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JFW
6-19-84

June 13, 1984

Technical Paper - "Physiological Innocuity of Asbestos in Water"

ACTION REQUIRED: Review for information

The enclosed presentation is forwarded for reference.

Please note that the statement on page 6, paragraph 2, line 13 about "EPA's position on the use of asbestos-cement pipes" is not an accurate representation of EPA policy and should not be quoted as such (see JFW correspondence, U.S. Environmental Protection Agency - Region 4 Letter on Comparative Risks of Water Pipe Materials, June 11, 1982). The authors have been advised accordingly.

If you have any questions, please do not hesitate to call.

JFW/bwm

Enclosure
cc: A. H. Kahn, Esq.

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PHYSIOLOGICAL INNOCUITY OF ASBESTOS

IN WATER

by

M. Cossette
P. Delvaux
T. Van Ha
C. L'Espérance, and
G. Belleville

All at the Société nationale de l'amiante
4125 rue Garlock, Sherbrooke, QC, Canada,
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presented at
the conference

HEALTH THREATENING TOXINS IN WATER

at the

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Brooklyn College of
the City University of New York

on

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BIOGRAPHY

M. Cossette graduated in Chemical Engineering from McGill University in 1960. He has held several positions in the asbestos industry. He has been director of several research organizations at Sherbrooke University. Currently, he has a research appointment in the Faculty of Medicine, and is also director of technological research at Société nationale de l'amiante. He is a member of the New York Academy of Sciences, and a Fellow of the American Society for Testing and Materials.

P. Delvaux has a DSc from Université Catholique de Louvain. He is specilised in chemical engineering and physical chemistry. He is currently Project Manager.

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C. L'Espérance has a BScA in Civil Engineering from Sherbrooke University. She is a specialist in hydraulic binders.

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ABSTRACT

PHYSIOLOGICAL INNOCUITY OF ASBESTOS IN WATER

COSSETTE, M. , Société nationale de l'amiante
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same address.

The various origins of asbestos in water are discussed including atmospheric precipitation, asbestos-cement pipe erosion, cooling tower blowdown, and the erosion of asbestos bearing rocks. The amplitude of the problem is considered based upon a discussion on the fine structure of asbestos, a comparison on number concentrations versus mass fractions, and the difficulties inherent in evaluating waterborne concentrations. The specific problem of septum formation in automatic laundries is touched upon.

The innocuity of asbestos-cement particles is discussed. The physiological effects of waterborne asbestos in experiemental animals are reviewed. Human epidemiology related to ingestion of waterborne asbestos is covered.

What industry is doing to improve the situation, including run off from mines, corrosion resistant asbestos-cement, and improvements in asbestos-cement technology is reported. The development of physiologically innert chrysophosphate fibers is described.

PHYSIOLOGICAL INNOCUITY OF ASBESTOS IN WATER

Respiratory hazards of asbestos:

Asbestos is a fibrous mineral of uparallelled properties. It is used in a multitude of different applications because it can confer superior properties on products (1), such as:

- stability to heat, moisture and microorganisms.
- insulation against noise, heat, and electricity.
- resistance to wear, and to deformation under load or impact.
- improved smoothness, hardness and opacity,
- resistance to chemical attack, leaching, and decay.

However, as early as 1906 Auribault, in France, reported health hazards associated with excessive exposure to asbestos(2). The following year Murray, in England, also reported industrial hygiene problems related to asbestos exposure (3). The following diseases have now been associated with the prolonged respiration of excessive concentrations of airborne asbestos fibers:

- asbestosis
- bronchogenic cancer
- mesothelioma

Accordingly, breathing asbestos at high concentrations for a long time is hazardous. On the other hand, ingesting asbestos in water is harmless.

FINE STRUCTURE OF ASBESTOS:

Some 95% of the asbestos produced i of the chrysotile variety. It is hydrated magnesium silicate composed of double layered sheets. One layer consists of tetrahedral silicon-oxygen groups, and the other layer consists of octahedral magnesium-hydroxyl groups. The silicon and magnesium groups are coordinated in space (Fig.1) and since the latter are larger, the sheets curl (Fig. 2) in one direction to accomodate the bulkier magnesium groups. Crystal growth of the sheet thus leads to a tubular structure that grows into a scroll with 12 to 20 layers (Fig. 3). The fibers also grow in length from one wall of a fissure in the rock to the other wall, in close-packed parallel orientation, thus forming a vein of cross fibers.

