Changing Approaches to Assessment of Environmental Inhalation Risk: A Case Study

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BOTH SOCIAL AND SCIENTIFIC APPROACHES TO decision making for regulation of the industrial environment have evolved during the twentieth century. Recently, historians have appropriately addressed both the social and the political determinants of environmental and occupational safety and health regulatory decisions. Although much of this new historical literature contributes to our understanding of contemporary problems (Derickson 1988; Sellers 1991; Rosner and Markowitz 1991; Corn 1992), and its importance cannot be overlooked, it is equally necessary to understand the developing scientific basis for regulatory decision making, including the effect of improved measurement methodology on regulatory policy.

For example, historians overlook a contemporary critical scientific concept utilized in the regulatory process: environmental assessment of health risks. Assessing the health risks from exposures to dangerous substances, a scientific endeavor, calls for more than scientific questions. Broad social and political issues arise in part because of the uncertainties and complexities involved in scientific measurement, in the definition of the extent of risk, and in the degree of control sought. Scientific concepts of environmental measurement directly affect the feasibility of decisions to control the industrial environment.

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In this article, we focus on approaches to assessing environmental inhalation risks from the 1930s to the present. We investigate the relation between improved technical environmental measurement and action taken to control a dangerous substance, thereby illustrating the close link between state-of-the-art science and policy decisions.

Our hypothesis is that although it is possible for protective health regulation to occur in the absence of a scientific database, the integration of new scientific findings and technical methodologies into the regulatory arena clarifies and focuses economic and political discussion and decisions. It provides scientific and technical options for environmental control that can be related, to a greater or lesser extent, to the health impact(s) the regulation is designed to reduce or prevent. Thus, the link between science and policy decisions was close in the case of asbestos. Science, economics, and politics were inextricably interwoven, resulting in vigorous debate and political engagements, producing regulations that incrementally improved with time, arguably largely because of improved scientific insight. This article is weighted toward the scientific changes. Table 1 indicates changes in U.S. Asbestos Standards from 1938 to 1986 (Corn 1992).

U.S. experience in setting acceptable workplace exposure levels to control inhalation risks from asbestos in the workplace will be presented as a case study to demonstrate how measurement criteria have changed since the 1930s in response to the proliferation of asbestos utilization, changes in understanding the disease manifestations associated with asbestos inhalation, the ability to make more accurate and sensitive measurements, public perception of the risks associated with asbestos, and, finally, regulation of the workplace, which called for legally mandated environmental standards.

Environmental Standards

The concept of environmental standards, as we understand it today, is a modern one associated with achieving an acceptable level of, and duration of exposure to, a potentially toxic agent based upon evidence that assumes predictive validity for the health effect(s) that will follow if the standard is exceeded. Generally, documentation of the link between exposure and effect(s) is implied in the discussion of a standard.

TABLE 1
U.S. Asbestos Standards, 1938–86

Year	Sponsor	Status	Million particles/cm	Fibers/cc
1938	Dreessen et al.	Recommended TLV	5	30[a]
1946	ACGIH	Adopted TLV	5	30[a]
1970	ACGIH	Adopted TLV	2	12[a]
1971	ACGIH	Proposed TLV	—	5
1971	OSHA	Emergency TWA	—	2
1975	OSHA	Proposed TWA	—	0.5
1976	OSHA	Adopted TWA	—	2
1976	NIOSH	Recommended TWA	—	0.1
1983	OSHA	ETS (TWA)	—	0.5
1984	OSHA	Proposed TWA	—	0.4 or 0.2
1986	OSHA	Adopted TWA	—	0.2

[a] Approximate fiber equivalent.
Abbreviations: ACGIH, American Conference of Governmental Industrial Hygienists; ETS, emergency temporary standard; NIOSH, National Institute for Occupational Safety and Health; OSHA, Occupational Safety and Health Administration; TLV, threshold limit value; TWA, time-weighted average.

A regulation, in contrast to a standard, is a promulgation by a body authorized to enforce enabling legislation. A regulation frames, in legal context, and usually in specific terms, requirements imposed by an agency on regulatees. It usually serves as an umbrella for standards (Corn and Corn 1975).

Setting standards, a policy decision, is closely linked to technical and scientific knowledge. Setting appropriate standards to control environmental hazards represents a class of problems that requires both scientific and political decisions (Corn 1984). Decisions about environmental risks require two different activities: measuring risk, which is an objective and probabilistic activity, and judging the acceptability of the risk, which is a matter of personal and social value judgment (Lowrance 1976). The history of setting standards for asbestos, a class of materials with an extensive toxicological literature, demonstrates that the database to answer the associated technological and scientific questions, like magnitude of biological effects and efficiency of controls, is always incomplete. Nevertheless, more is known about asbestos toxicity and the dose-response curve than about any other industrial material.

