



Limits of Epidemiology

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Epidemiology is called the "basic science of public health," but its contribution to this goal is constrained by a preoccupation with supposedly universal exposure-disease relationships that impedes consideration of the contexts in which exposures occur. Epidemiological studies of radiation and health, dominated by interest in radiation-cancer dose response, are a classical example. Radiation epidemiology uses an experimental model of investigation in which the sources of exposures and the other changes that occur because of their production are excluded from scientific interest. In this approach, problems of comparability and measurement are the primary obstacles to identifying underlying dose response phenomena. However, because exposure-disease relationships are not self-contained, homogeneous or independent phenomena, they constitute an inadequate object of epidemiological science. Historical and contemporary examples show that exposure-disease studies can be integrated into a broader public health perspective in which specific exposures are considered as agents acting in a context rather than as autonomous causes of disease. Public health interventions narrowly focused on exposure-disease relationships cannot address the more important public health effects of the industries and social arrangements that produce exposures studied by epidemiologists. Epidemiology can dramatically improve its contribution to public health and achieve a far greater level of social responsibility by recognizing the historical contexts of public health phenomena and the sciences that address them. [M&GS 1994; 1:74-86]

Epidemiology is the field of study of health and disease in populations. As such it is considered to be the basic science of public health, the activity of preventing disease and promoting health in populations [1]. This focus on primary prevention of disease in large groups has distinguished public health from medicine, which focuses on treatment and prevention of disease in individual patients. To provide the basic science for public health, as the clinical

disciplines do for medicine, epidemiology must try to explain, and thereby suggest ways to improve, the experience of disease and health in populations as distinct from individual patients.

Treatment for a patient is affected by the explanations that the basic medical sciences provide for a particular condition. Thus one kind of basic science suggests a pharmacological treatment, while another suggests a nutritional intervention. Furthermore, the understanding of pathological processes changes over time with basic scientific knowledge and the experience of clinical application, so that medical approaches for treating a given condition change.

Similarly, public health policy depends on epidemiological explanations of health

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and disease in populations. These explanations, as in any science, depend on the concepts and methods used to understand a given problem. Epidemiology is a fairly young discipline, yet it has undergone a variety of changes, including those brought on by the hygiene movement, the bacteriological revolution, the increasing application of statistical survey methods, molecular biology, and the environmental movement.

Despite a history of changing ideas about the causes and treatments of disease in populations, modern quantitative epidemiology is increasingly presented as the objective technique for uncovering universal laws about causes of disease in populations [2]. It is increasingly applied in clinical medicine, and some claim that it is a generic tool that can be used for the investigation of any human condition [3]. All sciences change in character over time, however, and the current dominant epidemiological practice is not, in historical terms, the end of the road, but rather a particular form of inquiry and explanation that will continue to be transformed in the context of changes in public health, medicine, science and society.

This paper first describes the character of explanation in modern epidemiology, a practice that has coalesced in English-speaking countries during the latter half of the twentieth century [4]. Conceptual problems with the object of inquiry in modern epidemiology are raised which suggest the field should adopt a less reductionistic approach. Some examples of alternative epidemiological perspectives are given in the third section. The limits of modern epidemiology in public health practice are considered in the fourth section, and the final section addresses issues of scientific objectivity and social responsibility. Epidemiological investigation of health effects of ionizing radiation is used as a primary example.

Explanation in Modern Epidemiology

The dominant mode of epidemiological explanation takes place fully within the limits of a scientific practice that has been termed Cartesian reductionism, an analytical approach characterized by a focus on factors considered in isolation from their context (Fig 1) [5]. Disease in populations, the stated focus of the discipline and the central feature distinguishing epidemiology from the clinical sciences, is to be explained in terms of a series of agents, exposures, or risk factors. Generically these include more than microbes, chemicals, or nutrients, but also anthropometric, physiological and genetic features as well as behaviors, mental states,



Figure 1. Disclosures about radioactive and chemical wastes released as a by-product of weapons production raise questions for epidemiologists about the social context of civilian and employee exposures to toxic substances

race and socioeconomic status. The method of the discipline is to observe whether disease occurs more (or less) commonly among individuals who have the exposure or factor than those who do not. The broader goal of explanation of the occurrence of disease in populations is pursued by enumerating all the risk and protective factors (the "independent variables") and the form of their relationships with a list of disease outcomes derived primarily from clinical practice (the "dependent variables"). The results of this research can be recognized in the lists of carcinogens, cardiovascular risk factors, and health risk behaviors that are targeted for modification by hygienic, behavioral or pharmacological intervention.

