy conservation in buildings. The Energy Research and Development Administration (ERDA)—now a part of the Department of Energy (DOE)—began a research, development, and demonstration program related to buildings shortly after it was established in 1975. This continuing program is one of the most comprehensive efforts ever made to advance the technology of energy use in buildings. To ensure that the program would yield maximum benefits, ERDA in 1976 asked the National Academy of Sciences to evaluate its program on energy conservation in buildings. The task was assigned to a committee formed under the National Research Council's Building Research Advisory Board (BRAB).

The resulting BRAB report, issued in 1978,[1] included both general recommendations on program development and administration and specific recommendations about existing DOE research, suggesting nine new areas for future consideration and the elimination or modification of several projects. In the general category, the most significant recommendations were that DOE should assume leadership in determining what research should be done on energy conservation in buildings and that it should develop a master plan for its research and development program.

A new BRAB committee is now conducting a broader study for DOE in an attempt to formulate an optimum research and development program on energy conservation in buildings. The committee expects to complete that study by mid 1980.

THE FRAGMENTED BUILDING COMMUNITY

Formulating an optimum R&D program on energy conservation in buildings is a difficult task, partly because of factors common to most R&D efforts—such as insufficient money and trained manpower to carry out the number of projects that researchers would like to undertake—and partly because of the complex nature of construction, regulatory restrictions, and the composition of the building community. The highly fragmented construction industry includes literally thousands of different organizations, most of which are relatively small, but important locally in constructing buildings. Building construction involves architects and engineers, general contractors, many specialty subcontractors, materials suppliers and distributors, equipment and product manufacturers, state or local building code officials, fire marshals, occupational health and safety inspectors, local planning and zoning bodies, lending institutions, insurance companies, and, frequently, several labor unions. Indirectly involved, through the preparation of standards and technical guidelines or through product certification programs, are professional and trade associations, federal government agencies, academic and research organizations, and testing laboratories.

Any building research program that does not consider such complexities of the construction industry is likely to fail, simply because it will be incompatible with the needs, concerns, and procedures of the various components of the industry. An example is the "Operation Breakthrough" program, established by the Department of Housing and Urban Development (HUD) in 1969 "to modernize the housing industry by facilitating volume production of quality housing for people of all incomes,"[2] which was generally unsuccessful primarily because of inadequate consultation with the representatives of professional societies, trade associations, consumer groups, and the building industry itself before the program was undertaken.

GOVERNMENT VERSUS PRIVATE RESEARCH

Developing a federal research and development program for energy conservation in buildings and community systems, such as utility companies, is complicated by the need to consider the different roles of government and private industry. For example, government programs should not duplicate research in the private sector; result in products which, while technically feasible, are not commercially marketable by private industry; or obviate the need for continuation or initiation of related research by private organizations.

DOE has sponsored a number of conferences to discuss research and development priorities in energy conservation in buildings and community systems. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers and the American Institute of Architects have also discussed the subject extensively. While a consensus is slowly developing on the most pressing needs, unanimity will probably never be achieved. Even where a consensus exists, there is frequent disagreement about the proper role of government.

CURRENT RESEARCH

Among the large number of subjects currently being researched are the following: fresh air requirements for buildings; performance standards for energy consumption in buildings; computer simulation of energy flow in buildings; thermal performance of building envelopes (walls, roofs, windows, and doors); passive solar energy design; buried structures; energy losses in existing buildings; and integrated community systems.

FRESH AIR REQUIREMENTS FOR BUILDINGS

Most building codes have long required that, for reasons of health and comfort, some minimum amount of fresh air must be continuously and mechanically introduced into sealed buildings that have controlled environments. When such requirements were written, little research had been done to determine just how much fresh air is actually needed for health and comfort; to be on the safe side, therefore, fresh air requirements were set well above the amount believed to be necessary. At the time, energy was both cheap and abundant; there was little concern over the energy wasted in conditioning superfluous fresh air. Now that energy is neither cheap nor abundant, attempts are being made to determine how much fresh air is really necessary to health and comfort. Work is also under way to develop new heat-exchange equipment to transfer heat between exhaust air and incoming ventilation air.

For low-rise residential buildings, most building codes do not require the controlled introduction of fresh air on the assumption that natural infiltration of air will suffice. Now, however, residential buildings are being constructed more tightly than before in order to conserve energy, and there is some concern that the air quality in new houses may be unsatisfactory unless positive ventilation or air purification systems are installed.

PERFORMANCE STANDARDS FOR ENERGY CONSUMPTION IN BUILDINGS

Since the oil embargo, various government bodies have enacted codes or regulations aimed at ensuring that any new building constructed within their jurisdictions is designed to use energy efficiently. Most of these codes and regulations are based on Standard 90-75 of the American Society of Heating, Refrigerating, and Air Conditioning Engineers. Virtually all are somewhat prescriptive in nature, in that they prescribe certain design features or the characteristics of various building elements.[3] Without disputing the need for energy codes and regulations, many building designers object to prescriptive codes because they limit innovation and creativity. In response to this objection, Congress has enacted legislation that requires the federal government to develop a performance standard that establishes overall energy consumption goals for buildings without specifying how the goals are to be met. Work is under way to develop this standard jointly at the Departments of Energy and Housing and Urban Development. It should be noted that the standard will not require the measurement of actual energy consumption of completed buildings. Rather, it will require that calculated average energy consumption for a building, under specified environmental and use conditions, will not exceed a specified amount, probably expressed in British thermal units per square foot of building floor space per year. Even so, the development of a performance standard that finds broad acceptance in the building community will be a difficult task. The challenge will be to establish consumption limits that take account of the vast number of factors that may affect energy consumption, while, at the same time, avoiding excessive complexity.

COMPUTER SIMULATION OF ENERGY FLOW IN BUILDINGS

From an energy flow standpoint, buildings are highly dynamic. The total amount of energy consumed and the distribution of that energy around a building can change markedly over brief periods as equipment and lights are turned on or off, as areas of the building are occupied or vacated, and as the load on cooling and heating machinery increases or decreases in response to changes in the outdoor environment or to internally generated heat. The energy consumption patterns are also conjectural in that it is impossible to predict for any given period of time what combination of internal and external conditions will exist that can affect energy consumption.

Until recently, engineers could not predict energy consumption for a building with any accuracy. Rough estimates were based on the average number of heating and cooling degree-days in the area and the energy demand loads in the building. Recognizing that such estimates were of little value during design in choosing between alternative courses of action, engineers—about ten years ago—began developing computer programs that would perform a dynamic simulation of the operation of the energy systems of a building. The most sophisticated of the early programs was sponsored by the U.S. Postal Service and has served as a model for much of the subsequent effort in this area.

Typically, such programs first calculate building heating and cooling loads and system equipment capacities on the basis of data on the size and construction of the building and assumed design conditions, such as maximum and minimum outdoor temperatures, that are provided by the building designer; then the program calculates energy consumption in the building, usually hour by hour for a year, by using a variety of data including the results of the previous calculations and weather tapes providing hourly data on outdoor temperature, humidity, wind speed and direction, and degree of cloud cover for a hypothetical or actual typical year for the region.

Considerable effort has gone into further development and refinement of such programs, both to enhance their current value as design tools and to permit their possibly more significant future use as regulatory mechanisms. Among the federal agencies that have sponsored work in this area are the Department of Energy, the U.S. Army Construction Engineers Research Laboratory, and the Office of Construction of the Veterans Administration. Private organizations, such as the Trane Company, have also developed and marketed computer programs. Efforts to further develop and to test their predictive accuracy are expected to continue for several years.

THERMAL PERFORMANCE OF BUILDING ENVELOPES

One of the most important factors in determining energy consumption in a building is the thermal performance of its walls, roof, windows, and doors—the building's envelope. For years, tables of thermal properties and various formulas have been used to estimate heat transfer, air infiltration, and solar radiation through various parts of the building exterior. These estimates were often inaccurate because much of the data on which they were based were extrapolated from tests of a limited number of small samples, and the validity of the formulas was never verified for some applications for which they were used. That the accuracy of these data and formulas was questionable, however, didn't really matter, because the information they provided was used primarily to determine heating and air conditioning loads for equipment sizing purposes, with oversized equipment compensating for errors. Now, heat transfer, air infiltration, and solar radiation calculations are being used to predict energy consumption rates, frequently on an hourly basis and sometimes for regulatory purposes, and for such uses the accuracy of the data and formulas now available is too low to be acceptable. In hopes of rectifying the situation, DOE, in cooperation with the Department of Commerce, has developed a national program plan through which the resources and expertise of government and industry will be brought to bear on the problem.

PASSIVE SOLAR ENERGY DESIGN

Because solar energy is regarded as "free" energy, the development of solar technology enjoys widespread support, and a large number of federally funded solar energy research, development, and demonstration projects are being carried out, as well as some privately funded solar energy research, mostly directed toward heating and cooling of buildings or heating domestic water. Most of this work is concerned with active solar energy systems in which solar energy is absorbed by either a liquid or gas, usually water or air, in a collecting device constructed for the purpose; the heated liquid or gas is then moved

mechanically by pump or compressor to a storage tank from which energy is drawn as needed.