Asbestos

Thirty years ago concerns about asbestos hazards centered on workers who, because of intense utilization, combined with minimum controls and minor precautions on the job, had been exposed to large amounts of fibers at work (Corn 1987). Manifestations of asbestos diseases appeared with increasing frequency in shipyard workers and others who had earlier been exposed to massive amounts of airborne fibers. Not until the 1960s, because of the long latency period associated with asbestos-induced cancer, did we begin to appreciate fully the legacy of death and disease that resulted from earlier high exposures to asbestos. At that time, Irving J. Selikoff of Mount Sinai School of Medicine and E. Cuyler Hammond of the American Cancer Society presented epidemiological evidence that indicated insulation workers who had worked with asbestos for 20 years or more were dying of cancer and complications of asbestosis at alarming rates (Selikoff et al. 1965). In 1972, asbestos became one of the first toxic materials regulated by the newly created Occupational Safety and Health Administration (OSHA). In the 1980s concern about health hazards associated with asbestos spread from persons who were occupationally exposed to those experiencing nonoccupational exposure. Asbestos precipitated regulation in the occupational environment by OSHA and in the nonoccupational environment by the Environmental Protection Agency (EPA): the Asbestos Hazard Emergency Removal Act (AHERA) and the Consumer Products Safety Administration (CPSA). Today, although concern still exists that people who work with asbestos are inadequately protected, anxiety and fear exist as well among the general public regarding the long-term effects of nonoccupational exposure to asbestos.

Although asbestos had been used in small quantities for centuries, large-scale asbestos mining and commercial production started in the twentieth century and greatly accelerated during World War II. Asbestos consumption rose from under 100,000 tons in 1912 to approximately 750,000 tons during World War II and to 800,000 tons in the 1970s (U.S. Department of the Interior 1982, 4–5). Asbestos is ubiquitous.

Industries that manufacture asbestos products, or utilize them, employ millions of people. In the mid 1970s, it was estimated that over 37,000 persons were employed in the manufacture of primary asbestos products, 300,000 worked in secondary asbestos industries, and millions worked in asbestos consumer industries; among the latter were 185,000

in shipyards and almost 2 million in automotive sales, service, and repair (National Cancer Institute 1978).

Asbestos exposure can cause serious illness and death. The major pathological effects of asbestos result from inhaling fibers suspended in ambient air. Asbestosis, a chronic, restrictive lung disease caused by inhalation of asbestos fibers, was the first known disease associated with exposure to this material. It is associated with heavy occupational exposure to asbestos (Dupré 1984). Unlike asbestosis and mesothelioma, lung cancer is not specifically associated with asbestos exposure because lung cancer also has a history of association with cigarette smoking. Although it is recognized that asbestos in the absence of cigarette smoking can induce lung cancer, issues of causation are often raised when lung cancer develops in asbestos workers who smoke (Dupré 1984).

Mesothelioma, a rare cancer of the surface-lining cells of the pleura (lung) or peritoneum (abdomen), generally spreads rapidly over large surfaces of either the thoracic or abdominal cavities. No effective treatment exists for mesothelioma. It occurs among insulators, those who work in asbestos plants, and shipyard workers. Mesothelioma has also been reported among persons living in the same house as asbestos workers or in the neighborhood of asbestos mining and milling. Mesothelioma, like asbestosis, is specifically linked to asbestos exposure (Dupré 1984).

The scientific evidence relating the type of asbestos inhaled to the manifestations of asbestos disease remains highly controversial. For example, in the United States the occupational permissible exposure limit (PEL) for asbestos does not differentiate types of asbestos. Other countries differentiate between fiber types and invoke different PELs. These issues are discussed in a variety of documents (National Institute of Occupational Safety and Health 1976; Dupré 1984). The dose-response considerations of several epidemiological studies that formed the basis of the OSHA PEL are discussed in the agency's promulgation of the asbestos standard (U.S. Department of Labor 1986, 22612–15).

Asbestos disease manifestations have been linked to the amount of asbestos the affected persons have inhaled. In general, larger quantities of inhaled asbestos, or high dose, have been related to asbestosis, and lower quantities, or low dose, to mesothelioma and lung cancer. There is current controversy regarding the association between certain types of asbestos and mesothelioma. Thus, chrysotile may not produce mesothelioma.

The first association of pleural mesothelioma was for crocidolite (Wagner 1960).

Documentation of cases of asbestos-related disease began early in the twentieth century (Ozonoff 1988). At that time, lack of knowledge about risks associated with asbestos and the small amounts of the mineral in use limited observations and understanding about the relation between asbestos and disease. In fact, the fibrotic disease described by Murray (1907), Auribault (1906), and others did not receive a name until Dr. W.E. Cooke called it asbestosis in 1927 (Cooke 1927).