Studying Disease in Populations

Before going further it may be helpful to clarify what is meant when it is said that epidemiology is the study of disease in populations. The populations of modern epidemiology are counts -- numbers of individuals -- who are grouped according to their exposure and disease status. Populations, in this context, are vehicles for making comparisons of rates or averages; they are not inherently defined as organized groups with unique histories involving economic, social and ecological relationships. Their features of organization, in the epidemiological context, are not considered to have etiological consequences. Epidemiological studies that do address factors such as economic position or occupation generally treat them only as individual attributes or exposure markers rather than as aspects of social and economic organization that provide the context for biopsychosocial development. Thus race, as a feature of individuals, can be studied without recognizing

racism as an historical feature of the organization of populations. Epidemiological studies labeled as "ecological" examine associations between average levels of exposure and disease in groups [6,7], not population organization and ecological relationships [8,9].

The view that disease in populations is a function of essential exposure-disease relationships is mirrored in the model for modern epidemiological study designs, the randomized experiment. In this approach, subjects with specific characteristics, including absence of a disease or outcome of interest, can be chosen for study. Next they can be allocated to be exposed or unexposed to a factor according to rules that, as in the well-shuffled decks of repeated card games, tend towards an even distribution of the heterogeneous study subjects between exposure groups over the course of many trials. During the period of application of controlled amounts of exposure (or non-exposure), all other conditions affecting the subjects can be held constant. Finally, the subjects are available to the researcher for determination of the outcome characteristics in members of each group, using a standardized protocol. The analysis of such a study amounts to a comparison of the frequency of the outcomes of interest in the groups. Differences in frequency that persist over many trials, or that are obtained in a small number of large trials, are attributed to the action of the experimental agent. It should be clear that any questions of context, such as where the exposures have come from, why some individuals but not others were exposed, or what other changes occurred in order to produce the exposures, have been eliminated from the realm of scientific interest.

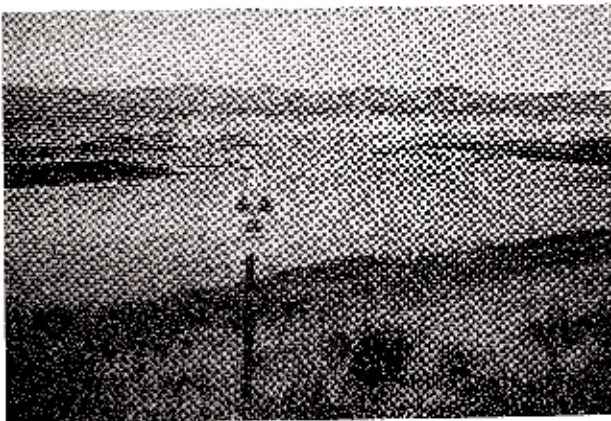


Figure 2. Releases of radioactive materials from nuclear weapons production plants, such as the Hanford facility in the U.S., have contaminated drinking water supplies and recreation areas, and have increased the risks of cancer and other illnesses to downstream populations. (Photo courtesy of Physicians for Social Responsibility)

Observational studies attempt to imitate the controlled experiment in various ways. An occupational study of the effects of gamma radiation on cancer might be restricted to workers of a certain type (e.g., males employed at a specific facility who worked longer than six months) to avoid some initial differences between exposure groups, and might compare workers that had received different cumulative radiation exposures within strata of age, other occupational exposures, and behavioral attributes of interest, to provide a summary estimate of the exposure-disease relationship "adjusted" for those other factors. In attempting to yield results that would have been obtained in an experiment, the observational study controls "extraneous" factors (and the context) in search of the separate, independent effect of the exposure. The assumption is that well-designed studies will provide estimates of the radiation-cancer dose response relationship that converge around the underlying value which characterizes the change in cancer rates for each unit change in radiation.

Problems in Epidemiological Explanation

Problems in epidemiological explanation can be approached from two related perspectives. This section addresses logical problems with the object of investigation of modern epidemiology, exposure-disease associations, and with interpretation of evidence about associations. Later sections address problems with the nature of the public health impact of the application of this knowledge. Problems in interpretation of exposure-disease associations receive great attention in the epidemiological literature. This attention is primarily focused on issues of measurement error and uncontrolled differences between groups being compared, issues that create difficulties because the magnitude and dose response form of observed associations may reflect these sources of bias rather than the association of interest. Despite these ambiguities, much refinement of method has occurred, and modern epidemiology has contributed to the identification of many pathogenic agents. Some, like cigarette smoke, produce large effects that are hard to miss. Others, like asbestos, have specific effects (mesothelioma) that rarely occur in the absence of the exposure. Much of epidemiology today, however, is focused on a search for evidence about weaker relationships and low exposure levels, where poor measurement and the presence of unmeasured differences between exposure groups become major potential problems [10]. Relatively small differences in

disease occurrence, such as those that are suspected in the case of low level radiation and many other environmental contaminants, are difficult to detect because very accurate measurements are necessary for quantifying exposures and disease excesses that are not far above the "background" levels. But small increments in disease incidence can have a great population impact when many people are exposed (Fig 2) [11].

