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Feasibility of Developing Source Sampling Methods for Asbestos Emissions

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W. M. Henry, G. M. Sverdrup, E. W. Schmidt and
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16. ABSTRACT

The objective of this program was to determine the feasibility of developing methods for sampling asbestos in the emissions of major asbestos sources: (1) ore production and taconite production, (2) asbestos-cement production, (3) asbestos felt and paper production, and (4) the production of asbestos-containing friction materials. Potential sampling methods must provide samples compatible with the provisional analysis methods using electron microscopy (U.S. EPA Report No. 600/2-77-178).

Two general criteria for source sampling methods were identified as: (1) the sampling method must be capable of collecting a representative sample and (2) the asbestos emissions must be collected in such a manner that they can be analyzed by the provisional analytical method. Concurrent investigations of potential emissions in the industries and of current knowledge of sampling fibers were undertaken to assess the feasibility of meeting the first criterion. The industry survey revealed that asbestos emissions can be divided into two classes: stack and fugitive. With respect to the second criterion, it is not feasible to undertake a methods development program for strict compatibility with the recommended procedure of the provisisional analytical method. However, methods development programs are feasible if the sampling method is to be compatible with the alternative procedures of the provisional method or general electron microscopy.

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by

W.M. Henry, G.M. Sverdrup, E.W. Schmidt, and S.E. Miller
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Contract No. 68-02-3169
Work Assignment 10

Project Officer

Kenneth T. Knapp
Stationary Source Emissions Research Branch
Environmental Sciences Research Laboratory
Research Triangle Park, North Carolina 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

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ABSTRACT

The objective of this program is to determine the feasibility of developing methods for sampling asbestos in the emissions of major asbestos sources. The sources of concern are: (1) ore production including asbestos mining and milling and taconite production, (2) asbestos-cement production, (3) asbestos felt and paper production, and (4) the production of asbestos-containing friction materials. Potential sampling methods must provide samples compatible with the provisional analysis methods using electron microscopy (U.S. EPA Report No. 600/2-77-178).

Two general criteria for source sampling methods were identified at the onset of the program. These criteria are: (1) the sampling method must be capable of collecting a representative asbestos size distribution from the local environment, and (2) the asbestos emissions must be collected in such a manner that they can be analyzed by the provisional analytical method to provide the required determinations.

Concurrent investigations of potential emissions in the industries and of current knowledge of sampling fibers were undertaken to assess the feasibility of meeting the first criterion. The industry survey revealed that asbestos emissions can be divided into two classes: stack and fugitive. Inherent differences between stack and fugitive emission environments may necessitate the development of two techniques or at least two modifications of a general technique for sampling. A development program for sampling methods is feasible given the nature of the emissions and potential sampling environments observed in the industry survey.

With respect to the second criterion, it is not feasible to undertake a methods development program for strict compatibility with the recommended procedure of the provisional analytical method. Strict compatibility requires the collection of a uniform deposit of proper loading by air filtration onto a 0.4 μm pore size polycarbonate filter. However, methods development programs are feasible if the sampling method is to be compatible with the alternative procedures of the provisional method or general electron microscopy. Such procedures require that the collected sample be transferable to an electron microscope grid for counting. The method of sample collection is not precisely specified.

Viewed on a component-wise basis, the essential areas for research toward method development concern collection techniques and removal of nonasbestos material. Practical options for the collection technique component are limited to either (1) electrostatic precipitation or (2) collection by cellulose ester or polycarbonate filters in spite of their known limitations. These techniques may be supplemented by precollection with an impinger to reduce loading. Past experience of analysts indicates that asbestos and nonasbestos material can be separated from each other in the laboratory by means of ashing, sonification, and two-phase liquid separation. These sample preparation procedures can alter the asbestos size distribution. The usefulness as well as the feasibility of a separation during sampling can be assessed only after more thorough data characterizing the industry emissions are obtained and evaluated. The applicability of inlet and probe technology appears to be simply an engineering task.

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SECTION 1

INTRODUCTION

Asbestos has been identified as a hazardous air pollutant and is therefore subject to a National Emission Standard for Hazardous Air Pollutants (NESHAP). However, a numerical standard has not yet been promulgated due in part to the absence of a reference source sampling method for asbestos emissions and a reference method for the analytical determination of asbestos in collected samples. A provisional analytical method has been established based upon electron microscopy (1). Research is continuing on the establishment of a reference analytical method based upon the current provisional method. This report describes the first phase of research leading toward the possible development of a reference source sampling method for asbestos emissions.

OBJECTIVE

The objective of this program is to determine the feasibility of developing methods for sampling asbestos in the emissions of major asbestos sources. The sampling methods must provide samples compatible with the provisional analysis methods described in Ref. 1 (EPA-600/2-77-178). Information is to be gathered in order that estimates can be made of time and effort required to develop methods.

PROGRAM DESIGN

The development of a reference sampling method involves feasibility assessment and subsequently a development effort. In general, a feasibility study is designed to gather information on the requirements that a reference method must meet, constraints placed upon potential methods by a variety of sources, and needed areas of research. This information can then be used to determine the feasibility of conducting a development program.

The development program, which is outside the scope of this study, involves conducting research on one or more potential sampling methods. After research on unanswered questions, potential methods are tested and either dropped from consideration or refined.

This feasibility study was designed to provide data which could be used to determine whether or not it is technically feasible to initiate a development program for a reference source sampling method and, if so, to estimate the required time and effort.

The hazardous pollutant of concern is asbestos. For purposes of sampling, asbestos is primarily chrysotile, amosite, and crocidolite. These exist primarily as fibers or groups of fibers of various diameters and lengths. By convention, fibers are those particles having parallel sides and length-to-diameter ratios of at least 3:1. The diameter range extends from 0.03 μm o.d. for hollow chrysotile fibrils to on the order of 10 μm for clumps of fibers. The diameter range of individual amphibole fibers is 0.1 to 0.2 μm. Commercial asbestos has diameter ranges of 0.75 to 1.5 μm and 1.5 to 4 μm for chrysotile and amphiboles, respectively.

The four industries of concern are:

- ore production
  - --asbestos production
  - --taconite production
- asbestos-cement
- asbestos felt and paper
- asbestos friction materials.

Taconite production differs from the other industries in that the fibers which are present are an extraneous impurity, not a desired component of the product. Fiber emissions from all the industries occur as stack emissions and fugitive emissions.

REPORT ORGANIZATION

This report is organized into 8 sections. Section 2 contains the conclusions derived from the feasibility study. Section 3 contains recommendations on the initiation of a development program for source sampling methods.

A background discussion of the characteristics of asbestos, industries, and asbestos source sampling methods is given in Section 4. This is followed in Section 5 by identification of two criteria for choosing an acceptable source sampling method and associated constraints upon potential methods. Potential components of a sampling method are presented in Section 6. Section 7 contains a discussion of the feasibility of source sampling methods. A feasible development program for a source sampling method is presented in Section 8.

SECTION 2

CONCLUSIONS

After review of each of the key system components of a sampling systems(s) it has been concluded that the development of a standard method for sampling asbestos emissions is feasible. This study has not uncovered any limiting industry anomalies or insurmountable technical problems.

It is not feasible to undertake a methods development program for strict compatibility with the recommended procedure of the provisional analytical method. Strict compatibility requires the collection of a uniform deposit of proper loading by air filtration onto a 0.4 μm pore size polycarbonate filter. However, methods development programs are feasible if the sampling method is to be compatible with the alternative procedures of the provisional method or general electron microscopy. Such procedures require that the collected sample be transferable to an electron microscope grid for counting. The method of sample collection is not precisely specified.

Inherent differences between stack and fugitive emission environments may necessitate the development of two sampling techniques or at least two modifications of the same technique.

Viewed on a component-wise basis, the essential areas for research toward method development concern collection techniques and removal of non-asbestos material. Practical options for the collection technique component are limited to either (a) electrostatic precipitation or (b) collection by cellulose ester or polycarbonate filters; although each of these options possesses negative features for the overall sampling and analysis procedure.

The negative features of cellulose ester filters include high pressure drop and sample losses in the transfer of collected asbestos to an EM grid. The negative features of polycarbonate filters include less than 100 percent collection efficiency and the tendency for collected asbestos to become detached from or move around on the filter during handling operations.

These collection techniques may be supplemented by precollection with an impinger to reduce loading. Past experience of analysts indicates that asbestos and nonasbestos material can be separated from each other in the laboratory; however, ashing, sonification, and two-phase liquid separation techniques can alter the asbestos size distribution. The usefulness as well as the feasibility of a separation during sampling can be assessed only after more thorough data characterizing the industry emissions is obtained and evaluated. The applicability of inlet and probe technology appears to be a straightforward engineering task.

SECTION 3

RECOMMENDATIONS

A development program for a source sampling system should proceed on a component-wise basis. This would entail mutual pursuance of research efforts on collection techniques and extraneous material separation during sampling. Subsequently the most promising of the techniques should be incorporated with each other and current state-of-the-art inlet and probe designs to form a sampling system(s). Finally the complete system must be laboratory checked and field demonstrated.

Investigation of collection techniques should center on electrostatic collectors and on collection by cellulose ester and polycarbonate filters despite the limitations of each of these options. More industrial data further characterizing the extraneous material needs to be obtained to assess whether a development program for removal of extraneous material should focus on separation during sampling, in the laboratory, or both. The advantages of precollection with impingers or other means to reduce loading should be evaluated experimentally.

SECTION 4

BACKGROUND

Three basic considerations which must be addressed when considering the feasibility of source sampling methods are: (a) the characteristics of asbestos, (b) characteristics of the total emissions, and (c) current sampling methods. Pertinent information on these areas provides a background upon which to base the feasibility assessment.

CHARACTERISTICS OF ASBESTOS

A variety of terms have been applied to asbestos with different connotations to mineralogists, the general scientific and technical community, and the public. For purposes of sampling it is sufficient to restrict attention to six classes of asbestos arising from two minerals: serpentines and amphiboles. About 95 percent of the asbestos used in the industries of concern is chrysotile, a serpentine mineral. The remaining five types of asbestos are amphiboles. They are amosite, crocidolite, anthophyllite, tremolite, and actinolite.

The several types of airborne asbestos may be in any or all of three forms; fibrils, fibers and fiber bundles with bundles being less prevalent than fibers or fibrils. It is important that sampling, sample preparation and analysis are conducted such that the integrity of the airborne form of asbestos is maintained. Disruption, either by breaking bundles or fibers apart or by clustering fibrils or fibers, during any step of the method will lead to false representation and conclusions especially regarding number concentration and size.

Characteristics of fibers which are important in the design of a sampling method include: (a) aerodynamic behavior in force fields, (b) light scattering if used as a direct detection technique, and (c) interaction with the collection medium. A fundamental characteristic of fibers is the length-to-diameter or aspect ratio which by common working definition must have a value greater than three for classification as a fiber.

Both fiber diameter, d_f, and aspect ratio (L/d_f) influence the aerodynamic behavior of asbestos. The fundamental physical unit of chrysotile is the fibril, a hollow crystal with mean internal diameter of 0.018 μm (1 μm = 10^{-6} m) and mean outside diameter of 0.034 μm within the range 0.03 to 0.04 μm. A large number of fibrils constitute a chrysotile fiber which commonly has a diameter between 0.75 and 1.5 μm. Chrysotile fibers are not perfectly straight and are often frayed and contain fibrils projecting from the fiber.

The amplibole asbestos fibers are rod-like with straight sides. The mean diameter range of elementary amphibole asbestos fibers is 0.1 to 0.2 μm. The diameter range of commercial amphibole asbestos fibers is about 1.5 to 4 μm.