As asbestos production began to expand, observations of asbestosis increased. In 1928 and 1929, the British government undertook an investigation of the condition of textile factory workers and reported to Parliament in 1930 that "inhalation of asbestos dust over a period of years results in the development of a serious type of fibrosis of the lungs." The commissioners recommended dust suppression. British asbestos industry regulations followed in 1931 (Legge 1934, 193–5). Clinical reports in the United States also confirmed occurrence of asbestosis among asbestos workers (Lynch and Smith 1930; Donnelley 1933; Ellman 1933). A number of books on public health, medicine, and related subjects began to incorporate sections on industrial hazards, and they included asbestos dust among those hazards (Lanza 1938; Lanza and Goldberg 1939; Clark and Drinker 1935).

By the 1940s, physicians identified asbestos dust as dangerous and unhealthy, and they understood that inhalation of the dust over a period of years could cause asbestosis. A 20-year gap, however, existed between the first identification of asbestos as the cause of fibrotic disease and the general acceptance of asbestos dust as a health hazard. Asbestosis also coincides with high levels of exposure to asbestos dust, which workers experienced in the early years of the twentieth century. It would be years before the dust was significantly reduced. In the meantime, American industries used increasing amounts of asbestos and found new applications, seldom considering the health of workers.

The first reported case of the association of asbestos dust and lung cancer appeared in 1935 (Lynch and Smith 1935), but the first rigorous epidemiological study appeared in 1955 when Sir Richard Doll (1955) documented a tenfold increase in the risk of lung cancer among a group of men employed 20 or more years at an asbestos textile plant in northern England. To complicate the matter, the latency period for cancer was

longer than for asbestosis, and lower levels of dust could cause cancer. Nevertheless, the foreshadowing of the coming tragedy had begun in the 1930s, when British and American medical reports associated asbestos exposure with the development of lung cancer. In England, Merewether (1949) demonstrated an excessive rate of lung cancer among 235 asbestos workers diagnosed with asbestosis. In 1964, the landmark Conference on Biological Effects of Asbestos, organized by the New York Academy of Sciences, resulted in a consensus among international investigators that asbestos was a cause of lung cancer (*Annals of the New York Academy of Science* 1965).

As in the case of asbestosis, the lengthy route from initial cognizance to confirmation and acceptance of the association between asbestos and cancer took decades. Tragically, large numbers of workers would become desperately ill during this time, and many would die from this painful disease. Furthermore, in the 1960s it became clear that the risk of disease was not confined to workers in mining and manufacturing, but extended as well to shipyard workers, insulation workers, and many others outside of primary or fixed-place industries.

In the United States, minimal attempts to control occupational exposures to asbestos began in the 1930s. The body of technical and medical literature about fibrotic disease associated with asbestos included rudimentary measurement techniques and technology; it was available in textbooks, journals, and government publications. A number of engineers concentrated on the potential workplace hazards of dust.

Measurement

In the 1930s, industrial hygiene and occupational medicine professionals developed the concept of dose–response, which implied measurement of dose and response and a relation between them. Since then, two essential principles have been utilized. First, there is a systematic dose–response relation between the severity of exposure to the hazard and the degree of response in the population exposed. A decrease in the level of exposure corresponds with a gradual decline in the risk of injury. Second, the risk becomes negligible when the exposure falls below certain acceptable levels. Analysis of environmental factors is implied in the dose–response concept.

Before exposure guidelines and techniques were used to measure hazards in the workplace, the keys to controlling hazards were observation and experience. Ludwig Teleky wrote:

> Twenty years ago (1928) the only method in use was a periodic examination of workers. To this has been added measurement of the amount of harmful substances in the air and the determination of their effect on health. In the development of industrial hygiene, it was necessary to find ways of measuring noxious substances in the air. It was not sufficient to rely on general terms like "much" or "damaging" or to infer from the incidence of disease in the factory that the air contained a damaging amount of dust or other substances. Only in the last decade has a fairly exact determination been possible, although attempts have been made since the middle of the last century. (1948, 128)

Early attempts to measure dust content in air consisted merely of allowing dust to settle or drawing a measured amount of air through a filter by suction. Simple instruments consisted of two bottles, each of 25-liter capacity, using cotton, asbestos, or nitrocellulose filters. One bottle filled with water stood on a higher level. The other rested on the ground with a piece of pipe attached for aspiration. The apparatus was cumbersome. Another dust-sampling device constructed on different principles impinged a jet of dusty air on a sticky substance. Kotze's Konimeter, constructed to measure dust in mines, allowed the dusty air to impinge at a high velocity through a narrow nozzle against a plate coated with an adhesive substance, thus retaining the dust particles for subsequent microscopic examination on the plate (Teleky 1948, 130).