What Should be Measured?

A more fundamental problem in epidemiological explanation is the development of theory about which aspects of exposure and outcome to measure. Outcomes generally reflect experience with diagnosis and treatment more than with etiological inquiry. Exposures are often measured due to convenience, availability of data, or convention, rather than based on biological models of disease process. Among workers exposed to penetrating ionizing radiation over long periods, for example, the total cumulative dose (derived by applying assumptions about relative biological effectiveness to measures of biologically absorbed radiation of different types) is typically studied. Sometimes only the doses received up to a certain number of years in the past are counted, on the assumption that cancers take time to develop. Alternatively, doses received in the distant past might not be relevant, and the doses that should be counted might only be those accumulated in some window of time around the emergence of the hypothetical mutation leading to a particular cancer death [12,13]. Then again, it might not be the simple cumulative dose that is critical, but whether the dose is delivered in one or a few short time periods, or is drawn out slowly. Other possible aspects of radiation exposure that might be important to measure are the peak dose, or the dose accrued in the context of other cocarcinogenic exposures or susceptibility states. Lack of understanding about mechanisms of radiocarcinogenesis means that problems of measurement are secondary to the more fundamental problem of knowing what to measure [14].

Like problems of measurement and comparability, questions about the biomedical basis for modeling exposure-disease associations are of concern within modern epidemiology [e.g., 2,15]. The former technical concerns lead investigation in the field to emphasize increasing control over measurement and extraneous factors that can distort the exposure-disease association, while concerns over the latter conceptual issues focus the discipline's theoretical attention on pathological processes of individual organ-

isms. Because control over measurement and extraneous factors is hindered when investigations are embedded in complex social and historical situations, this combination of influences supports the movement of the discipline away from engagement with issues of social theory, population biology and human ecology, and towards a more fundamental commitment to bio medical approaches.

The Broader Context of Exposure-Disease Associations

This direction is justified on the assumption that it will lead to the more accurate description of the underlying exposure-disease relationships that account for health and disease in populations. These relationships are seen as being self-contained, homogeneous, and independent phenomena. They are therefore appropriately studied in isolation, one at a time, according to the approach formalized in the experiment, in order to move "from time- and place specific observations to an abstract universal statement" [2, p 96]. In this approach, the experiences of particular populations "are only exploited to learn about the relation at issue in the abstract (in general), that is, without any spatiotemporal referent" [3, p 16]. Thus, modern epidemiology is oriented towards identifying the fundamental laws, not of the universe, but of exposure-disease associations.

The idea that epidemiology is about universal exposure-disease associations may create some discomfort, at least because epidemiologists presumably believe that biological organisms evolve and therefore are not historically constant vehicles for such processes. From a more contemporary perspective, it is already recognized in epidemiology that exposure-disease associations vary between different groups depending on host characteristics or other exposures. This variation, often called interaction or effect modification, raises important questions about the underlying phenomenon being investigated. For strong exposure-disease relationships, such as smoking and lung cancer, effect modification may be of minor interest. In some cases, however, and especially for low level exposures, variations in exposure-disease associations under different conditions may make the difference between no relationship and an important one. For ionizing radiation, it is recognized that associations may be modified according to age of exposure, sex, and perhaps other factors including diet, presence of other chemicals, and genetic characteristics. On the other side of the exposure-disease equations, disease categories are inevitably heterogeneous, with the association of exposure and disease showing more

or less variability for subgroups of broad disease categories used in epidemiological studies. For example, among A-bomb survivors, radiation is related to neoplasms, to solid tumors, and to leukemias in general, but to some types of each more than others [16]. We are always studying average effects.

In epidemiological practice, while effect modification is recognized, it is treated as a special case, a sub-class of universal associations that is "an inherent characteristic . . . an unalterable fact of nature" [17, p 586]. This status preserves the logical commitment to methods and theories predicated on the search for self-contained independent relationships that are, if not completely universal, at least homogeneous within subgroups. The belief in independent exposure-disease relationships leads to the centrality of the issue of controlling confounding bias through design and analysis. But there remains an uneasy contradiction within the field between, on the one hand, expanding epidemiological research (traditionally limited to middle-aged white men) to include women, non whites or the elderly, because of potential variation in exposure-disease relationships, and, on the other hand, the interest in techniques for quantitatively combining results from different studies [18] in order to produce a more reliable estimate of an exposure disease association based on the assumption that different studies of the same exposure-disease relationship are providing estimates of a universal underlying phenomenon.