There is not much reported in the open literature on determination of equivalent aerodynamic diameters, d_{ae}, for asbestos. Equivalent aerodynamic diameter is defined as the diameter of a sphere of unity density whose settling velocity is equal to that of the actual particle or fiber under consideration. The following relationships have been reported for amosite and crocidolite(2), the two amphiboles most often encountered within the four industries of concern.

$$d_{ae} = 2.18\, d_f \left(\frac{L}{d_f}\right)^{0.116} \qquad \text{amosite}$$

$$d_{ae} = 2.19\, d_f \left(\frac{L}{d_f}\right)^{0.171} \qquad \text{crocidolite .}$$

Additional properties which affect aerodynamic characteristics in force fields are specific gravity and electric charge. The specific gravity of chrysotile has been given as 2.4 to 2.6(3). Amosite and crocidolite have specific gravities in the ranges 3.1 to 3.25 and 3.2 to 3.3, respectively. Normal electric charge of chrysotile is positive while that of the amphiboles is negative.

The chemical nature of asbestos includes stability with respect to solvents and temperature. Chrysotile is the most soluble form of asbestos. Acids readily decompose the MgOH surface. Amphiboles are more resistant to acid attack. Chrysotile begins to lose its water of crystallization at about 300 C. At 850 C chrysotile is transformed to nonfibrous magnesium olivene. Amphiboles are more refractory than chrysotile. Loss of water and fiber deterioration of amphiboles occurs at higher temperatures (ca. 1000 C).

CHARACTERISTICS OF EMISSIONS

The four industries of concern were listed in the Introduction. Site visits were made to at least one plant in each of the four industrial categories. Descriptive summaries of these visits are provided in Appendix A. Information gathered on particulate emission source characteristics and the emissions environments are discussed below.

Characteristics of Particulate Emissions

The composition of emissions is determined by both the industrial process and the existing control technology. The likely general composition of particulate emissions is shown in Table 1. Chrysotile is the major asbestos component in all industries but taconite production. Amphiboles are present in the AC pipe, friction products, and felt and paper products industries.

Composition of the particulate emissions from the production process varies at different stages along the process. In the asbestos mining and milling industry, the percentage of asbestos in the material being handled increases from its initial concentration in the ground of 2-60 percent up to nearly 100 percent in the bagging operation as the ore is processed. In the taconite industry the concentration of fibers in the tailings collected along the process changes as increasing amounts of iron are separated from the ore. In the manufacturing industries, the concentration of asbestos in the emissions from the production line decreases from near 100 percent at the point of introduction of asbestos to an amount comparable to the asbestos concentration in the manufactured product.

TABLE 1. GENERAL COMPOSITION OF INDUSTRIAL EMISSIONS CONTAINING ASBESTOS

Industry	Asbestos	Nonasbestos
Asbestos mining and milling	Chrysotile	Rock containing asbestos
Taconite production[a]	Mineral clevage fragments	Rock containing fibers
Asbestos-cement pipe	Chrysotile, crocidolite Asbestos 15-35%	Portland cement 40-55% Silica 24-33%
Friction products	Asbestos 30-80%	Friction compounds, ZnO, sulfur, rubber, resin, brass wire
Felt and paper products	Chrysotile 80-90%	Resins, latex, cement, gypsum, starch, glue, fiberglass

(a) Controversy exists as to whether the amphibole fibers produced by the crushing of ore in the taconite industry are truly asbestos or not. Zoltai (4) reported that the appropriate mineralogical term for the fibers derived from the Peter Mitchell ore of Reserve Mining Company is: fibrous clevage fragments of cummingtonite-grunerite; however, he also indicated that there is no conclusive means by which these fibers and fibers of commercial amosite can be distinguished in micrometer size samples. For the purpose of sampling, there appears to be no reason to distinguish between cleavage fragments and amosite.

The composition of emissions leaving stacks is dependent upon control technology. As will be shown in Table 2, baghouses are used for specific parts of the production process and also for collecting emissions simultaneously from several operations thereby effectively mixing various compositions.

Both production processes and control technology influence the size of emitted particles. The size distribution of particles (including fibers) passing through a baghouse will have a smaller mean size than most fugitive emissions. Asbestos containing particles emitted from finishing operations will be present in the emissions of manufacturing plants. These particles consist of asbestos embedded in small chunks of the finished product and possess a size larger than that of the asbestos itself.

Emission Environment

A source sampling method must be able to extract a sample from the local sampling environment. The variables which characterize these environments can be used to categorize the environments with respect to feasibility of sampling methods.

The primary categorization is based upon control of air flows which potentially contain asbestos emissions. These two categories are (a) stack environments in which the air flow is constrained by a duct, and (b) fugitive emissions in which asbestos is entrained by uncontrolled air flow. Fugitive emissions of concern can occur as (i) ventilation air leaves a plant, (ii) indoor plant air escapes through open doors, windows, or panels, or (iii) outdoor emissions from mining, transport, and disposal operations.

Additional variables of the sampling environment include temperature, relative humidity, air flow velocity, temporal variations of the characteristics of the sampling environment, and physical accessibility. Physical accessibility is a practical constraint. The physical characteristics of process machinery and building structures limit the sampling volume itself, access to the sampling volume (e.g., suitable sampling ports). and the amount of working space around the sampling volume.

The characteristics of stack environments in the four industries are shown in Table 2. The values shown are approximate in nature but sufficient for establishing feasibility. Parameters shown include stack diameter, volumetric flow rate, the computed average gas velocity, temperature and moisture content.

Sampling environments likely to be encountered when sampling fugitive emissions of asbestos can be divided into two classes: (a)outdoor and (b) emissions from industrial plants; although, these environments are quite similar. Temperature and moisture content are at or near ambient for all environments. Air velocity in the outdoor environment is the ambient wind velocity for emissions from disposal sites. Air velocities encountered around mining operations are also close to the ambient wind velocity outside of areas in close proximity to blasting operations. Air velocities for fugitive emissions from plants are the ambient air currents through openings such as windows, doors, or natural draft ventilators. Some ventilators use large fans to exhaust air from drying operations.

The time dependence of the characteristics of the emissions and sampling environment place an additional constraint on a sampling method. The ability to collect a time-integrated sample over a period of time long in duration compared to the period of parameter fluctuation is necessary in order to collect a sample representative of the emissions.

This constraint has further consequences for a sampling method. Samples could be collected continuously or intermittently over a specified time period. As the length of sampling is increased to achieve time integration, the sampling rate must be correspondingly decreased if the same amount of asbestos is to be collected. The ability to determine accurate sample volumes of air must be maintained as the sampling rate and/or sampling durations are reduced.

SOURCE SAMPLING METHODS

As indicated by the industry review both stack sampling and fugitive emissions sampling must be considered. This section reviews each.

TABLE 2. CONDITIONS ENCOUNTERED IN INDUSTRIAL SURVEY OF SAMPLING ENVIRONMENT (STACK ENVIRONMENTS)

Industry	Process	Control Technology	Stack Diameter (inches)	Flow Rate (cfm)	Gas Velocity (FPM)	Temperature (F)	rh
Taconite Production/ Iron Ore Beneficiation	Car Dumper Plant	Baghouse	61	67,000	3,300	Amb +10	Amb
	Fine Crusher Plant	Baghouse	32	13,000	2,300	Amb +15	Amb
	Fine Crusher Conveyor-To-Concentrator	Baghouse	40	30,000	3,400	Amb +5	Amb
	Dry Cobbing Plant	Baghouse					
	Concentrator Plant	Cyclones					
	Filter Plant	Cyclones					
	Pelletizing Plant	Wet ESP					
	Dock Pellet Storage Silo	Uncontrolled	18	6,000	3,400	Amb +50	Saturated
Asbestos Mining & Milling							
Site 1	Ore Preparation	3 Baghouses	36	21,000	3,100	Amb	Amb
			26	12,600	2,200	Amb	Amb
			40	33,000	4,600	Amb	Amb
	Drying	2 Baghouses	48	29,000	2,300	100	Saturated
			50	38,000	2,800	120	Saturated
	Transport-Dry Rock Storage to Mill	Baghouse	56	32,000	1,900	60	Amb
	Milling & Bagging	Baghouse [4-Exhaust points from fiber dust system]	52x53	75,000	4,000	Amb	Amb
Site 2	Main Dryer	Baghouse	40	38,000*	4,400	250	Elevated
	Main Bagging	2 Baghouses	24	6,270	2,000	Amb	Amb
			30x30	13,000*	2,100	Amb	Amb
	Dryer	Baghouse	18x18	?	?	250	Elevated
	Bagger	Baghouse	26x26	1,500	320	Amb	Amb
	Bag Cleaner	Baghouse	16x16	2,500*	1,400	Amb	Amb
Asbestos-Cement Products							
Site 1	Wet End	Baghouse	31x40	12,000	1,400	Amb	Amb
	Wet End	Baghouse	41x53	22,000	1,500	Amb	Amb
	Finishing	Baghouse	27x72	27,000	2,000	Amb	Amb
	Finishing	Baghouse	27x122	28,500	1,200	Amb	Amb
Site 2	Blending, Processing, Finishing	Baghouse	30	26,300	5,400	Amb	Amb
	Air Over Curing Oven	None	60	50,000	2,500	Amb	Amb
Asbestos Felt	Blending	Wet Impinger	22	7,500*	2,200	Amb	Saturated
	Drying	None	--	--	--	--	--
	Trimming	Cyclone + Baghouse	16	4,400*	3,200	Amb	Amb
	Asphalt Saturator	Fiberglass Mat	--	--	--	--	--
Asbestos Friction Products	Mixing Preforming	Baghouse	30	23,000	4,200	Amb	Amb
	Finishing	Baghouse	30	46,000	4,200	Amb	Amb

* Design

Stack Sampling Methods

Historically, stack sampling methods for asbestos emissions have been based upon total particulate sampling methods. The Canadian standard reference method (5) specifies an in-stack filter in a sampling train essentially equivalent to U.S. EPA Method 17 (6). The filter holder and filter must be capable of withstanding temperatures up to 200 F. A cellulose ester membrane filter with 0.8 µm pore size is required. The probe must have a heating system capable of maintaining the temperature of the gas at the exit end of the probe high enough to prevent condensation.

The U.S. EPA has recommended (see Appendix G in Ref. 7) a method for sampling asbestos emissions which is also based on Method 17. Inasmuch as asbestos emissions are not affected by temperature below 300 F, the collection temperature of 250 F for total particulate sampling need not be maintained. Particulate matter may contain condensible material; asbestos does not. Relaxation of this constraint eliminates the necessity of employing a heated probe and filter system. Sampling in the stack at stack temperature reduces the distance travelled by the fibers going from the stack environment to the filter. Elimination of heating has the consequence that this method is no longer suitable for environments containing saturated water vapor or liquid drops.

Sampling conducted at iron ore beneficiation plants for fiber emissions has used both in situ and extractive sampling (7,8). Extractive sampling was used at a dock pellet storage silo ventilator stack because of saturated conditions in the stack. The sampling train was heated from the inlet through the 47-mm polycarbonate filter (7). Sampling of the baghouse exhausts from the ore car dump, fine crusher, and fine crusher conveyor-to-concentrator storage silos was accomplished by in situ filtration (7). With the exception of one test using a cellulose ester filter, all tests were conducted using a 47-mm polycarbonate filter. Sampling duration ranged from 15 seconds to 7 minutes depending upon the expected loading.

Fiber emission measurements have also been made for pelletizing operations (8). Temperatures at the four locations encountered in Ref. 8 ranged from 157 F to 270 F. Deviations from Method 1 to 5 (9,10,11) included: (a) the use of a 115-mm cellulose acetate filter instead of a glass fiber filter, (b) maintenance of 180 F for the sampling probe and heated filter, and (c) installation of a glass cyclone in the heated filter box ahead of the filter to remove some particulate material. A temperature of 180 F was chosen after deterioration of the cellulose acetate material was detected at 200 F.