Few such systems have been installed that save enough fuel to pay for the cost of the system; most have been subsidized by government to encourage their installation, and it is doubtful that active solar energy systems will be economically attractive for most building owners for many years. The high costs of active solar systems have stimulated interest in passive solar energy systems in which features are designed into a building that automatically provide the benefit of solar energy, but do not require special collectors, pumps, storage tanks, and the like. The simplest and most cost-effective forms of passive solar energy systems are properly sized and placed windows, building orientation, and siting. More sophisticated architectural techniques require specially designed roofs and walls that cause air to be heated and distributed throughout the building by natural circulation.[4]

BURIED STRUCTURES

The energy consumed for heating and cooling a building can be greatly reduced by covering it completely or partially with two feet or more of soil to provide insulation and mass to store energy. Several buried buildings, mainly residences, have been constructed over the past five years, and their energy efficiency appears to far surpass that of conventional buildings. A limited amount of research is being carried out to develop data on the thermal performance of buried structures and to investigate ways of constructing them that will provide an acceptable environment for the occupants.

DETERMINING ENERGY LOSSES IN EXISTING BUILDINGS

Most buildings today are being designed to use significantly less energy than those built five years ago; future buildings are expected to be even more energy-efficient. At the current replacement rate of older buildings, however, it will be many years before energy-efficient buildings substantially supplant older buildings. There are approximately eighty million housing units in the United States, two-thirds of which will probably still be in use in the year 2000; so, effective low-cost ways to upgrade existing buildings will be needed if the average energy consumption per building is to be reduced. Some simple steps to improve the energy efficiency of a building are self-evident, such as adding roof insulation and storm windows, but many are not. Each building poses different problems, and changes that are effective in one may be ineffective in another. The first step in modifying a building to reduce energy consumption is to find out where and how energy is being lost. Research is under way to develop techniques and devices that will assist in diagnosing problems and identifying energy-saving opportunities. Current effort is concentrated on developing better infrared devices for detecting and locating heat loss and improving techniques for using such devices.

INTEGRATED COMMUNITY ENERGY SYSTEMS

Thermal electric-generating plants operate at less than forty percent efficiency, and therefore a substantial amount of energy could be saved if effective use could be made of the waste heat from such plants. Dennis Hayes, writing in *Worldwatch 4*,[5] estimates that use of just twelve percent of this waste heat could reduce U.S. fuel demand by two percent. One of the most logical ways to use this low-temperature waste heat is to heat and cool buildings—an application that does not require high temperatures. Relatively few combined electric generating/heating plants have been built in the United States because fuel costs have been so low that the potential savings seldom justified the investment in equipment and piping needed to capture and distribute the waste heat.

Rising costs of fuel have changed this situation, and efforts are being made to optimize the design of such plants, to identify situations in which they are most applicable, and to determine the economic return that can be expected.[6] Integrated energy systems are seldom economically viable if the waste heat must be transported long distances; therefore, power plants in such systems must usually be located near heavily developed areas, an arrangement that is frequently opposed on environmental or esthetic grounds. Also, for maximum efficiency, the demand for waste heat must closely parallel the demand for electricity, which is often not the case. One solution, if the system is not owned by the electric utility company, would be for the producer of the waste heat to sell surplus electricity to the utility when the demand for waste heat is high; however, few utilities need or want to buy power under such circumstances.

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INSTITUTE OF MEDICINE


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Ethical Aspects of Health Science Policy

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Health sciences research, health promotion and disease prevention programs, medical practices, health care, and health manpower policies often have embedded in them value choices that require more visible and balanced analysis than now occurs. These issues are often unrecognized altogether, thus limiting the ability of the scientific community and the public policy process to address them in a constructive, analytical mode. Many of these issues of ethics and value choices are related to a wide range of science and technology; some, however, are specific to the fields of health and medicine embraced by the Institute of Medicine. Indeed, the Institute has explicitly incorporated ethical issues and value choices into all its undertakings for several years.

Broad challenges that arise when viewing science in its current social context include the possibility of nuclear war and massive

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epidemics in malnourished, crowded, and poor countries. As scientists and humanitarians, we wonder whether we are doing enough to meet such threats—both those generated by science and technology, as in nuclear war, or those soluble, in part at least, by science and technology, as in epidemics in less-developed countries.* We wonder: Could a wiser deployment of existing scientific resources—whether human, technical, or financial—greatly reduce the risk of such catastrophes and improve the future course of human experience? Are we sufficiently aware of the very severe and adverse side effects, such as environmental damage, which our burgeoning science and technology sometimes produce? Do we appreciate fully the risk that the enormous capability of modern science and technology may be used by the powerful few to the disadvantage of the weak many?

PRESSURES

There is enough in human history, including very recent human history, to make such concerns plausible. To the extent that science and technology have created, exacerbated, or inadvertently made possible some serious human problems, it is entirely conceivable that novel, intensified, or modified efforts in science and technology will solve them. All of us believe that science can help many human predicaments—but how? Whatever the course chosen, value conflicts can arise.

Health care is a case in point. Continued human suffering and disease demand continued and increased contributions from science. Nonetheless, value issues—and value conflicts—arise. Innovations in biomedical research may prolong and enhance the quality of life in general; but they may also involve risks to individual rights and health. The debate over recombinant DNA research, for example, was in part a debate over conflicting ethical views: Should recombinant DNA's promise of increasing the food supply and the availability of hormones and vaccines carry greater weight than the risk that recombinant DNA

*An example of how science can move to address a part of this problem is given in the accompanying study project article, "Pharmaceuticals for Developing Countries."

experiments might lead to the creation of new and potentially dangerous organisms?

There may be difficult choices between striving for increases in human longevity and reducing disabilities of the elderly so as to improve their quality of life. Does the desirability of altering individual behavior—for example, reducing smoking or discouraging high-risk sports—to diminish the probability of premature death deserve more weight than the satisfactions derived from risk-taking or health-damaging behavior? The testing of new drugs through randomized clinical trials, and related epidemiological research, offers similar and still unresolved problems. Initial human trials of new drugs have often been conducted on institutionalized populations, such as prisoners or mental patients. Occasional flagrant abuses have stimulated serious concerns about ethical issues in such drug testing, including the validity of the consent obtained from such persons or the fairness of selecting them to accept risk for the benefit of all members of society.

Randomized clinical trials are essential to the progress of the health sciences. But further work is needed to clarify the conditions under which a clinical trial should be done, the proper role of patient choice in selection of therapies, criteria for determining when a clinical trial should be stopped as evidence of the superiority of one therapy emerges, and the justification for using placebos.

INFORMATION AND PRIVACY

Ethical dilemmas also are encountered in epidemiological research. To be scientifically adequate, such research must sometimes examine individual medical records. Although the information contained in medical records ostensibly is protected by a right to privacy and by the traditionally confidential nature of the physician–patient relationship, these factors actually offer much less privacy than is commonly assumed. The Privacy Protection Study Commission in the United States has recently made recommendations to enhance the privacy of medical records. Although the commission recommended safeguards in the conduct of epidemiological research involving medical records, it did not recommend the requirement for informed consent for release of records. This would be a difficult requirement to implement and might seriously hinder epidemiological research of great importance to the public health.*

A major technological advance that facilitates epidemiologic research is the development of computerized health information systems. These systems increase the amount of health data on a given individual that can be stored practically, and thus ease the maintenance of easily accessible records on large population groups and the complex analyses of such data. They also increase the probability that individuals who do not have a legitimate interest in such information will be able to obtain it, thus compromising the individual's privacy. This problem assumes great importance with comprehensive national health systems. If the government pays, the government has a right to know, and a responsibility to enhance the public health. Yet, individual privacy and personal preferences must be protected. Here, again, values conflict.

From this array of choice and conflict, we have elected to concentrate on special ethical dilemmas encountered in two areas of health research and care: the allocation of resources for research pertinent to health and the conduct of clinical research, particularly large-scale clinical trials.

ALLOCATING RESOURCES

In the effort to decrease disability, death, and disease, and to improve the quality of life, a vigorous health enterprise has grown in the United States and in other developed nations, particularly in the last three decades. Its strength is apparent in increased availability of health care services, a highly trained cadre of health professionals, broad health insurance coverage, a smaller gap between rich and poor in physician contact, innovative systems for the organization and management of health services, and, underlying the whole enterprise, an explosive growth of knowledge in the life sciences.

Additional signs of progress in health care in the United States during the past decade include declines in death rates from cardiovas-

*For further commentary, note the essay "Strengths and Limitations of Epidemiology" by Brian MacMahon, beginning on page 91 of this volume.

cular diseases, in infant mortality rates in certain disadvantaged populations—American Indians, for example—in overall maternal and infant mortality rates, in the population of public mental hospitals, and in age-adjusted death rates for the population as a whole. Of course, important health problems still remain, but their nature has changed. Indeed, the total profile of illness, disability, and death in the United States has changed substantially in recent decades. Accidents, violence, and other trauma have become increasingly important as causes of disability as well as early death. Accidents are now the leading cause of death among all persons age one to thirty-eight and are in the top six causes of death for all age-groups from one to seventy-five. Motor vehicle accidents, a twentieth-century burden, occur disproportionately to young people. Homicide and suicide are now the second and third leading causes of death for persons fifteen to twenty-three, and are on the rise. The major illness in the United States is cardiovascular disease, ranking first in total economic cost, first in potential years of life lost, and second in number of hospital bed days, physician visits, and limitation of major activity. Malignancies, particularly those of the lung and breast, mental disorders including schizophrenias and depression, and the problems due to alcohol and other drug abuse are also widely prevalent. These problems account for a majority of all complaints brought to physicians and to hospitals, and are exceedingly costly in early deaths, disabilities, and dollars.