Contextual Complications

Although some relationships may be fairly stable over a large range of contemporary contextual variation (this is argued by some, for example, in the case of serum cholesterol and coronary disease in adult males), change in biological response to exposure should be expected on longer evolutionary time scales. The view that exposure-disease associations generally vary with context suggests that there is no underlying universal dose response relationship to be uncovered [19]. Rather, for any given exposure and outcome, there is some range of contexts in which the change in outcome per unit change in exposure exhibits more or less stability. From this perspective the fundamental object of inquiry in modern epidemiology, dose response, should be recognized as essentially contextual (developmental or historical) rather than universal, vastly complicating the reductionist program and, indeed, challenging the very de-contextualization on which it is based.

Description of the quantitative impact of disease agents is important, has practical

implications, and should continue to be a part of epidemiology. The practical importance of the activity, however, does not mean that the study of exposure-disease associations constitutes a sufficient or rigorous object of inquiry for a basic science of public health. This is so because the object of inquiry itself, the exposure disease association, is not a self-contained, homogeneous, or independent phenomenon as presumed by the approach that treats the experiment as a "paradigm" for research [20]. This approach has been called modern epidemiology [2], analytical epidemiology [21], occurrence research [3], and risk factor epidemiology [22, 23]. It is essentially a kind of human toxicology, an approach limited to the identification of risk factors using an analytical approach in which the historical context is a nuisance to be avoided by design or controlled by analysis. Such an approach justifies conclusions of leading methodologists in the field that war and epidemics are not problems for epidemiology [3, pp 4-5], and that "social class is presumably causally related to few if any diseases" [2, p 90] because it is only agents or risk factors, not characteristics of the organization of populations, that are eligible to be causes of disease. This limitation of causal explanation to the pathogenic action of risk factors in individual organisms is codified in the lists of "criteria for establishing causality" rehearsed in textbooks and journals [e.g., 2, 21, 24].

Expanding Epidemiology

Modern epidemiology can be contrasted with perspectives that recognize the roles of specific exposures but that place these exposures in a context that is itself of interest in scientific explanation and public health intervention, an approach closer to human ecology than to human toxicology [25]. Examples of broader views of the scope and goals of epidemiology can be found throughout its history. The mid 19th-century work of the young Rudolf Virchow has been revived as an early example of a quantitative approach to understanding disease in populations that, while recognizing the importance of specific agents or exposures, did not reduce the explanation of disease to a matter of these isolated factors themselves [26-28]. Virchow, in investigating an epidemic of typhus in Silesia, was deeply moved by the suffering of the people, and his explanations stressed the conditions that fostered the epidemic: lack of agricultural land, malnutrition, poor housing, low wages, and language barriers for the large Polish minority. His report to the government advocated land reform, progressive taxation, establishment of agricultural communes, local political autonomy, and, lastly,

creation of a system of public hospitals. Virchow's conclusion: "Medicine is a social science, and politics nothing but medicine on a grand scale" [26, 27].

Pioneers of a New Epidemiology

Other 19th century research that did not exclude the context of exposures was done in France [29] and England. The public health research that Friedrich Engels conducted in England was particularly insightful [26]. He documented the health problems that arose from crowding, lack of sanitation, malnutrition, and abuse of alcohol to alleviate chronic pain. Like Virchow, he quantified excesses of disease and death through statistical study without naming the analyzed factors, be they occupational, nutritional or behavioral, as the autonomous causes of disease. Unlike Virchow, however, Engels did not believe that reform of the political system would ever create the underlying conditions for adequate public health. Rather, he identified the capitalist economic system itself as the source of ill health. Increasingly reductionist epidemiological thinking emerged in the context of Pasteur's discovery of microbes, the development of a more effective (and less damaging) allopathic medical practice, and the increasing dominance of statistics in quantitative investigation. Not all epidemiology, however, was converted to the theory that so successfully reduced the cause of disease to a germ, simultaneously distracting attention from the material living and working conditions in which disease arose. During the 1920s Joseph Goldberger showed that pellagra was not an infectious disease, as many at the time thought, that it was related to nutritional deficiency, and that its occurrence in the U.S. South depended on a share-cropping system that locked large numbers of people in poverty [30]. Unfortunately, his more global analysis of the economic arrangements in which pellagra and other public health problems proliferated was ignored by policy makers in favor of supplementing flour with niacin, a solution that probably contributed (along with access to electricity, refrigeration and dietary improvements) to the reduction of pellagra, but left in place the rural South's underdeveloped economic circumstances that continue to make the region the location of some of the worst public health conditions in the U.S. Yet Goldberger's well documented research strategies can help contribute to today's critical evaluation of methodology in the field.

