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SUPPLEMENTAL ANALYSIS OF THE TECHNOLOGICAL FEASIBILITY AND ECONOMIC IMPLICATIONS OF A 0.1 FIBER PER CUBIC CENTIMETER EXPOSURE LIMIT FOR ASBESTOS

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Prepared for:

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1.0 EXECUTIVE SUMMARY

The National Institute of Occupational Safety and Health has recommended a 0.1 fiber/cc TWA exposure limit and a 0.5 fiber/cc ceiling exposure limit be set as permissible limits for asbestos exposures in the work place. Accordingly, the Occupational Safety and Health Administration (OSHA) contracted CONSAD Research Corporation to conduct a supplementary analysis of these lower exposure limits with regard to the feasibility of control and economic implications to affected industries. Emphasis was also placed on determining potential substitutes for asbestos and competitive products. A parallel, yet extremely important change was to evaluate the feasibility of monitoring asbestos exposures at the 0.1 fiber/cc level. CONSAD subcontracted this investigation to Clayton Environmental Consultants who alse evaluated the technological feasibility of controlling asbestos exposures.

It is Clayton's judgment after a careful review of: 1) currently attainable and reported exposure levels, and 2) advancing control technology and related reductions in exposure levels, that the primary asbestos industries can generally comply with a 0.2 fiber/cc time-weighted average (TWA) exposure level, but not a 0.1 fiber/cc level, using both the best application of techniques now available and nearly developed technology likely to be implemented within the next two years.

The exception to this is the dry-woven textile segment where exposure levels cannot be reduced below 1.0 fiber/cc without major breakthrough in new processing technology. Where this kind of breakthrough has occurred in the textile segment -- development of the "wet" process used by one of the asbestos textile manufacturers -- exposures can be reduced to levels consistent with the 0.2 fiber/cc projected limitation.

The determination that 0.1 fiber/cc exposure level is not technically feasible even by application of best available technology rests largely on careful evaluation of the likely background level in primary asbestos industries (other than dry woven textiles). In these plants, raw fiber is being received, stored, and handled and finishing operations are being conducted with manual materials-handling procedure. In such instances, the ubiquitous nature of asbestos in such facilities as a result of worker carelessness, control system malfunction, inadvertent spillage, and less-than-perfect work practices will result in a finite background fiber concentration upon which even slight TWA exposure elevations -- mainly in the fiber handling and finishing operations -- will yield integrated TWA exposures on the order of 0.1 to 0.3 fiber/cc. Therefore, it is the contractor's judgment that even the best applications of known control measures including exemplary work practices point to a feasible, realistically achievable TWA exposure level for asbestos in the primary industry segments (other than dry woven textiles) of 0.2 fiber/cc for asbestos fibers greater than five microns in length.

In evaluating the potential of replacing asbestos in product lines, it is evident that there does not exist one material that can be used in all asbestos applications as a substitute. In most instances, the materials evaluated for these applications are more expensive than asbestos and would require some modification of the manufacturing process. Furthermore, significant cost and performance penalties may result from a switch to non-asbestos materials. Nevertheless, there exists a significant research and development effort in the asbestos industry to find suitable replacements for asbestos. Presently, there is a well-defined trend to substitute other materials for asbestos in reinforced plastics with over 50% of the reinforcement of phenolic molding compounds provided by non-asbestos substitutes. In the floor tile segment, manufacturers are running trials on a new cellulose fiber to be used in place of asbestos. An intense research and development effort is ongoing in this country to replace asbestos in friction materials and some success has been reported. Fiberglass is most commonly reported material being evaluated to replace asbestos in certain paper and textile applications. Additionally, newly developed synthetic fibers (e.g., Aramids, Ceramics, Graphite) may also play some role as asbestos substitutes; however, their evaluation must be considered on a product-by-product basis. Replacing asbestos in cement products of A/C pipe and sheets, is under heavy research investigation with some success reported in England and Japan using alkali-resistant glass. However, little is reported in the U.S. on the use of this material in domestically produced cement products.

Competitive products also will play a role in the event of reducing the exposure limit to 0.1 fiber/cc. As the exposure limit is lowered, the probability increases that using an asbestos-containing product will be subject to OSHA regulations. In certain instances, where a competitive product performs on a comparable cost/performance basis as asbestos products, some end-users may well be forced to switch to other products rather than face governmental restrictions. Therefore, in cases where asbestos-containing products exist in very competitive markets, OSHA regulations and their ancillary requirements for monitoring, medical surveillance, showers, etc. may make these products less attractive and thus cause a decline in their relative market share. If this trend continues for any given product, certain asbestos applications may cease to exist.

2.0 INTRODUCTION

On December 13, 1976, the National Institute for Occupational Safety and Health (NIOSH), made a recommendation to the Occupational Safety and Health Administration (OSHA) that no worker be exposed to an airborne concentration of asbestos in excess of 100,000 fibers over 5 um in length per cubic meter on an 8-hour time-weighted average basis (i.e., 0.1 fibers/cc). In addition, the proposed recommendation states that no worker should be exposed to peak concentrations in excess of 500,000 such fibers per cubic meter of air based on 15-minute sampling periods (i.e., 0.5 fibers/cc). To date, OSHA has formally proposed reducing asbestos exposures in the workplace to 0.5 fibers/cc TWA and a 5 fiber/cc peak exposure limit. In July 1976, CONSAD submitted its final report on the technological feasibility and inflationary impact of the 0.5 fiber/cc exposure limit. The purpose of the report to follow is to conduct a supplemental analysis of affected industries involved with asbestos in order to determine the technological feasibility of reducing exposures to 0.1 fiber/cc and to assess the economic implications of such an action.

The technological feasibility analysis focused on three major areas of concern: determining further engineering control to reduce asbestos exposures; identifying potential areas where a change in the manufacturing process may be anticipated to control exposures, and; assessing the feasibility of accurately monitoring asbestos exposures at these low limits, i.e., 0.1 fiber/cc. Another major effort not covered adequately in the previous TFA/IIS for asbestos was an evaluation of the possibility of substituting different materials for asbestos in the manufacturing process or other products for asbestos containing products. To these ends, potential substitutes are identified and their relative merits (i.e., cost, performance, availability are discussed as compared to asbestos products. Finally, an attempt was made to evaluate the overall economic implications of further reducing exposure limits to 0.1 fiber/cc if it is feasible to attain. However, it was not in the scope of this study to determine the industry-wide cost of compliance with a 0.1 fiber/cc exposure limit, nor to evaluate the economy-wide inflationary impacts associated with such a recommendation. This document is intended to provide sound data base upon which the feasibility of monitoring and controlling asbestos exposures at 0.1 fiber/cc can be evaluated and to identify the potential for replacing asbestos in many of its product applications.

For the most part, this report focuses on the major primary asbestos industry segments. Chapter 3.0 briefly discusses the contractor's methodology for the technological, substitution, marketing, and monitoring assessments and generally describes overall data gathering procedures and major sources of information. Chapter 4.0 presents an overview analysis of technological, substitution and market considerations common to most segments. Chapter 5.0 is presented on a product-specific basis corresponding to the nine major industry segments identified in the previous TFA/IIS for asbestos. These include:

- Asbestos-cement pipe;
- Asbestos-cement sheets, shingles and siding;
- Asbestos friction materials;
- Vinyl asbestos floor tile;
- Asbestos reinforced plastics;
- Asbestos paper products;
- Asbestos paints, coating and sealants;
- Asbestos gaskets, seals and packing materials;
- Asbestos textiles.

Each of these major product categories contains a background discussion concerning the products, the feasibility of engineering controls, a discussion of material substitutes and competing products, and an analysis of the economic implications that may result from lowering the asbestos exposure limit. Chapter 6.0 consolidates the most important points brought out in the product-specific discussions in Chapter 5.0 and broadens the focus to evaluate the overall implications of the recommended exposure limit of 0.1 fiber/cc. The feasibility of monitoring and accurately counting asbestos fibers in the workplace environment is presented in Chapter 7.0. Included are alternatives to the present phase-contrast microscopic method and a review of pertinent asbestos exposure data to determine the accuracy and precision of the NIOSH approved monitoring method. Appendices are provided at the end of the report to emphasize and document discussions in the major text.