Several broad issues of prevention and adequate care apply to these illnesses. For example, the behavioral and environmental components of these problems in the United States and other industrialized countries are very significant: the risk of smoking for cardiovascular diseases and cancer, of careless driving for accidents, and of environmental substances for cancer. Some population groups—particularly the poor and socially deprived—do not benefit adequately from biomedical advances. Finally, certain age-groups, such as the elderly and adolescent, tend not to receive adequate health care.

The uneven distribution of advances in health care are even more apparent in the poorer countries. Indeed the burden of early death and long-term disability in most developing countries of the world today is very great and may prove to be critical unless modern science and public health can better focus on these problems. Severe and common tropical diseases, and a much wider range of infectious diseases, are embedded in the context of widespread malnutrition and population exceeding the carrying capacity of the land. Susceptibility to a wide range of diseases is heightened by the marginal character of subsistence. This interplay of nutrition, population, and health raises ethical questions for countries with strong scientific capability. For example, the United States has great health research resources, but since World War II has given little attention to tropical medicine. In recent years, we Americans have neglected—in research, education, and practice—some of the most important disease problems in the world today. Some developed countries, especially Sweden, have provided exemplary leadership in this regard; and we are happy to report an upsurge of interest in the United States during the past year in the health of the people of developing countries.

STRATEGIES

This international burden of illness in both developed and developing nations poses difficult questions of resource allocation. Modern societies must decide which strategy—or combination of strategies—to pursue to ease this burden. Such strategies include continued commitment to advancing biomedical science and technology; broadening the spectrum of health science to include the behavioral and social sciences pertinent to health; more humane and efficient health care services, in both their content and organization; improving the education of health professionals; improving our data systems in the health area; and strengthening the process of health policy formulation.

The challenge of allocating resources among these various strategies is mirrored by similar problems within each category: How, for example, are resources available for research in the health sciences to be apportioned among the many promising lines of inquiry? Much of the public's interest in and support for the life sciences has been predicated—often explicitly—on the belief that these sciences would benefit the health of mankind. Many scientists have at least tacitly supported this concept, some have actively fostered it, and a good many are deeply committed to its fulfillment, at least as a long-term agenda. Thus, the health sciences community as a whole, though not necessarily any individual scientists, has to face the ethical dilemmas embedded in the task of allocating resources for the sciences pertinent to the health of the public. Even if, as we hope, a large amount of money is devoted to fundamental research, simultaneous efforts must be made to adapt the basic knowledge already acquired to the alleviation of current health problems—that is, to applied research. Several factors govern the setting of priorities in applied research, including the magnitude of each health problem, the scientific opportunity and estimated probabilities of success, the curiosity of individual investigators, and the public's perception of the importance of each health problem. Most would agree that exclusive reliance on any one of these factors to set priorities would be unwise. The question is, therefore, how to balance these considerations.

BURDENS AND DOLLARS

There is interest in the policy world in linking measures of the burden of illness to the allocation of health research dollars for the applied health sciences. Some suggest that the higher the burden of a particular disease, the larger should be the investment made in research on that disease. The formulation of research need not be narrow. It may include, for example, clinical investigation set on a broad foundation of basic research into structures, functions, and systems pertinent to the disease in question.

If burden of illness data were relied upon more heavily in establishing research priorities for applied investigations, the sometimes intense pressures to devote large sums of money to rare though poignant diseases might be balanced reasonably with other considerations. Data on burden of illness might tend to support certain advocacy groups and dampen others.

But the approach has its limits. Even though a particular disease may be rightly deemed most burdensome, progress in the treatment or prevention of that illness at present may be minimal because of an inadequate science base. By contrast, work on another disease might be in a very productive stage, even though the disease is not as burdensome. Burden of illness is a significant but not overriding factor in determining allocation. Also, important as scientific opportunity is, we cannot forget that what is now scientifically obscure may become tomorrow's exciting opportunity—especially when excellent investigators turn their attention to a new problem area.

Having acknowledged the importance of integrating several factors in establishing priorities, the question of how to do so is the heart of the matter. What approach, formula, or process is available, or could be designed, which would bring more rationality to establishing research priorities? We simply do not know. But these questions are being considered more carefully than ever before, and we suggest that this continuing problem of resource allocation might be eased by additional knowledge about the actual process of research: What patterns of support and institutional environments are most conducive to scientific advance? What critical mass of information must be accumulated in the basic sciences to produce practial application? Recent work of this nature—"research on research"—has proved most useful and should be fostered.

CONTROLLED CLINICAL TRIALS

Clinical research poses questions as difficult as that of allocating resources for research. The increased presence of high technology in health care and a general increase in the complexity and cost of medical practice have produced, among other effects, a greater need for clinical trials and health care research generally. Clinical trials—particularly the broad scale, multisite ones—pose complex ethical problems at several levels. On an individual level, problems of informed consent often arise, as do problems of an altered patient–physician relationship in experimental settings. More generally, clinical trials pose value problems such as when to halt a trial—that is, how to determine when sufficient data have been accumulated to stop the experiment or, if a therapy appears very promising, when to stop depriving the control groups of it; how to match the imperatives of good statistical design with patient and provider rights; how to determine when the data from animal studies or clinical observations are strong enough to justify trials in humans; and how to compensate individuals who are injured through their participation in clinical research.

Additional problems include the difficulty in assessing the risks for humans of agents found to be carcinogenic in animals and the uncertainties faced in formulating standards for regulatory agencies to use in determining, from clinical trial data, that a drug is sufficiently safe and effective to be made widely available. Does this latter requirement impinge seriously on freedom of choice as, for example, in the laetrile controversy? Regarding international cooperation, difficult problems arise when a protocol is judged to be unacceptable in one country on grounds of informed consent, patients' rights, or similar problems, but is acceptable in another country. Another cluster of problems involves setting priorities for the funding and conduct of selected trials from the universe of all possible trials—a choice that cannot be avoided given the difficulty and expense of mounting such trials.

Even after clinical trials have established the effectiveness of selected interventions, value-laden problems remain. Thus, the recent swine flu controversy illuminates ethical problems in mass immunization programs. This particular campaign demonstrated that, when vaccinations are given on a large scale, some individuals will be adversely affected, even if the risk of complications is very low; vaccinations, like most medical procedures, are not entirely risk-free in all instances, even though they are among the most effective preventive measures available. Another example of disease prevention efforts raising value choices is the growing evidence that such matters of life-style as inappropriate alcohol consumption and tobacco use are closely related to morbidity and mortality. Such information has encouraged some health leaders to suggest stringent policies to restrict the use of these substances, raising questions of individual liberty and state coercion.

There are numerous questions related to informed consent and research design. For example, difficult choices must be faced in organizing clinical trials focussing on specific groups from whom it may be difficult to obtain truly voluntary and informed consent—children, those in great pain, the mentally ill, or the elderly. It is

difficult to decide what level of detail about possible risks should be presented to individual subjects when obtaining informed consent without introducing bias into the study. Similar problems are involved in obtaining voluntary, informed consent for participation in a study over time rather than only once, typically at the outset of a study. Generally, attention must be paid to meshing ethical considerations with the evolving methodologies for research design, such as the problems sometimes posed by randomization of subjects. Other problems are faced in interpreting results from small sample sizes, with particular reference to the ambiguity of negative results; and in selecting standards of comparison for an experimental intervention—that is, should a new drug be compared to a placebo, the best existing therapy, or a combination? This last problem is related to the long-standing matter of determining the research required for using an old drug for a new purpose, as in current clinical trials inquiring whether aspirin can protect against strokes.

How is the research community to satisfy the need for information on the natural history of a disease, in order to measure the impact of some new intervention, if there already exists some treatment that alters the course of the disease in a way that is clearly beneficial? Or how are we to regard the large array of diagnostic, therapeutic, and preventive interventions already in widespread use whose benefits and risks have not been established scientifically and whose continued practice involves exposure of individuals to some harm, however well intended the intervention may be? Tonsillectomy is a good example. Conclusive data on the benefits of this operation are not yet in hand, despite its extraordinary prevalence. Some mortality and morbidity are associated with it. Should the practice be halted until needed data are available? How would this be done? Would this be fair to practitioners who, on the basis of clinical experience, are firmly convinced of the usefulness of the operation or fair to families who have recently had a child tonsillectomized?

WHAT IS USEFUL?