In 1922 Leonard Greenburg and G.W. Smith combined the principle of collecting dust by impingement with the water-washing or bubbling method to construct the impinger. Greenburg, who was a Public Health Service officer, had been assigned to the Bureau of Mines (Corn 1989). The impinger method of dust collection remained the standard dust collection method for over 40 years. After the apparatus took dust out of a measured amount of air, the dust was counted. Dust particles collected by the impinger method were counted first by means of a microscope and later through projection and microphotography.

The corollary to measuring airborne hazards and analyzing environmental factors in the workplace was determining the concentration of a material that would not cause injury; in other words, determining the

concentrations at which individuals were exposed, but not injured. A body of data accumulated, for a variety of compounds, that gave exposures not associated with injurious affects. Terms for measurement of what was considered acceptable levels include MAC (maximum allowable concentration), PEL (permissible exposure limit), and TLV (threshold limit value). Determining "safe" concentrations was, and still is, politically controversial and value laden.

In the United States industrial hygienists began to publish tables of MACs: the upper limit of concentration of an atmospheric contaminant believed not to cause injury to an individual exposed continuously during his working day and for indefinite periods of time (Baetjer 1981). Manfred Bowditch, Cecil Drinker, Philip Drinker, M.M. Haggard, and Alice Hamilton published "Code for Safe Concentrations of Certain Common Toxic Substances Used in Industry" (Bowditch et al. 1940). Even before the MAC table was published in 1940 the Committee on Ventilation and Atmospheric Pollution of the American Public Health Association issued reports (1931–40). Members of that committee were also on the American Conference of Governmental Industrial Hygienists TLV Committee. The American National Standards Association set standards as well. MACs evolved into TLVs and were institutionalized by the American Conference of Governmental Industrial Hygienists (ACGIH) (Corn 1989). TLVs were first published by ACGIH (1950) in the *Archives of Industrial Hygiene and Occupational Medicine*. Since then, the TLVs have continued to be published annually by the American Conference of Governmental Industrial Hygienists. These controversial contributions of the American Conference of Governmental Industrial Hygienists have been used by both government and industry. They have been misunderstood, misused, and consistently maligned (Castleman and Ziem 1988). Nevertheless, they were utilized over the years in attempts to control asbestos in the workplace.

Toxicological Sciences

In addition to retrospective population studies revealing the effects of toxic substances on those exposed, much of the data utilized to determine the magnitude of a risk depends on toxicological science. The development of one branch of toxicology, inhalation toxicology, has been a major factor in assessing environmental and occupational exposures to

airborne toxins like asbestos. Toxicologists ask key questions to determine exposure limits: What airborne concentrations of a toxic substance pose significant hazards to health? What concentrations can be accepted for specified periods of exposure time without undue risk to health? The importance of available toxicological information in these determinations cannot be overestimated.

Traditionally, toxicology has been defined as the science of knowledge of poisons. Inhalation toxicology is the science of knowledge of inhaled poisons or toxicants. It includes the following subject areas:

1. the physical and chemical characteristics of material in the air
2. the basic biology of the respiratory tract
3. the deposition and retention of inhaled materials in the body and their interaction with critical biological units
4. the manner in which such interactions with the respiratory tract and other systems produce disease

Answers to the questions these subjects raise provide the basis for assessing the health risks of airborne materials like asbestos. Concern for the effects of inhaled toxicants can be traced back for centuries. Smoke and odors from coal aroused attention in thirteenth-century London and, early in the Industrial Revolution, dust from coal that fueled steam engines became a cause for alarm. Despite the early incidence of air pollution and industrial poisonings, these problems were seldom seriously considered. The field of inhalation toxicology, as we know it today, can only be traced back decades.

By the mid-twentieth century, air pollution incidents began to create public awareness that airborne materials could cause disease. Three famous smog episodes resulted in marked increases in morbidity and mortality from respiratory causes: the first took place in 1948 in Donora, Pennsylvania; the second, in 1952 in London; and the third, in 1962 in London. Until the first episode, except for some early pioneering occupational studies by Theodore Hatch, Cecil Drinker, and Philip Drinker, there was little interest in the occupational or environmental health hazards of airborne materials and very little research in the field of inhalation toxicology. In spite of toxicology's long history, not until research was performed in the twentieth century did our knowledge of how industrial pollution produced disease begin to expand. After World War

II, chemical agents, radioactive materials, and automotive exhaust emissions focused public attention on the health effects of airborne materials.

A perusal of the early years of inhalation toxicology reveals how hard won were some of the advances in techniques of dealing with inhalation risks. Experiments began in the nineteenth century and continued through the 1950s.