The visible fibers are actually bundles of tube-like fibrils and a fiber with a diameter of say 1/100 of an inch might be made up of 3×10^{10} fibrils (3 trillion fibrils). In water, the fibers tend to split into astronomic numbers of fibrils and the media have pounced upon this fact to panic the general public with headlines claiming that the local water supply contains millions of fibers per litre.

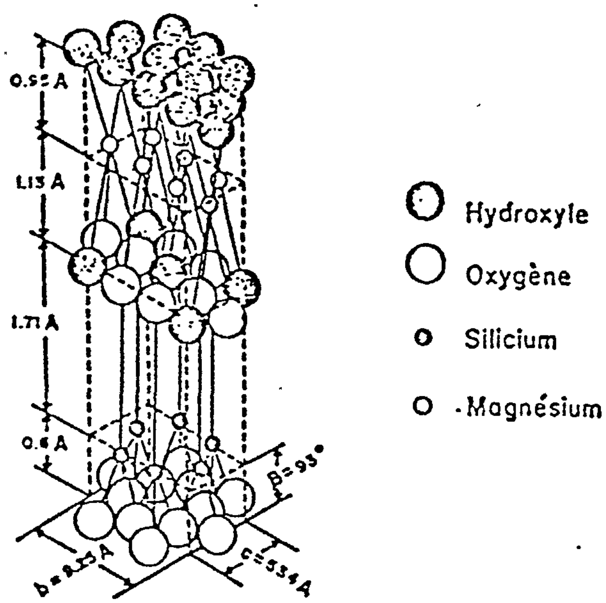


Fig. 1 Unit cell in the crystalline structure of chrysotile (after Cossette, Lemonde and Massey. L'Union Médicale Can <u>100</u> 759 (1971)).

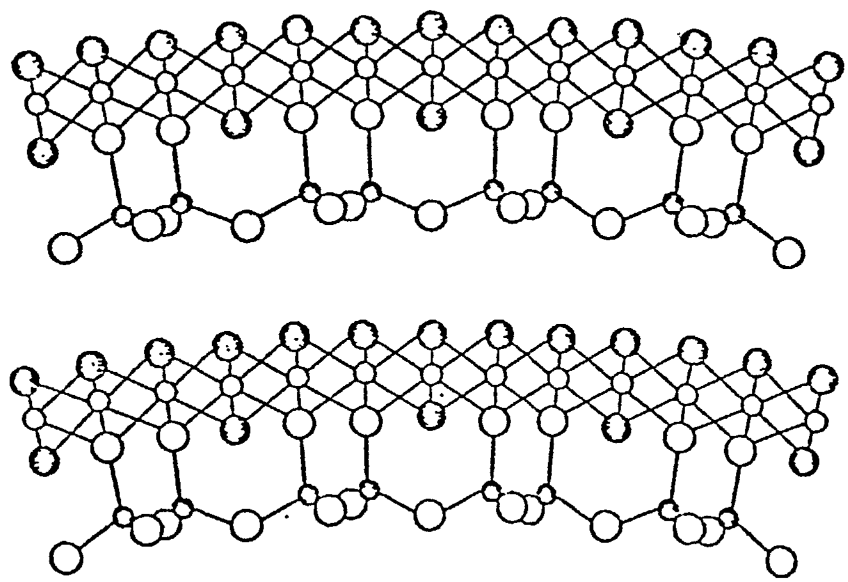


Fig. 2 Simplified chrysotile structure showing the :curvature fo crystal planes (after E. Martinez. Can. Inst. Mining &Metallurgy Trans. Vol. LXIX, p. 414-20 1966).

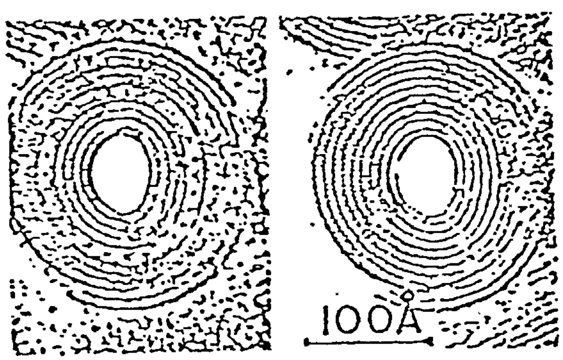


Fig. 3 End view of chrysotile fibers after K. Yada (in Acta Crystallographica, Vol 23 Part 5 p. 704-7, Nov. 1967).