More holistic approaches to epidemiology continued in some third world countries. In Chile, the physician Salvador Allende came to believe that he would make the



Figure 3. Sign posted by Tennessee Department of Public Health near site of Oak Ridge nuclear weapons facility. (Photo courtesy of Physicians for Social Responsibility)

greatest contribution to the health of his people not by treating patients one at a time, but by working against the devastating effects of under development [26]. As president of Chile, he realized Virchow's vision of politics as medicine on a grand scale. Latin America - where it is clear that the immediate public health problems of disease in populations have less to do with specific exposures than with a position in the international economic system that sustains a lack of decent jobs, housing, clean water, food, and democratic control of institutions -- is now home to a number of alternative currents of development in epidemiology. In these circumstances it is difficult to sustain the first world mirage that substantial public health advances can be achieved through the enumeration and regulation of unhealthy exposures on a case-by-case basis.

Pressure for change in epidemiology also comes from groups that have been exploited on the basis of race, gender and class, and from environmental and peace activists. One aspect of an expanded public health agenda that is drawing attention from official agencies and academics in the U.S. is environmental racism [31,32]. Increasingly, studies are documenting the systematic preferential location of toxic waste sites and polluting industries in areas that are predominantly inhabited by people of color and the poor (Fig 3). The primary issues here are not the identification of specific chemicals associated with particular diseases, threshold exposures for health effects, or dose response estimates; rather, the generation of exposures or potential exposures, environmental equity, and democratic decision-making are of primary concern. The specific effects of contaminants as well as medical means for treating problems once they occur are of great interest

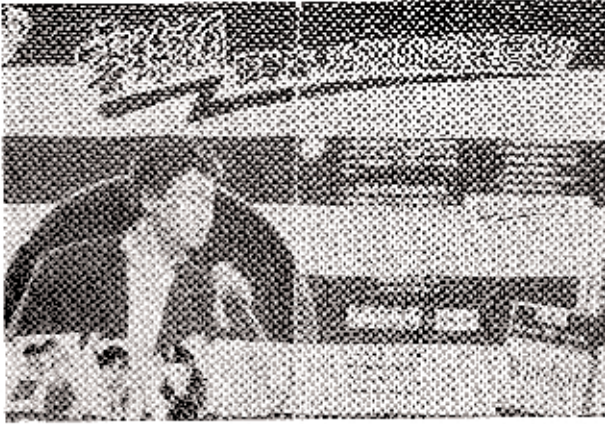


Figure 4. Education about the health consequences of smoking has led to a sharp decline in U.S. tobacco sales. To counter their domestic losses, tobacco companies have intensified their marketing in countries that impose few regulations. This Korean billboard offers free rock concert tickets in exchange for coupons clipped from cigarette packs. (Photo courtesy of Tobacco Control)

and importance, but as those issues are viewed in a larger context, they can potentially be connected to other health problems and the development of coordinated solutions. Thus, contamination of Native American lands in the south western U.S. by uranium mine tailings, nuclear weapons testing, and radioactive waste disposal can be connected to the long history of expropriation and destruction of Native lands, ecosystems, and means of subsistence, which have devastated Native public health for centuries.

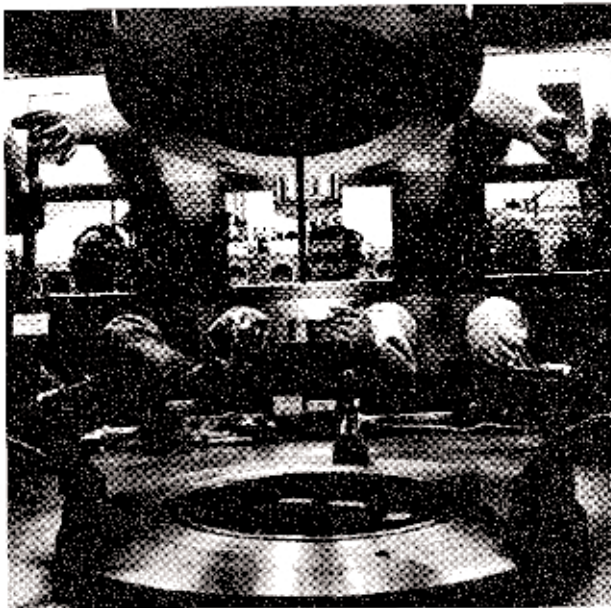


Figure 5. Plutonium workers at the U.S. Department of Energy's nuclear weapons research facility in Los Alamos, New Mexico. (DOE photo)

Application of Epidemiology to Public Health

Epidemiology as a basic science of public health affects the nature of public health interventions. Because of its declared object of inquiry, modern epidemiology generally leads to interventions directed at specific individual exposures, and it is therefore important to consider the consequences of trying to intervene on specific exposure-disease associations in isolation from their context. Before addressing radiation and health, let us consider smoking and health, a textbook example of the early application of modern epidemiology for which public health consequences can be evaluated over three decades.