Inhalation toxicology determines the toxic effects on animal species following carefully controlled inhalation of toxic material(s). The determination is entirely dependent on the rigor with which the investigator standardizes the exposed animal population and controls for the delivery of the toxicant over what are usually extended periods of time, under controlled conditions of temperature and pressure.

Early advances in inhalation chamber technology and in aerosol and gas generation systems contributed to building the hardware to study inhalation toxicology; exposure characterization emerged as an early technique. We will not discuss here the equally significant advances in measuring effects in exposed animal populations, but instead we will focus on one aspect of inhalation toxicology: chamber design and toxicant delivery systems.

The experimental study of effects of airborne agents can be traced back to the nineteenth century, when investigators began to develop exposure techniques and equipment to meet their needs while researching the effects of airborne toxicants on animals. One such early recorded experiment occurred in 1865. Eulenberg described controlled animal inhalation exposure studies. He used a cubical wooden chamber, $12\frac{3}{4}$ inches high with two glass walls for exposing small laboratory animals to high concentrations of numerous toxic and asphyxiant gases. The inner walls of the chamber were coated with rubber-containing varnish. Auxiliary equipment included a gasometer for measuring flow rates and a manometer for measuring chamber pressure. The airflow was driven by water displacement (U.S. Department of Health, Education, and Welfare 1959).

In 1875 and 1876 Van Jns reported on a carefully designed chamber for exposing small laboratory animals to dust. The chamber was totally enclosed, and it measured 20 cm × 20 cm × 10 cm. The dust feed was an ingenious arrangement of a mechanical shaker on a dust-filled funnel, from which the dust was dispersed by a motor-driven bellows into the exposure chamber. The exposure chamber was used to study effects

of the inhalation of diatomaceous earth (U.S. Department of Health, Education, and Welfare 1959).

Lehman and his associates published a number of papers on inhalation toxicity based on work done at the Hygienic Institute in Munich that utilized inhalation chambers for the dynamic exposure of cats, rabbits, guinea pigs, and frogs. Their reports on inhalation experiments described an inhalation chamber for gases (Dubitzki 1911); a dust exposure unit (Saito 1912); a mist exposure unit (Lehman, Saito, and Majima 1912); and additional gas and vapor units (Lehman and Hasegawa 1913). These early investigators distinguished between exposures of animals to particulates and to gases. The chambers required for dust exposures posed difficult problems of generating, distributing, and controlling the dust. (These papers were published by the U.S. Department of Health, Education, and Welfare [1959].)

Other investigators used chambers for dust exposure. In 1918 Mavrogodato used a simple wooden box to expose guinea pigs to coal, shale, flue, and flint dust. A two-bladed electric fan dispersed the material contained in a wooden trough. The concentrations of dust, varying from 27,000 to 45,000 milligrams per cubic meter, were determined by inserting a cotton-plugged tube in the side of the chamber and withdrawing a volume of dusty air (Mavrogodato 1918). Gardner used a box containing animals on trays in the upper portion and a barrel of finely divided granite that was agitated by a paddle wheel in the lower part. To compensate for the variation of dust concentration with location, the animals were placed in different positions each day (Gardner 1930).

In 1929 Sayers et al. designed a 250-cubic foot chamber used at the Pittsburgh Experiment Station of the U.S. Bureau of Mines to expose guinea pigs to static concentrations of halogenated hydrocarbons. Concentrations were established by pouring the desired amount of liquid onto a large, flat surface in the chamber. Distribution was aided by a fan, and air samples were taken at regular intervals throughout the exposure (Sayers et al. 1929). Similar experimental studies continued through the 1930s.

A 1932 handbook on animal experimentation methods in occupational medicine reviewed techniques of animal exposure. Areas discussed included inhalation of dusts, fumes, droplets and fogs, vapors and gases, as well as feeding, skin absorption, and injection (U.S. Department of Health, Education, and Welfare 1959). The DuPont Haskell Laboratory,

the U.S. Bureau of Mines, the U.S. Public Health Service, and the Dow Chemical Company carried out experiments.

Fairhall and Sayers (1940) described a chamber used by the Division of Industrial Hygiene of the U.S. Public Health Service. This box-type chamber had heavy glass fronts fitted against soft rubber gaskets, which could be removed to clean and transfer animals. The dust feed passed through an air elutriator to provide uniform dust dispersion. Air samples of the chamber atmosphere were taken at a rate of one cubic foot per minute (cfm) through filter paper disks mounted on a side wall. The samples could be analyzed chemically and microscopically for concentration, particle size, and composition.