By outlining these many problems, we do not mean to suggest that clinical trials are impractical, unwise or unethical. Indeed, the need for such investigations has never been greater. We increasingly need solid experimental data on the risks, benefits, and appropriate uses of specific health care interventions-diagnostic, therapeutic, and preventive. We need to know what is useful, for whom, and in what circumstances. We need to know whether certain interventions pose serious risks not readily discernible in the short run. We need to reestablish periodically the utilities of existing procedures in new situations and settings. In brief, we need to strengthen the linkage of health care and research to health outcomes, to increase the science base of health care. Clearly, the communities of health care practitioners and health sciences researchers should be brought into closer contact. Clinical trials—despite the problems they may pose—remain one of the principal, vital bridges between these sectors. We have benefitted from clinical research done in the past and have an obligation to future generations to maintain a strong program of clinical research to further improve health care. We can do this most usefully for future generations if we address these questions openly, with the best intellectual capabilities of the scientific community, and if we consider carefully the complex interplay of clinical, statistical, and ethical considerations involved in health care research. These issues will only grow in importance and prominence.

TOWARD AN ETHICALLY ORIENTED HEALTH SCIENCE POLICY

Recognizing that such ethical problems as touched on here are likely to become increasingly vivid in the next decade, we tentatively suggest some desiderata for health science policy, oriented to the future improvement of worldwide health status. Although they are especially aimed at policy formulation in the United States with its large commitments to biomedical and behavioral sciences, these suggestions may have some relevance to other countries. We propose that health sciences policies should;

- Nurture the growth of fundamental knowledge regarding the essential nature of living organisms, especially the human organism.
- Address the research needs and opportunities of all agencies whose missions relate to health. It is time for a broadly integrative view of all research and development directly relevant to health.
- Assess recent and foreseeable changes in the burden-of-illness and inquire whether research directions are keeping up with changing circumstances. This analysis should include plausible threats to health, such as possible long-term effects of the new chemical environment, importation of new diseases from one country to another, and demographic trends, especially the increasing proportion of elderly people.
- Recognize the recent broadening awareness of the many factors relevant to the health of the public. In light of this new understanding, what concomitant readjustments are needed in the sciences mobilized for health and what tasks must each health-related agency accomplish to bring research to bear on its problems? Such considerations should include the behavioral and environmental aspects of health and the implications of these relationships for research priorities.
- Consider opportunities for international collaboration in such research as randomized clinical trials, where the costs are great and might therefore be shared among the nations likely to benefit from the

findings. The mutual stimulation of international collaboration can become a strong asset in future health research.

• Weigh options for the long-term financing of health care research in a way that views research expenditures as an integral part of total health care expenditures; that is, research as a tool for improving the care and maintaining the quality of services provided.

• Give high priority to the need for research that measures the health outcomes of diagnostic, therapeutic, and preventive interventions.

• Increase the attention of the U.S. health sciences community to addressing the disease burdens of developing countries.

• Encourage the continued development and refinement of measurements of the burden of illness in ways that can specify with increasing reliability the nature and scope of health problems.

The suggestions must all be associated with a set of fundamental, recurring themes: the desirability of guiding the uses of sciences toward widely shared ends—for example, the relief of human suffering, more equitable distribution of resources, more peaceful resolution of disputes; the desirability of broadening participation in the conduct of scientific activity and in the benefits of the applications of sciences; the desirability of maintaining the highest standards of excellence, technical competence, and efficiency in the conduct of research; and the value of scientists participating analytically in the uses of science—at the interfaces of fact and value—neither avoiding nor dominating the processes by which the social uses of science are decided.*

*During the summer of 1978, the Nobel Foundation in Sweden sponsored an international symposium in which major ethical problems from a wide range of scientific fields including the health sciences were examined. One of the purposes of these discussions was to draw out the many parallels and similarities in these problems, despite their origin in different scientific sectors. This symposium gave us the opportunity to set down some reflections of many of the issues under examination within the institute's core program in ethical and value choices in the health arena. Because the NRC, like the activities of the Nobel Foundation and the symposium, spans the full range of sciences, we thought the comments developed for the Nobel presentation would be appropriate for this volume.

Study Projects

INSTITUTE OF MEDICINE

PHARMACEUTICALS FOR DEVELOPING COUNTRIES

"Consider the following case history. An African country, the year, 1974. It had a per capita income of $62.00, an infant mortality rate of 20 percent, and a life expectancy of 30 years. Every man, woman, and child in the population had malaria. Forty percent had tuberculosis (1 out of 4 with active cases, spitting blood), 25 percent suffered from river blindness (onchoceriasis), 3 percent had leprosy, and 50 percent of children under 5 died. The national health budget came to less than US $1.00 per capita. The average health budget for all countries in Africa reporting was US $1.17 per capita. This is the quality and health and life, differing only in detail, endured by 500 million people in developing nations."[1]

That pattern of disease, human misery, and premature death is the norm for the less developed countries of the world, most of whom lie in the tropics. The causes—embedded in culture, in patterns of behavior, in environment, in sheer poverty—determine the occurrence, and often the outcome, of the overwhelming majority of diseases in these poorer countries. Progress against these diseases, and consequent improvement in the social and economic well-being of the peoples in the developing nations, seems an almost insuperable task: These countries' social institutions will have to undergo profound evolutionary changes, economic and political policies and practices will have to be modified, deeply rooted behavioral patterns will have to give way to health-oriented practices, and environmental determinants of disease, such as arthropod vectors and polluted water, will have to be controlled.

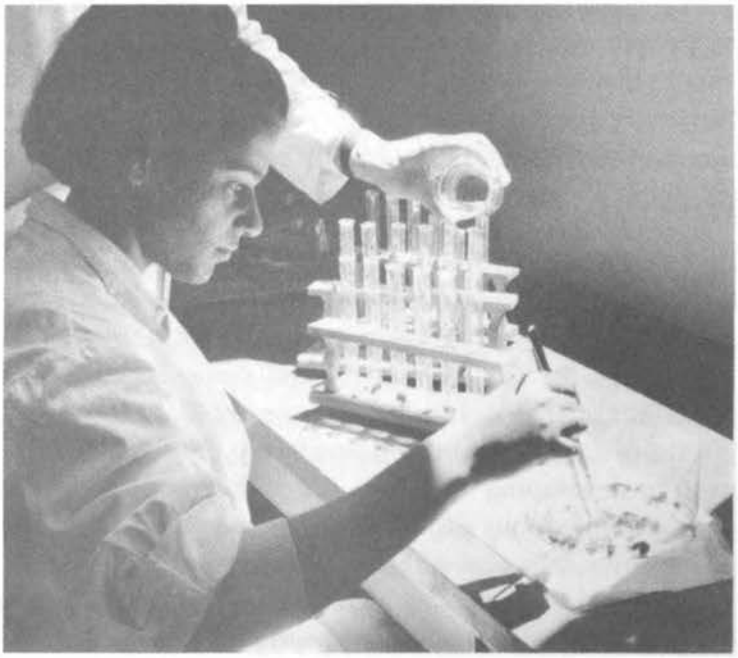
If the necessary social and cultural changes were to come about, and if the environmental determinants of disease were controlled, the morbidity and mortality patterns would undoubtedly change drastically. The diseases due to infectious and parasitic agents, aggravated by rampant malnutrition, and resulting in chronic disability and premature death, would likely disappear. However, no major improvements in these principal determinants of disease appear on the horizon. Nor do the industrialized nations understand enough about effecting social and cultural change to offer acceptable advice on how to do it. Thus, for the present—and for the foreseeable future—hundreds of millions of people will continue to be infected with parasitic and microbial agents that sap their strength, disfigure and cripple them, and shorten their lives.

ALTERNATIVES

Effective measures for the control of vectors such as mosquitoes have been developed. Important drugs and vaccines have been developed for treatment and prevention of many infectious diseases. This technology for vector control, and for prevention and treatment of infectious diseases, has largely come about through the needs and efforts of the industrialized countries. The technology has also been used in developing countries, since they also are inflicted by many of the same infectious diseases prevalent in industrialized countries. Yet, even when safe and effective vaccines and drugs do exist, such as measles and poliomyelitis vaccines, and the newer antibiotics, access to the pharmaceuticals is limited or impossible for large segments of the populations in the developing world because of costs, problems with storage, supply, and distribution, and rapid deterioration in hot and humid climates prevailing in most developing countries.

Although effective drugs may be available, treatment for some diseases may require close supervision by highly trained personnel, which is rarely available to the rural poor or to those who live in the septic fringes of the developing world's rapidly growing cities. Examples include typhoid and cholera. Treatment might also be ineffective or unsafe unless the patient can be taught a sophisticated pattern of cooperative behavior because of the need for long-term therapy, the requirement for treatment by injection, and the inherent hazards of the drugs and the consequent need to detect unwanted side effects as early as possible.

For still other diseases, there are no truly safe and effective vaccines or drugs; this is particularly true for many of the parasitic and other infectious diseases that are widespread in the developing world, but not in the industrialized countries. Examples include American trypanosomiasis (Chagas' disease) and onchocerciasis, or river blind-



ness. The industrialized countries, and particularly the United States, have not focused the power of their science and technology on the problems involved in dealing with these diseases. And herein lies the challenge.

The need is illustrated by the six parasitic and infectious diseases chosen by the World Health Organization (WHO) for particular attention and study in its Special Program for Research and Training in Tropical Diseases.[2] These are malaria, trypanosomiasis, leishmaniasis, filariasis, schistosomiasis, and leprosy.