ORIGINS OF THE ASBESTOS FOUND IN WATER

One prolific source of asbestos found in water comes from rain that washed the fibers out of the air. No matter where you go on earth you will find airborne concentrations of asbestos in the order of one hundreth of a fiber per cm^3, or 10,000 fibers/m^3. Drill core samples of ice deposits two million years old, taken during the last international geophysical year, indicate that the quantity of asbestos washed out of the air has remained essentially constant during that time and so we conclude that the industrial asbestos contribution to atmospheric pollution has been insignificant. None the less, all sources of surface water, as opposed to water from wells, contains asbestos (it always has), to which humans are well adapted.

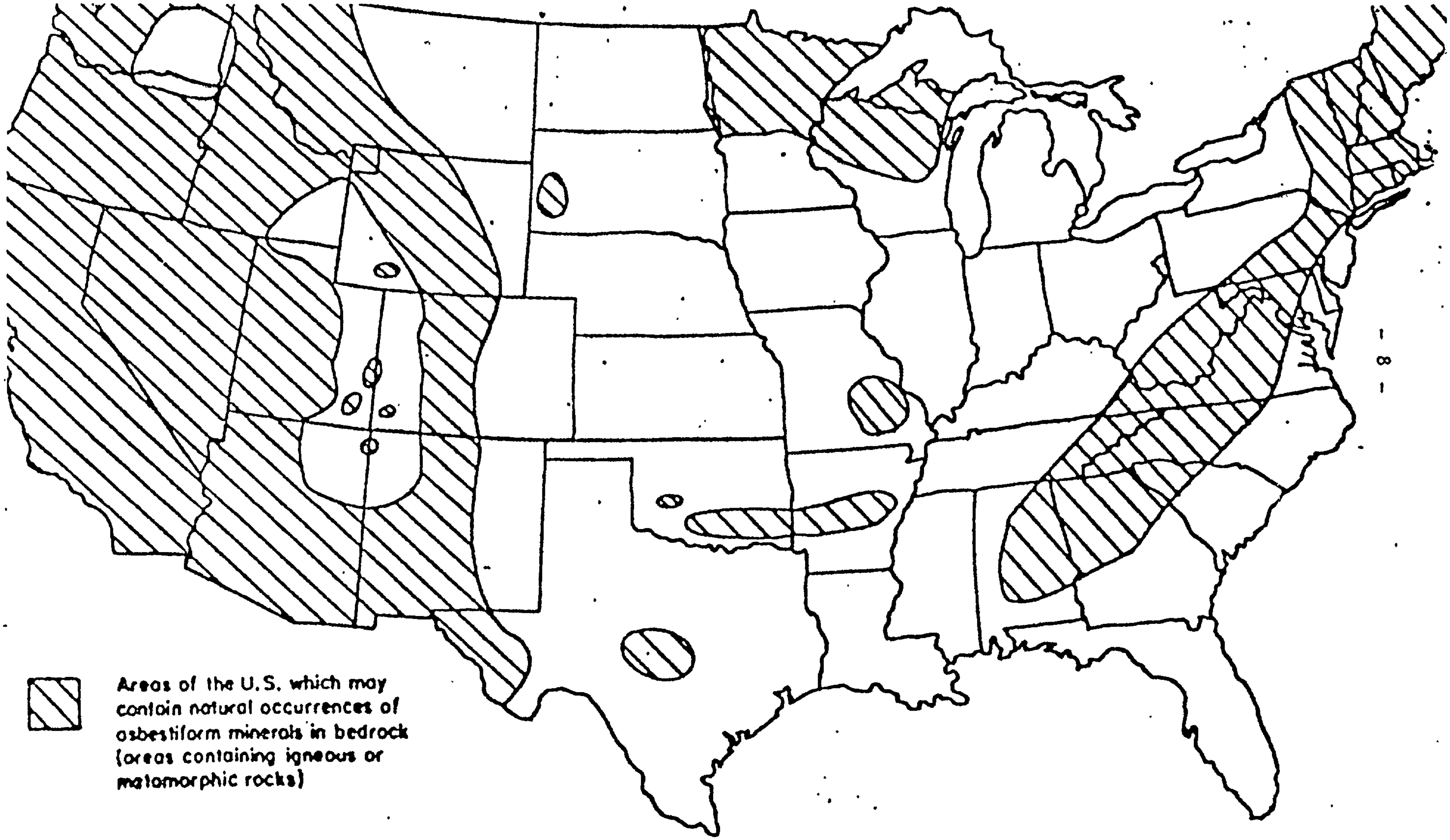
One well documented minor source is the transport of drinking water in asbestos-cement pipes. When these are used to transport acid water, such as swamp water containing tannic and humic acids, if the pH is below 6.5 there may be a gradual leaching of the cement with the consequent release of asbestos fibers in concentrations approaching those found in surface waters. In one notorious case the concentration was high enough to plug the efficient filters in a laundromat. However, asbestos-cement pipes are still the most hygienic pipes for drinking water. The EPA's position on the use of asbestos-cement pipes is as follows (4): "The health risk associated with use of any of the pipe system discussed would indeed be very small. The general order of increasing health risk for non agressive water would be asbestos-cement less than cement lined, less than polyvinyl-chloride, vinyl coated, epoxy coated, other resin base coated, with coal tar coated the greatest."