Apparatus and methods for testing toxicity continued to develop. The 1940s produced studies of organic solvents and dusts and witnessed discussions of the principles influencing the design and operation of constant flow chambers for gas and vapor inhalation exposures. Formulas were derived from the data to predict equilibration time for chamber concentration. Effects of airflow, chamber size, the character and quantity of the interior surface, the shape of the chamber, the relative areas of air inlet and door opening, and the number and size of animals influenced chamber concentrations, equilibrium times, surface effects, and animal loadings.

By mid-century a first generation of exposure units for inhalation toxicology studies existed. These chambers still required improvements in distribution of toxicants to the animals, uniform rate of toxicant delivery (particularly dusts), and improved characterization of the toxicant, i.e., the description of the exposure. These developments continued and were necessitated by the investment in the 1950s, 1960s, and 1970s in major inhalation facilities by the Defense Department (Wright Patterson Air Force Base), the Department of Energy (Lovelace Foundation and Battelle Northwest), the U.S. Public Health Service/Environmental Protection Agency (Human Inhalation Facilities at Chapel Hill and Ranchos Los Amigos Hospital in Los Angeles), the National Institutes of Health (NIH), the National Institute of Environmental Health Sciences (NIEHS), and selected private institutions such as the Chemical Industry Institute of Toxicology and the Haskell Laboratories of DuPont.

The large infusion of government funds to support increased regulatory effort in the 1960s and 1970s rapidly advanced the state of the art, which today permits an investigator to expose animal or human subjects

to well-characterized, consistent challenge atmospheres of toxicant gas or particles. Mixed exposures (multiple agents) are still rare and probably represent the next stage of development. Complex mixtures are seldom generated for inhalation toxicology. Studies continue to focus on single, or at most two, toxicants in air. Thus, the scientific foundation for inhalation toxicology has been evolving for most of this century, providing another means to assess risks associated with toxicants, asbestos included.

The Dreessen Study: Setting Guidelines

The first suggested guidelines for asbestos, in the MACs, appeared in 1938 in *Asbestosis in the Asbestos Textile Industry*, a study done by Dreessen and others for the asbestos textile industry in North Carolina that was published by the U.S. Public Health Service (Dreessen et al. 1938). The authors studied the process that produced dust in asbestos textile factories and recommended dust control. They made dust counts with a midget impinger, estimated the dust exposure of each worker, and concluded with the following statement:

> The percentage of persons in different occupational groups who were affected by asbestosis or any of its symptoms varied with the average dust concentration to which they were subjected and with their length of employment. The only cases of asbestosis, three in number, found below 5 million particles per cubic foot were diagnosed as doubtful; well established cases occurred at higher concentrations. It appears from these data that if asbestos dust concentrations in the air breathed are kept below this limit new cases of asbestosis would not appear.
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> . . . Because clear-cut cases of asbestosis were found only in dust concentrations exceeding 5 million particles per cubic foot [mppcf], and because they were not found at lower concentrations, 5 million particles per cubic foot may be regarded tentatively as the threshold value for asbestos dust exposure until better data are available. (Dreessen et al. 1938, 91)

Sampling methodology for airborne fiber concentration utilizing the impinger counted all particles present.

Today the Dreessen study is regarded as a flawed and extremely limited cross-sectional epidemiological investigation. Nevertheless, the Dreessen number for a "safe" level of asbestos in air stood for 30 years and became the basis for the TLV guideline, a guideline that was not

critically appraised until the 1964 meeting of the New York Academy of Science that led to publication of "Biological Effects of Asbestos" and confirmed asbestos as a carcinogen (*Annals of the New York Academy of Sciences* 1965).

The first edition of *Documentation of Threshold Limit Values* contained the following statement:

> The present threshold limit relates to the prevention of asbestosis. It was recommended by Dreessen et al. after a study of 541 employees in three asbestos textile plants using Chrysotile. Only three doubtful cases of pneumoconiosis were found in those exposed to dust concentrations under 5 mppcf, whereas numerous well marked cases were found above 5 mppcf. Counts were from impinger-collected samples in ethyl alcohol and distilled water. Both fibrous and non-fibrous particles were counted, but the latter greatly predominated. While chemical analyses of collected samples of air-borne dust corresponded to those of settled dust samples, it is believed that dust counts of particulates by conventional methods can be expected to give only an indirect measure of the risk of asbestosis because of the great relative importance of long fibers. (American Conference of Governmental Industrial Hygienists 1962, 11–12)

The impinger used in the Dreessen study was developed to measure particles and fibers in air. Because asbestosis was a fibrotic disease, measurements were developed to quantitate the risk of the environment causing fibrotic disease. In the 1960s, however, increasing awareness of the carcinogenic properties of inhaled asbestos led to concern. With new understanding that asbestos forms only fibers in air because of mineral breakage characteristics, measurements began to focus on fibers alone and not on fibers and particles. New measurement techniques were developed, and fibers per cubic centimeter of air were counted rather than fibers and particles. Increased knowledge of which fibers reached the lungs pointed to the need for new ways to measure and evaluate samples. Furthermore, because carcinogens were assumed to have no threshold, the concept of threshold limit value needed reevaluation in the case of asbestos. In 1968 ACGIH proposed reducing the TLV for asbestos from 5 mppcf to 2 mppcf, and in 1972 to 5 fibers per cubic centimeter greater than 5 micrometers (5 f/cc $>$ 5 μm).