Perhaps as 250 million people have *malaria,* and an even greater number is at risk. The number of people suffering from the African form of *trypanosomiasis,* sleeping sickness, is completely unknown; perhaps 50 million are exposed. In Latin America, a related parasite causes Chagas' disease, which affects approximately 12 million people, with at least 50 million more exposed. Between 9 and 12 million people are infected with *leishmaniasis.* The number at risk amounts to tens if not hundreds of millions. An estimated 20 million people are infected with filariasis, with at least ten times that number at risk. An estimated 250 million people in 70 countries are infected with *schistosomes,* making schistosomiasis the most widespread, serious communicable disease after malaria. Finally, an estimated 12 to 15 million people are afflicted with *leprosy,* with perhaps 50 to 100 million more at risk.

One might expect that this overwhelming toll of misery and disease would have caused much of the world's scientific talent and resources to be devoted to finding methods for control, prevention, and treatment. That is *not* the case.

DICHOTOMIES

Research directed at better understanding, treatment, and prevention of these diseases is being pursued in several European countries—
notably Great Britain, Germany, and Switzerland—and in the United States. In Europe, efforts to find preventive and curative agents for these diseases began even before 1900 during the colonial era. These efforts have, however, declined steadily in the past few decades. In the United States, home to at least half the world's biomedical research

talent, and to a very large fraction of the world's research-based pharmaceutical industry, the level of effort devoted to research and development in these areas is not large in absolute terms, and amounts to very little in relative terms. Thus, less than one percent of the research budget of the National Institutes of Health (NIH) is directly devoted to prevention or treatment of these diseases, and a very similar situation prevails in the American research-based pharmaceutical industry.

CONFERENCE

There is, then, an apparent dichotomy between the nature and magnitude of the disease problems in the developing world, and the almost complete lack of involvement in efforts to resolve them by the American academic researchers and the American pharmaceutical industry. At the federal government's request, an Institute of Medicine committee undertook a study of the underlying reasons for this situation for the purpose of making recommendations to the Congress and to the Executive Branch. An important aspect of this study was a conference at the end of January 1979, which addressed the principal issues in four stages:

Stage 1 depicted the socioeconomic, cultural-behavioral, and environmental settings that characterize the developing countries, and indicated how this combination of factors determines the occurrence and outcome of many of the infectious and parasitic diseases encountered in these countries. The discussion moved into a consideration of how these factors also interfere with effective disease control measures. The safety, efficacy, and availability of vaccines and drugs for the prevention and treatment of the six major infectious and parasitic diseases selected by WHO for special attention was also discussed. The limitations of existing preventive and therapeutic agents were utilized for discussion of needed developments in the fields. Lastly, the current level of research on and development of vaccines and drugs, and on manpower training, was analyzed.

Stage 2 dealt with the problems and constraints that inhibit the American pharmaceutical industry and the American biomedical scientific academic community from actively pursuing research on these diseases, from the development of pharmaceuticals for their prevention and treatment, where none now exist, and from the search for improvements over the existing products of technology, where such is needed.

Stage 3 considered promising developments in basic biomedical science, in the packaging, storage, and administration of pharmaceuticals, and in the better design and execution of clinical trials. Together, these should provide direction and stimulation for further study and exploitation by industry and the academic community.

Stage 4 built on the previous three stages and identified and examined the principal variables, the potential consequences of legislative and policy changes, of increased financing, and of changes in education patterns on the formulation of better strategies and a more effective public policy to deal with the principal issues addressed in the conference.

Quite deliberately, the focus of the conference was a precise definition of the factors now inhibiting the development of new and improved pharmaceutical entities and on potential solutions, particularly insofar as any necessary changes in American public policy are concerned. This orientation differed from that of other recent conferences dealing with the problems of providing pharmaceuticals for developing countries. As a result, some very important and closely related issues were barely mentioned, and others omitted. Thus only passing mention was made of the fact that drug purchasing patterns by developing countries are *not* necessarily based on established patterns of need, and may consume disproportionately large fractions of the total health budget.[3]

Other issues given only brief exposure pertain to local manufacture, the advantage of purchasing drugs in large quantities, or in bulk, the use of generic equivalents of existing proprietary brands, and the difficulties posed by corruption within public agencies charged with the purchase, storage, and distribution of pharmaceuticals within a particular country.[4]

Further, and also given much less attention than their importance warrants, are the inappropriate prescribing patterns within the developing countries, and inadequate education of prescribers and consumers, resulting in inappropriate drug use, and in the purchase of a great variety of drugs where perhaps fewer entities bought in greater quantity might very well result in better medical care and significant economic savings.[5]

Finally, the industry's use of promotional practices which are inappropriate in the developing countries, and which may not be permitted, or which are at least sharply circumscribed in the industrialized countries, is considered peripheral to the central issues.[3,4]

ACHIEVEMENTS

What are the important issues to consider for development of new and better pharmaceutical agents for the developing world? What, particularly, is the United States' role? What three-way linkages between the federal government, industry, and the academic scientific community are needed to further such efforts?

Such three-way linkages were established and functioned quite well on several previous occasions: the development of penicillin[6] and of the antimalarial compounds during World War II, the clinical evaluation of new psychoactive drugs,[7] and—most recently—in the search for anticancer drugs. Admittedly, and certainly for penicillin and the antimalarials, these combined ventures were stimulated by World War II. With the psychopharmacology program, it was the need for efficient, high-quality clinical research on a wide variety of substances. With the anticancer agents, the stimulus was provided by a universal fear of a complex of dreaded diseases. Other reasons, those favoring and those inhibiting joint ventures, are being explored. But first, what is the actual situation with regard to preventive and therapeutic agents for the six disease complexes addressed by the World Health Organization?

Several important drugs for treatment of *malaria* have come into widespread use since World War II. A major problem, however, is the emergence of drug-resistant strains of the malaria parasites. This has compromised the effectiveness of the safest and most widely used antimalarial, chloroquin. That problem is being attacked in two ways:

by using combinations of drugs now used for other purposes, and by research on the basic biology and immunology of the parasite made possible by *in vitro* cultivation of the parasite in 1976.[8] The latter has rekindled hope for an effective vaccine.

The treatment of *leishmaniasis* today still requires the use of highly toxic antimony compounds. Amphotericin B, an alternative to the antimony compounds, is generally used for the treatment of systemic fungus infections, but is highly toxic, must be given intravenously, and is used only as a last resort.

For *African trypanosomiasis,* the exceedingly toxic suramin and the older arsenical compounds are available. Neurotoxicity has caused other drugs to be abandoned, despite initially promising results. For *American trypanosomiasis* (Chagas' disease), treatment is even less satisfactory, although a toxic nitrofuran derivative (Lampit) can be used for a 120-day treatment program to deal with acute infections. No effective treatment exists for the chronic form of the disease.

Treatment for *filariasis* is totally inadequate. Severe allergic reactions occur in patients treated with diethylcarbamazine, making treatment difficult. Toxic and allergic side effects severely limit the application of the only effective drugs—diethylcarbamazine and suramin—in the treatment of the form of filariasis causing river blindness (onchocerciasis).

Schistosomiasis is an instance where important recent developments have occurred. Several good drugs are available for single-dose treatment, either by injection or orally. The development of niridazole, hycanthone, and oxamniquine have brightened the treatment picture of this very widespread disease. However, none of these drugs is effective against *Schistosoma japonicum,* which affects more than thirty million people. Two new drugs, praziquantel and C9333-Go, are currently in clinical trials and promise to be useful against all three *Schistosoma* species.

Several compounds highly active against *leprosy* have been developed recently, with rifampicin appearing as a most useful addition to the older drugs. More experience has also been gained with the use of corticosteroid drugs to suppress some of the major complications of therapy.

No effective vaccine exists for any of these diseases, although

there is new hope in that direction with the cultivation of the malaria parasite.[8] Similarly, the leprosy bacillus, *Mycobacterium leprae*, has recently been cultivated in quantity in the armadillo, but development of an effective vaccine is still far off. The prophylactic approach, or the use of treatment before exposure to prevent clinical disease, is only successful in malaria, and even that limited success is compromised by the development of resistant strains.

In all, there are very few safe and effective agents for prevention or treatment of the major parasitic diseases found largely in the developing countries. Those in existence only cover two or three of the six disease complexes. For the remainder, treatment involves highly toxic agents that are often difficult to administer; and no effective treatment at all exists for American trypanosomiasis, or for *Schistosoma japonicum* infection. This pattern—in which good drugs are available against a few diseases, a multitude of fairly effective but toxic drugs is available to treat the majority, and no drugs at all exist for use against other diseases—characterizes the situation with most of the parasitic and infectious diseases encountered in the developing countries.

UNIVERSITIES AND INDUSTRY

The humanitarian need is clear. Also, the biology of the parasites, the host-parasite interactions, the definition of logical points of attack against these infecting agents, and the discovery and development of effective drugs should be of intrinsic interest to American researchers. Why, then, are the American academic scientific community and the American pharmaceutical industry not more involved in research on the better understanding and treatment of these infectious and parasitic diseases?