Cooling towers (of the type used at Three Mile Island) use asbestos-cement heat exchange surfaces and some asbestos may be eroded or corroded and become suspended in the water. This water may be released periodically (under blow-down conditions) after reaching a significant asbestos concentration. However, this blowdown is sent to sewage or to a flowing stream where adequate dilution is ensured.

Possibly the most significant source of waterborne asbestos is erosion of asbestos bearing rocks by water streams (5,6). Surprinsingly, such rocks cover nearly half of the USA (Fig.4). At some US locations, the asbestos concentration reaches 556 million fibers per litre according to Polissar (7,8).

NUMBER VERSUS MASS CONCENTRATIONS

It has been calculated and reported (9) that even very high number counts correspond to mere traces when converted to mass concentrations. For example, 100,000 fibers per litre is approximately one part per trillion. The number concentrations are in use in accordance with the general



GEOGRAPHIC DISTRIBUTION OF IGNEOUS-METAMORPHIC ROCK TERRAINS principle that in the case of particulate hazards, the risk is a function of the number rather than the mass concentration.

Another factor of signal importance is the length of fibrils that make up the visible fibers. The fibrils are much shorter and the vast majority are less than 5μm in length. Although fibers of these dimensions may show in vitro cytotoxic effects, they are not associated with any pathophysiologic effects (9). Reports of pathophysiologic effects with shorter fibers are generally faulted because the specimens used contained significant proportions of longer fibers, or because the specimens used were contaminated with organic reactants. Numerous authors have reported such contamination of the UICC samples to which so much fine scientific effort has been therefore devoted, and the results of which are therefore increasingly questionned.

DETERMINATION OF ASBESTOS IN WATER

Such determinations are fraught with difficulty and experienced analysts are required to obtain reproducible results. The EPA Method (10) calls for the use of a transmission electron microscope capable of selected area diffraction. The sample is filtered through a 0.1μm Nucleopore or 0.22 μm Millipore membrane using volumes of 50 to 500 cm^3 to get a maximum filter loading of 20μg /cm^2. Samples containing excess organic matter must be treated by low temperature ashing and resuspension by mild ultrasonification.

In the case of Millipore filters these are placed on the microscope grid and dissolved by condensation washing. Nucleopore filters are coated with carbon and dissolved in chloroform by means of a Jaffe wick.

With a magnification of 10,000 to 20,000 the fibers are counted till a count of 100 fibers is reached, or till 20 grid squares have been evaluated. The asbestos fibers are discriminated from other particles by morphology and selected area electron diffraction. Results are reported in fibers per litre and in mass per litre.

CARCINOGENIC EFFECTS OF ASBESTOS IN WATER (11)

A U.S. Environmental Protection Agency (EPA) scientist has concluded that "long-term, high-level ingestion of various types of asbestos fibers in more than one animal species failed to produce any definite, reproducible, organ-specific carcinogenic effect." (12) The statement, was made in an article authored by Dr. Lyman W. Condie, Target Organ Toxicology Branch, Toxicoloby and Microbiology Division, Health Effects Research Laboratory, Cincinnati. Ohio.

In the article, "Review of Published Studies of Orally Administered Asbestos," Condie critically examines ingestion studies that have attempted to answer the question of whether or not ingested asbestos is a health hazard. In all, eleven (11) studies are analyzed. The extensive animal feeding experiments conducted by the U.S. National Institute of Environmental Health Sciences (see A/C Advisory, Volume 1, Issue 10) are not reviewed as they were not published at the time.