The third edition of the *Documentation of Threshold Limit Values* contains a paragraph that is more critical of the Dreessen study and a lengthier description of results relevant to a standard:

> A conference on the biological effects of asbestos in 1965 called attention to the very real probability that the 5 mppcf limit recommended by Dreessen is inadequate to give complete working-lifetime protection against all forms of asbestos. Medical data on which the limits had been based were inadequate; more than half of the asbestos workers studied were under 30 years of age and thus provided an insufficient exposure time for asbestosis to develop. Of the 105 workers exposed to less than 5 mppcf, 82 had worked less than 5 years; 101 less than 10 years; only 4 had more than 10 years' exposure. Seven of 36 workers exposed to 5–9.9 mppcf had asbestosis; 3 of 50 workers exposed to 10–19.9 mppcf for less than 5 years had asbestosis. Moreover, it was a "point-in-time" study; many of the ill were missing and the dead uncounted, hence not considered in the over-all evaluation of the limit. (American Conference of Governmental Industrial Hygienists 1971, 17–19)

Additionally, in the United States the inadequacy of the method of measuring exposure by microscopically counting dust particles and fibers after collection with the midget impinger was becoming apparent. A more sensitive method was required in order to address the fiber content of the airborne particulate matter (Edwards and Lynch 1968). The new methodology of the U.S. Public Health Service in the late 1960s utilized a cellulose acetate membrane filter to collect airborne fibers and dust. Phase contrast microscopy, the technique used to count collected fibers after rendering the membrane filter transparent, was adopted by the U.S. Public Health Service in the late 1960s.

Improved methods for exposure assessment during the 1950s and 1960s developed in tandem with new and better epidemiological methods. Thus, historical-perspective, occupational-cohort studies of the 1950s, 1960s, and 1970s furnished OSHA with 13 epidemiological studies to defend the acceptable risk level associated with the 8-hour, time-weighted average permissible exposure limit of 0.2 f/cc $>$ 5 μm, the federal inhalation standard promulgated in 1986 (U.S. Department of Labor 1986).

In the United Kingdom there was growing appreciation during the 1960s of the need to review the hygienic standard for asbestos. The British Occupational Hygiene Society issued its standard in 1968 (British Occupational Hygiene Society 1968). Permissible dustiness was described in categories that ranged from high to negligible, referring to airborne concentrations of asbestos fibers in air that was expressed as fibers per cubic centimeter of air. Of the several permitted methods for measurement of fiber concentration, the membrane filter technique used in the United

States quickly became the preferred methodology, which meant the results obtained in both countries could now be compared. The U.K. standard was, in reality, a guideline not enforceable by law until the later establishment of the Health Executive, a governmental entity analogous to OSHA in the United States.

Threshold Limit Values

TLVs are based upon analysis of environmental factors as a means to control toxic hazards. The critical assumption in the TLV concept is that there is a level of exposure below which there is no adverse health effect for noncarcinogenic substances. In contrast, we assume a threshold does not exist for a carcinogenic substance. The TLV approach sought to determine the concentration of a material that already caused injury and to set threshold values based on the concentrations measured. Setting threshold values for the working environment was believed to permit control of the environment and to reduce to a minimum the likelihood of injury. However, values must be constantly reviewed. The danger that values would be "frozen" by time and usage and that newer and more accurate data would be ignored became a reality in the case of asbestos. The TLV for asbestos was developed to protect against asbestosis, a fibrosis of the lungs. As the carcinogenic effects of asbestos became known, the TLV proved inadequate to protect for cancer.

Until the passage of the Occupational Safety and Health Act of 1970, the TLVs remained merely recommended guidelines, not enforceable standards. The growing concern in the 1970s about the adequacy of the TLV for asbestos came about partly because researchers were discovering the carcinogenic properties of inhaled asbestos and partly because asbestos use was increasing.

Sampling methodology for airborne asbestos has changed since publication of the Dreessen report in 1938. New instruments have been devised, new measurement techniques have been developed, and inhalation toxicology has been refined. Industrial hygienists no longer count the same types of dust particles, employ the same methods, or ask the same questions. Toxicologists and medical scientists have redefined diseases associated with asbestos. Nevertheless, the TLV based upon the Dreessen study remained on the books for more than 30 years, inade-

quately addressing the need to control asbestos at the lower levels that were linked to carcinogenic effects.