Measurements of asbestos emissions from baghouse-controlled sources have been reported (12). The industries included two asbestos cement plants, an asbestos textiles plant, and two asbestos mills. An extractive sampling system was used upstream of the baghouses. Samples were drawn through a cyclone prior to filtration by a 10 cm, 0.8 µm pore size membrane filter. On the downstream side the cyclone was not used. In some instances sampling locations for extractive isokinetic sampling were inaccessible. High volume samples with membrane filters were used within the baghouse itself for the downstream measurements. A recent study (13) suggests sampling simultaneously using 3 filters at different flow rates in an attempt to insure proper loading.

Fugitive Emission Sampling

Commonly used sampling strategies for measuring fugitive emissions have been categorized (14,15) as:

- The quasi-stack method which involves capturing the entire emissions stream with an enclosure or hood and sampling these confined emissions with standard stack sampling techniques.
- The roof-monitor method which involves measurement of the emissions by traverses across well defined openings such as ventilators, windows, and access doors (16).
- The upwind-downwind method which involves measurement of upwind and downwind concentrations using ground based samplers. The source strength is calculated using a diffusion model and measured meteorological parameters.
- The exposure-profiling method which involves the direct measurement of particle flux downwind of a source by simultaneous multi-point sampling over an effective cross-section of the fugitive emission plume. The sampling conditions must be isokinetic.

Several devices have been used for monitoring airborne asbestos (17). The most common method is high-volume filtration using cellulose ester membrane filters (18,19). An array of hi-vol samplers is commonly used to measure fugitive emissions outdoors.

Passive samplers have also been used to collect particulate matter for measurement of particle flux. An example is the isokinetic sampler reported in Refs. 20 and 21 which collects particles electrostatically on a metal foil as the air stream passes through the sampler under the air stream's own inertia. While such samplers meet environmental constraints, an additional constraint on the amount of sample collected is imposed upon the sampler by virtue of its design. That is, the sampling volume is limited by the product of the effective cross section of the sampler and the prevailing air velocity. To obtain a measurement of airborne concentration, as opposed to particle flux, a separate continuous record of local air velocity must be maintained.

SECTION 5

CRITERIA AND CONSTRAINTS

CRITERIA

A source sampling method for asbestos emissions must meet certain requirements if it is to be accepted as an approved sampling method. Two standards upon which to base a judgment of acceptability were determined at the onset of the program. The first criterion is that the sampling method must be capable of collecting a representative asbestos size distribution from the local environment. The second criterion is that the asbestos must be collected in such a manner that it can be analyzed by the provisional analytical method to provide the required determinations.

CONSTRAINTS

A number of constraints, arising from different sources, restrict potential sampling methods if they are to meet the two basic criteria. The establishment of these constraints provides the framework for the conduct of the feasibility study on the development of a source sampling method. General constraints identified at the onset of the program are presented in Tables 3 and 4. These constraints arise from several factors as shown in Figure 1.

Constraints on the Acquisition of a Representative Sample

Constraints on a method for the collection of a representative sample arise from two basic areas: (a) the required determinations and (b) the characteristics of the particulate emissions and sampling environment.

Required Determinations--

Health concerns have led to the establishment of national emission standards for hazardous air pollutants. The standard for asbestos is contained in 40 CFR Subpart 61b. The emission standard for the four

TABLE 3. CONSTRAINTS ON A SOURCE SAMPLING METHOD FOR ASBESTOS FOR THE ACQUISITION OF A REPRESENTATIVE SAMPLE

RS1	Ability to collect asbestos fibrils and fibers over the diameter range $0.03 \leq d_f \leq 10$ μm for determination of number and mass concentration by counting techniques.
RS2	Ability to collect asbestos fiber bundles over the diameter range 0.2 μm to several tens of μm for the determination of number concentration by counting.
RS3	Ability to extract a sample from the local environment characterized by air velocity, temperature, and moisture content.
RS4	Ability to collect a time-integrated sample.

TABLE 4. CONSTRAINTS ON A SOURCE SAMPLING METHOD FOR ASBESTOS TO BE COMPATIBLE WITH THE ANALYTICAL METHOD FOR ASBESTOS DETERMINATIONS

	Compatible With the Provisional Method		
	Strictly Compatible With Recommendations	Compatible With Alternatives	Compatible With Electron Microscopy
AM1	The sample must be collected uniformly over a 0.4 μm pore size polycarbonate filter	The capability to take the collected sample. alter it (e.g., by ashing), and obtain a uniform dispersion on a polycarbonate filter is required	
AM2	The collection filter must have an asbestos loading in the proper range for counting	The capability of obtaining an asbestos loading on a polycarbonate filter in the proper range for counting is required	
AM3	The collection method is air filtration	The collection method is air filtration	The collection method is not limited to air filtration
AM4	The collection medium is 0.4 μm pore size polycarbonate filter material	The collection medium is 0.4 μm polycarbonate or cellulose ester filter material	The collection medium is not specified; however, it must be compatible with a procedure to transfer the collected asbestos to an em grid
AM5	The collection of non-asbestos matter must be minimized	The capability to reduce the amount of collected non-asbestos material (e.g., by ashing) must be available	
AM6	Special care in the handling of polycarbonate filters must be exercised	Polycarbonate filters are not necessarily required for use in the field	
AM7	Fiber bundles must be collected for counting		The counting of fiber bundles is not necessarily required
AM8	Count and equivalent volume determinations must be made		The specific determination is not specified

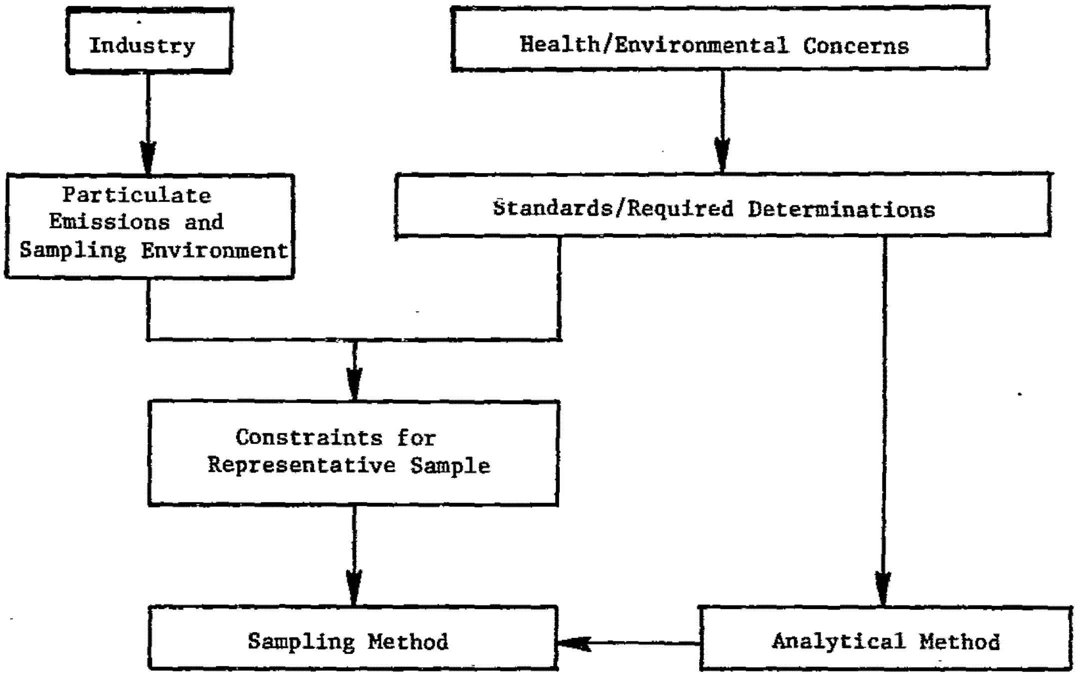

Figure 1. Factors leading to constraints on a source sampling method for asbestos.

industries of concern (i.e., ore production, asbestos-cement, asbestos felt and paper, and asbestos friction products) specifies that there be no visible emission to the outside air from any operations or that the emission containing asbestos be cleaned before such emissions escape to the environment.

OSHA regulations for the work place environment specify an exposure regulation for workers in 29 CFR Section 1910.1001. The 8-hour time-weighted average airborne concentration of asbestos fibers with length greater than 5 µm is not to exceed two fibers per cm^3 of air.

As shown in Figure 1, these standards in principle specify certain required determinations of asbestos. For example the OSHA regulation requires that a count determination be made on the collected sample.

Required determinations arise from sources other than codified standards. Based upon discussions with the EPA Project Officer and other EPA scientists, determinations of asbestos have been defined which are more stringent than those identified above. These determinations are compatible with the provisional method (1) for asbestos determinations.

The number of asbestos fibers per cm^3 of air must be determined over a fiber size range including fibrils, fibers, and fiber bundles. The concentration of bundles is reported separately. Classification of asbestos into one of the following categories is made after electron diffraction:

- chrysotile
- amphibole group
- ambiguous (incomplete spot patterns)
- nonasbestos
- unknown (no spot pattern).

Determination of the length and diameter of fibrils and fibers is required for subsequent calculation of the mass concentration. This determination is not made for fiber bundles.

Two constraints placed upon a sampling method by the required determinations are listed in Table 3 as the first two constraints. The ability to collect asbestos fibrils and fibers for determination of number and volume concentrations by counting places the following requirements on a sampling method.

(a) The overall collection efficiency for asbestos must be known over the diameter range 0.03 μm to 10 μm. Furthermore, the collection efficiency must be such that combined with the variables of sampling rate and time and asbestos concentration, sufficient asbestos (based on number) can be collected to provide good counting statistics for the analytical determination.

For example, asbestos contributing to the majority of the number concentration may not be concentrated in the same diameter size range as the asbestos contributing to the preponderance of the volume concentration. Per unit length, one fiber of 0.4 μm diameter will contribute 100 times as much volume to the total volume as will a fibril with d_f = 0.04 μm. From previous experience it can be expected that the fibrils will contribute the most to the total asbestos number concentration; fibers will contribute the most to the volume concentration. Ideally, an asbestos sampling method must be able to collect sufficient asbestos for both number and volume determinations without impairing one of the two determinations by collecting too much material (e.g., too many fibrils for the number determination with an appropriate loading for the volume determination) or too little material (e.g., appropriate loading for the number determination with too few fibers for the volume determination). This ideal may, in fact, be very difficult to obtain. The number of fields which can be counted under the electron microscope is small because of economic constraints to be discussed later. This implies that if the same number of fields are to be counted for both number and volume determinations, approximately the same number of fibrils and fibers should be present for equal counting statistics for the number and volume determinations. Considerations of the effects of competing constraints on selection of a sampling method will be discussed in the summary of the requirements for a sampling method.

(b) No fiber size separation during sampling will be required if sufficient numbers of fibrils and fibers can be collected simultaneously by the same mechanism. An alternative approach could consist of collecting more fibers by selective concentration or sampling larger air volumes while simultaneously collecting a second sample of fibrils.

The second constraint in Table 3 provides for determination of the number concentration of fiber bundles. If an accurate determination of the number concentration of fiber bundles is required, the sampling method must be capable of collecting sufficient quantities of these bundles for such a determination. The large bundle sizes coupled with the wide size range of such bundles suggests that a separate sampling method could be required to collect these bundles efficiently over their size range. Information on the effective size of such bundles with respect to the collection mechanism under consideration (e.g., aerodynamic diameter for capture on a surface from an air stream) is required in order to determine if an additional sampling method would be required for bundles.

