1 μm in diameter and ranged from several micrometers to 20 μm in length.

The "clustering" of mesothelioma within certain families in Karain and Tuzköy has been noted, but genealogical surveys indicate that blood relationship was not a factor (*3, 4*). On the other hand, if such families live in close proximity to a small asbestos outcropping, in effect a point source, or are otherwise exposed to environmental asbestos, they might jointly be at greater risk to asbestos disease. As in Karain, quarried rock, building stone, and other environmental samples were also taken in the two nearby villages (Karlik and Yezilöz) where no mesothelioma has been reported. No asbestos was found in specimens obtained from these villages. In Tuzköy (with mesothelioma) samples of the whitewash ore used extensively by the villagers as material for whitewashing were examined. One of these was essentially a tremolitic talc with high aspect ratios, 10:1 or more, and most tremolite fibers had diameters of 1 μm or less. Tremolite fibers were also observed in settled dust samples from Tuzköy. The dimensions of these fibers were very similar to those of the tremolite fibers in the whitewash material. In lung tissue specimens obtained from patients in this village with pleural disease, fibrous zeolite predominated in the lung burden but tremolite fibers were also found.

Pleural mesothelioma has recently been diagnosed in a third Cappadocian village, Sarihidir (*4, 11*). Cases of calcified pleural plaques and chronic fibrosing pleuritis in this village have been described in (*2*). Samples of street dust collected in Sarihidir contained as much as 5 percent chrysotile and tremolite, by weight. In addition, palygorskite and erionite fibers were also present.

The Cappadocian villages where cases of mesothelioma have been reported have not been known before to be the sites of asbestos-containing rocks. The absence of reports of such rocks in these villages may be due to several factors: (i) compared with asbestos deposits elsewhere in Turkey (and worldwide), the Cappadocia asbestos outcroppings are much smaller and less obvious; (ii) several geological factors mitigated against their occurrence and thus their discovery in Cappadocia; and (iii) the small numbers of asbestiform fibers in a matrix of zeolite fibers were lost to observation.

Our findings are consistent with the relationship established in other circumstances between asbestos exposure and pleural disease. However, animal experiments have shown that erionite alone is capable of producing tumors (*13*). Whether an enhanced tumorigenic effect may exist as a result of exposure to both asbestos and erionite or possibly other durable fibers is presently unknown and warrants investigation.