3.0 ASSESSMENT METHODOLOGY

3.1 Technology Assessment

The assessment of technological feasibility with reference to the NIOSH-proposed 0.1 fiber/cc exposure level comprised updated information gathering and compilation and evaluation on a product segment-by-segment basis. Updated existing data obtained from CONSAD/Clayton's TFA/IIS for the 0.5 fiber/cc exposure limit included a multi-level investigation covering: 1) an updated literature review, 2) direct inquiries - telephone interviews and visits - to selected asbestos industries, and 3) selected plant visits. Because this study supplements the earlier, comprehensive analysis with reference to the proposed 0.5 fiber/cc level, primary focus has been placed on the conception, planning, and application of control methods in the intervening time period since the first study. At the same time, it must be recognized that the evolution and implementation of control techniques in the primary asbestos industries -- engineering methods, process changes, equipment substitution, and work practices -- represent a continuum of advancing technology, largely void of major "breakthroughs." This occurs in large part because the workplace asbestos standard has been a "moving target" at which industry has been aiming over a period of several years. Thus, even the increasingly better application of well-known, proven control methods on a more consistent, exacting basis has resulted in steady, sometimes dramatic decreases in airborne asbestos fiber concentrations in many industries.

The assessment methodology, accordingly, has depended largely on CONSAD's and Clayton's continuing interaction with the asbestos industry. Specifically, an attempt was made to identify those organizations who: 1) were likely to know of or be applying "best technology," and 2) have extended cooperation and demonstrated interest to the extent that plant visits and critically-meaningful dialogue short of on-site visits would help to indicate current trends with respect to advancing control technology.

The most useful documentation for the assessment of technology has been the opportunity in several instances to see firsthand, and relate simultaneously, recently-measured exposure levels with actual operations at representative work sites. This on-site observation and assessment of the various operations, including the nature and extent of local and general controls and work practices, has also proven, in the contractor's judgment, to be extremely reliable information.

During these visits and in the course of continuing discussions with industry representatives, several innovative and adaptive control techniques have been identified that, taken together, define the frontier of advancing technology for controlling asbestos in the workplace.

These techniques are identified and described in Section 4.0 as they impact the various major product lines in the primary asbestos industries.

Two initial processing steps common to most major segments of the primary asbestos industries -- fiber receiving/storage and fiber introduction -- are treated initially in an overview discussion that precedes the detailed segment-by-segment analysis.

3.2 Assessment of Potential Substitutes

To obtain data on the potential for substituting other materials for asbestos, several approaches were utilized. First, CONSAD conducted a multi-file retrospective computer search of major informational data files. These files included:

- NASA 1962 - current;
- NASA Technical Briefs;
- Market Abstracts 1972 - current;
- Engineering Index 1970 - current;
- NTIS 1970 - current;
- Chemical Abstract Condensation Applied Section Volumes 69-85; and
- Miscellaneous data bases.

The output from those files for the most part included citations and abstracts of references. Promising sources were categorized by product segment and attempts were made to obtain copies of complete items. Much of the literature was from foreign sources that could not easily be accessed; however, some of the abstracts provided useful information

The second approach involved telephone interviews with industry personnel; those people associated with the asbestos industry; the manufacturers of substitute materials and other knowledgeable sources. From these conversations, CONSAD solicited information on material substitutes, their application, availability and cost information on products that compete with asbestos-containing products and finally their judgment concerning the economic implications of a 0.1 fiber/cc exposure limit for asbestos.

A third method utilized to gather information and data was to conduct a limited number of on-site interviews with asbestos industry research and development and marketing representatives. Meetings have been conducted with the Asbestos Information Association, Johns-Manville Corporation, Raybestos-Manhattan Corporation, and Bendix Corporation. It is believed that the information that the contractor has been able to gather from these various efforts represent a thorough search of the possible substitutes for asbestos in these major product segments. A major difficulty in obtaining this information is that a great deal of the research and development work to find suitable substitutes for asbestos is being conducted by the manufacturers of asbestos-containing products, and due to the competitiveness of the market, specific data is proprietary and confidential.

3.3 Economic/Market Assessment

In order to determine the economic implications of a further reduction of the asbestos exposure limit to 0.1 fiber/cc as recommended by NIOSH, an analysis of the various markets in which asbestos products compete was undertaken. This work can be considered an extension and refinement of CONSAD's economic study conducted for the proposed 0.5 fiber/cc. Major markets have been more carefully defined and further divided into sub-markets of the nine major product segments of the primary manufactures of asbestos products. To these ends, information was obtained on the size of these sub-markets in terms of their consumption of asbestos fiber, sales volumes and/or units of material sold. Additionally, products which compete with asbestos products were identified and an attempt made to determine the market shares of the major competing products, including asbestos-containing items. The above information was obtained from a variety of sources, including:

- Producers of asbestos products;
- Trade associations for asbestos products;

- Trade associations for non-asbestos products;
- Producers of non-asbestos products;
- Trade periodicals;
- 1972 Census of Manufacturers (U.S. Department of Commerce);
- Marketing Study of Asbestos Industry, Ministry of Industry and Commerce, Government of Quebec, (done by Sores Inc, and A.D. Little of Canada, Ltd.).

Existing trends in share of market were identified for some sub-markets where asbestos products and non-asbestos products compete. Prices of asbestos products and competing non-asbestos products are indicated. Trends in share of market are also presented for domestic sales and imports in industry segments where asbestos product imports are a significant force, i.e., the asbestos textile industry. Additionally, relative prices of domestic and imported asbestos products are delineated. Information concerning trends in share of market and price data was provided by the following sources:

- Producers of asbestos products;
- Trade associations;
- Building Construction Cost Data (R.S. Means Company);
- Asbestos magazine.

- Trade associations for non-asbestos products;
- Producers of non-asbestos products;
- Trade periodicals;
- 1972 Census of Manufacturers (U.S. Department of Commerce);
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- Producers of asbestos products;
- Trade associations;
- Building Construction Cost Data (R.S. Means Company);
- Asbestos magazine.

An attempt was made to determine the price sensitivity of present asbestos-containing products as a method to qualitatively evaluating what effect the increased cost of compliance for OSHA stands would have on the continued economic viability of the product. For the most part, this information was obtained from conversations with the major producers of asbestos products. However, in the water and sewer pipe market in which asbestos cement pipes compete, consulting engineers, municipal water works personnel were contacted for their input.

Finally, in order to put into prospective what overall implications would result from an imposed 0.1 fiber/cc asbestos limit, a brief discussion is presented on the effects of a rigid enforcement of the current 2 fiber/cc in end-use applications, i.e., the construction industry. To these ends, information was obtained from producers of asbestos products, construction industry officials and OSHA's TFA/IIS on the proposed asbestos exposure limit for the construction industry.

4.0 OVERVIEW CONSIDERATIONS

4.1 Technological Feasibility

This section of the report presents an overview of the technological feasibility analysis for the primary asbestos industry segments by Clayton Environmental Consultants. Within each segment-specific section in Chapter 5.0, the information crucial to technological feasibility is organized in the following manner:

- Review of Process;
- Current Controls and Work Practices;
- Reported Exposure Levels;
- Currently-Achievable Exposures;
- Future Controls Under Development; and
- Projected Lowest-Achievable Exposures.

Before beginning the segment-specific analyses for the primary asbestos industries, it is helpful to first cover two important processing steps common to all segments, "fiber receiving and storage" and "fiber introduction."

4.1.1 Fiber Receiving and Storage

The starting point of an evaluation of control measures and their impact on exposure levels in the primary asbestos industries must begin with consideration of the significant characteristics of a critical, industry-wide pre-processing operation: fiber receiving, warehousing, storage and staging. Because this functional operation is common to all of the asbestos industries where raw fiber is introduced in a manufacturing process, this discussion applies to all segments, as does the following discussion on fiber introduction.

Asbestos fiber is currently transported in a dry state by rail cars or trucks and contained in paper or plastic bags as palletized shipments. At a plant operation, this material is unloaded manually or, more often, by powered forklift trucks. The palletized cargo is brought to a raw-fiber warehouse for intermediate storage before being distributed to a staging area(s) within the plant operations near the fiber introduction work station(s).