An additional requirement of a sampling train for the collection of fiber bundles is that the bundles be collected without fragmentation. Fragmentation will increase the number of fibrils and fibers and, if fragmentation is complete, reduce the number of fiber bundles.

Emissions and Sampling Environment--

As shown in Figure 1, characteristics of the particulate emissions and their local environment place additional constraints on a sampling method for the acquisition of a representative sample. The type of asbestos emissions and their environments are dependent upon specific industries. Within the four industries of concern material and process variations and control technology combine to establish emission and sampling environment characteristics.

The following variables constitute the characteristics of the emissions and their environment which directly affect the choice of a sampling method:

- relative amount and composition of nonasbestos particulate matter
- type of asbestos
- asbestos concentration and size distribution
- presence of corrosive gases
- air flow dynamics--duct or stack flows vs. fugitive emissions
- temperature
- time dependence of the variables above.

The sampling environment provides constraints on the ability of the sampling method to extract a representative sample from the environment. The third constraint in Table 1 requires that this be accomplished under two basic conditions: (a) in duct or stack flows and (b) in open air for fugitive emissions. The relative extent to which asbestos emissions fall into these two categories is determined by processes within the four industries of concern. This third constraint necessarily requires that the sampling apparatus operate under local temperature conditions.

The time dependence of the five variables listed above places an additional constraint on a sampling method. The fourth constraint in Table 3 for a sampling method, the ability to collect a time-integrated sample, is necessary in order to collect a sample representative of the emissions over a period of time long in duration compared to the period of parameter fluctuation.

This constraint has further consequences for a sampling method. Samples could be collected continuously or intermittently over a specified time period. As the length of sampling is increased to achieve time integration, the sampling rate must be correspondingly decreased if the same amount of asbestos is to be collected. The ability to determine accurate sample volumes of air must be maintained as the sampling rate and/or sampling durations are reduced.

Combined Constraints for Representative Sampling--

The combined constraints on a sampling system resulting from characteristics of the source emissions, their local environment, and the required determinations on the collected sample can be categorized according to potential components of a sampling system. These components are:

- inlet system
- transport system
- collection system.

The inlet system must capture a representative sample from the air. The sample is then transported to the collection system by the transport system. The inlet system may contain a precutter which segregates particles according to a particular property (e.g., aerodynamic diameter or electrical mobility for charged particles in a field) and delivers particles or fibers with specified values of that property to the downstream portion of the inlet. In the downstream portion of the inlet system or in the transport system provision can be made for incorporation of dilution air into the sample flow stream.

The collection system must be capable of handling a range of incoming particulate concentrations. Constraints placed upon the collection system by the sampling environment and required determinations do not limit the collection system to collection by a membrane filter. Potential collection strategies include filter collection from the airstream, the use of cyclones, electrical and thermal deposition, and collection by impingers or impactors. However, the analytical method further constrains the collection methods which can be utilized.

Constraints Arising from the Analytical Method

As shown in Figure 1, the analytical method for making the required determinations places additional constraints on a source sampling method. These constraints can be classified as technical and economic.

Technical Constraints--

EPA desires that a source sampling method for asbestos be compatible with the provisional analytical method reported in Ref. 1. At the same time it is recognized that the analytical method is only a tool, subject to change, used to make certain required determinations. The constraints placed upon a sampling method by the requirement of compatibility are presented in Table 4. The compatibility requirement is broken down into three alternative requirements. These are (a) strictly compatible with the recommended procedures of the provisional method, (b) compatible with alternative procedures (not considered optimal) of the provisional method, and (c) compatible with electron microscopy but not necessarily with the procedures of the provisional method.

As shown in Table 4, relaxation of the requirement of strict adherence to the recommended procedures of the provisional method provides for many potential alternatives for a source sampling method. If the sampling method is to remain compatible with alternative recommendations of the provisional method, polycarbonate filters need not be used for sample collection.

Sample preparation to reduce nonasbestos material is permitted. Dilution of the sample to achieve a different loading is also possible. Finally, if the sampling method is only to be compatible with general electron microscopy, the collection principle in the sampler need not be air filtration.

Three practical concerns associated with EM analysis which influence the selection of a sampling method are: (a) uniformity of fiber dispersion across the EM grid, (b) loading, and (c) nonasbestos interference. If the collected particulate matter is directly transferred to the EM grid as outlined by the provisional method, these three concerns apply directly to the filter collection. Otherwise these concerns apply to the transfer process resulting in a deposit on the EM grid.

(a) Only a small portion of the sample is viewed under the electron microscope. Consequently, it is vital that the portion of the sample selected for viewing be representative of the loading of the entire sample collection. For example, if the sample is collected on a polycarbonate filter and transferred to an EM grid, the collected fibers should be uniformly distributed across the filter surface.

(b) Loading is an additional constraint. The optimum loading on an EM grid is in the range 10 to 20 fibers per 200-mesh grid opening (90 x 90 μm^2). Ideally, the sampling method will provide such a loading regardless of the conditions encountered.

(c) Nonasbestos material on the EM grid interferes with the microscopist's ability to distinguish the asbestos from other material. Extraneous material can be removed during sample preparation by ashing (22,23), sonification (22,23), or two-phase liquid separation techniques (24,25); however, such a procedure may also alter the collected asbestos. Fibers and bundles can be broken apart into fibrils and asbestos losses can occur. Therefore, the sampling method should separate asbestos from the coexisting nonasbestos particulate matter to the extent possible.

Economic Constraints--

The provisional method is a relatively expensive analytical method. Both the sophisticated equipment and the labor intensive nature of the counting procedure contribute to this characteristic of the provisional method. As a result, a source sampling method should collect an asbestos sample in such a manner as to minimize the labor required for the counting and classification procedure. This can be accomplished by (a) providing a sample for counting as free from nonasbestos material as possible, and (b) providing a sample with an asbestos loading in the optimal range for counting.

IMPLICATIONS OF CONSTRAINTS ON FEASIBILITY

The implications of the constraints identified in Tables 3 and 4 are presented in Table 5. The terms RS and AM refer to constraints arising from representative sampling and the analytical method respectively. The numerals refer to the order of the constraints listed in Tables 3 and 4.

The implications listed in Table 5 indicate that compromise is necessary between practicality of sampling and the ideal requirements for a collected sample imposed by the desired determinations of count and volume. Three levels of compatibility between a sampling method and analytical methods are presented in Table 4. It is not feasible to undertake a methods development program for strict compatibility with the recommended procedures of the provisional analytical method. However, methods development programs are feasible if the sampling method is to be compatible with the alternative procedures of the provisional method or general electron microscopy.

TABLE 5. IMPLICATIONS OF CONSTRAINTS

Constraint[a]	Implication for the Development of a Source Sampling Method for Asbestos
RS 1 AM 8	A single collector cannot be used to simultaneously collect asbestos over the diameter range 0.03 to 10 μm and provide optimum loading for both number and volume concentrations by counting.
RS 2 AM 7	The potential breakup of fiber bundles must be minimized by providing a short straight transport path between the sampling inlet and the collector.
RS 3	The difference in air velocity between stack and fugitive emission environments necessitates the development of at least two sampling techniques designed for air velocities in the two types of environments.
RS 3	Saturated conditions will be encountered. The sampling system must be able to collect samples in these environments.
RS 3	Elevated temperatures are not a constraint.
RS 4 AM 2	A continuous monitor to assess the level of asbestos loading in the collector is not practical. A series of sample volumes could be collected separately to provide one with an acceptable loading.
AM 1	Strict compatibility with the recommended practices of the provisional method is not possible if collection methods other than air filtration by polycarbonate filters are to be considered.
AM 1	If the sampling method is strictly compatible with the provisional analytical method, the sampling rate through the filters must be within the range for optimal filtration by a polycarbonate filter.
AM 1, 3, 4, 6	Direct air filtration or filtration of a liquid containing collected asbestos is feasible. Uniform electrical deposition of asbestos on a surface needs further research.
AM 5	The size and chemical characteristics of the asbestos and non-asbestos particulate emissions preclude the use of inertial or magnetic forces in a sampling system for material separation. It is highly probable that material separation techniques will need to be used during sample preparation.

(a) RS = Constraint for representative sampling. RS 1 is the first constraint listed in Table 3.

AM = Constraint imposed by the analytical method. AM 1 is the first constraint listed in Table 4.

SECTION 6

FEASIBILITY OF METHOD DEVELOPMENT

In determining the feasibility of developing a sampling method it is desirable initially to view the method as a sum of generic components rather than the system as a whole. Using this approach key system components may be identified and options reviewed and assessed. The components may then be combined, giving proper consideration to component compatibility, to generate the most desirable complete method.

An essential element in determining the feasibility of developing a standard method is a brief review of the state-of-the-art of the pertinent components. Such a review should aid in (a) determining specific areas where research needs exist and where they do not; (b) identifying and eliminating specific component options and (c) properly focusing efforts directed toward method development.

For the subject task, asbestos sampling, the system can be viewed in four parts:

(a) System Inlet
(b) Transport Probe
(c) Extraneous Material Separation
(d) Collection Technique.

Viewing the system in this piece-wise fashion not only facilitates feasibility assessment but also provides an approach for determining in what areas state-of-the-art deficiencies lie and thus where development efforts should be concentrated.

Table 6 gives a summary of the system components of interest.

TABLE 6. SYSTEM COMPONENTS

Component	Factors Influencing	Options	Deficiencies (Areas of Needed Research)
Inlet and Probe	Sampling Environment	Stack Sampling Fugitive Emissions Sampling	None, State-of-the-Art Sufficient
Extraneous Material Separation	Relative size, concentration and physico-chemical properties of extraneous material and asbestos	(1) Inertial Separation (2) Other Mechanical Separation (3) Chemical Treatment (4) Pyrolytic Treatment	Physical Characterization (size distribution and relative concentration)
Collection Technique	Physical and Aerodynamic Properties of Fibrils, Fibers and Fiber Bundles	(1) Electrostatic (2) Filter (3) Impinger and Filters	Collection Substrate Compatability with Analytical Procedures

INLET AND PROBE

The inlet design is important to insure that proper representative sampling is conducted. This requires isokinetically removing the airborne asbestos emissions from their environment. The characteristic sizes of the asbestos fibers likely to be present (0.03 to 4 μm diameter) are compatible with standard inlet designs (26-28) and isokinetic methods* (10,11). Thus the current state-of-the-art is adequate and no further development necessary.

Likewise, for the probe design, current procedures are applicable to the case of asbestos sampling (5,7 App. G). The probe should transport the sampled asbestos from the inlet to the collection medium or monitoring instrument without disrupting the sample. In many sampling instances a heated or special noncorrosive probe is required, however the industry survey (Table 2) reveals that for the case of asbestos emissions no extreme environments are likely to be encountered.

At this juncture it is also appropriate to mention that other monitoring techniques necessarily associated with any standard sampling method such as flow monitoring have been adequately developed for other methods and are applicable to an asbestos method. Thus no further treatment of such is given in this report.

EXTRANEOUS MATERIAL SEPARATION

Undesirable nonasbestos material (extraneous material) will be present (see Table 1) in the sampling environment thus complicating the measurement of the airborne asbestos. Ideally one would like to remove the extraneous material at the time of sampling to facilitate ease of subsequent analysis.