In the case of the academic community, the reasons are not difficult to define. Most of the financial support for research and training in the biomedical fields in the United States comes from the grant and contract mechanisms administered by the National Institutes of Health (NIH), a branch of the Public Health Service in the Department of Health, Education, and Welfare. DHEW's legislative mandate covers the health needs of the American people. The small amount of research, which the Public Health Service supports on diseases occurring chiefly in the developing world, is partly justified on the basis of the actual or potential needs of tourists, and other travelers. The Department of Defense, the State Department, and other federal agencies operate under much broader mandates, which are dictated by their specific missions and which include tropical diseases.

A broadening of the DHEW legislative mandate to include active concern with the health of people everywhere, and a consequent additional appropriation of funds to NIH—a recommendation of a policy paper[10] prepared by the committee—for support of research on diseases of developing countries would be followed by a significant increase in academic research and training on the biology, immunology, and host-parasite interactions involved in the tropical parasitic diseases. There is ample precedent for this contention.[9] Indeed, a strong recommendation to the Congress to broaden the statutory authority of DHEW along just such principles resulted from another and quite unrelated study by the Institute of Medicine.[11] Stimulation of training and research within the academic community will very likely lead not only to much better understanding of the tropical parasitic diseases, but also eventually to the development of vaccines, and to new, safer, and more effective drugs.

Shortly after the end of World War II, interest in the search for new drugs began to disappear from the academic scene and is now found almost exclusively in the research-based pharmaceutical industry,[10] where the necessary technology also resides. Clinical trials, including decisions on drug uses, then become joint activities among industry, the academic scientific community, and government. For vaccines, on the other hand, government or academic laboratories usually took the initiative, with industry providing the necessary technology when larger-scale production and distribution were indicated. Then, the same triad—government, industry, universities—collaborated on further development of the new vaccine. Thus, the participation of industry is absolutely essential for development of new drugs, and very important for production and distribution of vaccines. Consequently, a broadened legislative mandate for DHEW and appropriations of the necessary funds for research may very well energize the academic community to work on infectious and parasitic diseases of the developing countries, but will most likely *not* lead to development of new and better drugs. These measures will *not* by themselves bring the research capabilities of the American pharmaceutical industry into play against the tropical and parasitic diseases. What, then, are industry's problems, and what else needs to be done?

Simply put, in contrast to the academic scientific community, the research-based pharmaceutical industry faces a complex array of problems and disincentives, which together comprise formidable barriers to the industry's becoming more involved in research on ways and means to deal with the disease problems of the developing world. These can be grouped into three categories: economic, political/legislative, and regulatory.

The cost of research in the pharmaceutical industry is paid for out of current earnings. This means that the successful discoveries and developments of the past are paying for the research done today. Informed estimates suggest that not more than ten percent of industrial ventures repay their investment, and not more than one percent become financial successes. Additionally, the interval between a firm's commitment to a course of research and development, and a successful product reaching the marketplace, is estimated at from ten to fifteen years, and the investment over that time may be scores of millions of dollars. To that can be added the opportunity costs; namely, a company's decision to pursue a particular line of research and development means that other potentially fruitful lines of research will not be pursued. These factors make industry conservative when pursuing new ventures.[12]

Further on the economic issue: At present, the American pharmaceutical industry exports approximately forty percent of its products, but only five to fifteen percent of its products go to the developing countries. Thus, the American pharmaceutical industry is relatively inexperienced when it comes to dealing with the Third World. With only a small fraction of its overall market now in developing countries, the industry's interest in that part of the world is understandably not very great. Also, the major portion of the industry's drug exports to the developing countries are not tailored to the needs of those countries, but were developed for the industrialized countries and can also—for a variety of reasons—be sold in the developing countries. Tranquilizers head this list.

Another point. Drugs that are very expensive in industrialized countries are frequently quite cheap in the developing countries, because the company's revenue from these drugs is principally generated in the industrialized world. The market for drugs tailored to the needs of the developing countries, and especially for treatment of the parasitic diseases, might be little to none in the industrialized countries. Return on the investment would then have to come from sales in the developing countries. But without subsidies these countries probably could not pay high prices for large quantities of such drugs.

Veterinary medicine may well constitute the principal market for such drugs in the industrialized countries. Quite possibly, agents (and the techniques used to develop them) that are effective against human parasites may also be active against animal parasites.

OTHER OBSTACLES

American pharmaceutical companies do not obtain the same tax incentives when pursuing problems relevant to other parts of the world as when working on problems of direct import to the American people. Add the risk of expropriation if an American firm were to locate its facilities in a developing country, and the potential attractiveness of such ventures pales rapidly. At the regulatory level, it is very difficult for an American company to gain approval to use a drug in the United States if the development of that product and the pertinent clinical research were both done abroad. This applies in other countries that insist that the necessary clinical research must be done in the country in which licensure is sought. If a drug is developed and appears effective against a tropical parasitic disease, it must first be tested in a country where that disease occurs. If found safe and effective, it can then presumably be licensed for use in that country, but could easily run into sharp restrictions against its wider use unless safety and efficacy studies were done in many or all other countries in which licensure is sought. Certainly, if a license to use such a drug in the United States were sought for any reason, it could usually not be granted under current regulations until or unless appropriate clinical studies were conducted in this country. This is expensive and time-consuming.

Also, under currently applicable requlations, a drug developed within the United States, and potentially effective against a parasitic disease, may not be exported for use where that disease occurs until or unless that drug has first been licensed for that use within the United States. Catch-22.

Why, then, should industry concern itself with the problems of the developing countries? There are, of course, the immediate humanitarian reasons. There is the opportunity for the pharmaceutical industry to improve its image, in both the industrialized and the developing countries.

There is also a less obvious, but equally compelling reason. The past decade has seen a marked decline in the number of new chemical entities reaching the market as drugs.[13] Although increasingly stringent regulatory activities receive much of the blame for this decline, the true cause may reflect exhaustion of the richest veins mined from the basic research in the past three decades. Consequently, new efforts in basic biological research are needed for new developments in vaccines and drugs, particularly against the infectious and parasitic diseases, and in the search for drugs against the cancers.

Certainly, advances both in the basic biomedical sciences, such as immunology, and in the more applied fields, such as in pharmaceutical research, offer opportunities for significant progress against the parasitic diseases. Recent advances in our understanding of the metabolism of several of the parasites may make it possible to design drugs to kill the parasite while doing little or no damage to the host. Further, practical advances have occurred in the delivery and use of drugs, including better packaging, protection against severe climates, and long-lasting, sustained release injections.

Thus, the industry can anticipate both a better world image and a widened base of research knowledge as reasons to invest resources in the search for progress against the tropical parasitic diseases. By themselves, however, these considerations are not sufficient. The industry, when contemplating more vigorous involvement in research programs on the parasitic diseases, sees high risks and potentially low profits, regulatory obstacles, and a dearth of tax incentives. Imaginative developments in legislation, regulatory policy, and economic incentives are needed to cope with the constellation of obstacles and disincentives currently inhibiting greater involvement of the industry. To reduce the risks, for example, one or more pharmaceutical companies might undertake research in parasitic diseases in partnership with one or more governmental agencies—American or foreign—and with an international financial institution.

The project's intention, then, is two-fold. First, the Committee on Pharmaceuticals for Developing Countries has suggested methods to improve access to available effective pharmaceuticals by the peoples of the developing countries. Second, the committee illuminates mechanisms by which the prowess of the industrialized countries in pharmaceutical research and manufacture can be applied to the diseases of the poorer countries. As a corollary, the committee identifies policy and legislative initiatives needed to deal more effectively with health problems of enormous magnitude.

The committee noted that opportunities exist for artful technology transformation, adaptation, and transfer in the production and distribution of vaccines. Coupling the complexities and economics of vaccine manufacture with the desire of many developing countries to create indigenous vaccine capabilities, it was suggested that the major vaccine manufacturers continue in their role, but that quality-control facilities be developed in the poorer countries initially, to be followed by construction of local plants to package and to monitor the quality of vaccines. This approach would facilitate adaptation and transformation of existing technology to local conditions, provide facilities and opportunities to establish local competence in the requisite technology, and create a resource that could be used to meet a variety of epidemiological needs.

In its paper on implications for U.S. public policy, the committee offered several suggestions. For example, the committee noted that a variety of needs were not being addressed, and promising opportunities were not being exploited—needs for new drugs to treat major tropical diseases and the opportunities provided by recent advances in biology.

The reasons, as pointed out earlier in this article, are traceable both to a lack of necessary policies and to the nature of the regulations. The fact is that the development of particular drugs is left largely to market-determined judgments by the pharmaceutical companies, whatever the public need. There is no clearly defined public policy to capture scientific advances and to transform them into technology. In tandem, regulatory burdens dampen the enthusiasm of the pharmaceutical companies to pursue risky ventures that do not, at the same time, carry the promise of large returns—the situation that characterizes the pursuit of those pharmaceuticals to be primarily or even exclusively used in developing countries.

Noting that public policy is seriously deficient when it relies utterly on the signals of the marketplace to assure optimal investments in research to discover and develop new drugs, the committee suggested that the Congress commission a study to, among other things, consider ways to bridge the gaps that occur between market decisions and public needs and between scientific discoveries and technological applications.