Despite widespread clinical observations of smokers' symptoms and the physical and biological plausibility of smoke as a lung pathogen and carcinogen, it was evidence from epidemiological studies of the 1940s and 1950s that led, in the United States, to the Surgeon General's 1964 report on the health hazards of smoking [33]. Modern non-infectious disease epidemiology had its first major success in identifying associations between cigarette smoking and lung cancer and other prominent diseases. Subsequently, public health efforts were initiated to reduce the prevalence of smoking through education about smoking hazards and through control of cigarette advertising. Over the last three decades there has been a remarkable shift in the prevalence of smoking and the burden of smoking-related diseases, a shift that can be attributed in part to the epidemiological explanation of the cause of smoking-related diseases. Smoking prevalence has declined substantially among better educated, higher income people in North America, parts of Western Europe, Australia and New Zealand [34]. Smoking prevalence has declined little or none among lower educated and lower income people in those countries [35], and is increasing rapidly in many of the most populous parts of the world [36]. Thus in the three decades following epidemiology's major success, more people are exposed to and made sick from the disease agent than ever before [37].

Tobacco and Epidemiology

The populations studied by modern epidemiologists were the exposed and the unexposed defined by the model of the experiment. They were not highly organized groups with economic systems and social relations. Thus, the cause of the lung cancer epidemic was identified as cigarette smoking, an individual behavior, while tobacco agribusiness, the commercial sale of cigarettes, and the social circumstances that make

smoking a rewarding habit, could not be recognized by epidemiological studies as targets for intervention. When educational efforts and social options led some groups to reduce smoking levels, tobacco companies redirected advertising to replace those markets with others, often assisted by governments with their own financial stakes in tax revenues and contributions to trade balances (Fig 4) [38].

Not only has the identification of the association between smoking and disease failed to stem the world-wide epidemic of smoking-related diseases, it has redistributed smoking prevalence so that it increasingly adds to inequalities in health between the poor and the rich within countries of the North [39], and between countries of the North and the South [40]. Such redistributions may be expected when interventions are directed only towards consumption rather than towards both production and consumption [41], and it is only the behavior of consuming cigarettes, not the organized production and promotion of tobacco, that has been considered by epidemiological studies. Health inequalities are further exacerbated through replacement of local food crops by tobacco for commercial markets and by toxic exposure of industrial and agricultural workers during manufacture and application of agricultural chemicals.

Three Sources of Radiation Exposure

A related situation can be described with radiation and health. The problem as now defined in the terms of modern epidemiology is one of quantifying the extent of the increase in cancer (or birth defects or some other physiological or disease outcome) produced by every unit increase in an individual's dose of ionizing radiation. The accurate quantification of this relationship will supposedly provide the basis for the rational determination of how much radiation exposure would be permissible, and regulations would be designed accordingly. As in the case of the evaluation of smoking and health, the situation of an individual's exposure is separated from the context of the production of the exposure and the other effects of that production on health and society.

Most manufactured exposures to radiation take place within the context of the energy, military, and medical industries. The military industry, which has produced many of the exposures studied by epidemiologists, developed in support of the creation of tens of thousands of nuclear weapons (Fig 5). Nuclear proliferation and the threat of catastrophic nuclear war continue. Attempts to clean up the most toxic remains of this pro-

duction are just beginning, will go on for decades if not centuries, and cannot possibly restore many areas to safe states.

The history of environmental contamination and human suffering in areas used for production and testing is horrible, and the stories of the affected people and places are indeed chilling [42,43]. The public health consequences of direct contamination, however, are only a small part of the much larger health impact of the exposure context, the industry without which the exposures would not have occurred. This military enterprise and the research infrastructure that supports it have used huge proportions of national budgets and engaged hundreds of thousands of people in activities that have as their main purpose not social welfare, but development of means of destruction, diverting human and economic resources from potential projects to improve living conditions throughout the world. The expense and sophistication of nuclear technology itself has generated a scientific and bureaucratic elite that has perpetuated itself through secrecy, concentration of power, and elaboration of a xenophobic and divisive brand of patriotism [44]. This social context is highly undemocratic and contributes to inequalities of wealth and power justified on the basis of special knowledge of an elite group that is supposedly uniquely qualified to make decisions, promoting disregard for protection and rights of workers, indigenous peoples and others that are excluded from participation in decisions affecting health conditions.

The Health Effects of Industries and Social Policies

The use of nuclear technology for power production could not have occurred without the support of the infrastructure and research base created for military purposes. Once the commitment had been made, however, the commercial industry contributed to the hopes for ever-increasing energy consumption with the promise of a clean and cheap source of power. The industry proliferated widely in the absence of political and technical solutions to the problems of waste disposal. Energy would be produced without limit in centralized locations controlled by a technical elite rather than with a technology that could be widely distributed and controlled more democratically. This vision of electric power generation has in part prevented the development of a policy alternative to unlimited growth that is ecologically sound, sustainable, equitable, and consistent with reduced inequalities in health between the majority of the world's people that use little energy and the minority that consumes most of the energy.