Castleman and Ziem (1988) and Roach and Rappaport (1990) argue that the process of establishing TLVs was flawed, primarily because the TLV committee membership included industry specialists, and that the TLVs were not health based, but rather were feasible with existing control technology. These charges may or may not be true. They do not detract from our hypothesis that measurement of exposure during that period permitted improved control of airborne asbestos in the workplace. Political and economic factors were always present during consideration of asbestos controls.

The Occupational Safety and Health Administration

Under present regulatory procedures in the United States, OSHA's permanent health standards for airborne contaminants require an initial determination of concentrations of the agent in air. The National Institute for Occupational Safety and Health (NIOSH) is the research agency charged under the Occupational Safety and Health Act to recommend standards to OSHA in rule making. OSHA has regulated asbestos since 1971. Until OSHA the only federally mandated exposure standards existed in regulations of the Walsh Healey Public Contracts Act of 1958; in addition, a few states established their own values. Initial promulgation of an OSHA air standard in May 1971 was a 12 f/cc of air PEL. In December 1971, OSHA issued an emergency temporary standard of 5 f/cc and, in June 1972, OSHA promulgated 5 f/cc PEL as a new final standard (Corn and Corn 1984, 191). These limits were intended primarily to protect workers against asbestosis and to offer a limited degree of protection against asbestos-induced forms of cancer based on the no threshold assumption for carcinogens.

In October 1975, OSHA published a proposed rulemaking to revise the asbestos standard because the agency believed that "sufficient medical and scientific evidence had been accumulated to warrant the designation of asbestos as a human carcinogen," and that "advances in monitoring and protective technology made re-examination of the standard desirable" (U.S. Department of Labor 1986). The 1975 proposal was to reduce the PEL to 0.5 f/cc.

The basis for the proposed reduction in PEL to 0.5 f/cc was contemporaneous OSHA policy that assumed no safe threshold level for carcinogens was demonstrable. The Occupational Safety and Health Act required the agency to set the PEL at a level as low as was technologically and economically feasible. (This policy was rejected by the Supreme Court in the Benzene Decision.[1])

In 1976 the PEL was reduced to 2 f/cc, a limit that remained in effect until 1986. It took from 1976 to 1986 to reduce the PEL to 0.2 f/cc. "The 0.2 f/cc, 8-hour limit reduces significant risk from exposure and at that time was considered by OSHA, based upon substantial evidence in the record as a whole, to be the lowest level feasible" (U.S. Department of Labor 1986, 22616–19).

Summary

Approaches to assessing environmental inhalation risk from asbestos have undergone profound change. In addition to social and political changes, a number of factors have come into play:

1. new technologies
2. new measuring instruments
3. new biological data
4. increased utilization of asbestos
5. regulatory imperatives
6. a redefinition of health risks associated with asbestos.

This has occurred over a period of little more than 60 years.

Early air-sampling instruments were developed to measure particles and fibers in air. Because asbestosis was a fibrotic disease, all measurements quantitated fibrotic disease risk in the environment by focusing on fibers and particles. Subsequently, the understanding that asbestos forms only fibers in air refocused measurement on fibers, not fibers and particles. As research clarified which fibers reached the lungs, new ways to sample and evaluate air were required. At the same time, changes in understanding of the disease process created the need for a better way to

[1] Industrial Union Department *v* American Petroleum Institute. 1980. *Federal Register* 51 (119):22612.

measure risk. In the 1960s, acceptance of the knowledge that asbestos causes both cancer (based on the no threshold assumption for carcinogens) and fibrosis raised the question of which fiber sizes should be measured and what the standard should be. The scientific assumption, prevailing both in 1985–86 and today, of a linear nonthreshold dose–response curve for carcinogens was applied to estimates of risk for asbestos exposure in the workplace, which led OSHA to lower the U.S. standard.

In summary, we have attempted to illustrate the close link between state-of-the-art scientific and technical knowledge and policy decisions to control a toxic substance in industrial society. In the best of all possible worlds the science should permit valid estimates of risk and construct measurement techniques that lead to the desired control. If awareness comes early, then the process of policy making should be an iterative one, with incrementally more restrictive control as knowledge of the toxicant improves. The imperative for control of asbestos, as with many other toxic materials, was regulation, not science. That, however, is another story. Regulation of the workplace environment activated use of the science that permits valid estimates of risk and the techniques for measurement and control. The evolving science became part of the debates on control and constantly refocused them. Setting acceptable workplace exposure levels to control inhalation risk from asbestos did not occur on a wide scale until after 1970. After at least 60 years of less than intense development, the American approach to regulating asbestos in the workplace is now based upon explicit techniques published by the government for assessing risks that permit valid risk characterization.

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