A. N. ROHL, A. M. LANGER
Environmental Sciences Laboratory, Mount Sinai School of Medicine, New York 10029

G. MONCURE*
Department of Geology, University of Wyoming, Laramie 82071

I. J. SELIKOFF, A. FISCHBEIN
Environmental Sciences Laboratory, Mount Sinai School of Medicine

References and Notes

1. J. C. Wagner, C. A. Sleggs, P. Marchand, *Br. J. Ind. Med.* **17**, 260 (1960), M. L. Newhouse and H. Thompson, *ibid.* **22**, 261 (1965); I. J. Selikoff, J. Churg, E. C. Hammond, *J. Am. Med. Assoc.* **188**, 22 (1964); J. C. Cochrane and I. Webster, *S. Afr. Med. J.* **54**, 279 (1978).
2. M. Artvinli and Y. I. Baris, *J. Natl. Cancer Inst.* **63**, 17 (1979).
3. Y. I. Baris, M. Artvinli, A. A. Sahin, *Ann. N.Y. Acad. Sci.* **330**, 423 (1979).
4. ———, T. Savas, M. L. Erkan, *Rev. Fr. Mal. Respir.* **7**, 687 (1979).
5. The possible relationship between a high incidence of pleural disease and exposure to mineral fiber in Cappadocia has bearing on a troubling public health question that has been unresolved for nearly a decade. With the definition of significant hazards associated with exposure to asbestos and a concomitant search for substitutes, concern has been expressed that replacement fibers might have a similar biological potential. This concern was heightened with the publication of the hypothesis of Stanton *et al.* (*6*), based on experimental data, that the carcinogenicity of inorganic fibers depends more on their size and shape than on their crystal structure, surface character, or chemical composition. The finding that intrapleural implantation into animals of fibrous materials of diverse types and size distributions produced malignant tumors was attributed to fiber shape and a narrow size range of fibers; the "simplest incriminating feature for both carcinogenesis and fibrogenesis seems to be a durable fibrous shape, perhaps in a narrow size range" (*6*). Stanton observed that long, thin (that is, on a micrometer scale) fibers produced proportionally more mesotheliomas when implanted in the chest of the rat. The experiments of F. Pott and K. H. Friedrichs [*Naturwissenschaften* **59**, 318 (1972)] and F. Pott, F. Huth, and K. H. Friedrichs [*Environ. Health Perspect.* **9**, 313 (1974)] also suggested that the carcinogenic (mesothelioma) potency of a mineral depended upon shape factors, fibrous forms tending to be more carcinogenic than their nonfibrous counterparts. These observations were limited to animal studies. Adequate data on human experience with fibers other than asbestos were not available, and asbestos remained the only fiber known to produce mesothelioma in man.
6. M. F. Stanton *et al.*, *J. Natl. Cancer Inst.* **58**, 587 (1977).
7. A. M. Langer, I. B. Rubin, I. J. Selikoff, F. D. Pooley, *J. Histochem. Cytochem.* **20**, 735 (1972); M. J. Smith and B. Naylor, *Am. J. Clin. Pathol.* **58**, 250 (1972).
8. G. Ataman, *C.R. Acad. Sci.* **287**, 207 (1978).
9. F. D. Pooley, in *Dusts and Disease: Proceedings of Conference on Occupational Exposures to Fibrous and Particulate Dust and Their Extension into the Environment*, R. Lemon and J. M. Dement, Eds. (Pathotox, Park Forest South, Ill., 1979), p. 41.
10. F. A. Mumpton, unpublished report of a reconnaissance study of the association of zeolites with mesothelioma cancer occurrences in central Turkey (March 1979).
11. Y. I. Baris, personal communication.
12. ———, A. A. Sahin, M. Ozemi, I. Kerse, E. Ozen, B. Kolacan, M. Altinors, A. Goktepeli, *Thorax* **33**, 181 (1978).
13. Y. Suzuki, A. N. Rohl, A. M. Langer, I. J. Selikoff, *Fed. Proc. Fed. Am. Soc. Exp. Biol.* **39** (Abstr.), 3 (1980).
14. We are particularly grateful to Y. I. Baris, Department of Chest Diseases, School of Medicine, Hacettepe University, Ankara, for his generous assistance in reviewing clinical evidence and in obtaining environmental and tissue samples. We thank the staff of the Thoracic Medicine Department of the Karolinska Hospital, Stockholm, Sweden, for providing tissue specimens. We thank G. Boman and V. Schubert for providing clinical information about some of the patients from whom tissue specimens were obtained for analysis in this report. We also particularly thank R. Lilis for her many valuable clinical observations. This study was supported by grant ES 00928 from the National Institute of Environmental Health Sciences. We gratefully acknowledge assistance from the Mobil Foundation.

* Present address: Conoco, Inc., Ponca City, Okla. 74603.

28 July 1981; revised 9 November 1981

Accumulation of Airborne Polychlorinated Biphenyls in Foliage

Abstract. *Plant foliage accumulates the vapor of polychlorinated biphenyls (PCB's) from the atmosphere, and there is a variation in the amount that is accumulated from one plant species to another. This differential accumulation factor between species remains constant over more than two orders of magnitude of PCB concentrations in plants. The relationships between foliar and atmospheric PCB concentrations hold promise for cost-effective atmospheric PCB monitoring through foliar analyses.*

Polychlorinated biphenyls (PCB's) have become a component of our atmosphere. Reports on the atmospheric transport of PCB's over the North Atlantic, the Gulf of Mexico, and the North Pacific Ocean indicate that these compounds remain airborne over long distances (*1*). There is growing evidence that atmospheric transport is the primary mode of global distribution of PCB's from sites of use and disposal (*2*). Airborne PCB's are often associated with suspended particulates in urban areas, but over rural areas of North America more than 99 percent of the atmospheric PCB's are in the vapor phase (*3*).