Medical uses of ionizing radiation preceded the military and energy uses by decades, and while there have been important diagnostic and therapeutic applications, many disasters and victims were created in the process [44]. These include patients subjected to x-ray and radium treatments, children exposed to x rays during pregnancy, and many of the clinicians that treated them. In medicine, consideration of the context of radiation exposures could encourage greater attention to preventive rather than diagnostic and curative measures, and, within the context of the latter, could draw attention to overuse of tests and treatments with marginal benefits.

In all three radiation industries, the existence of a technology that proponents pushed as a quick fix for complex social problems -- international conflict, energy policy and medical care encouraged the attitude that it would not be necessary to address the global issues of political relationships, ecological sustainability, disease prevention and humane healing, but only to put faith in a technology that would provide the power to solve what was perceived to be a specific problem by itself. The health effects of these policies occur not only through agents like ionizing radiation, but more importantly through their effects on society, on social inequalities, and on living conditions that are essential to public health.

Smoking and health and radiation and health are only two examples of how the nature and object of epidemiological explanation limits its scientific scope and public health application. Similarly, a focus on high-fat diet as individual behavior fails to address consequences of the animal-oriented agriculture systems that support mass high-fat diets. These consequences include production of export crops in the context of local malnutrition, use of vast quantities of non-renewable energy resources, occupational exposure to pesticides and herbicides, topsoil loss, and generation of methane greenhouse gases.

Two responses to this situation are suggested by approaches reviewed above. One is that epidemiology is simply not about these broader issues, rather, they are the responsibility of other disciplines. Another is that epidemiology has addressed the broader issues of context in the past, and that it has only lost that ability and interest because of the economic and political context of its dominant modern practice. Epidemiology is not alone among disciplines in its reductionism, and it cannot carry the burden, by itself, of adopting an ecological perspective. Rather, all health-related disciplines should adopt a broader perspective within their particular

practice, encompassing and transforming the concepts and tools that have developed in each area.

Scientific Objectivity and Social Responsibility

Many scientifically trained people, as well as non scientists who have felt comfortable putting their faith in the experts, have been attracted to reductionist science because of the very characteristics criticized here. According to this logic, it is only by excluding the context and focusing on particular factors considered independently of historical conditions that science can produce objective knowledge that has a greater claim to authority than other forms of knowledge. Although this perspective continues to thrive in the biomedical sciences, including epidemiology, it has been thoroughly critiqued by historians, philosophers, and practitioners of science of the latter half of the twentieth century [5, 45-52].

Science and Conceptual Frameworks

The basis of the critique of value-free objectivity is simple: it is impossible to know the world without intellectual tools, including languages and socially produced concepts. Whether explicit or not, all scientific investigations depend on conceptual frameworks. There can be no unmediated experience. These ideas have been extensively developed in various directions by many authors, especially since the seminal work of Thomas Kuhn [45], and they provide a basis for the most fundamental challenge to reductionist epidemiology by removing its justification as a unique means to provide objective analyses of health and disease problems. The choice is not between objective science and a science that is contaminated by social and political values. Risk factor epidemiology does not achieve objectivity by systematically examining exposure disease associations separated from contexts of military, energy, or agriculture policy, and issues of economic inequalities and democracy. Rather, it makes a political commitment to the status quo by excluding these issues from public health consideration.

Shattering the myth that scientific inquiry can be independent of society amounts to recognizing the "distinction between the claim that the world is out there and the claim that truth is out there" [53]. Belief that truth is something which is found "out there" rather than something that is made from observations of the world using socially and culturally produced languages and concepts is partly a reaction to the mis-

taken perception that the only alternative to value-free scientific objectivity is relativism and the abandonment of any basis for making comparative evaluations of scientific explanations. But recognition that all knowledge, including scientific knowledge, is rooted in social constructs does not negate the idea of objectivity in the sense of fairness, justice, and intellectual honesty. This has been called "strong objectivity" by Sandra Harding [46], a concept that she has counterpoised to the "weak objectivity" perpetuated by practitioners of Cartesian reductionism. Strong objectivity depends on explicating assumptions and goals through self critique rather than denying them by constructing a myth of socially unmediated scientific experience. Consideration of social responsibility as part of an analysis of the construction of scientific knowledge is therefore not something to be tacked on to scientific practice after the fact, but is a necessary part of being objective in the sense of being explicit about assumptions. The development of an alternative to reductionist epidemiology depends on such a commitment.