Spillage from these raw-fiber containers -- in the rail car or trailer, in the warehouse, or in any portion of the plant -- adds significantly to the exposure levels. This occurs not only to the warehousemen or truck operator who transports the fiber, but also to other persons in the plant subjected to the ubiquitous, background presence of asbestos as it may be spread throughout the plant or entrained by pedestrian or vehicular traffic. This background level becomes increasingly significant with reference to the very low fiber levels of interest, such as 0.1, 0.2, or even 0.5 fiber/cc. Background levels alone can equal or exceed these concentrations without preventative steps to avoid spillage, to vacuum any spillage, and to otherwise suppress fiber reentrainment from floors on a general basis. Accordingly, it is extremely important to avoid tearing, ripping, or damaging the asbestos bags or containers during shipment, unloading, stacking, and unstacking, and transport within the plant operations.

Current Controls and Work Practices

Several currently available practices and techniques are used increasingly to avoid asbestos-bag damage. These include inflatable dunnage, lined rail cars, palletized loading, shrinking film wrapped pallets, and double-sealed bags. Consistent, routine taping of broken or torn bags and vacumming within the shipping cars prior to unloading are critical to minimize exposure to the warehousemen, to workers at fiber introduction, and to meet low plant-wide background levels.

All spills subsequent to unloading must be vacuumed promptly to avoid elevated exposure in both the receiving and warehouse areas and in the fiber introduction step after damaged bags have been staged.

Bulk shipments of compressed asbestos pallets and Kraft-paper-wrapped high-density blocks are available from selected suppliers. The high-density block of asbestos -- which produces less dust in receiving and warehousing -- is expected to be used more widely as one of several process modifications to minimize fiber emissions now produced during bag opening. Application will become more widespread as techniques for fiberizing the densified raw fiber continue to be developed in several product lines.

Reported Exposure Levels

A limited survey of several primary asbestos industry segments, plus a review of recently-published exposure levels, show the time-weighted average (TWA) asbestos exposure in receiving and storage to range widely from 0.1 to 2.5 fibers/cc. Even the lowest reported levels have been achieved with less than full-scale application of effective, currently available control measures.

Currently Achievable Exposures

If the control methods and work practices outlined above are implemented routinely, Clayton believes the TWA exposure levels for unloading, storage, and transport of raw fibers can be maintained consistently below 0.3 fiber/cc. This will require:

1. Repair of damaged containers;
2. Immediate clean-up of spillage and floor accumulation of asbestos-containing solids; and
3. Floor cleaning at least once per shift with a power-vacuum unit -- preferably combined with wet floor cleaning.

Future Control Methods Under Development

Additional control measures now being developed, in addition to wider usage of high-density fiber blocks, include improved packaging (general movement toward plastic bags), stronger pallets, standardized minimum number of sizes for bags, and improved transportation practices.

Projected Lowest-Achievable Exposures

Clayton believes, on the basis of judgment and currently-attainable exposure levels, that asbestos exposures in the fiber receiving and storage pre-processing stages can, within about two years, be controlled consistently below 0.2 fiber/cc if the same level of progress demonstrated in the past two years can be maintained.

4.1.2 Fiber Introduction

In addition to fiber receiving and storage, another processing step common to all primary asbestos industries is the introduction of raw fiber into the process. Because this step is functionally similar in most of the major product lines, the assessment of technological feasibility is addressed here, prior to the segment-by-segment analyses.

The most significant difference in processing technique with reference to fiber introduction among the various segments is the degree to which the raw fibers must be opened or "fiberized" in the initial stages of processing. This fiber-opening effect is achieved by techniques known as "milling", "willowing", "fluffing", "blockbusting", "beating" and "hydropulping". The significant difference among these techniques -- requirements or product-specific processing -- will definitely affect the degree and timing of use of high-density raw-fiber consumption in the various operations. For example, the "Paints, Coatings and Sealants" mixing process requires a very high degree of fiber opening, often denoted as "fluffing". This is accomplished much more readily when the raw fiber is introduced to the process in a relatively uncompacted state. On the other hand, the use of high-density blocks of raw fiber finds best application, under currently prevailing practice, in the papermaking segment of the industry, especially when hydropulpers, as opposed to beaters, are used to mix and homogenize the wet-stock batch prior to the paper-forming operation.

Current Controls and Work Practices

The fiber introduction step currently takes place almost exclusively by manual bag-dumping methods, although semi-automated bag-dumping stations for fiber introduction are being tried in a few instances. The primary advantage of automated bag-dumping is the distance and degree of physical enclosure separating the worker loading the conveyor-fed equipment from the bag opening per se. Although it appears very likely that automatic bag-dumping stations will eventually be used on a widespread basis, there is no documented evidence as to the additional protection afforded the worker by this method. Nevertheless, judgment suggests that semi-automated bag-dumping would help lower exposures at fiber introduction better than the best designed and ventilated manual dump stations.

The fiber-introduction processing step is accomplished in current operations largely by the use of evacuated, hooded dump stations with enclosed empty-bag receptacles contiguous to the dumping hoods, but also kept under negative pressure. In the "Paper" segment, however, pulpable kraft-paper bags can be added to the wet blending operation without a bag-emptying and drying operation. A similar bag-to-batch addition situation occurs in the "Floor Tile" segment where polyethelene containers are compatible with both the process mixing operation and product quality, thus eliminating the need for manual bag emptying and dry-bag disposal.

The use of semi-enclosed local exhaust ventilation represents the most important control method applicable to worker protection at the fiber introduction step. When a worker empties a bag manually by slitting, shaking, and/or dumping within a semi-enclosed dump station (kept under negative pressure), the disposal and related handling of the bag becomes paramount with reference to exposure level. The newer generation bag-dumping hoods have an empty-bag receptacle incorporated within the evacuated enclosure so that several empty bags can be accumulated and then removed in semi-sealed containers to suitable larger disposal receptacles. This technique is proven and and currently available, but needs to be used on a more routine basis than at present in order to achieve the lowest attainable fiber exposure levels.

1. Adequately exhausted fiber introduction enclosures which contain facilities for proper disposal of empty bags;

2. Regular performance checks and preventative maintenance on local exhaust systems;

3. Immediate clean-up of spillage and floor accumulation of asbestos-containing solids using central vacuum-cleaning systems;

4. Floor cleaning at least once per shift with a power-vacuum unit -- preferably combined with wet floor cleaning; and

5. Mechanically-supplied, contaminant-free make-up air (tempered relative to ambient conditions) in sufficient volumetric flowrates to balance the combined local exhaust capacity in a given work area.

These measures, together with the consistent, exacting application of control measures described above, would, in Clayton's judgment, achieve exposure levels consistently below 0.4 fiber/cc on a time-weighted average basis for bag-opening, fiber introduction operations.

Future Control Methods Under Development

Additional control measures now being developed, in addition to wider use of high-density fiber blocks and semi-automated dumping stations, include recyclable bulk containers and reinforced bag construction. The use of bulk fiber shipments with closed, automated, pneumatic conveyance represents another promising concept now in the first stages of development.

Projected Lowest-Achievable Exposures

Although the fiber introduction step has been very troublesome, historically, with respect to control of worker exposures, an exacting application of hooded, manual bag-dumping stations, with integrated empty bag collection and the maximum, increasing use of high-density fiber blocks and process-recyclable containers should, in the contractor's judgment, allow a consistent maintenance of TWA worker exposures below 0.2 fiber/cc within about two years.

4.1.3 Engineering Control Costs

In the current, supplemental analysis, we have identified only two newly-available control techniques that need to be considered as incremental costs necessary to achieve TWA asbestos exposures of 0.2 fiber/cc. These include the 1) semi-automated bag-dumping station that will be widely used for the fiber introduction step and 2) a new operator-driven mobile floor cleaning unit that incorporates wet scrubbing together with vacuuming. Although these two techniques are now being introduced, their incremental benefits have not yet been documented with reference to worker exposures to asbestos. Nevertheless, their use suggests some added benefit in maintaining exposure levels below 0.2 fiber/cc.

The machinery required for the bag-opening station costs $15,000 plus an additional $75,000 in installation costs (labor and materials) according to Johns-Manville Corporation. For future systems, the contractor estimates that the total installed costs would be approximately $40,000 per station. The cost for the new mobile unit ($11,000) is not markedly different from the dry sweepers cited in the previous TFA/IIS. It is not believed that these costs will significantly change the control costs estimated earlier to achieve 0.2 fiber/cc.