From the very early study of Bonser and Clayson (1967) to the more recent studies of Hilding, et al. (1981) and Bolton and Davis (1982), Condie assesses the experimental findings and comments on the strengths or weaknesses of each. On the Webster study, the only asbestos feeding study involving primates, Condie cautions, "The five year exposure time appears too short for the carcinogenesis process to occur if the time element of the baboon's reaction to asbestos is similar to that of a human." And on the oft-quoted Gibel et al study involving administration of asbestos filter material to rats, he notes, "... the authors stated that no conclusions could be made from their test results regarding the pathogenesis of the tumors caused by the oral intake of asbestos material." This is because the results are confounded by the presence of several unidentified chemicals in the filter material.

Condie concludes:

The bulk of the experimental evidence indicates that the long term, high-level ingestion exposure to various types of asbestos fibers failed to produce any definite, reproducible organ-specif[illegible] carcinogenic effect. Although comparisons between studies are confounded by different rat strains utilized, by different dose levels or exposure conditions, and by different types of asbestos employed, the vast majority of the asbestos ingestion studies were either negative or equivocal.

These studies also cast some doubt on the hypothesis that peritoneal mesotheliomas and gastrointestinal cancers result from the ingestion of asbestos fibers cleared from the lungs following inhalation exposure.

ANIMAL STUDIES (13)

In 1977, the (U.S.) National Academy of Sciences' Safe Drinking Water Committee (14) provided underlying principles to guide the U.S. Environmental Protection Agency (EPA) when assessing effects of long-term, low dose exposures to carcinogenic substances. The very first principle was, "Effects in animals properly qualified, are applicable to man." The Committee stated, "The premise underlies all of experimental biology and medicine...," and the third principle declared, "The exposure of experimental animals to toxic agents in high doses is a necessary and valid method of discovering possible carcinogenic effects in man."

Animal studies support epidemiologic findings that there is no association between the ingestion of asbestos fibers in drinking water and adverse health effects. Test animals have been fed diets containing substantial portions of asbestos, without inducing related tumors or shortening lifespans.

Smith, W.E., "Asbestos, Talc and Nitrites in Relation to Gastric Cancer," American Industrial Association Journal 34:227-228 (1973). This was a life span experiment in which hamsters were fed abnormally large amounts of asbestos. Dr. Smith concludes:

> In 45 hamsters maintained throughout their lives on diets containing 1% of the chrysotile or amosite varieties of asbestos, we found no gastric carcinomas and no tumors in the gastrointestinal tract except for a neoplasm in the mesentery of the colon. We are unable to relate that lesion to the treatment, since ashing has revealed no asbestos fibers in it.

Webster, I., "The ingestion of Asbestos Fibers," Environmental Health Perspectives, 9:199-202 (1974). Dr. Webster fed baboons heavy doses of crocidolite over considerable periods of time to determine if peritoneal or gastrointestinal cancers could be induced. The report states:

> In none of the many baboons used was there any evidence of a peritoneal tumor or gastrointestinal tumor.

Gross, P. et al., "Ingested Mineral Fibers: Do they Penetrate Tissue and Cause Cancer?" Arch. Environmental Health, 29(6):341-347 (1974).

Twenty-one months of intimate contact of rat GI (gastrointestinal) mucosa with very high concentrations of chrysotile asbestos failed to produce cancer or any other kind of lesion. Short-term and long-term feeding (up to 1-1/2 years) of chrysotile and crocidolite by a second laboratory resulted in no tumor production in the GI tract or mesothelium during the lifetime of the animals.

Bonser, G. M. and Clayson, D.B., "Feeding of Blue Asbestos to Rats," 45th Annual Report of the British Empire's Cancer Campaign, 242 (1976). An experiment was performed to ascertain whether feeding asbestos to rats would induce peritoneal tumors. Sixty-five rats were fed 1,500 milligrams of crocidolite asbestos per kilogram body weight for life. No tumors were observed.

Wagner, J.C. et al., "Animal Experiments with Talcs" Inhaled Particles IV, Pergammon Press, 647-654 (1977). Thirty-two rats were fed 100 milligrams of chrysotile or talc over a five month period. No significant increased incidence in tumors was observed.

Smith, W.E., et al., "Health of Experimental Animals Drinking Water With and Without Amosite Asbestos and Other Mineral Particles," Journal of Environmental Pathology and Toxicology, 3:277-330 (1980). This study is the first and, to date, only experiment in which animals were actually exposed to asbestos fibers via drinking water for their entire lifetimes. Tumor incidence was compared with hamsters that did not consume asbestos. Dr. Smith concludes:

> In the present experiment, no malignant tumors were found in hamsters maintained on drinking water containing 13,000 million amosite fibers per liter.