Classically, extraneous material has been removed by employing differences in either physical or chemical form between the undesired material and the material of interest. For the case at hand, the broad size range of asbestos present stretching from the diffusion dominated region (0.03 μm) to the interial behavior region (4.0 μm) makes complete separation of extraneous material from the asbestos impossible by traditional mechanical means such as impactors or cyclones. However if further investigation were to reveal a

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*Only for the case of extremely long (on the order of cm) or clustered asbestos fibers, neither of which are likely emissions from the industries considered, will standard particulate inlet considerations not be applicable.

large portion of the extraneous material to have a characteristic size larger than 4 μm then removal by an inertial device during sampling could be quite beneficial. The apparent nonhomogeneous form of the extraneous material makes other types of separation (such as magnetic for metallic material) impractical. Thus, at this time, it would appear that chemical or pyrolytic separation of the nonasbestos material holds the most promise. Such techniques are more appropriately suited to analytical procedures than sampling procedures and as such are not of concern within the scope of this study.

COLLECTION TECHNIQUES

Because of their nonsphericity, fibers pose a unique sampling problem. The physical behavior of asbestos fibers in air has been reviewed elsewhere (28). The short discussion which follows will be limited to concerns directly related to collection and detection of asbestos.

Generally speaking detection and analysis of asbestos may be accomplished either by direct measurements or by collection on a substrate coupled with subsequent analysis. Whereas techniques of the former type have advantages of real-time data gathering and ease of operation there are serious drawbacks limiting their application to fiber detection. With the latter techniques problems may arise during handling and preparation of samples for analyses.

Direct Detection

Techniques classically used to directly measure particle size and/or concentration include electrical mobility, diffusive mobility, inertial separation and optical analyses. Of these only the optical techniques have been pursued to a great extent for analysis of fibers. Because of the nonspherical nature of fibers and interference by nonfibrous aerosols, direct measurement using electrical, diffusive or inertial techniques does not appear promising.

Optical measurements of fibrous aerosols have been conducted with some success though limitations do exist. There is some evidence (2,29), that fiber concentration can be measured with an optical particle counter. However there may be errors associated with fiber orientation. The presence of nonfibrous particles is not considered. Also the technique, as with other optical techniques, is not applicable to fibers with diameters less than about 0.3 μm. Lillienfeld (30) presents an optical instrument which is designed to overcome fiber orientation problems (and thus nonfibrous aerosol interference), but is still quite limited as to size of fiber detectable and concentration range both maximum and minimum.

Given the current state-of-the-art there is no instrument which is universally adequate for direct measurement of asbestos fiber aerosol. Furthermore development of such an instrument and subsequent incorporation into a standard method does not appear feasible in the near term.

Fiber Collection

The most prevalent and well tested methods of asbestos fiber detection involve collecting the fibers and subsequently analyzing them by microscope techniques. The collection mechanism and substrate must be compatible not only with the sampling situation but also with the analytical procedure. Attention has been given to collection of fibers with various filter media, electrostatic and thermal precipitation, impingers, and cyclones.

Thermal Precipitation--

Thermal precipitation of asbestos fibers ontc a suitable medium is a possible collection mechanism although low efficiencies for long fibers have been noted (29). The most detrimental characteristics of this technique however may be the long sampling periods typically required for adequate collection, on the order of months for ambient concentrations (2). This drawback may be overcome by using a larger precipitation unit however subsequent practical problems associated with using the precipitator and handling the samples may result. For these reasons thermal precipitation does not appear to be a promising collection technique.

Electrostatic Precipitation--

Electrostatic precipitation suffers many of the same drawbacks as thermal precipitation for application to the subject sampling situation, however a recently developed instrument (21) has given promise to using an electrostatic sampler in source emissions environments. High efficiences (87-100 percent) were reported for several types of applications. Although the currently available commercial instrument would need to be modified (especially with regard to flow rate determination) it would appear to be feasible for collecting asbestos fibers. The use of such a system has the advantage of collecting the sample on a cylindrical tube (aluminum in the current instrument) which could conceivably be sealed in the field for easy transport back to the laboratory without fear of losing or disrupting the sample. Compatibility of the collection substrate and preparation of samples for analysis would be key issues in determing utility of such an electrostatic collection scheme in a standard sampling method.

Collection by Impingers--

Impingers may also be used to collect asbestos fibers. By collecting the fibers in liquid many of the handling and transporation problems associated with filters are eliminated and the collection is highly suitable for most analytical procedures. In addition a greater volume of sample may be collected with an impinger. However the collection efficiency is poor for submicrometer fibers, and therefore for the case of asbestos with many fine fibers and fibrils, impinger collection alone is not appropriate. However impingers may be useful as a precollection method to avoid undesirable heavy loading on high efficiency filters.

Air Filtration--

The use of high efficiency membrane filters has traditionally been the desired method for collecting asbestos fibers. However, the use of filters for collection and subsequent preparation for analysis is not without problems.

When sampling asbestos with high efficiency filters the investigator must consider the analytical procedure in making his selection. Clearly glass fiber filters are unacceptable because of the possible ambiguity which may result in viewing the asbestos fibers among the glass fiber substrate. Of the common filter materials prominantly used in the U. S. only cellulose ester membrane or polycarbonate membrane filters are realistic choices.

The cellulose ester filter (a spongelike collection substrate) has the advantage of superior handling characteristics compared to polycarbonate filters and has a collection efficiency of nearly 100 percent for all size fibers at all flow rates. The only disadvantages are that the pressure drop across the cellulose ester is greater than that for the polycarbonate at a given face velocity and some loss of fibers is likely to occur during preparation for analysis.

The polycarbonate filter is less than 100 percent efficient for certain circumstances (2) and is difficult to handle in field applications. However the polycarbonate is most suited to the electron microscope analytical procedure (1).

The constraints associated with EM analysis are important considerations when filters are used to collect asbestos. The three general constraints of uniformity of particle dispersion on the EM grid, loading, and nonasbestos interference were discussed in Section 5. With respect to filtration, filter loading is a real problem. Complications will result if the loading of the asbestos material is either too light (leading to statistically invalid conclusions) or two heavy (making counting, sizing and subsequent data analysis impractical for even the most patient microscopist). They can be reduced during the collection phase by adjusting sampling rates and times to achieve a loading in the optimal range. This, however requires a good deal of knowledge about the sampling environment. If light or heavy samples are obtained, the only solution then lies in concentrating or diluting the samples as required during preparation. These procedures are time consuming and add possibilities of further error in the data.

Inertial Collection--

Cyclones are commonly used to collect particulate matter in emission sources (31). A cyclone cannot be used to collect fibrils or the smallest fibers because of their small inertia. Cyclones could be used to collect fibers and fiber bundles if in the collection process, the fibers and bundles were not broken into fine fibers and fibrils on the cyclone walls. Cyclones do not appear to be suitable for collecting asbestos over the required asbestos size range.

SECTION 7

FEASIBILITY ASSESSMENT

The feasibility of developing a method for asbestos sampling depends on:

(a) Developing an appropriate collection technique(s),

(b) Determining the ability to remove extraneous material,

and (c) Evaluating the applicability of current inlet and probe technology to the selected collection technique.

After review of each of these elements it has been concluded that the development of a standard method for sampling asbestos is feasible. This study has not uncovered any limiting industry anamolies or unsurmountable technical problems. The sampling method would require different inlet and probe configurations for fugitive and source sampling, respectively, however the same collection technique(s) should be applicable.

COLLECTION TECHNIQUES

As indicated in previous sections the practical options for the collection technique component are limited to either (a) electrostatic precipiation or (b) membrane filter collection by cellulose ester membrane or polycarbonate filters. These techniques may be supplemented by precollection with an impinger to reduce loading. Table 7 summarizes the collection options with the corresponding concerns associated with each and the advantages of each.

Though a significant effort would be required to develop a standard method with one of these techniques, such a development seems quite feasible. This statement of feasibility is supported by the field experience of Battelle and others. Ultimately however the feasibility of an actual method can only be demonstrated through a development program.

EXTRANEOUS MATERIAL REMOVAL

Past experience of analysts would indicate that it is feasible to separate asbestos and nonasbestos material in the laboratory. However the usefulness of

TABLE 7. SUMMARY OF COLLECTION OPTIONS

Collection Technique	Areas of Concern	Advantages
A. Electrostatic Collector	1. Adaptability of current commercial design to controlled flow design 2. Compatability of aluminum substrate with analytical procedures	1. High loading capacity compared with filters 2. Ease of handling and maintenance of sample
B. Filter (Cellulose ester membrane)	1. Loading constraints in environment of interest 2. Pressure drop across filter and associated pumping requirements 3. Preparation procedures for subsequent EM analysis	1. High efficiency of collection 2. East of handling and transport
C. Filter (Polycarbonate)	1. Loading constraints in environment of interest 2. Efficiency of filter for asbestos collection 3. These filters load quickly developing a high pressure drop 4. Handling and transport problems associated with field applications	1. Compatability with analytical procedures 2. Low pressure drop across a lightly loaded filter
D. Impinger & Electrostatic collector	1. Same as A 2. Influence of impinger on electrostatic collector operation 3. Requirement for handling two media (impinger and collector) and making two analyses for each sample taken	1. High loading capacity 2. Ease of handling
E. Impinger & Filter	1. Same as B or C 2. Requirement for handling two media (impinger and filter) and making two analyses for each sample taken	1. High collection efficiency 2. High loading capacity 3. Compatibility with analytical procedures

as well as the feasibility of a separation during sampling can only be assessed after more thorough data characterizing the industry emissions is obtained and reviewed.

APPLICABILITY OF INLET AND PROBE TECHNOLOGY

The applicability of inlet and probe technology to the selected techniques is feasible. The demonstrated versatility of the developed technology would lead to the conclusion that the applicability to an asbestos sampling method is simply an engineering task for both fugitive and source sampling applications.

SECTION 8

APPROACH TO SYSTEM DEVELOPMENT

We recommend proceeding with a system development program on a component-wise basis. This would include mutually pursuing the R&D efforts outlined below for collection technique and extraneous material separation. Subsequently the most promising techniques should be incorporated with each other and current state-of-the-art inlet and probe designs to form a sampling system(s). The integration efforts must be assessed under the constraints discussed above. Consideration must also be given to the practicality (with regard to both engineering and utility aspects) of the system. Finally, the complete system must be laboratory checked and field demonstrated. Figure 2 shows a flow chart for such a research program.