The estimated domestic production of PCB's in North America between 1930 and 1975 was 570×10^6 kg, and an additional 1.4×10^6 kg was imported. Further manufacture in the United States was banned in 1979. The PCB's were used primarily as coolant-dielectric fluids in transformers and capacitors; as plasticizers in coatings, adhesives, and printing and copy papers; and as addi-

0036-8075/82/0430-0520$01.00/0

tives in industrial fluids for hydraulic systems, turbines, and vacuum pumps. They were also used in smaller quantities for other specialized uses (*4*). As of 1975, about 340 × 10^6 kg were still in service, some of which could continue for another 20 years. Of the remainder, 25 × 10^6 kg probably degraded or were incinerated, 130 × 10^6 kg went into landfills and dumps, and approximately 70 × 10^6 kg are circulating in the environment. The dynamic PCB burden in the atmosphere over the United States is conservatively estimated at 18,000 kg (*3*). Although the apparent major sources of airborne PCB's, from the vaporization of plasticizers and from open and burning dumps (*5*), decreased substantially during the 1970's, the drop in the atmospheric concentrations of PCB's has been slow.

Leaves of terrestrial plants accumulate airborne PCB's (*6*). In areas where the lowest levels of foliar contamination by PCB's are found and where no horizontal gradient in the foliar PCB concentration is apparent, the assumed source is the "background" level of vapor-phase PCB's in the atmosphere. Both PCB's and polybrominated biphenyls in soil contaminate plant roots but cause little contamination of leaves and stems. Those PCB's that are found in leaves and stems are carried by vapor transport from the soil rather than by translocation through the plant (*7*). Our current translocation studies with corn and goldenrod plants show that less than 1 percent of the ^{14}C-labeled Aroclor 1242 entering the roots is translocated to aboveground portions of these plants over an entire growing season. To detect such low concentrations, special care is required to contain the volatile ^{14}C-labeled PCB's within the soil so as to prevent foliar contamination by atmospheric transport.

Background levels of foliar PCB's in Washington County and Saratoga County, New York, were defined by field studies, as were gradients in the foliar PCB content around known sources. Standard procedures were used to collect, prepare, and analyze leaf samples. Field samples were placed in plastic bags (free of PCB's), frozen in coolers containing Dry Ice, freeze-dried, ground, and stored in glass bottles. Ground tissues were extracted with petroleum ether, concentrated, passed through Florisil columns, concentrated to measured volume, and analyzed by gas chromatography with an electron-capture detector. Although both Aroclors 1242 and 1254 were detected and measured, only total PCB's are reported here since the quantities of Aroclor 1254 (< 20 percent of the total) were too variable.

Table 1. Reproducibility of field data for the PCB content in foliage. Concentrations are expressed in micrograms of total PCB's per gram (dry weight) of samples as described in the text. The percent S.D. for all samples is ± 13.6.

Species (replications)	Mean ± S.D.	% S.D.
Red clover (5)	0.12 ± 0.01	± 8.3
Red clover (5)	0.18 ± 0.04	± 22
Goldenrod (7)	0.25 ± 0.02	± 8.0
Field corn (5)	0.21 ± 0.03	± 14
Field corn (5)	0.32 ± 0.03	± 9.3
Staghorn sumac (5)	11.3 ± 3.4	± 30
Staghorn sumac (5)	12.6 ± 0.6	± 4.8

Table 2. Background levels of PCB's in leaves from Washington County and Saratoga County, New York, collected in mid-September 1979. Concentrations are expressed in micrograms of total PCB's per gram (dry weight).