Hilding, A.C., et al., "Biological Effects of Ingested Amosite Asbestos, Taconite Tailings, Diatomaceous Earth and Lake Superior Water in Rats," Archives of Environmental Health, 36:298-303 (1981). Rats were fed asbestos during their lifetimes and were examined at autopsy. The dose levels for the treated animals were the equivalent of 5.5. billion fibers per liter (low dose group) and 78 billion fibers per liter (high dose group) of drinking water. The investigators conclude:

> The most significant finding in our study was the total absence of gastrointestinal cancer in the animals exposed to the test materials.
>
> Under the conditions of our study, ingested asbestos... had no demonstrable carcinogenic effect on the gastrointestinal tract or on other body tissues of the rat.

Bolton, R.E., Davis J.M.G., and Lamb, D., "The Pathological Effects of Prolonged Asbestos Ingestion in Rats," Environmental Research, 29:134-150 (1982). Animals in three treatment groups were exposed to amosite, crocidolite and chrysotile asbestos in a margarine-based dietary supplement. The dose level resulted in an average weekly consumption of 250 milligrams of asbestos per rat per week. The researchers conclude:

> These studies show no evidence of widespread penetration of, or damage to, the gastrointestinal mucosae of laboratory rats following ingestion of large amounts of asbestos fiber. No primary malignant tumors of the gastrointestinal epithelial tissues were found, and there was no obvious link between the other malignant tumors that developed and the asbestos exposure.

McConnell, E.E., et al., "Chronic Effects of Dietary Exposure to Amosite and Chrysotile Asbestos in Syrian Golden Hamsters," and "Chronic Effects of Dietary Exposure to Amosite and Tremolite in Fischer 344 Rats," Proceedings of the U.S. EPA Summary Workshop of Ingested Asbestos, Environmental Health Perspectives, in press. The National Institute of Environmental Health Sciences sponsored a $6 million study on the effects of ingested asbestos in rats and hamsters. Asbestos was administered at a dosage of 1% of total diet for the entire lifetimes of approximately 10,000 animals. First phase conclusions follow:

> The clinicopathologic results in this study showed that the chronic ingestion of 1% amosite or chrysotile (SR and IR) asbestos in the diet did not adversely effect body weight gain and seemed to enhance survival.

> Under the conditions of the bioassay, amosite asbestos and SR (short range) and IR (intermediate range) chrysotile asbestos were not carcinogenic when ingested by male and female Syrian golden hamsters.

The second phase was considered a definitive study for determining neoplastic and non-neoplastic effects. The agency concludes:

> Under the conditions of this lifetime bioassay, tremolite or amosite asbestos was not toxic, did not affect survival, and was not carcinogenic when ingested at a level of 1% in the diet by male and female F344 rats.

NIEHS officials reported in October, 1982 that the lifespan of rats fed chrysotile and crocidolite asbestos also were not affected by exposure. In-house histopathological reviews also showed no carcinogenic effect. These results will be peer-reviewed and published in 1983. These animal feeding studies are the most extensive ever carried out to assess the possible effects of ingested asbestos fibers.

EPIDEMIOLOGIC STUDIES (15)

To determine whether the swallowing or ingestion of asbestos in drinking water represents a health hazard, statistical or epidemiological studies, in which the medical experience of one group, exposed to a high level of ingested asbestos, is compared to the experience of another group, exposed to a lower level or no ingested asbestos have been reviewed.

Mason, et al in 1974 conducted a study to determine whether fibers present in the drinking water in Duluth, Minnesota produced increased cancer mortality. The study concluded:

> Thus, in Duluth, one would expect a greater excess of cancer in the esophagus and stomach than in the rectum, but this did not occur (16).

In 1976, B.S. Levy of the Minnesota Department of Health continued the investigation made by Mason. Levy was the Acting State Epidemiologist for Minnesota and his co-authors were associated with the University of Minnesota School of Public Health and the Mayo Clinic.

Gastrointestinal cancer incidence data for the cities of Duluth and St.Paul were gathered and compared in the same manner as in the Mason study. (Minneapolis and St. Paul have populations similar to Duluth, but they have few, if any, asbestos fibers in their water supplies). The authors concluded:

> ...there was no consistent pattern of statistically significant differences observed. (17).