4.2 Substitutes for Asbestos

At the outset it should be pointed out that there does not presently exist a substitute material that is able to replace asbestos in all of its major product applications. Substitute materials are available for many applications, but they may not match asbestos materials on a strict cost/performance basis in many instances. Historically, asbestos has been an extremely versitile fiber able to impart reinforcement, heat and chemical resistance to various products. The unique properties of chrysotile asbestos fibers are briefly outlined in Table 4.1.

Many factors have encouraged the search for suitable substitutes for asbestos for many years. These factors include:

- Significant price increases for asbestos (See Table 4.2);
- Significant world-wide shortage of asbestos fiber;
- Concerns regarding the health effects of exposure to asbestos;

TABLE 4.1: Unique Characteristics of Asbestos

Property	Comment
Alkali resistance	Attack only occurs at extremely high concentrations and temperatures.
Fine Fiber Diameter	Provides many reinforcing fibers per unit weight.
High Tensile Strength	300,000 to 500,000 psi depending upon test method and particulate source.
High Impact Resistance	Not brittle and will not degrade readily in length upon processing.
Temperature Resistance	Good; brittle at high temperatures; temperature at maximum ignition loss, 1800° F.
Surface Charge	Positive - provides chemical bond to many mediums, i.e., asphalt.
High Modulus of Elasticity	Approximately 12-20 million psi.
Fiber Characteristics	Curly and flexible which is beneficial in forming characteristics in manufacturing process; also interlaces when formed into sheets and paper which enhances product strength.
Dispensibility	Readily dispensible in aqueous slurries.
Cost	Provides low cost/performance or cost/physicial property ratio.

Source: Johns-Manville Corporation

TABLE 4.2: Asbestos Fiber Prices: 1970 and 1977

	1970 Price/ Ton[1]	1977 Price/ Ton[2]	Percent Change
A/C Pipe	$218	$561	157
A/C Sheet	$184	$434	136
A/C Shingles and Siding	$113	$269	138
Disk Brakes (FM)	$184	$434	136
Segment Lining (FM)	$ 73	$146	100
Vinyl-Asbestos Floor Tile	$ 42	$100	138
Latex Sheet Underlayment	$137	$299	118
Commercial Paper	$113	$269	138
Reinforced Plastics	$ 60	$130	117
Roof Coatings	$ 54	$112	107
Sheet Packing	$184	$434	136
Beater-Add Gaskets[3]	$184	$187	2
Asbestos Textiles	$425	$1093	157

[1]Add $14-16 for freight to Northeastern areas.
[2]Add $30 for freight to Northeastern areas.
[3]Grade of fiber changed.

Source: Johns-Manville Corporation.

- Health concerns regarding the use of certain asbestos containing products (i.e., drywall spackling compound);
- Administrative burdens imposed by OSHA's current standard for occupational exposure to asbestos;
- OSHA's October 1975 proposed amendment to the asbestos standard (i.e., 0.5 fiber/cc exposure limit);
- Increased workers' compensation costs;
- Increased incidence of common law product liability suits;
- Increased difficulty in obtaining product liability insurance coverage; and
- Increase in advance publicity regarding health effects of asbestos.

The above factors are illustrative of the incentives which industry has had in recent years to find substitutes for asbestos even without the added impetus of a 0.1 fiber/cc exposure limit. The development of adequate asbestos substitutes is a painstaking, lengthy and costly undertaking for industry; however, it is evident that a major research and development effort is presently underway to find suitable replacements in products where it is both technically and economically feasible. To delineate some of the difficulties encountered in actually substituting other materials for asbestos in a major product line, Appendix A presents a case study of Johns-Manville's success in developing a non-asbestos molded insulation product. It has been emphasized that even though valuable knowledge may be gained by the manufacturer in a successful search for an asbestos substitute, it is not necessarily transferable to other product applications. It may be fair to say that the research and development efforts to replace asbestos will be as unique as the individual production and product/performance requirements.

As stated previously, the following Chapter 5.0 is organized by major product segment. For each of these major asbestos-containing products, the potential of material substitution for asbestos in that particular application is reviewed as determined by industry research and development. Due to the competitiveness of the industry, much of the specific detail on actual material compositions and costs is proprietary, and unavailable. However, general comments can be made. Additionally, Appendix B lists the various materials and fibers reported as potential substitutes for asbestos. For each material the potential product applications are listed as reported by the literature and industry sources. Cost comparisons and general performance comments are also given. This listing is not intended to be comprehensive, but taken with the discussion of substitutes in Chapter 5.0 for each major product, a fair interpretation of the potential for replacing asbestos in certain applications can be gained.

A final general comment on substitutes. In CONSAD's many conversations with members of the asbestos producing and user industry, one of their major concerns is that other materials or fibers considered as adequate asbestos substitutes will themselves have adverse health effects. A case in point is the introduction of potassium titanate fibers in 1971 by Dupont, tradename FYBEX, as a replacement for asbestos in reinforced plastics and possibly friction materials. However, in 1974, Dupont withdrew this material from the market because it showed signs of being potentially hazardous to man. Appendix C is a brief accounting of the development of FYBEX fibers, its potential applications and general toxicity as related to CONSAD by Dupont. In the international community, a three-pronged study into the carcinogenic activity of man-made mineral fibers used in industry as asbestos substitutes, is being undertaken by the International Agency for Research on Cancer (Lyon, France). Physical similarities between the man-made fibers and asbestos have led the European glass-fiber and textile industries to ask IARC to carry out epidemiological studies in 70 factories in 15 countries, laboratory studies on animals and fiber-dust measurements in manufacturing plants. The results of this study have not yet been reviewed. (1) As important as the evaluation of potential health hazards for asbestos substitutes seem to be, it should be emphasized that this type of evaluation is not within the scope of the present study. CONSAD has reported on items that were uncovered in the course of investigation, but has not actively researched the potential toxicity of identified substitute materials.

4.3 Asbestos Industry Market

In order to gain a perspective on the relative size and importance of the major segments of the primary asbestos industry, asbestos fiber usage by product category are presented in Table 4.3. For consistency, the product categories are listed in the same order as in the previous TFA/IIS study conducted for the 0.5 fiber/cc standard. The data given is for 1974. However, it is reported that the consumption levels for 1976 are very similar to these amounts with the exception of joint cements and reinforced plastics which have decreased significantly due to substitution efforts. Additionally, Table 4.4 presents an update of overall segment sales for the primary segments of the asbestos industry. These figures are for 1974 and, in some cases, represent a refinement based on more recent data of the sales information than those presented in the TFA/IIS.

TABLE 4.3: United States Asbestos Fiber Usage - 1974

	Tons Consumed	Percent of U.S. Asbestos Usage
A/C Pipe	139,000	16%
A/C Sheet, Shingles and Siding	52,000	6%
Friction Materials	55,000	6%
Vinyl-Asbestos Floor Tile	110,000	13%
Reinforced Plastics	18,000	2%
Paper Products	330,000	38%
Paints, Coatings, and Sealants (65,000 C&S + 13,000 joint cement)	78,000	9%
Gaskets, Seals and Packing	29,000	3%
Textiles	12,000	1%
Miscellaneous	53,000	6%
Total	876,000	100%

Note: The asbestos fiber consumption levels for 1976 are very similar to 1974 levels, except the fiber consumption for joint cements and reinforced plastics has decreased considerably, due to substitution for asbestos.

Source: Johns-Manville Corporation

TABLE 4.4: Estimated 1974 Sales for Asbestos Industry: Primary Manufacturers and Secondary Fabricators (in millions)

	Primary Manufacturers	Secondary Fabricators[1]
A/C Pipe	$250	$ 53
A/C Sheet, Shingles and Siding	$ 60	
Friction Materials	$300	
Vinyl-Asbestos Floor Tile	$260	
Reinforced Plastics	$120	$294
Paper Products	$142[2]	$340
Paints, Coatings and Sealants	$275	
Gaskets, Seals and Packings	$134	$280
Textiles	$ 40[3]	$162

[1]Secondary processors or fabricators represent those firms that purchase products from one or more segments of the primary industry and either fabricate these materials (for example, cutting and drilling of cement sheet) or process them together with other materials for incorporation into an end product.