Although highlighted through an examination of the issues relating to "Pharmaceuticals for Developing Countries," the problem of bridging these gaps also exists with regard to development of new pharmaceuticals for domestic consumption. Moreover, the implications of this study may well ramify well beyond new pharmaceuticals and the pharmaceutical industry.

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HEALTH PROMOTION AND DISEASE PREVENTION

In the United States—as elsewhere in the world—infectious diseases were the chief causes of illness and death at the turn of the century. Infant mortality from all causes was high; data from the National Center for Health Statistics show that in 1900 almost one-fifth of all white male children died before they were a year old. Infant mortality has declined to a record low of about fifteen per thousand live births and—on the whole—Americans are living longer. Between 1900 and 1975, the average life expectancy at birth had increased from 47.3 to 72.5 years.[1]

As infectious diseases were brought under control in the United States and average life spans increased, more people began to live long enough for common chronic diseases to develop.[2] Today, chronic diseases (usually associated with middle and old age) are the leading causes of illness and death, followed by accidents and violence. Data developed by the National Center for Health Statistics in 1974 show that approximately twenty-two million people in this country had at least one chronic, activity-limiting condition.[3] Some of these, such as heart disease, cancer, and arthritis, are believed to result largely from environmental stresses and life-styles (occupational hazards, diet, smoking, alcohol abuse, and lack of exercise, for example); genetic factors may play a part in some of these conditions, as well. Obviously, some portion of those chronic disorders caused by environmental or behavioral stresses could be prevented; in fact, occupational and environmental hazards are already under close scrutiny as unhealthful and public education programs are attempting to combat such problems as smoking, alcoholism and other drug abuse, poor nutrition, and overweight. According to Julius Richmond, Assistant Secretary for Health, Department of Health, Education, and Welfare (DHEW), "Disease prevention and health promotion is an idea whose time has come."[4]

The concepts of health promotion and disease prevention are increasingly being endorsed by public health policymakers and political leaders. National fitness programs were fostered by President Kennedy; the first Surgeon General's report on smoking was issued during the Johnson Administration; the Environmental Protection Agency was established during the Nixon Administration; and President Carter has urged adoption of a number of programs related to disease prevention, including comprehensive national health insurance and health and nutrition education. Congress and state legislatures have also indicated concern for disease and injury prevention; government actions have resulted in the development of poison information and control centers, automobile seat belt and air bag requirements, protective packaging for drugs, controlled lead content in paints, and flammability standards for children's sleepwear, among others.

The Institute of Medicine was asked by the Office of the Assistant Secretary for Health in August 1978 to prepare a report summarizing the state of the art on health promotion and disease prevention to serve as the basis for a Surgeon General's report on prevention. The report will discuss basic concepts of health promotion and disease prevention and the data on which they are based, discuss the concept of health risks, provide examples of preventable diseases and injuries and possible prevention strategies for them, and explore relevant policy options. The institute's report is part of its continuing effort in this area.

Although disease prevention and health promotion may be "an idea whose time has come," efforts to modify present patterns of health care delivery to place greater emphasis on prevention are constrained by doubts regarding the health benefits and cost-effectiveness of preventive services, at a time when total funds for health are limited. Additional constraints are the absence of third-party reimbursement for preventive services and the difficulty the present medical care system has in providing preventive services effectively and economically, attuned as it is to treating the sick rather than counseling the healthy.

Despite these problems, there have been a number of successful public health programs directed toward disease prevention. Immunizations have made various infectious diseases of childhood a rarity. Stepped-up vaccination programs against measles are being undertaken. Smallpox is now close to worldwide eradication because of a carefully planned international immunization effort, and the lessons learned from that campaign might well be applied to control of many of the infections from which we still suffer.[5] Fluoridation of water to prevent dental caries has been outstandingly successful. The greatest decline in cardiovascular mortality in the United States has occurred since broad-based federal efforts have been undertaken to identify hypertensive individuals and encourage their continued control activities and since segments of the U.S. population have made rather substantial life-style changes—less fat in the diet, less cigarette smoking, and more physical activity. The link between these factors and the decline in cardiovascular disease mortality is as yet unproved, but highly suggestive.

The campaign against tobacco use has been not entirely successful. Department of Health, Education, and Welfare 1976 data show that among adult Americans about thirty-eight percent of men and thirty percent of women smoke cigarettes, and that, while there has been more than a ten percent decrease in male smokers since 1964, there has been a much smaller decrease among women, so that rates for women seventeen–twenty-four years old exceed those of men.

Because of our greater understanding of the social, environmental, behavioral, and biological factors that play a role in the major diseases of today, a broad approach to health promotion and disease prevention is both necessary and timely. Such an approach would include an exploration of the interaction of the physical, socioeconomic, and family environments, a detailed consideration of behavioral factors that affect health, and an examination of the medical care services that are mobilized against disease.[2]

GENETIC DISEASES

Genetic diseases are due primarily to one or more mutant genes or to alterations in the number, size, or arrangement of chromosomes. Such disorders take a high toll in infants and young children. Preventive efforts vary, depending on the nature of the disorder and the availability of screening and diagnostic tests to detect either the carrier state in parents or the presence of the harmful genetic component in

offspring, before or after birth. Diagnosis by amniocentesis, followed by selective abortion, is a secondary preventive measure; diagnosis and treatment of affected fetuses or screening of newborns and prompt initiation of treatment is possible for some disorders, such as phenylketonuria (PKU).

Preventive measures are made difficult by cultural and emotional factors that may impede obtaining a complete family history, limited availability of genetic screening and counseling services, and lack of medical insurance coverage for these activities.

INFECTIOUS DISEASES

Despite the advances of the past seventy-five years, many types of infections persist as major sources of morbidity and mortality. Among them are four categories for which little or no effective prevention has been established—some viral infections, sexually transmitted diseases, parasitic diseases, and hospital-acquired infections. Air travel and population mobility increase the likelihood of importing infections against which most Americans have no immune defense.

Prevention strategies include improvements in the physical environment, vector control, immunization, chemoprophylaxis, surveillance and targeted treatment, and education.

CHRONIC DISEASES

Chronic diseases are most often caused by combinations of various genetic, environmental, and behavioral components, some of which may be potential targets for preventive efforts. For example, modifications in life-style—such as cessation of smoking, weight control, and exercise—may reduce the risk of heart disease, the primary cause of death in the United States. For cancer—the second most common cause of death—primary prevention requires, among other actions, the reduction of hazardous substances in the environment. Secondary prevention entails periodic physical examinations, including self-examination, since early detection of disease presumably enhances the possibility of cure.

Arthritis, one of the most debilitating and commonly reported chronic diseases, costs the national economy an estimated thirteen billion dollars a year in lost wages and medical care bills. The cost in human suffering cannot be measured. There is no known cure, but effective treatment can control the disease and prevent crippling.[6]

If a genetic role becomes more clearly defined in chronic diseases, such as arthritis, lung cancer, hypertension, juvenile diabetes mellitus, and arteriosclerosis, it should become simpler to identify people at risk, thus facilitating preventive efforts.

MENTAL DISORDERS

An estimated twenty million Americans (almost ten percent of the population) suffer from some form of mental illness. Although mental health promotion activities have been attempted, their success is not clear. The specific protection approach to prevention attempts to identify individuals most likely to develop a specific mental disorder and to lessen that probability by intervention. (Some programs have been tried that take this approach to preventing schizophrenia.) Because mental retardation can have many causes, it offers a variety of possible approaches to prevention—better care of pregnant women and reducing environmental hazards, among others.

Two constraints on more effective prevention of mental disorders are the lack of data on the effectiveness of preventive measures and the ethical and legal problems of specific preventive measures. The role of endorphins (opiate-like compounds produced by the body) in mental disorders is a new field of particular promise.

Violent crime in the United States continues to increase and has become a leading cause of death and injury. In 1977, according to the National Center for Health Statistics, there were almost 20,000 homicides; in over eighty percent of cases, homicides occurred among family members or other people who knew each other.[7] Suicide reportedly caused the death of almost 29,000 Americans in 1977. Despite these high rates, many actual suicides are unreported. Even injuries due to violence are susceptible to environmental changes that make the means of aggression less lethal, reduce motive, or decrease opportunity.

HEALTH EDUCATION

Perhaps one of the most important aspects of preventive medicine and health promotion is education to enable people to make informed decisions about their health care needs.

In the Public Health Service's *Forward Plan for Health FY 1978–82,* "health education" was redefined and extended to:

> encompass not only knowledge transmission but also the range of practices designed to motivate, stimulate, and provide skills to help people live longer free from disease and disability.[8]

Specifically, consumer health education should (1) inform people about health, illness, disability, and ways in which they can improve and protect their own health, including more efficient use of the delivery system; (2) motivate people to want to change to more healthful practices; (3) help them learn the necessary skills to adopt and maintain healthful practices and life-styles; (4) foster teaching and communications skills in all those engaged in educating consumers about health; (5) advocate changes in the environment that facilitate healthful conditions and healthful behavior; and (6) add to knowledge through research and evaluation concerning the most effective ways to achieve the above objectives.[9]

Some of the problems encountered in designing education programs are to avoid fragmentation, to maintain relevance to consumer needs and wants, and to consider the diverse life-styles, cultural backgrounds, and environmental conditions of the audience.