The Levy study was updated in 1981 by Eunice Sigurdson, R. N., M.P.H., of the Minnesota Department of Health. She reaffirmed previous findings, stating:

> ... there is currently no observed etiologic or causal association between exposure to amphibole fibers in the Duluth drinking water supply and the development of cancer (18).

In 1976, Thomas R. Fears of the National Cancer Institute published an article addressing the question: "Is there an increase in risk from cancer associated with naturally-occuring asbestos?" The abstract of the study states:

> The study of cancer mortality rates in these matched counties provides no evidence that naturally-occuring asbestos is a great hazard to the general population of counties with asbestos deposits (19).

Donald T. Wigle, M.D., Ph.D. and M.P.H., Bureau of Epidemiology, Health and Welfare, Canada, conducted an extensive study in 1977 of municipalities in the Province of Quebec. These comparison studies presented an unusual scientific opportunity to analyze cancer mortality in populations exposed to as much as 1.3 billion fibers per liter of drinking water. Despite the extremely high levels of asbestos in drinking water, this study concludes:

> A study of twenty-two municipalities in Quebec did not reveal excess cancer mortality that could be related to the presence of asbestos fibers in drinking water supplies (20).

The Wigle study was also updated in 1981 by Toft, Wigle et al. Similar conclusions were made:

> The mortality rates for persons living in two localities in which asbestos was present in high concentrations in water samples from the distribution system were analyzed. Although there are serious limitations to this type of study, no consistent increase of mortality rates for any cancer was demonstrated (21).

Two studies were made in Connecticut concerning the use of asbestos-cement water pipe and the incidence of cancer. The first was co-authored by officials of the U.S. Center for Disease Control, U.S. Environmental Protection Agency (EPA), Yale University School of Medicine and Connecticut Department of Health Services. The Harrington study stated:

> This study detected no changes in incidence rates or patterns in Connecticut for cancers of the stomach, colon, or rectum over the period 1935-1973, that could be construed as related to the introduction around 1950 of asbestos-cement pipes to carry domestic water supplies to some or most of the residents of certain towns (22).

The second study was entitled "Asbestos Cement Pipe and Cancer in Connecticut, 1955-1974." The principal investigator, J. Wister Meighs, M.D., is Director of the Connecticut Cancer Epidemiology Unit and Clinical Professor of Epidemiology, Yale University School of Medicine. The Meigs study used essentially the same methods as those used in the Harrington study, but the procedures and techniques were more sensitive and refined. The study was supported in part by the National Cancer Institute and the U.S. Environmental Protection Agency.

Following are the conclusions of the Meighs study:

> These analyses give no consistent indication that use of asbestos-cement pipe in Connecticut public water supplies has been followed by increases in incidence either of "all cancers" or of the individual sites considered.
>
> Therefore, the lack of coherent evidence of cancer risks from use of asbestos-cement pipe is reassuring. (Emphasis in article). It is consistent with most reports from other areas of the United States (23).

The Kanarek study (24) was conducted in five California counties in the San Francisco Bay Area by Dr. Robert C. Cooper (principal investigator), doctoral candidate Marty Kanarek (project coordinator) and others. The study found a statistical correlation between the ingestion of asbestos in drinking water and certain cancers. The Kanarek study was an indirect study in which census tracts with differing amounts of asbestos fibers in their drinking water were compared for cancer incidence, after attempting to take into account certain variables.

By its own admission, the study is of limited value in its relevance to asbestos-cement pipe:

> Samples were taken before and after passage of water through lengths of asbestos-cement pipe. In most of the districts sampled, there was not a substantial increase in fiber counts after passage through asbestos-cement pipe. The amount of asbestos-cement pipe in the various distribution systems was not included as a variable in the analysis because of difficulty of determining its locations, age and dimensions.
>
> The study design was that of an indirect epidemiological approach in which the observational unit was the census tract. Studies such as this one can only suggest associations, and cannot pinpoint definite causation. (Quotation from doctoral thesis).

The U.S. Environmental Protection Agency (EPA) has stated of the Kanarek study:

> The University of California investigators are among the first to report finding an association between ingested asbestos and cancer rates. They caution that causative inferences must necessarily be limited because of the indirect nature of the data being compared. This means that the results of this study do not prove that there is a link between Bay Area water and cancer (25).