[2]Dollar estimates for this market generally does not reflect actual sales transactions. Approximately three-fourths of this market represents captive, intra-company sales. For example, Armstrong Cork, GAF Corporation, and Congoleum produce 85% of all American latex sheet flooring and transfer this production to themselves to make resilient sheet flooring.

[3]Approximately one-third of this market does not reflect actual sales, but rather intra-company transfers of asbestos textiles to make friction materials.

Source; IIS 0.5 fiber standard, CONSAD Research Corporation and conversations with industry officials for revisions of A/C Pipe and Gaskets, Seals and Packings estimates.

REFERENCES FOR CHAPTER 4.0

1. Chemical Week, September 29, 1976, page 33.

5.0 PRIMARY ASBESTOS SEGMENTS

5.1 Asbestos - Cement Pipe

5.1.1 Background Information

Asbestos-cement (A/C) pipe was developed in Europe in response to the need for an anticorrosive, high pressure pipe to carry seawater for firefighting purposes. Introduced into the United States market in 1929, asbestos-cement pipe is currently used to convey potable water under pressure, and for non-pressure applications such as drainage of storm water, sewage and other types of liquid wastes. Other uses include electrical conduit and vent pipe. Pipe fittings can also be manufactured from asbestos cement. Standard pipe sizes range from 2 inches to 36 inches in diameter but asbestos-cement pipe can be made in diameters up to 80 inches.

The points more or less common to all asbestos-cement products are strength, resiliency, flexiblity, durability, inertness and fire resistance. Asbestos plays a major role in all of these characteristics. In pipe, asbestos imparts a flexural strength which allows a certain amount of deflection without failure. The laminar structure of the pipe which results from the basic method of manufacturing also contributes to greater strength. Because of the nature of the raw materials used to manufacture asbestos-cement pipe it resists corrosion and most chemical action and is not subject to electrolysis. Ease of installation and the integrity of joints are valuable properties of pipes made from this material.

Formulations for asbestos-cement pipe are determined by the type of curing used in the operation and by the quality and types of raw materials used. In the United States, curing of the product is accomplished in a short time in an autoclave. The autoclave process makes use of silica to react with free lime as it is formed and thus speeds up the rate of hydration of the cement. In other countries, where curing is carried out under moist conditions at ordinary temperatures, silica is not required.

Representative formulation ranges are shown:

Autoclave Cure		Normal Cure	
Asbestos	15-23%	Asbestos	15-25%
Cement	42-53%	Cement	75-85%
Silica	34-40%		

A/C pipe has won considerable acceptance as a high pressure water pipe. In 1974, more than 50 million lineal feet of A/C water pipe was sold in the U.S. for the 4" to 16" standard water pipe size. Industry sources estimate that over 50% of all A/C pipe made goes into water pipe applications. Non-pressure sewer pipe represents the second major market for A/C pipe. According to Johns-Manville estimates, 35% of all A/C pipe is sold in the sanitary sewer market with the remaining usages distributed over a wide range of asbestos-cement pipe products. The consumption of asbestos fibers for the enti. A/C pipe market including water and sewer pipe application was approximately 139,000 tons in 1974 or 16% of total U.S. fiber consumption. Next to asbestos papers, asbestos cement pipe ranked second in overall domestic fiber consumption.

5.1.2. Technological Feasibility

Review of Process

Basic raw materials used for the production of asbestos cement (A/C) pipe include asbestos fiber, portland cement, silica sand and water. After fiber introduction to the process (see Section 3.1.1), conveying equipment carries the raw fiber to a dry mixing step. Agitation in this step serves two purposes: opening or fluffing the fiber, and mixing the cement constituents. Sand and portland cement are added at this point, typically being conveyed pneumatically to an enclosed, live-bottom mixer.

The dry mix next passes by conveyor to a wet-mixing operation just upstream of the pipe-forming machine. The wet mortar flows to the pipe-forming machine vats, where the asbestos cement slurry is picked up on a rotating, screened cylinder mold and transferred on a traveling belt over suction boxes, where as a wet mat it is wrapped on a mandrel. Wrapping continues to attain proper thickness. Pipe sections are generally cast in 10- to 15-foot lengths. After an initial setting time, the pipe is stripped from the mandrel, then air cured, and final cured in an autoclave using saturated steam.

Cured pipe sections are then transported to the finishing operations. Here the pipe is cut to uniform lengths and machined in a variety of ways - sawing, lathing, drilling, and outfitted with a coupling. To ensure a tightly-fitting pipe joint, the ends of the pipe sections are machined smooth; such finishing is carried out on a lathe.

The finished pipe is inspected, and each section of "pressure pipe" (pipe used for conveying water under pressure) is tested hydrostatically.

In addition to full and partial lengths, pipe plants also produce a variety of standard and special fittings. Pipe coupling is the most widely-used fitting. To mate with the machined pipe, inside surfaces of the coupling must be grooved to hold a rubber seal.

Other fittings (tees, elbows, reducers, etc.) are produced on a less-frequent schedule. Most pipe plants also produce specialty fittings and pieces on an individual basis. Operations required for fittings production include sawing, drilling, machining, boring, and bonding. Some specialty applications require pipe lengths machined over their entire length; this is accomplished with a lathe.

Current Controls and Work Practices

Fiber loss to the work environment at the dry-mixing stage is controlled by maintaining negative pressure inside the mixer -- itself an appendage to a local-exhaust dust-control system. The mixer generally receives and dispenses raw material by screw conveyor.

Local exhaust is also employed at the wet-mixing operation. Introduction of the dry mortar into the mixer and initial agitation until the solids become wet produce the dust at this step. Once the mortar becomes wet, little additional fiber becomes airborne.

A significant portion of the fiber emitted between fiber introduction and wet mixing may result from material-handling equipment such as screw conveyors and bucket elevators. Dust control in conveying equipment is obtained through continuous exhaust of hoods and maintenance of negative pressure within the closed mixing equipment.

No special control equipment is used during pipe formation, air curing, and steam curing. Nevertheless, good housekeeping is essential at these steps, since spills of mortar or fragments of pipe will dry, ultimately resulting in fiber release due to pedestrian and vehicular traffic.

Aside from fiber introduction, pipe-finishing machining operations represent the major potential source of airborne fibers in an A/C pipe plant. Extensive local exhaust and hooding must be used near the tool cutting surface to capture and control fibrous solids, including chips. The use of single-point cutting tools, rather than saws or cutting and machining equipment using abrasion, substantially reduces fiber emissions at the finishing step.

Control equipment for coupling and fittings production is essentially the same as that described for pipe finishing. Local exhaust near the working point of the tool is used to capture and remove solids. Variability in production techniques and in pipe size make design of tight-fitting hoods difficult.

Reported Exposure Levels

Several plant visits, plus continuing correspondence and phone interviews with industry representatives, together with a review of recently-published exposure levels (1, 2, 3), show the time-weighted average (TWA) asbestos exposures in asbestos cement pipe plants to range widely from 0.1 to 4.8 fibers/cc. In Clayton's judgment, however, even the lower reported levels have generally been achieved with less-than-full-scale, optimum application of currently-available, proven control measures and work practices.

Currently Achievable Exposures

Available, proven control measures and work practices which could be used now to better advantage to assure low exposure levels include the rigorous application of well-known methods, such as:

1. Regular performance checks and preventative maintenance on local exhaust systems;

2. Immediate clean-up of spillage and floor accumulation of asbestos-containing solids;

3. Floor cleaning at least once per shift with a power-vacuum unit -- preferably combined with wet floor cleaning; and

4. Mechanically-supplied, contaminant-free make-up air (tempered relative to ambient conditions) in sufficient volumetric flowrates to balance the combined local exhaust capacity in a given work area.

These measures, together with the consistent, exacting application of control measures described above would, in Clayton's judgment, achieve exposure levels consistently below 0.4 fiber/cc on a time-weighted average basis for asbestos cement pipe operations.

Future Controls Under Development

Wet mixing immediately after fiber introduction is being used in at least one cement pipe plant. This process modification precludes any mixing and thus eliminates one potential source of fiber loss to the work environment.

Advancing control technology for reducing exposure to asbestos in the finishing operations includes redesign of machinery with integrated local exhaust. Standard milling equipment and machinery with minor modification have been used in pipe finishing. Significant reduction is worker exposure could be achieved if the machinery were redesigned for improving dust capture.