Recognizing social responsibility as an integral part of scientific inquiry, however, forces us to make judgments about social responsibility, an ethical dilemma that is denied by those who believe that objectivity is obtained by separating science from human values. What, then, is to be the basis of moral judgment, and how are conflicts between different cultures and classes to be resolved? Most philosophical approaches consider this question against the standard "that there must be necessary, universal grounds for all moral principles" [54, p 9], either searching to establish the basis for these universal grounds or accepting a defensive posture of moral relativism. Philosopher Cornel West argues that the search for universal moral certainty is doomed, but that various brands of moral relativism are unacceptable. He dissolves the problem of choosing between universal and relative moral principles by substituting a historical basis of thinking about morality which holds "that there are moral truths or facts, but that they are always subject to revision . . . relative to specific aims, goals, or objectives of particular groups, communities, cultures, or societies" [55, p 10]. West calls for "a historical assessment and political reading of our morality and morale, in order to shed light on how we can make them more contagious to others captive to the prevailing cynicism and nihilism [of our culture]" [55, p xiii]. Such an ethical position can support a socially responsible scientific practice but requires full engagement with, rather than denial of,

the ethical aspects of the social construction of scientific knowledge.

An Alternative Epidemiology

If we accept a broad critique of the dominant practice of epidemiology, as opposed to the view that the discipline is essentially on track but needs fine tuning, the first question that arises is, "If this isn't the right way to do it, then what do you propose?" The answer to this question must emerge through the developing work of diverse groups of researchers and practitioners who are struggling to make the field more relevant to improving public health conditions throughout the world. There are many examples in the current literature of attempts to work out more or less contextual explanations of health and disease phenomena [5, 8, 9, 11, 25, 47, 51, 56-58], although they are not yet connected in a coherent set of theories, assumptions and techniques that could constitute a real new paradigm [see 59 for a discussion of competing paradigms in epidemiology].

An alternative practice that is shared by large numbers of scientists will no doubt require much time and larger scientific, social and political change. Such change will be affected by relationships between professional practices including medicine and public health, and broader based efforts to improve public health conditions, including civil rights, economic justice, environmental, anti-war, and other activities. Epidemiology is already being affected by involvement of non-professionals with new ideas about appropriate research questions, evidence, and interpretations of findings [60].

How would such an epidemiology be practiced, and what would its products look like? First, it would not just ask questions about what is good or bad for health in general, but it would analyze differential effects - good or bad for whom? Second, it would look for connections between many diseases and exposures, what is common about them, instead of always isolating exposure-disease pairs. Third, it would look for side effects of interventions and exposures, the unintended consequences that may be more important than the intended ones. Fourth, it would develop ways to utilize historical information, the developmental narratives of particular populations and even individual people, with the aim of connecting the particular and the general. Fifth, it would address the conceptual framework of the research, including analysis of assumptions and the social construction of scientific knowledge, as a central part of any research reporting, as central to a research manuscript as consideration of measurement error or selection bias [49].

Sixth, such an epidemiology would recognize that the problem of controlling confounding factors comes from the search for independent relationships, not from the world we study, and that the "nuisance factors" of the reductionist perspective can become the essential context of exposure and disease of an ecological perspective. Finally, it would entail a humility about the scientific research process and an unrelenting commitment to playing a supportive role in larger efforts to improve society and public health.

Efforts to articulate an alternative epidemiology are connected by attention to the historical contexts of public health phenomena as well as to the science that addresses them. These positions are contrary to the dominant assumptions that there can be an ahistorical, value-free epidemiology that is about ahistorical, independent exposure-disease associations. Research into the health effects of ionizing radiation is a stereotypical example of the application of the reductionist program, preoccupied as it has been with the search for the shape and magnitude of a presumably universal dose response relationship and its consistency across populations, and the quest for an ahistorical constant that will be analogous to the fundamental laws of nature supposedly uncovered by the discipline that produced the exposures under study, physics. Meanwhile, the public health disasters of runaway military spending, uncontrolled energy consumption, and dominance of high-technology curative medicine over preventive environmental and medical practices, go unseen by the "basic science of public health."

Our dominant epidemiology begins with the assumption that things work separately and independently, that exposures can be separated from the practices that produce them. An epidemiology oriented towards massive and equitable public health improvement requires reconstructing the connections between disease agents and their contexts. This is necessary for the successful application of scientific knowledge to public health practice, for the resolution of intractable technical and conceptual problems inherent in current exposure-disease studies, and for the development of a socially responsible epidemiology. The practical, technical, theoretical, and ethical goals are complementary. Such a direction will allow us to recognize the health consequences of industries and social and economic arrangements as well as the roles of specific disease agents. As social, economic and political arrangements that provide the conditions for public health and human development become an explicit part of the epidemiologi-

cal explanation of health and disease in populations, efforts to oppose injustice and inhumanity can be recognized as an integral part of a comprehensive public health agenda. Current global public health crises demand more than a piecemeal approach.

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