Species (number of sites)	Mean ± S.D.	% S.D.
White pine (6)	0.032 ± 0.007	± 22
Field corn (6)	0.088 ± 0.015	± 17
Trembling aspen (8)	0.088 ± 0.012	± 14
Staghorn sumac (10)	0.110 ± 0.014	± 13
Goldenrod (15)	0.250 ± 0.030	± 12

Data for six species were reported. Leaves only were sampled from goldenrod (*Solidago graminifolia* L. Salisb.), white pine (*Pinus strobus* L.), and field corn (*Zea mays* L.) (leaf blade only above the upper ear). Leaflets were sampled from staghorn sumac (*Rhus typhina* L.). Leaves with their petioles attached were sampled from trembling aspen (*Populus tremuloides* Michx.). Samples of red clover (*Trifolium pratense* L.) included leaves, stems, and flowers. Much lower concentrations of PCB's are present in petioles, stems, and flowers than in leaves.

The PCB concentrations for field samples plus analytical errors for four species (Table 1) range from 0.12 to 12.6 μg per gram of sample (dry weight). All replications were made at the same site at the same time. The percent standard deviation (S.D.) for all replicated samples combined is ± 13.6, which indicates that over 95 percent of the data are within ± 35 percent of the mean. This value of 35 percent was used as one of two criteria for locating areas that could be used for background levels of foliar PCB's.

Areas with apparent background levels of foliar PCB's were selected arbitrarily at first from available field data and then refined somewhat through the use of two criteria: (i) that sampling of multiple species occurred at the site and (ii) that none of the species exceeded its previously estimated mean background level by more than 35 percent. Apparent foliar PCB background levels were found to be species-dependent (Table 2), with some species accumulating severalfold more PCB's in their leaves than others. Therefore, foliar PCB data from a single site may be highly variable, depending upon the species present. A tenfold concentration difference has been found in the foliar PCB content among 18 species studied to date, with apparent background levels of foliar PCB's (in micrograms per gram or parts per million) ranging from 0.03 for *Pinus strobus* to 0.32 for *Solidago nemoralis* Ait.

The PCB content in foliage is much higher than background levels in the environs of exposed PCB dumps where vapor-phase PCB's from the dumps are added to the background concentrations. Most of our studies were conducted around such sources. One area, east of a former PCB dumpsite, was sampled extensively because a narrow, steep drainage ravine protected it from the erosion

Table 3. Differential accumulation of PCB's in aspen, sumac, and goldenrod over a concentration range exceeding two orders of magnitude. The PCB concentrations [PCB] are expressed in micrograms per gram (dry weight) and as multiples of the background level (MBL values) for each species. These MBL values were obtained by dividing the PCB content by the background PCB content shown in Table 2, 0.09 for aspen, 0.11 for sumac, and 0.25 for goldenrod. Samples were collected in mid-September 1979 at various distances (< 1200 m) and directions from the Patterson Road PCB dump, Fort Miller, New York. All sites were beyond a natural drainage ravine that prevented PCB contamination of soil and water.

Site	Value	Aspen	Sumac	Goldenrod	Mean ± S.D.	% S.D.
1	[PCB]	0.10	0.11	0.26	0.16 ± 0.09	± 57
1	MBL	1.11	1.00	1.04	1.05 ± 0.06	± 5.7
2	[PCB]	1.20	1.30	3.50	2.00 ± 1.30	± 65
2	MBL	13.3	11.8	14.0	13.0 ± 1.1	± 8.6
3	[PCB]	1.32	2.05	4.45	2.61 ± 1.64	± 62
3	MBL	14.6	18.6	17.8	17.0 ± 2.1	± 13
4	[PCB]		19.1	56.5		
4	MBL		174	226		
5	[PCB]	58.2	68.6	182	103 ± 69	± 67
5	MBL	647	624	728	666 ± 55	± 8.2

and runoff from the dump while the established growth of weeds and brush over the inactive dumpsite eliminated any visible airborne transport of dusts laden with PCB's. Downwind from the dump, the odor of PCB's was always apparent during the growing season. Within this area (and others where dusts contaminated with PCB's were not apparent), the differential in the foliar accumulation of PCB's persisted among the species studied. In some instances, the quantitative increases exceeded two orders of magnitude (Table 3). These data show that a site may be classified for the accumulation of PCB's in terms of multiples of the background level (MBL) values. The MBL values for a site are characteristically more uniform than values of the foliar content of PCB's. The S.D. for MBL values at a site are below ± 25 percent.