Wet machining has been used at some areas in the A/C pipe finishing and fitting production, and development work is underway to determine if:

1. Wet suppression can be adapted to the pipe lathes; and

2. Wet finishing reduces the fiber release at this processing stage.

Considerable automation could also be incorporated eventually in machinery redesign, thereby reducing employee exposure.

Project Lowest Achievable Exposures

Tightening of the materials-handling equipment between fiber introduction, dry-mixing and wet-mixing processes, and/or use of immediate wet mixing will further reduce the background fiber concentration near those areas in a plant.

Systematic reduction in background fiber levels should reduce exposure at the pipe formation and curing steps to below 0.2 fiber/cc or less.

Implementation of latest-available equipment will result in further exposure reduction in the finishing area. Exposure should be controllable to within 0.2 fiber/cc range by use of closely fitting local exhaust systems designed specifically for each individual unit. Table 5.1 presents reported and projected asbestos fiber concentrations for A/C pipe processes.

TABLE 5.1: Reported and Projected Asbestos Fiber Concentrations - Asbestos Cement Pipe

Process-Related Work Areas	TWA Asbestos Exposure Level (fibers/cc)		
	Reported Range	Currently Achievable	Projected Lowest Achievable
Fiber Receiving & Storage	0.2 - 2.5	0.3	0.2
Fiber Introduction	0.1 - 4.8	0.4	0.2
Dry Mix - Wet Mix	0.4 - 3.0	0.4	0.2
Pipe Formation	0.1 - 1.4	0.3	0.2
AirCure/Autoclaving	0.2 - 0.3	0.3	0.2
Sawing	0.1 - 1.9	0.4	0.2
Finishing Lathes	<0.1 - 0.7	0.4	0.2
Coupling Cutoff & Machining	0.2 - 2.3	0.4	0.2
Fittings & Specialties	1.5 - 2.1	0.4	0.2
Drilling	<0.1 - 0.5	0.4	0.2
Rework Saw & Crushing	2.0 - 2.9	0.4	0.2
Floor Sweeping	<0.1 - 0.3	0.3	0.2
Quality Control Inspection	<0.1 - 0.2	0.2	0.1

5.1.3 Potential for Material Substitution

Asbestos has been used as a microreinforcement fiber for cements and concretes for many years. Even though the section deals with asbestos-cement pipe, the potential for material substitution can be discussed in the context of other asbestos cement products as well, i.e., cement sheets.

Asbestos is used in cement pipe as a reinforcement fiber imparting greater elasticity modulus and tensile strength to the cement mix. It is able to withstand the autoclave (heat and pressure) process in the manufacture of the pipe and resists the alkali attack of portland cement. Other fibers currently considered for use in cement and concrete composites include steel, glass, alumina, polypropylene, and carbon. Other fibers such as nylon, polyethlene, rayon, rockwool, cotton, acrylic, polyester, and other organic fibers have been considered in the past, but have been ruled from serious consideration due to either high cost, low effectiveness or inadequate resistance to the alkaline cement environment in portland cement. Similar to asbestos, all of these fibers have relatively high tensile strength ($>$ 50,000 psi). However, the moduli of elasticity of the fibers vary from a low of 500,000 psi for polypropylene to a high of over 30 million psi for carbon, steel, and alumina (asbestos has a modulus elasticity of 12-20 million psi). The low modulus ($> 10^6$ psi) fiber (polypropylene) provides improvement in impact strength and ductility of the composite but has little effect on flexural and compressive strength. Fibers having a modulus 10×10^6 psi usually provide improvement in impact strength and ductility, as well as in static and dynamic flexural and compressive strength. (4)

Other than greater elasticity modulus and an increase in strength of the cement composite, there exist other parameters for successful reinforcement. These are:

- Large fiber surface areas;
- Good adhesions between cement mix and fiber surface area;
- Optimum fiber quantity, i.e., as the quantity of fibers increase, the strength of the composite material rises;
- Greater than critical fiber length (critical length is reached when fibers tear rather than get extracted from the matrix; and
- Aging and deterioration resistance of fibers within the matrix, i.e., fibers must retain their strength over time from the alkaline attack from cement.

A comparison of these micro fibers was tabulated in A/C Underground (5), an international magazine for the asbestos cement industry, and is presented as follows:

Type of fiber	E-modulus	Strength	Fibre surface	Cohesion	Critical length	Age resistance
Steel	+	+	+	++	+	(+)
Asbestos	+	+	++	++	++	++
Carbon	+	+	+	-	-	++
Glass	+	+	+	-	-	-
Organic fibres	-	(±)	+	-	-	(±)

As is evident, asbestos has demonstrated an excellent reinforcing ability, which accounts for its widespread use in pipe and sheet applications. Steel fibers have also demonstrated outstanding reinforcement abilities. However, in thin sheet applications, the cement cover may be insufficient to protect the fibers against rust. Carbon fibers have the strength and elasticity, and chemical resistance, yet there apparently exist problems in proper binding within the matrix. More importantly however, is the fact that the carbon fibers are approximately 40 times as expensive as asbestos and probably do not represent an economically viable substitute at this time.

There has been much research recently on glass reinforcement of cement composites. Although the tensile strength of E-glass is quite high, it is very susceptible to chemical attack from the strong alkalis in portland cement. This phenemonon results in loss of strength with time depending upon storage conditions.(6) The Pilkington Glass Group, a member of Fiberglass Limited in England, developed a zirconium (ZiO_2) based soda-lime systems which makes a glass significantly more resistant to alkaline attack. This alkali-resistant glass, tradename Cemfil, is reported to suffer little, or no loss of strength in cement composites with age.(4) In the United States, Owens-Corning has been experimenting with alkali-resistant glass as a substitute for asbestos in asbestos cement pipes and sheets.(7) They have reported that at this time, the product is experiencing difficulty in the manufacturing process and lacks the strength of asbestos cement at the end of the process. To date, they do not have a commercially acceptable product as a substitute for asbestos.

Another major research effort is presently being conducted at Brookhaven National Laboratory and has led to the development of a glass-polymer composite (GPC) sewer pipe.(8) It reportedly may be potentially competitive on a technical and economic basis with pipe now used for non-pressure sewer lines, particularly in the 8- to 24-inch range. This composite is produced by mixing crushed waste glass (from urban solid waste components) with a monomer (either methyl methacrylate or polyester styrene) and polymerizing by chemical initiating techniques. Theoretically, in a 1972 market study conducted for Brookhaven by A.D. Little, Inc., it was reported that GPC has technical advantages over cement, concrete, and asbestos-cement with its superior acid and chemical resistance, its low permeability and smooth tight joints.(9) The availability of an adequate supply of waste glass, the principal raw materials for GPC was not well defined, but presumably a number of government and private programs were to be initiated that would generate this material from municipal solid wastes. Possible applications for GPC other than sewer pipe could conceivably be in block brick, wall panels and decorative products. As of this writing, Brookhaven is under contract to the Energy Research and Development Administration to evaluate the properties of its glass-polymer sewer pipe. Field testing of full scale sewer pipe sections has been in progress since 1972. To date no deterioration has been reported.(10)

Substitution for asbestos in cement pipe is still in the research and development phases. Alkali-resistant glass may be the most promising material introduced. However, as reported in the literature and through correspondence with industry representatives, its performance and adequacy in specific pressure and non-pressure pipe applications have not yet been fully evaluated.

5.1.4 Competitive Products and Market Structure

Asbestos-cement pipe competes with a variety of other pipes in the water and sewer markets as evidenced by Table 5.2. The following discussion examines these two markets separately with regard to the acceptance of A/C pipe products.

Water Pipe Market

Three factors account for the market acceptance of A/C pipe for use in water supply systems. Conventional iron pipe* is corrosive and will emit iron particles into the water system, affecting taste

*Cast iron pipe; new product is called ductile iron pipe which presently has 90% of the total iron pipe market.