When reanalyzing the statistical associations observed, one of the co-authors (Conforti) stated:

> Although the indirect method of analysis is an inexpensive design for a first look at an epidemiologic hypothesis, the underlying assumptions of the method make definitive conclusions untenable.
>
> These findings in no way lend themselves to the interpretation regarding the possible regulation of asbestos in drinking water. Only research of the direct method design would allow for such conclusions (26).

In 1982, the U.S. Environmental Protection Agency reported findings of an epidemiologic study of asbestos-cement water pipe use and gastrointestinal cancers in Escambia County, Florida. Asbestos levels ranged from 700,000 to 32.7 million fibers per liter for a period of approximately twenty-five years. Agency scientists concluded:

> These results of the analyses in this study do not show any statistical association between the deaths due to certain cancer types and the use of asbestos-cement pipe in Escambia County, Florida (27).

In August, 1982, Dr Lincoln Polissar of the Fred Hutchinson Cancer Research Center published an important study on asbestos in drinking water, cancer incidence and cancer mortality in Washington State. This research was also funded by the U.S. Environmental Protection Agency. Naturally-occurring asbestos levels in this study ranged from 37 million to 556 million fibers per liter of drinking water. The population has been exposed to such levels for over fifty years. The author concluded:

> Results of this study and prior studies of cancer in relation to waterborne asbestos are inconsistent and provide little evidence that asbestos in community water supplies has altered the risk of any cancer. (7).

A case-control, interview-based study also was conducted on this same population group. Such studies seek to determine whether persons with a given disease are more apt to have been exposed to the agent under investigation (asbestos) than disease-free individuals. The principal investigator, again Dr. Lincoln Polissar, reported:

> We found no convincing evidence for increased cancer risk from imbibed asbestos (8).

This is the most sophisticated epidemiologic study ever conducted on the question of the potential health effects of ingested asbestos.

WHAT INDUSTRY IS DOING TO IMPROVE THE SITUATION:

At the asbestos mine and mill sites, industry is wetting the mine tailings primarily to prevent air pollution but this also leads to the formation of a thick erosion resistant crust at the dump surface. This is effective in preventing surface run-off during heavy rainfalls. Increasingly, covering of vegetation is used despite the difficulties of growing anything in sterile mine tailings.

Regarding asbestos-cement pipes, research is going on aimed at increasing the corrosion resistance of the asbestos-cement. It has been found by Delvaux, et al (28) that since corrosion of asbestos-cement is governed by the law of diffusion, accordingly control of the pore size distribution can go a long way toward moderating the corrosion under moderate pH conditions. For other asbestos-cement products exposed to aggresive waters such as asbestos-cement canal bulkheads used for seawalls in salt or brakish waters, effective durable coatings of clhorinated rubber are being developped.

CHEMICALLY PASSIVATED FIBERS

The chemical passivation of fibers is a most promision development. In 1966 Kogan et al (2) published epidemiological studies on two cohorts of workers exposed to asbestos-cement dust in the absence of raw asbestos. This leads to the conclusion that the asbestos released from the asbestos-cement was inoccuous. J.A. LePoutre subsequently noticed a similar phenomenon at a large Belgian asbestos-cement plant. In 1978 Wehner et al (30) published a study on rats exposed only to asbestos-cement dust that confirmed the experience with humans.

In 1980, Deruyterre et al (31) showed thas asbestos emitted from asbestos-cement had calcium atoms scattered at the surface and it was postulated that this might explain the passivity of such fibers. At the same conference Dunnigan et al (32) presented results on fibers produced from chrysotile by phosphorylation with $POCl_3$ that indicated excellent physiological passivation. Subsequent publications by Marshall et al(33) on the surface alteration of asbestos, Flowers (34) on metal micelle coated fibers, and Dunnigan (35)on silane coated chrysotile, all reported varying degrees of passivation obtained by chemical reactions with the fiber surface.

Eventually, Lalancette et al developped the phosphorylation process to take advantage of a gas phase reactant that can penetrate the interstices between the fibrils in a fiber bundle (37,38) to modify every single fibril. The product was dubbed chrysophosphate fibers. The process consists merely of adsorbing the $POCl_3$vapor onto the chrysotile, heating the resulting material to form pyrophosphate groups at the fiber surfaces, and ventilating the product to remove the byproduct hydrogen clhoride from the chrysophosphate fibers.

CONCLUSION

Asbestos in water comes mainly from natural sources. Number concentrations of waterborne asbestos may be astronomically high without corresponding to significant mass concentrations. The quantitative determination of asbestos in water is difficult and

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