RESEARCH AND DEVELOPMENT FOR EXTRANEOUS MATERIAL REMOVAL

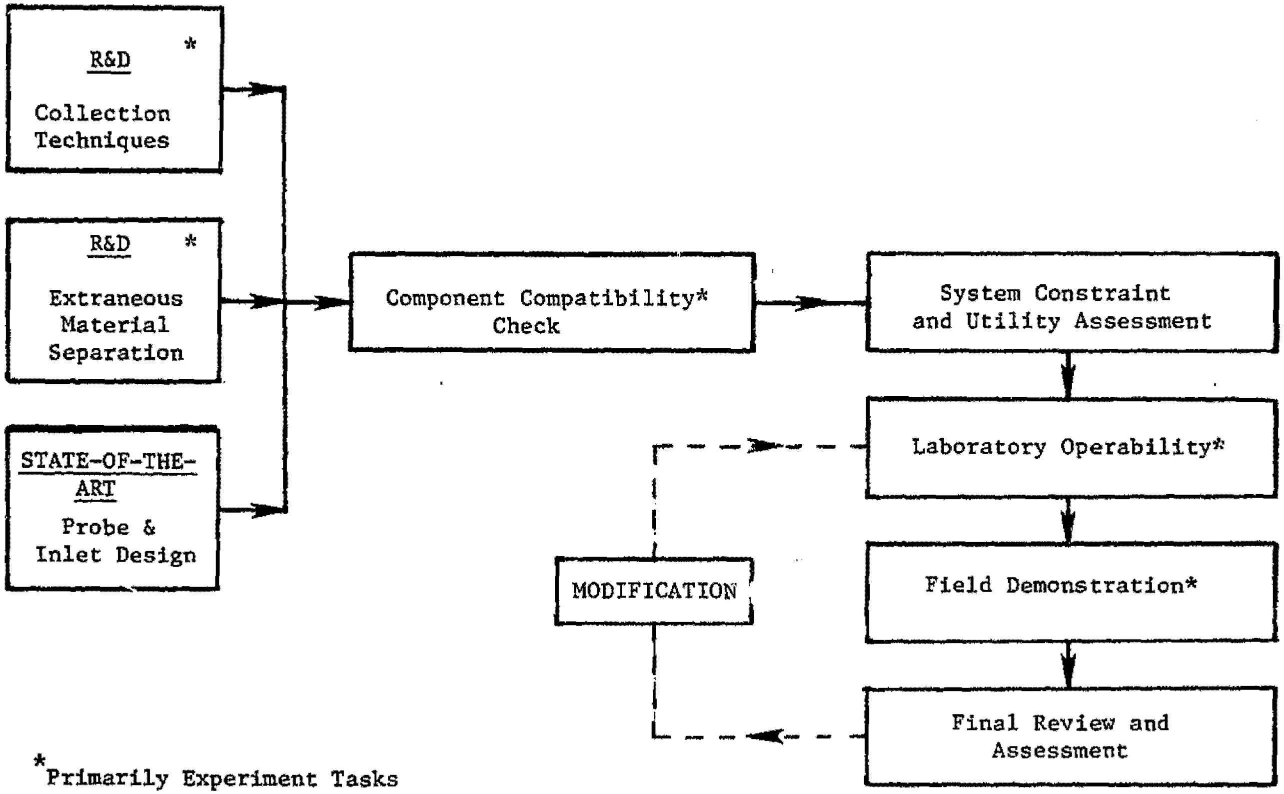
Achievement of the ability to separate extraneous material from asbestos without altering the asbestos size distribution would be a major breakthrough. Separation during sampling does not appear promising. Further research on separation techniques should begin with the laboratory techniques of ashing, sonification, and two phase liquid separation to determine how each of these techniques affects the collected asbestos size distribution.

RESEARCH AND DEVELOPMENT FOR COLLECTION TECHNIQUES

Electrostatic Collector

A feasible asbestos sampling method might incorporate an electrostatic collector to remove the asbestos from the air. A device designed and tested to perform such a task in certain circumstances is currently commercially available (21) at a reasonable price giving promise to the possibility that such a collection device could practically be incorporated into a standardized method. To do so however will require an appropriate research effort.

The necessary research program would include several tasks: (a) suitability and/or adaptability of the isokinetic electrostatic sampler (21) to the



*Primarily Experiment Tasks

Figure 2. Sampling method development program flow chart.

specific situations of concern; (b) compatibility of method with analytical procedures; (c) compatibility of method with other system components and (d) field test, calibration and verification of the method as part of the final system.

(a) Suitability and/or adaptability of the sampler to airborne asbestos collection. This task would primarily involve investigation of (i) flow monitoring possibilities of the current device, and (ii) loading and disruption characteristics. The current device is designed to sample isokinetically with no provisions for flow monitoring. As part of a standardized method, it will be necessary to monitor the flow volume in order to subsequently determine concentration levels. This will require external monitoring of the air flow around the sampler or adaptation of the sampler to a forced flow sampling train through which gas flow can be monitored using traditional methods. The electrostatic principle has shown promise with regard to high-collection efficiency in an emissions environment, however a complete R&D effort should include as part of this initial task a laboratory determination of the loading limits in the specific case of asbestos collection and a specification of efficiency as a function of loading for the appropriate electrostatic device.

(b) Compatibility with analytical procedure. Concurrently with the first task a study should be pursued to determine (i) the problems associated with extracting the sample from the collector and preparing the corresponding samples suitable for analysis, and (ii) the bias such a procedure generates (e.g., agglomeration and clustering of fibers or break-up may occur during collection and handling thus leading to unrepresentative results).

(c) Compatibility with other components. This task would assess the constraints placed on other selected components by the selection of electrostatic collection. This task would include a laboratory demonstration of a complete system employing electrostatic collection.

(d) Field tests. As a final step in system development field tests should be conducted using the laboratory proven system(s) and intercomparisons (if appropriate) of the systems performance made.

Filters

As pointed out by Spurny and Stöber (32) a need exists to standardize the filter type (if indeed a filter collection is to be used) employed for asbestos collection. No experimental data are available to quantify concerns of the field-worthiness, high efficiency and small handling losses of cellulose ester membrane filters. Therefore, since we are faced with a choice of two filter media, cellulose ester or polycarbonate, a comparative research effort should be undertaken to document their respective merits for each phase of the required task; (i) collection efficiency (including loading constraints), (ii) handling losses and (iii) preparation losses and biasing. Such a task would be experimental in nature aided to a certain degree by the past work of Gentry, Spurny and others (2,32,33,34). The selection of the filter medium could then be made on a sound scientific basis.

After the appropriate medium has been selected the research effort should continue, as with the electrostatic collector, to include component compatibility and field tests.

Impingers

The use of impingers will be appropriate only if loading is of concern. Thus further R&D regarding the usefulness of impingers for asbestos collection should be deferred at this point.

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APPENDIX A

DESCRIPTION OF THE INDUSTRIES

ASBESTOS ORE PRODUCTION

Asbestos production can be divided into the two phases mining and milling. Mining operations include (1) drilling to place explosives, (2) blasting, (3) surface scraping, (4) sorting, (5) screening, (6) conveying, (7) shoveling, (8) transport by truck, and (9) dumping (A-1).

Asbestos Mining

Two open pit mining operations were visited in California. At the first mine blasting is conducted every other day. Slurry explosives are used to reduce dust generation. The explosives are detonated in 6 inch diameter, 33 inch deep holes. Moisture and asbestos content are about 10 and 3.8 percent respectively.

The ore is transported from the mine to the ore preparation area where it is fed into a series of crushers and screens. Initially a jaw crusher reduces the size of the ore to 5 inches in combination with screens. A water spray is used at the discharge of the jaw crusher to reduce the dust. The ore then travels to a cone crusher where it is reduced to 1-1/8 inches and finally an impact crusher in which it is reduced to 0.5 inches. At this point ore over 0.5 inches in diameter is discarded. The remaining ore is transported via a 1500-ft covered conveyor to the mill site. Three baghouses are used to control the dust in the ore preparation stage. Dust collected by the baghouses is mixed with water in a screw conveyor to form a paste which is conveyed to a nearby disposal site.

At the second mine moisture and asbestos concentrations are 16-18 and 60 percent. The ore is screened to one inch at the mine before the 60 mile transit to the mill.

Asbestos Milling Operations

Milling operations consist of extracting asbestos from the ore, cleaning, and grading the asbestos. Asbestos is separated from the rock by means of crushing the ore to liberate the asbestos and then extracting the asbestos by aspiration over vibrating screens.

In the first milling operation which was visited, the moisture content of the ore is reduced to less than two percent by either a vertical dryer or a nearly horizontal rotary kiln. The exhaust temperature from the dryers is about 250 F. The emissions from the dryers are controlled by baghouses. After the ore is dried it is conveyed to an enclosed storage area kept under negative pressure.

The finely crushed and dried ore is conveyed from the storage area to the mill where the asbestos fibers are separated from the coexisting rock by means of a series of vibrating screens, fiberizers, and shaker screens. The screens are fitted with aspiration hoods that entrain the asbestos into an air stream which then flows through cyclone collectors. The cyclones grade the fibers into three classes: short, medium, and long. The rock is expelled to an exterior tailings dump.

The asbestos fibers are machine packaged in a hooded area. The smaller fibers are compressed into dense bundles, while the longer fibers are blown into containers and loosely packed to minimize fiber damage. Two types of bags are used--multi-ply paper and reinforced plastic bags.

Emissions from the milling operation are controlled by baghouses. The baghouse catch is transported to a belt conveyor via enclosed screw conveyors and chutes. The belt conveyor deposits the material into a mixing screw conveyor which discharges wetted waste onto belt conveyors for transport and disposal. A dust suppressant chemical is added at the mixing screw conveyor.

A wet milling process is used at the second milling operation which was visited. As the ore enters the mill, it is slurried by spraying with water as it passes over a 1/4 inch screen. The fine fraction is then passed through a cyclone separator and through a series of fiber opening and separation stages. The iron oxides are removed by magnetic separators.

The separated asbestos slurry is filtered through a large filter press system containing six banks, each about 30 feet long. Shriver filter presses with 48 x 48 inch plates operating at 80 psi pressure remove the water.

The filtered asbestos is then extruded through 1/2 inch orifices and conveyed into a dryer. A knife blade cuts the pellets into about one inch lengths. A rotary dryer with concurrent air flow is used to dry the pellets. The dryer operates at 1200 F, with an exhaust temperature of approximately 250 F. Some of the pellets are broken in mills to release the fibers, others are shipped in pellet form.

The primary control is via three baghouses, each of which possesses an exhaust duct of sufficient length to permit appropriate sampling. The exhaust gas from the dryer is hot (∿250 F) and contains moisture, necessitating the use of insulated baghouses to avoid condensation as the gases cool. The bags are the pulse-air cleaning type.

The waste from the baghouses and the tailings from the milling operation are conveyed to the dump site in a wet condition. When the waste reaches a pre-determined level, it is covered with a foot or more of top soil and seeded with rye.

TACONITE PRODUCTION

Taconite production was considered in this program because amphibole fibers contained in the ore are released from the ore as it is crushed and further processed.

Taconite production activities can be broadly classified into four areas: mining, beneficiation, agglomeration, and handling of taconite and tailings. Each of the activities is briefly described below.