Table 5.2: Water and Sanitary Sewer Pipe Price and Market Estimates

Water Pipe Market (pressure pipe)	Price (8" Standard Size) 6"	12"	Market Share (Estimates) Rural (4" - 6")	Suburban Middle-Sized Cities	Big Cities (6" - 12"+)
Ductal Iron	$4.47/Ft. (Los Angeles)	$10.19/Ft. (Los Angeles)	?	10%	50%
A/C	$2.49/Ft. (Los Angeles)	$7.38/Ft. (Los Angeles)	20%	50-60%	30%
PVC	$3.94/Ft. (Thick Wall) (Oakland, Cal.) $1.87/Ft. (Thin Wall) (Texas)	$9 - 10/Ft. (Thick Wall) (Johns-Manville)	70% (Thin Wall)	30-40%	5%
Sanitary Sewer Market (Gravity Flow)			Standard 8" Diameter		
Clay	$1.50/Ft. (Western Pa.)		45%		
PVC	$1.65/Ft. (Western Pa.)		20%		
A.B.S. Truss Pipe	$1.65/Ft. (Western Pa.)		20%		
A/C	$1.50/Ft. (Western Pa.)		10%		
Concrete			--		

*(Concrete Pipe is generally used for diameters greater than 24", rather than the standard 8" size for sanitary sewer pipe.)

Source: CONSAD estimates based on conversations with ARMCO Steel Corp., Johns-Manville Corp., Los Angeles Water and Power Company, East Bay Municipal Utility District, Trans-Tex Supply and [illegible].

and appearance. Corrosion also weakens iron pipe, leading to leaks and eventually breaks. While iron pipe has a quite long expected service life, the non-corrosive property of A/C pipe makes it attractive. Second, A/C pipe is produced with a smooth bore. This provides a low coefficient of friction, thereby helping to keep down pumping costs. Third, A/C pipe has traditionally had a lower per foot selling price than iron pipe. In interviews with operators of water supply systems who are large purchasers of A/C pipe, CONSAD found that the single most important determinant of product choice is price, except for those limited situations where corrosion is known to be a serious problem.

In spite of its lower selling price per foot, there are some applications for which A/C pipe is considered inferior to iron pipe. In areas where pipes will be subject to quite high pressure (i.e., 150-200 psi) in order to maintain adequate pressure at the outlets engineers may opt for ductal iron steel pipe in spite of its cost disadvantage.

Until the appearance of A/C pipe, iron pipe dominated the water pipe market. Historically, A/C pipe found it difficult to penetrate the market in the large, older cities of the eastern United States. It has had much greater market acceptance in smaller cities and towns, and in the Southwest and West Coast regions of the country. With the growth of these areas, A/C pipe has experienced an expansion of sales and increase in its share of the water pipe market.

Around 1961, thin wall PVC pipe was introduced into the water pipe market. Like A/C pipe, PVC pipe is highly anti-corrosive. In addition, PVC pipe has an even lower coeffecient of flow friction than does A/C or iron pipe, and it is light and flexible. In thin wall applications its current price is less than A/C pipe. At present, thick wall PVC pipe (i.e., 12" diameter) has American Water Works approval which is generally required for urban areas. It has a price which is comparable to that of iron pipe. Given its anti-corrosive property, weight, and flow coefficient, PVC represents a formidable potential competitor to both A/C and iron pipe in water systems.

One of the principal competitive advantages A/C pipe has had over iron pipe is the corrosiveness of iron pipe. In recent years, iron pipe manufacturers have responded to this technical disadvantage by offering polyethelene sheet covered pipe. Such covering adds approximately $1 per lineal foot to pipe costs.

With the introduction of PVC pipe and the development of polyethelene liners for iron pipe, the ability of asbestos cement pipe to retain a place in the pressurized water pipe market depends even more heavily than before on its traditional price advantage. As shown in Table 5.2, 6" unlined iron pipe is selling for $4.47/lineal foot, 6" thick wall PVC

*Thin-wall PVC pipe is presently not approved by the American Water Works for urban areas.

pipe (Johns-Manville tradename, "Blue Brute") is selling for $3.94/ lineal foot and 6" A/C pipe sells for $2.49/lineal fc-- CONSAD interviews with users of A/C pipe indicate that if the selling price of A/C pipe were to rise to the level of iron pipe or higher, it would lose a significant share of its market and there would be a significant movement toward PVC pipe. Additionally, if it were to rise above the cost of of polyethelene coated iron pipe, there would be no significant use in which it would remain the product of choice. It is anticipated A/C pipe's share of the water market will be static in the future. PVC pipe's share of the market will grow but primarily at the expense of ductal iron pipe.

Sewer Pipe

Non-pressure sewer pipe represents the second major market for asbestos cement (A/C) pipe. According to Johns-Manville estimates, 30-35% of all A/C pipe is sold in the sanitary sewer market. The important performance characteristics for sewer pipes are acid resistance, resistance to infiltration and exfiltration, flow coefficient, and weight per unit length. In the southern half of the United States, low flow rates due to relatively flat land and high temperatures combine to stimulate anaerobic bacterial action that produces acid. Because A/C pipe is subject to acid corrosion, its principal market is in the northern half of the country. In these markets where acid is not a problem, A/C pipe competes with vitrified clay, concrete and plastic pipe for use in sanitary sewer systems. (Refer to Table 5.2.) As compared with vitrified clay and concrete, A/C pipe has the advantage forming tighter joints. In addition, it is available in longer lengths, thereby reducing the number of joints and possibility of leaks and infiltration.

In the past few years, techniques have been developed to produce plastic sewer pipe in large diameters (8" to 15") where A/C pipe has been most successful in competing with concrete and clay. TRUSS pipe, a proprietary product of Armco Steel, encases a light-weight concrete between walls of acrylonitrute-bulactient-styrene (ABS). This pipe is highly chemically resistant, rigid, smooth surfaced, available in 12' to 40' lengths and provides very tight seals. Extruded PVC pipe with similar properties is also becoming available in sizes larger than 8" in diameter. Offering lower flow resistance than A/C, PVC pipe can be installed at a less steep angle, reducing installation costs. PVC pipe already dominates the small diameter (4" - 6") sewer pipe market. There have been some technical problems of blistering with mass-produced PVC pipe. This has made some engineers shy away from using it. But, assuming the manufacturing problems can be overcome, PVC is likely to claim a substantial share of the sewer pipe market in the very near future in which A/C pipe is positioned.

Given the technical advantage of plastic pipe for sewer applications, long term continued use of A/C pipe requires that it have a lower selling price than PVC or TRUSS pipe.

In 1977, in western Pennsylvania, prices for 8" sewer pipe were \$1.50/lineal foot for A/C pipe, \$1.65/lineal foot for TRUSS pipe, \$1.65/lineal foot, \$1.65/lineal foot for PVC pipe, and \$1.50/lineal foot for clay pipe. Clearly, unless A/C pipe price can be significantly reduced relative to the plastic pipe prices, it will eventually be displaced in the market place. It is anticipated that PVC and TRUSS pipe will take over greater shares of the market for gravity sanitary sewers at the expense of both A/C and clay pipe.

5.2 Asbestos-Cement Sheets, Shingles and Sidings

5.2.1 Background Information

Asbestos-cement products represent the largest market for the world's supply of asbestos. Sheet products have found a variety of uses in the building field including roofing, siding, and bulkheads, curtain wall, cooling tower fill, industrial insulating board and decorative trim. They are available in flat or corrugated sheets. The shingle and siding products are usually textured and painted, but they may also be integrally colored. Sizes range from a small shingle, 12-inches x 24-inches to sheets 4 feet x 12 feet. Thickness of asbestos cement sheet products usually vary from 3/32-inches to 3/16-inches.

The addition of asbestos to cement products imparts flexural properties much greater than those of unreinforced concrete. Because asbestos is inorganic and inert it contributes to the durability and fire resistance of these products. Asbestos-cement products are virtually unaffected by the atmospheric environment.

Asbestos-cement products can be cured in a short period of time in an autoclave or over several weeks in a moist atmosphere. For autoclave curing silica is used in the formulation to react with the free lime formed. Product formulations range as follows:

Autoclave Cure		Normal Cure
Asbestos	12-25%	12-25%
Cement	45-54%	75-88%
Silica	30-34%	--

In 1974, the U.S. domestic consumption of asbestos for asbestos-cement sheet applications was approximately 43,000 tons, while A/C shingles and siding consumed an estimated 9000 tons of asbestos annually. These tonnages represent about 6% of the total U.S. fiber consumption. The primary sub-markets in which A/C sheet products compete are: (1) roofing and walling for industrial buildings, (2) cooling tower fill sheets, (3) corregated bulkheads for canals, (4) laboratory table tops, and (5) the electrical switching gear market.