These results led to the establishment of field plots along an easterly transect, with each plot containing the major forage crop species of the area and one or more continuous PCB air monitors. Preliminary data from the tested forage crops indicate that there is more than a hundredfold range of PCB accumulations in harvested portions of various crops. It is expected that these studies will provide guidelines for the selection of forage crops to keep them within the federal limit for PCB's of 0.2 part per million (*8*) in areas where atmospheric PCB concentrations are elevated. Although this research is being done to predict contamination of vegetation from various sources of vapor-phase PCB's, perhaps of broader significance is the potential use of PCB measurements of vegetation to monitor annual changes in atmospheric PCB's.

EDWARD H. BUCKLEY
Boyce Thompson Institute at Cornell University, Ithaca, New York 14853

References and Notes

1. T. F. Bidleman and C. E. Olney, *Science* **183**, 516 (1974); G. R. Harvey and W. G. Steinhauer, *Atmos. Environ.* **8**, 777 (1980); C. S. Giam, E. Atlas, H. S. Chan, G. S. Neff, *ibid.* **14**, 65 (1980); E. Atlas and C. S. Giam, *Science* **211**, 163 (1981).
2. R. W. Risebrough, B. W. deLappe, W. Walker II, in *Marine Pollutant Transfer*, H. L. Windom and R. A. Duce, Eds. (Lexington, Lexington, Mass., 1976), pp. 261–321; B. Fuller, J. Gordon, M. Kornreich, *Environmental Protection Agency Report EPA-450/3-77-045* (Mitre Corporation, McLean, Va., 1977), pp. 5-1 to 5-14; S. J. Eisenreich, B. B. Looney, J. D. Thornton, *Environ. Sci. Technol.* **15**, 30 (1981).
3. *Polychlorinated Biphenyls* (National Academy of Sciences, Washington, D.C., 1979), pp. 11–25.
4. O. Hutzinger, S. Safe, V. Zitko, *The Chemistry of PCB's* (CRC Press, Cleveland, 1974), pp. 7–9.
5. I. C. T. Nisbet and A. F. Sarofim, *Environ. Res.* **5**, 273 (1972).
6. M. L. Beall, Jr., and R. G. Nash, *Agron. J.* **63**, 460 (1971); G. F. Fries and G. S. Marrow, paper presented at the 175th national meeting of the American Chemical Society, Anaheim, Calif., 13–17 March 1978; W. Klein and I. Weisgerber, *Environ. Qual. Saf.* **5**, 237 (1976).
7. Y. Iwata, F. A. Gunther, W. E. Westlake, *Bull. Environ. Contam. Toxicol.* **11**, 523 (1974); V. Wallnöfer and M. Königer, *Nachrichtenbl. Dtsch. Pflanzenschutzdienstes (Braunschweig)* **26**, 54 (1974); Y. Iwata and F. A. Gunther, *Arch. Environ. Contam. Toxicol.* **4**, 44 (1976); L. W. Jacobs, S. F. Chou, J. M. Tiedje, *J. Agric. Food Chem.* **24**, 1198 (1976); M. Suzuki, N. Aizawa, G. Okano, T. Takahashi, *Arch. Environ. Contam. Toxicol.* **5**, 343 (1977); P. N. Moza, I. Scheunert, W. Klein, F. Korte, *Chemosphere* **6**, 373 (1979); J. B. Weber and E. Mrozek, Jr., *Bull. Environ. Contam. Toxicol.* **23**, 412 (1979); G. F. Fries and G. S. Marrow, *J. Agric. Food Chem.* **29**, 757 (1981); H. J. Strek, J. B. Weber, P. J. Shea, E. Mrozek, Jr., M. R. Overcash, *ibid.*, p. 288.
8. *Fed. Regist.* **44**, 38339 (1979).
9. Supported in part by New York Department of Environmental Conservation (NYDEC) contract C-143563. The analyses of PCB's were carried out by Raltech Scientific Services, Inc., Madison, Wis., under NYDEC contract 144633, with external quality control and standardization provided by J. Daly, New York Department of Health.