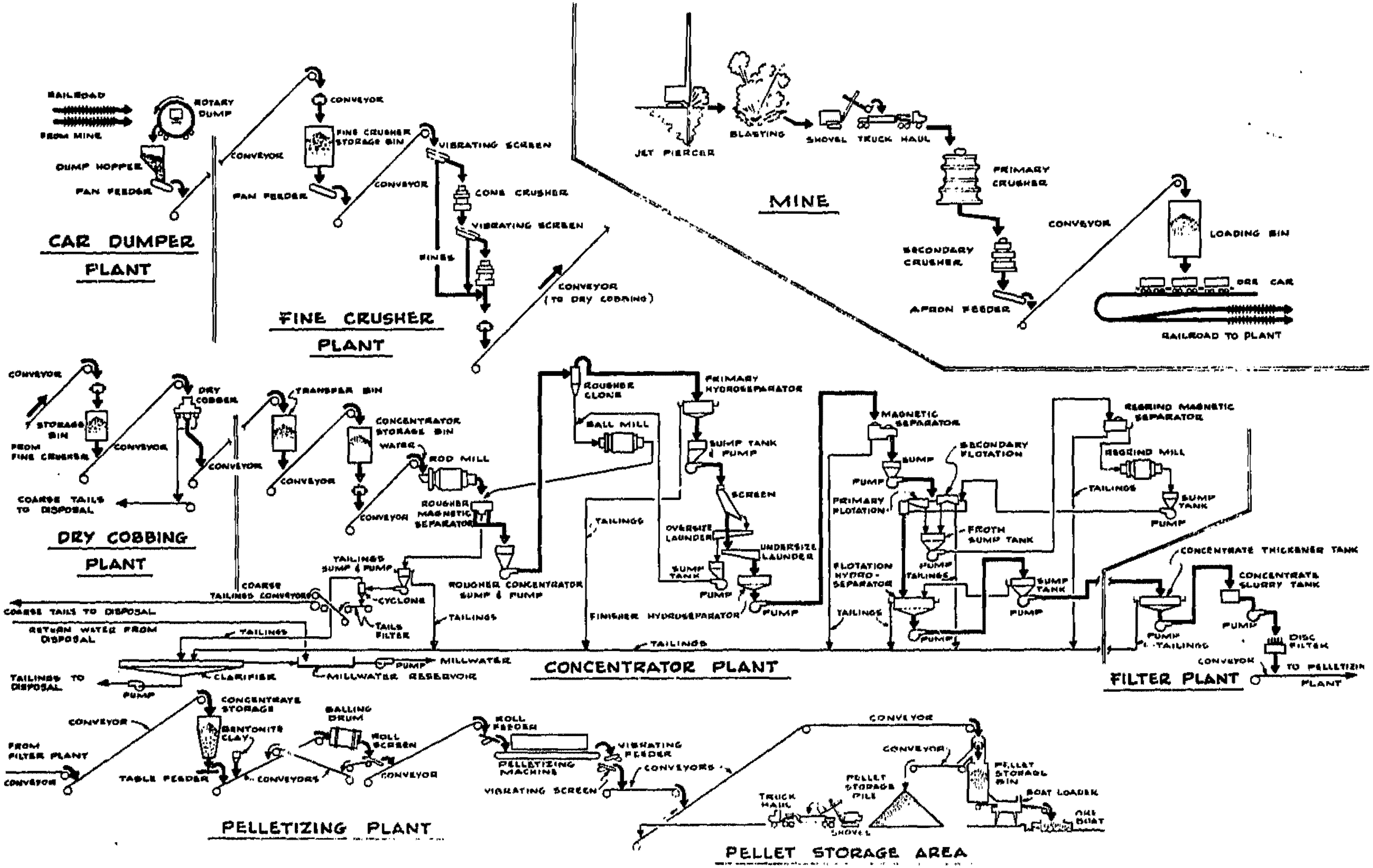


Figure A-1. Process flow diagram for taconite production.

Mining

Mining operations include drilling, blasting, removing, and hauling rock. Three principal types of drills are used: jet piercers, rotary drills, and percussion drills. Figure A-1 is a diagram of the specific process visited under the current program. In this mine a jet piercer is used. Emissions from the mining process are uncontrolled.

Beneficiation

Iron ore beneficiation includes crushing, grinding, and concentrating operations. Crushing circuits usually consist of primary, secondary, and tertiary crushers combined with screens to separate the desired fraction.

Grinding circuits consist of rod mill-ball mill combinations or autogeneous mills. Generally water is added at this point and the material is handled as a slurry through the concentrator. In both cases the material is subjected to size classification by screens or cyclones and concentration by magnetic separators, gravity separators, flotation, or some combination of these methods.

Typically the rod mill discharge is pumped to magnetic separators referred to as cobbers. The nonmagnetic material is discarded to the tailings. Some plants classify this material to separate the coarse tailings from the fine tailings. These plants generally use the coarse tailings for dike construction or road building material whereas the fine material is pumped directly to the tailings thickeners. The magnetic fraction is pumped to primary ball mills and ground further; the ball mill discharge is then pumped to classifying cyclones with the coarse material (underflow) returning to the ball mill and the fine material (overflow) pumped to rougher magnetic separators. The rougher magnetic separators discard the nonmagnetic fraction to the tailings and the magnetic fraction is ground to a finer size in secondary ball mills. The secondary ball mills discharge to classifying cyclones with the coarse material returning to the rougher magnetic separators or secondary ball mills. The finer material is pumped to either a dewatering device such as hydroseparators, thickeners, siphonsizers, etc., or magnetic separators. In some plants there are cleaner and finisher magnetic separators. In essence, some plants use two stages of magnetic separation; others use three or four stages of magnetic separation. In addition to the above flow schemes, some plants use gravity separation devices such as jigs, spirals, heavy media separators, flotation, or various combinations of these techniques. Also some plants are using autogeneous grinding circuits instead of the conventional methods described above.

The final product from the beneficiation section is a filtered iron concentrate containing approximately 9 percent moisture, 60 percent iron, and 2 to 7 percent silica with a size ranging from 80 percent minus 0.0445 mm (325 mesh) to 90 percent minus 0.0127 mm (500 mesh). This material is transferred to large bins which feed the agglomeration section.

At the site visited in this program beneficiation operations take place at the fine crusher, dry cobbing, and concentrator plants. When the ore cars arrive at the plant, they are automatically fed into a rotary dumpster at the car dumper plant as shown in Figure A-1. The dumpster dumps two 85 long ton railroad cars simultaneously without uncoupling. The process is capable of dumping 8,000 long tons per hour of -4 in. taconite. The ore is dumped into a large hopper below the railroad tracks and processed through a pan feeder on the way to the fine crusher plant. Dust is generated by the dumping operation and the pan feeder. Dust control from this operation is achieved by drawing the air in the hoppers and pan feeder through a baghouse located near the roof of the plant.

From the car dumper plant the ore is conveyed to the fine crusher plant where it is further crushed and screened before entering the dry dobbing plant. The coarse tailings are separated from the ore at this location. Up to this point in the process all operations have been "dry" and dust control is achieved by drawing the surrounding air through bag houses.

When the ore enters the concentrator plant, water is added for the first time. The slurry then passes through a series of rod mills, magnetic separators, sump concentrators, and primary and secondary hydroseparators. Fine tailings are removed during each operation.

The ore slurry is pumped to the filtering plant where the final tailings are removed. This is accomplished via several large concentrate thickener tanks, slurry tanks and a large disc type filter. Dust is controlled in the concentrator plant and filter plant by cyclone collectors.

Agglomeration

Agglomeration operations in the taconite industry produce sinter and pellets. Sintering causes the fine particles to bond together into porous agglomerates which are strong enough to diminish dusting problems but porous emough to permit good gas dispersion through a bed or the material in a furnace. Pelletizing operations form balls in the diameter range 0.95 to 1.27 cm.

As shown in Figure A-1, in the pelletizing plant Bentonite clay is mixed with the ore in a balling drum. The material is then screened and fed into a pelletizing machine. The pelletizer is gas fired and operates at 1700 F. As the pellets pass from the pelletizer, they are screened (vibrating type) and conveyed to an outside pellet storage area. The air from the pelletizing machine is exhausted into a wet electrostatic precipitator unit.

Handling of Taconite and Tailings

Taconite pellets are conveyed to large storage piles near the plant to await transport. Dusting from these piles and from ventilator stacks of loading silos constitute potential fugitive emission sources.

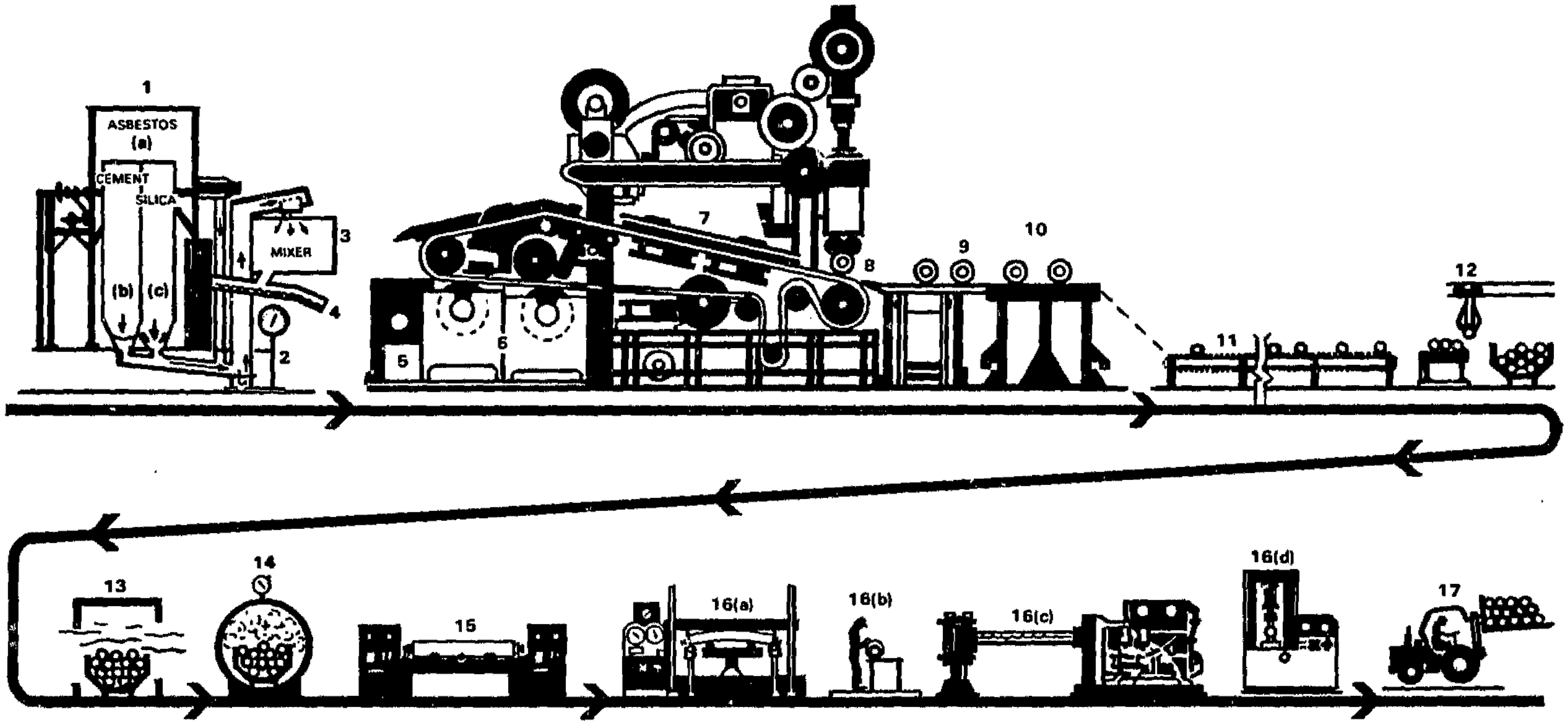
Tailings are conveyed to a disposal site by rail and water slurry pipelines. At the site visited in this program, tailings are dumped into a man-made lake to minimize fugitive emissions from erosion.

ASBESTOS-CEMENT PRODUCTS

The largest single use of asbestos fibers in the U.S. occurs in the manufacture of asbestos-cement (AC) products of which the AC pipe industry is the largest segment. A flow chart for the production of AC pipe is shown in Figure A-2.

Two AC pipe plants were visited. The first plant contains two production lines. The AC pipe is made from a blend of asbestos, Portland cement, and sand.