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SWELL STRUGGLING WITH THE CIG'RETTE POISONER.

APPENDIXES

Appendix A
Brief Description of the Academy Complex and NRC Structure

NATIONAL ACADEMY OF SCIENCES

Created by a congressional charter signed by President Lincoln in 1863, the National Academy of Sciences (NAS) is a private, honorary society of scientists and engineers, dedicated to the furtherance of science and its use for the general welfare. Although the academy is not a federal agency, it is called upon, by the terms of its charter, to examine and report on any subject of science or technology upon request of any department of the federal government. Whether contracted by the federal government or supported by private organizations, analytical studies are conducted by committees established in the Institute of Medicine (IOM) and the National Research Council (NRC). The latter is the "operating arm" of the National Academy of Sciences and of the National Academy of Engineering (NAE).

In addition to its scientific advisory activities, the NAS awards medals and honoraria, publishes reports and the journal, *The Proceedings of the National Academy of Sciences,* organizes symposia, arranges U.S. participation in international organizations and programs, and—on occasion—issues public statements on matters of importance to the scientific community.

NATIONAL ACADEMY OF ENGINEERING

The National Academy of Engineering was established in 1964 under the charter of the National Academy of Sciences as an essentially autonomous organization of outstanding engineers. NAE elects its own members and shares responsibility with the National Academy of Sciences for serving the federal government through the medium of the National Research Council. The NAE also conducts symposia, publishes special reports, participates in international activities, and awards medals.

INSTITUTE OF MEDICINE

The Institute of Medicine was chartered by the National Academy of Sciences in 1970 to deal with problems associated with the adequacy of health services for all sectors of society. Through its own committee structure, the institute conducts studies of policy issues and problems related to health and medicine. It issues position papers for public consideration, cooperates with the major scientific and professional societies in the field, conducts symposia, and disseminates information to the public and the relevant professions.

THE NATIONAL RESEARCH COUNCIL

The National Research Council, which was established by the NAS in 1916, includes as its principal components "assemblies" organized along the disciplinary lines of science and engineering, and "commissions" designed to consider the interaction of science and technology with societal questions—a dual structure facilitating its response to the increasingly complex problems facing American society today.

The major units of the Research Council are the Assemblies of Behavioral and Social Sciences, Engineering, Life Sciences, and Mathematical and Physical Sciences, and the Commissions on Human Resources, International Relations, Natural Resources, and Sociotechnical Systems. The assemblies are concerned with fundamental scientific and technical questions, the vitality of the national scientific endeavor, and those national problems that may usefully be addressed within the scientific or engineering disciplines represented in each assembly. The commissions are able to bring to bear whatever disciplines may be necessary in dealing with a wide variety of societal concerns that are substantially affected by scientific or engineering considerations.

The work of the Research Council is overseen by a Governing Board composed of members drawn from the governing bodies of the NAS, the NAE, and the IOM. The President of the NAS is, by virtue of that office, the Chairman of the Governing Board, while the President of the NAE is its Vice Chairman. Members of the assemblies and commissions are appointed by the Chairman of the NRC for three-year terms. Each year, the assemblies and commissions, and the Institute of Medicine, present their annual program plans and projected expenditures for the coming year to the Governing Board for approval.

Through the Research Council, the academies are able to enlist the talents of a very broad representation of the nation's leading scientists and engineers and other members of the scholarly and professional communities to serve on the many committees organized under the assemblies and commissions. Although such committees are the primary mechanism for carrying out the work of the Research Council, all committee reports are subject to critical review under the supervision of a Report Review Committee made up of members of NAS, NAE, or IOM. Institutional responsibility is assured by this system, and also by the procedures for selecting and appointing committee members, all of whom are subject to approval by the Chairman of the NRC after approval by the respective assemblies or commissions. In a typical year, about 7,500 individuals serve, without compensation, on some 800 committees, boards, panels, and subcommittees, the costs being met by contractual or grant agreements between the National Academy of Sciences and the federal agencies or private foundations concerned.

Appendix B of this report lists 1978 reports by the National Research Council. The listing illustrates the nature and diversity of the problems and issues addressed by the Research Council.

Appendix B

Reports of the NRC Published in 1978*

ASSEMBLY OF BEHAVIORAL AND SOCIAL SCIENCES

CETA: Manpower Programs under Local Control. (Committee on Evaluation of Employment and Training Programs; by William Mirengoff and Lester Rindler; 347 pp.; available from the Office of Publications; ISBN 0-309-02792-6; $10.50.)

Counting the People in 1980; An Appraisal. (Committee on National Statistics, Panel on Decennial Census Plans; 192 pp.; available from the Office of Publications; ISBN 0-309-02797-7; $7.25.)

Deterrence and Incapacitation: Estimating the Effects of Criminal Sanctions on Crime Rates. (Panel on Research on Deterrent and Incapacitative Effects, Committee on Research on Law Enforcement and Criminal Justice; Alfred Blumstein, Jacqueline Cohen, and Daniel Nagin, eds.; 440 pp.; available from the Office of Publications; ISBN 0-309-02649-0; $15.25.)

Developing Manpower Legislation: A Personal Chronical. (Committee on Evaluation of Employment and Training Programs; by Wm. H. Kolberg; 99 pp.; unpublished.)

*Reports from the Office of Publications are available from the Office of Publications, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418. For National Technical Information Service (NTIS) reports, write to the National Technical Information Service, Springfield, Virginia 22161. For reports available from a committee, write to the committee, National Academy of Sciences. Other reports are available from the sources noted. Prices and availability subject to change.

Employment and Training Programs: The Local View. (Committee on Evaluation of Employment and Training Programs; William Mirengoff, ed.; 195 pp.; available from the committee.)

The Federal Investment in Knowledge of Social Problems [Volume 1: Study Project Report]. (Study Project on Social Research and Development; 128 pp.; available from the Office of Publications; ISBN 0- 309-02747-0; $7.00.)

The Funding of Social Knowledge Production and Application: A Survey of Federal Agencies [Volume 2: Study Project Report]. (Study Project on Social Research and Development; 505 pp.; available from the Office of Publications; ISBN 0-309-02780-2; $17.50.)

Knowledge and Policy: The Uncertain Connection [Volume 5: Study Project Report]. (L. E. Lynn, Jr., ed.; 190 pp.; available from the Office of Publications; ISBN 0-309-02732-2; $8.25.)

Statistical Data Requirements in Legislation. (Committee on National Statistics; by Lenore E. Bixby; 31 pp.; unpublished.)

Symposium on Biodynamic Models and Their Applications. Held February 15–17, 1977, Dayton, Ohio. (Committee on Hearing, Bioacoustics, and Biomechanics; *Aviation, Space, and Environmental Medicine,* January 1978.)

ASSEMBLY OF ENGINEERING

Ad Hoc Committee on the Transportation of Plutonium by Air. (Aeronautics and Space Engineering Board; letter report to U.S. Nuclear Regulatory Commission; 3 pp.)

Aeronautics and Space Engineering Board, 49th Meeting, June 23–24, 1977. (Aeronautics and Space Engineering Board; letter report to the National Aeronautics and Space Administration; 8 pp.)

Best Available and Safest Technologies for New Offshore Drilling and Production Operations for Oil and Natural Gas. (Marine Board; letter report to U.S. Geological Survey; 4 pp.)

Better Management of Major Underground Construction Projects. (U.S. National Committee on Tunneling Technology; 167 pp.; available from the committee.)

Committee on Advanced Energy Storage Systems. (Energy Engineering Board; letter report to U.S. Department of Energy; 10 pp.)

Committee on Minorities in Engineering: First Annual Report, 1974–1977. (Committee on Minorities in Engineering; 12 pp.; available from the committee.)

Committee to Review the Washington Metropolitan Area Water Supply Study. (Committee to Review the Washington Metropolitan Area Water Supply Study; letter report to Baltimore District Corps of Engineers; 33 pp.)

Conference on Electrical Insulation and Dielectric Phenomena. Annual Report. (Committee on Dielectrics; 405 pp.; ISBN 0-309-02861-2; $25.00.)

Controlled Nuclear Fusion: Current Research and Potential Progress. (Ad-Hoc Committee for Review of the Space Shuttle Main Engine Development Program; 64 pp.; available from the Office of Publications; ISBN 0- 309-02863-9; $4.75.)

Digest of Literature on Dielectics, Volume 40, 1976. (Committee on Digest of Literature, Conference on Electrical Insulation and Dielectric Phenomena; Michael R. Wertheimer and Arthur Yelon, eds.; 792 pp.; available from the Office of Publications; ISBN 0-309-02787-X; $45.00.)

Energy Modeling for an Uncertain Future [Study of Nuclear and Alternative Energy Systems, Supporting Paper 2]. (Modeling Resource Group, Synthesis Panel, Committee on Nuclear and Alternative Energy Systems; 242 pp.; available from the Office of Publications; ISBN 0-309-02781-0; $9.75.)

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