8 May 1981; revised 11 January 1982

Expression of *Treponema pallidum* Antigens in *Escherichia coli*

Abstract. Treponema pallidum *DNA was cloned in a bacteriophage. Clones were screened for expression of* Treponema pallidum *antigens by an in situ radioimmunoassay on nitrocellulose, with the use of subsequent reactions with syphilitic serum and radioiodinated* Staphylococcus aureus *protein A. One clone, which gave a strong signal, codes for at least seven antigens that react specifically with human antibodies to* Treponema pallidum.

Syphilis continues to cause significant morbidity throughout the world despite the availability of penicillin. Yet the failure to culture the organism, in or on artificial media, has placed a severe restriction on the study of *Treponema pallidum*. The organism can be propagated in the rabbit testis, but purification of *T. pallidum* in its motile, virulent form has not yet been achieved. Thus, purified treponemal antigens are not available for experimental studies in biology, pathogenesis, serodiagnosis, and immunity.

Recombinant DNA technology offers the potential for producing substantial quantities of specific purified treponemal antigens. We report here the cloning and direct expression of *T. pallidum* DNA in *Escherichia coli*.

DNA extracted from relatively purified, motile, virulent *T. pallidum* grown in rabbit testicles (*1*) was partially digest-

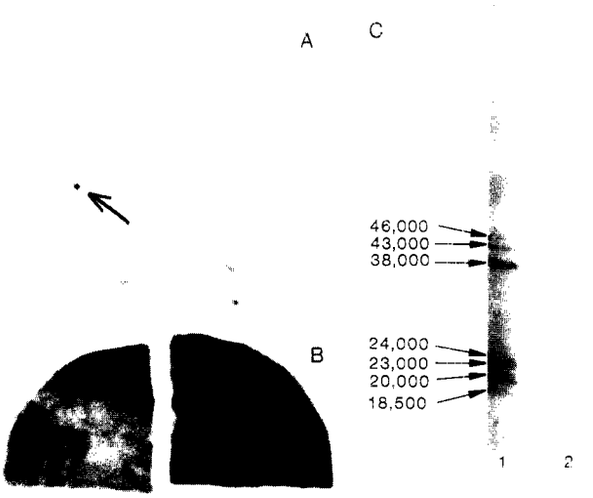

Fig. 1. (A) Autoradiogram of the primary screening of the *T. pallidum* gene bank. About 150 plaque-forming units of in vitro packaged recombinant Charon 30 were plated on a 150-mm petri dish of NZC agar with *E. coli* K802 (*3*). The soft top agar was made with agarose for greater strength. The plate was incubated and the grown phage was blotted to nitrocellulose. The blot was immunologically screened with human secondary syphilitic serum and ^{125}I-labeled protein A, and exposed to Kodak XAR-5. The plaque giving the strongest signal (arrow) was designated as clone Tp3a. (B) Serological specificity of Tp3a. Clone Tp3a was grown as almost confluent plaques and blotted onto a filter that was cut into quadrants. The upper quadrants were assayed with the serums from two patients with secondary syphilis, the lower quadrants with two serums from normal humans. (C) Molecular weight determination of *T. pallidum*–specific antigens expressed by Tp3a. Equivalent amounts of top agar containing plaques of Tp3a and Charon 30 were made up to final sample buffer concentrations of SDS and β-mercaptoethanol and boiled (*4*). The samples were placed on the gel in lanes 1 and 2, respectively, of a gradient (8 to 20 percent) polyacrylamide–SDS gel. After electrophoresis and transfer to nitrocellulose, the preparation was screened with the syphilitic serum used in the primary screening. The molecular weights were determined by comparison to ^{125}I-labeled standards ranging from 94,000 to 14,400 daltons (Pharmacia).

0036-8075/82/0430-0522S01.00/0