The asbestos used is primarily chrysotile and is a blend from two different sources--South Africa and Canada. No U.S. asbestos is used in the process. The asbestos is shipped to the plant in 100 lb plastic bags. Upon arrival each bag is inspected and repairs are made immediately if



FLOW CHART OF A-C PIPE MANUFACTURE

1. **Production line bins**—raw materials enter the line as follows:
   - (a) **asbestos**—from the willow where the fiber is separated into individual strands and thoroughly mixed
   - (b) **cement**—directly from receiving hoppers
   - (c) **silica**—from grinding mill
2. **Electronic Scales**—for precise weighing; accurate control for uniform results
3. **Wet Mixer**—blends raw materials thoroughly
4. **Conveying Trough**—water carries stock to wet mix vat
5. **Wet Mix Vat**—thorough dispersion of reinforcing fibers
6. **Screen Cylinder Mold**—picks up slurry and deposits on moving felt
7. **Vacuum Box**—excess water removed
8. **Felt deposits stock on Mandrel**—wall thickness built up under pressure to proper size
9. **Mandrel (with pipe)**—removed from machine; next mandrel positioned
10. **Loosener**—frees pipe from mandrel; prevents distortion
11. **Slow-down Conveyor**—provides pre-cure time; initial set
12. **Mandrels**—removed and pipe stencilled for identification
13. **Air Cure Room**—strict control of time, temperature and humidity
14. **Autoclaves**—high pressure steam curing imparts maximum strength and excellent chemical stability
15. **Lathes**—trim and machine ends to exact dimensions
16. **Testing Equipment**—checks for adherence to rigid specifications
   - (a) **flexure testing** machine
   - (b) **inspection**
   - (c) **hydrostatic tester**
   - (d) **crush tester** (laboratory)
17. **Materials Handling Equipment**—transfers pipe to shipping area

Figure A-2. Process flow diagram for A-C pipe production.

required. The bags are opened in a "white room" and dumped onto a conveyer (under a hood exhaust) which transports it to a willows machine. The willows machine breaks open the asbestos fibers and fluffs them in order to achieve better mixing. The asbestos is then conveyed to a large holding bin from which it is dry mixed with the cement and silica. The blending formula varies with the type of pipe being manufactured. The empty plastic bags (which contained the asbestos) are placed into a larger plastic bag, sealed, and labeled "asbestos hazard". The larger plastic bags are subsequently autoclaved shrinking them into small bundles. The bundles are then disposed of at the waste disposal site.

After the raw materials are dry mixed, a homogeneous slurry is formed by the addition of water. The slurry is delivered to cylinder vats for deposition onto horizontal screen cylinder molds. A thin layer of asbestos-cement is formed on an endless felt conveyer. After partial drying the sheet is wound around a mandrel into pipestock of the desired thickness. The pipe section wrapped around the mandrel is removed from the machine and then freed (loosened) from the mandrel by an electrolytic loosener. A one-hour precure time is provided by a very slow moving conveyer before the mandrel is removed.

After the mandrel is removed the pipe is stenciled for identification and transported to a temperature-humidity controlled air-cure room where it remains for approximately 12 hours. Final curing is achieved in one of seven high-pressure autoclaves. The autoclaves operate at 120 psi, under live steam at 340 F. The process takes about 15 hours--four hours to reach steady-state, eight hours soak time, and three hours to cool.

After autoclaving, the pipe is fed into an automated lathe and both ends are simultaneously machined to ensure proper mating with connectors. This operation takes approximately 15 seconds, and produces large quantities of dry, asbestos-containing waste. Rubber gaskets and couplings are added at this point, and the pipe subjected to a series of tests on the following machines: flex testing machine, hydrostatic tester (500 to 750 psi), and crush tester. Pipes passing the above tests are transferred to the storage and shipping area.

All machining operations at the plant are hooded, and the exhaust gases vented to a central baghouse. In addition, each machine is supplied with a three inch vacuum line which is used to thoroughly clean the machines at the end of each shift. The baghouse waste is sprayed with water and collected in metal dumpsters. Each dumpster holds approximately 4,000 lbs of waste and they collect between 16 and 18 loads every 24 hours. The waste is trucked to a landfill disposal site located on the premises.

At the second AC pipe plant, both chrysotile and crocidolite are used in manufacturing AC pipe. The chrysotile which is used comes from California and Quebec. The crocidolite is imported from South Africa. The asbestos is shipped to the plant in plastic bags. The bags are opened in a "white room", approximately 8 ft wide by 10 ft long. The asbestos is dumped onto a conveyer, under an exhaust hood, and transported to a holding tank where it is mixed with cement and silica. The blending formula varies with the type of pipe being made. The blend is obtained by dry mixing, and then fed to a large tank where a slurry is formed by the addition of water. The slurry is distributed via a 13 ft wide trough into two vats where two thin layers of felt are formed and simultaneously wrapped around a mandrel. When the desired thickness is obtained, the pipes pass progressively through two curing ovens. The first oven has a temperature gradient of approximately 350 F (front) to 250 F (back). The second oven is controlled at 140 F. From the curing ovens, the pipe is loaded onto carts and placed into one of three large autoclaves. Autoclaving takes approximately 12 hours--one hour up, one hour down, with a 10 hour soaking period.

After autoclaving, the pipe is fed into a lathe (automated system) and both ends are simultaneously beveled. This operation takes approximately 15 seconds. The pipe is then hydrotested at 525 psi, a rubber gasket is added and the pipe is ready for shipment.

In addition to the main process line, there are several smaller process areas which are primarily made up of coupling lathes and cut-off saws. Above the pipe forming line there are two large roof exhaust fans. These exhaust fans, plus a 3 ft. square exhaust duct between the curing ovens, are primarily heat removal systems.

The smaller process areas, scattered throughout the plant, each contain a hood exhaust system. The exhaust gases are vented, via a series of ducts, to two dust collectors (baghouse type with shaker cleaning). The baghouses are automated and incorporate a 2 hour and 15 minutes cleaning frequency. The waste is collected in plastic bags, sealed, labeled as asbestos hazard and stored. A major portion of the waste is recycled back into the system. However, when the amount of waste exceeds the storage capacity it is transported to a waste disposal site and covered with top soil. The water and solid-waste are both recycled back to the process whenever possible. Excess waste is bagged and disposed of at the waste-site.

Three potential sites exist at this plant for sampling controlled asbestos emissions. These sites are (a) the baghouse exhaust ducts, (b) the exhaust duct between the curing ovens, and (c) the roof top exhaust fans. There are two types of fugitive emissions which could contain asbestos: (a) the autoclave exhaust and (b) ambient airflow through openings in the building structure.

FRICTION PRODUCTS

Major categories of production processes for asbestos friction products are: (a) dry-mixed and wet-mixed, molded brake linings, (b) wet-mixed, two-roll forming brake linings and clutch facings, and (c) woven, wire-reinforced brake linings and clutch facings (1). The production processes can be segmented into the following general operations: mixing, forming and processing, curing, and finishing.

Mixing

As implied by the name, mixing of input streams for the first production process is accomplished either by dry mixing of asbestos, friction material (e.g., aluminum oxide), and bonding agent or wet mixing in blenders. Input streams for wet mixing in the second process include asbestos, friction material, and solvents. Mixing is accomplished in a blender. The input streams for the third process include wire-reinforced woven tape or cloth, asbestos, and a friction material bath. Mixing is accomplished by running the continuous strip of tape or cloth through a bath.

Forming and Processing

Operations encountered in the molding process include preforming in a press, cutting and grinding into flat blanks, steam heating to soften the resin, and bending in presses. Operations encountered in the second production process utilizing roll-forming include forming a continuous sheet of material in the two-roll mill (similar in concept to paper production), chopping or punching, drying, and bending when required. Operations encountered in the third production process include drying the roll after it has passed through the bath, pressing, and cutting.

Curing

Curing is accomplished by baking ovens in all three production processes.

Finishing

Finishing operations vary according to the process and product. These operations generally include sanding, grinding, drilling, dusting, inspecting, and branding.

Emissions

Potential emissions of asbestos are most likely to occur in the dry mixing operations and in the finishing operations. Control technology for these operations frequently involves fabric filtration with baghouses. The finishing operations in the friction plant visited in this program consist of cutting, grinding, sanding, drilling, and dusting. Emissions are controlled by passing the surrounding air through baghouses. Nonasbestos material includes resin, graphite, and carbon black. The waste from the baghouses is transported to a pelletizer by means of a screw conveyor. The waste is mixed with cement and water in the pelletizer, and the resulting pellets are used as landfill.

ASBESTOS FELT AND PAPER

In general, asbestos paper is produced by first mixing asbestos, binder, pulp and water into stock for subsequent handling. Typical binders are starch, glue, water glass, resins, latex, and gypsum (A-1). A thin uniform layer of stock is deposited onto a screen and subsequently dried and pressed between rolls. The continuous sheet then passes over heated rolls and calender rolls. The paper is cut to size as it is wound onto a spindle. Potential emissions arise from the handling of asbestos as it enters the process. Baghouses are used to control these emissions.

A block diagram of the asbestos roofing felt plant which was visited as part of the industry survey is shown in Figure A-3. The manufacturing process closely resembles the general process described above.

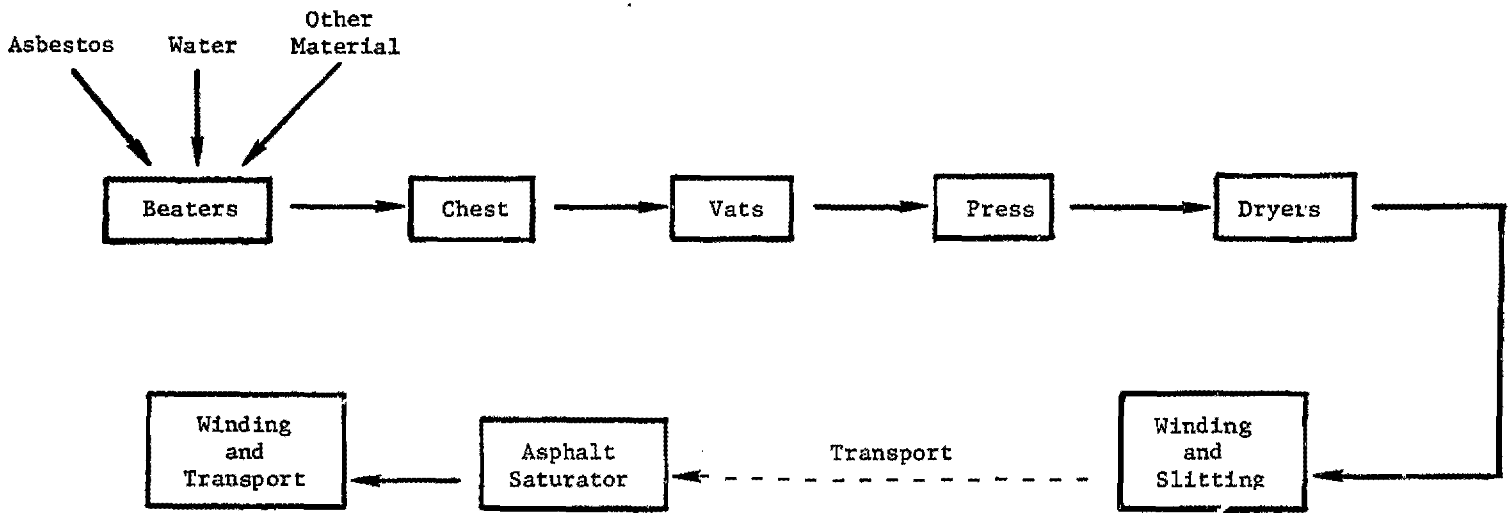


FIGURE A-3. BLOCK DIAGRAM OF ASBESTOS FELT MANUFACTURING OPERATIONS

At the slitting operation the full reel of felt is cut down to exact size rolls (by width) with slitter knives. The dust and excess trim is sucked into pipes and blown to a cyclone. The trim separated by the cyclone is returned to the beaters to reenter the process. The dust escaping the cyclone goes to a baghouse. The dust that is captured in the baghouse is also returned to the beaters.

Emissions from the beaters are controlled by a wet impinger. The impinger collects dust in the moist air stream by injecting a water spray into the air stream. The dust particles are incorporated into the larger water droplets through collisions. These water droplets are then removed from the air stream by impaction. Material captured by the impinger is returned to the beaters. The exhaust from the impinger unit is saturated with water vapor.

The final operation in the process involves saturating the continuous roll of felt with asphalt in a hot asphalt bath. Emissions from this operation pass through a filter to remove organic vapors. The filter is a continuous roll of fiberglass passing through the exhaust duct of the saturator. The filter is not designed as a particulate emission control device.

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