5.2.2 Technological Feasibility

Review of Processes

Wet-processed asbestos cement sheet production closely parallels manufacturing of A/C pipe. Asbestos fiber is combined with cement, silica, and water and the sheet is formed, cured, and finished. A "dry" process is also used to make certain shingle-type products.

Wet Process

Fiber is introduced manually either directly or via conveyor to a dry mixer by bucket elevator and/or screw conveyor. Silica sand and cement are added at this point, and the solids are mixed until uniform. Such mixing opens the fibers and prepares the mix for wet mixing.

Wet mixing occurs in a second vessel, where water is added to form a slurry. The slurry flows into vats from where it is deposited on rotating cylinder molds. A thickened wet mat is formed continuously and transferred from the mold to a moving felt and then to an accumulator roll. The sheet is then formed further in embossing rolls or by large hydraulic presses. After initial set and partial curing, it is removed from the press for further curing -- in either heated air or steam-heated autoclaves.

After curing, the asbestos cement sheet is sized and trimmed in cut-off saws. To obtain specified sheet thickness, some sheet products must be sanded to a uniform thickness.

Sheet formation operations sometimes include initial fabrication such as dye cutting, punching, or hole drilling.

Dry Process

The dry process, used for manufacture of some shingle-type products, begins by opening fiber in a hammer mill or similar device and dry mixing with cement and silica. The mixture is metered onto a moving, wetted belt and then passed under compression rollers to remove air. Water is sprayed on the material and compression continues under rolls. Surface granules can be added before final compression and embossing.

Finishing begins with rough tripping and cutting to size after additional air curing. Nail holes may be punched, and the shingles are cut to exact size. Paint is applied by spraying after final curing takes place.

Control Methods and Work Practices

As in the A/C pipe segment, paper-bag addition cannot be used to eliminate bag slitting and dumping because of product contamination with cellulose.

Well-applied local exhaust of enclosed mixing equipment and finishing operations represents the most important engineering controls for A/C sheet and related shingle manufacturing. Dry-mix conveying and materials-handling equipment can lose fiber to the work area unless kept thoroughly enclosed and under negative pressure. Wet mortar itself is not a significant fiber source. Nevertheless, stringent housekeeping controls are crucial when handling wet-mixed mortar, for if spillage dries without being removed, pedestrian and vehicular traffic will cause substantial entrainment of airborne fibers. No special controls are used at the drying or curing steps other than good housekeeping to minimize fiber release.

The degree and adequacy of dust control equipment and work practices cover a wide range for cutting, trimming, and sanding finishing operations. Local exhaust with hoods or enclosures are generally used to some extent for major pieces of finishing or fabricating equipment.

Reported Exposure Levels

Several plant visits, plus continuing correspondence and phone interviews with industry representatives together with a review of recently-published exposure levels (1, 2, 3) show the time-weighted average (TWA) asbestos exposures in asbestos cement sheet operations to range widely from < 0.1 to 8.7 fibers/cc. However, even the lower reported levels have generally been achieved with less-than-full-scale, optimum application of currently-available, proven control measures and work practices.

Currently-Achievable Exposures

Available, proven control measures and work practices which could be used now to better advantage to assure low exposure levels include the rigorous application of well-known methods, such as:

1. Regular performance checks and preventative maintenance on local exhaust systems;

2. Immediate clean-up of spillage and floor accumulation of asbestos-containing solids using central vacuum-cleaning systems;

3. Floor cleaning at least once per shift with a power-vacuum unit -- preferably combined with wet floor cleaning; and

4. Mechanically-supplied, contaminant-free make-up air (tempered relative to ambient conditions) in sufficient volumetric flowrates to balance the combined local exhaust capacity in a given work area.

These measures, together with the consistent, exacting application of control measures described above would, in the contractor's judgment, achieve exposure levels consistently below 0.4 fiber/cc on a time-weighted average basis for asbestos cement sheet production.

Future Controls Under Development

Elimination of the dry-mixing operation, as in A/C pipe manufacture, is a promising potential development. Considerable process development work will be required, however, to establish the feasibility of such a process modification.

Other likely developments include more automation of finishing operations to eliminate or substantially reduce operator exposure at these typically high-emission-level operations.

Projected Lowest-Achievable Exposures

Table 5.3 shows the projected lowest-achievable exposures that can be attained as a result of the exacting application of control methods mentioned previously and the timely implementation of new technology as it is developed. In summary, the contractor believes that TWA exposures in the asbestos cement sheet operation can be maintained consistently below 0.2 fiber/cc within two years.

5.2.3 Potential for Material Substitution

As noted previously, asbestos is used primarily for its reinforcement properties in cement sheet applications; however, it also imparts

Table 5.3: Reported and Projected Asbestos Fiber Concentrations
Asbestos Cement Sheet

Process-Related Work Areas	TWA Asbestos Exposure Level (fibers/cc)		
	Reported Range	Currently Achievable	Projected Lowest Achievable
Fiber Receiving & Storage	0.2 - 2.5	0.3	0.2
Fiber Introduction	0.1 - 8.7	0.4	0.2
Dry Mix - Wet Mix	0.4 - 8.4	0.4	0.2
Sheet Formation/Stripping	<0.1 - 3.5	0.4	0.2
Dry/Cure	0.2 - 2.5	0.4	0.2
Cut/Trim	<0.1 - 6.7	0.4	0.2
Sand	<0.1 - 8.0	0.4	0.2
Finishing & Fabrication	0.1 - 3.6	0.4	0.2
Quality Control Inspection	<0.1 - 0.7	0.2	0.1

heat and chemical resistance to boards where such properties are desired. The potential for substitution for asbestos in cement composites was presented in Section 5.1 for asbestos cement pipe, but this discussion is also relevant for cement sheet applications. Fibers of steel, carbon, glass, ceramics and organic, have been evaluated for these applications, and in some instances, marketable products have been developed.

The Ashai Glass Company of Japan has introduced a slate cement board, tradename Suncrete, which utilizes alkali-resistant glass as the reinforcing agent.(11) The product is reported to be incombustible, water resistant, has good processibility and has high impact strength. It still includes 5% asbestos fibers, but that is compared to 12-25% asbestos content of conventional A/C sheets. Another asbestos-free non-combustible building board is presently being marketed by the Cape Boards and Panels (Uxbridge, England) under the tradename Supalux.(12) It is reported to be a replacement for the firm's Asbestolux board (containing asbestos) for all fire-resisting applications, such as casing for structural steel work, suspended ceilings, ceiling linings and soffits, fire bricks and fire-resisting particians.

There has been a great interest in ceramic fibers recently for various composite applications. Ceramic fibers were developed primarily for thermal applications and in some cases have been used as a reinforcing material. As reported by Johns-Manville, research on ceramics as a reinforcement for cement resulted in a product with reduced plasticity, reduced strength even at partial substitution and was difficult to process as compared to asbestos reinforcement. However, in thermal applications, it has been reported that the strong market showing for ceramic fibers in the past few years has been a combination of increasing concern for energy conservation, the trend toward high temperature manufacture and governmental regulation (i.e., OSHA regulation for occupational exposure to asbestos). (13) In some instances, ceramic fibers have replaced asbestos in thermal applications; however, ceramics have been used primarily to replace other conventional high termperature material (i.e., firebrick in refractory applications which operate at temperatures greater than the upper limits for asbestos). The cost of ceramic fibers is on the order ten times the cost of asbestos on a pound for pound basis, although on a product utilization basis, the costs are reported to be reduced to a differential of two to three times.

The literature has also identified other materials that conceivably could be used to replace asbestos in some of its traditional cement applications. In the USSR, slag pyroceramics is one of the new building materials produced from metallurgical slag. Applications include industrial floors, decorative and protective facings, dividing walls and particians, and roof coverings. (14) It is reported to be non-toxic and more wear-resistant, durable and chemical resistant than ceramic products and does not show water absorption or warping like asbestos cement. The Soviets also report on an experimental fiberboard made from basalt material that is lightweight, temperature resistant and purportedly superior to asbestos slabs. (15) In Czechoslovakia, research was reported of a basalt type of mineral wool, "A-Fiber", which has been developed as a substitute in asbestos cement. (16) However, it was determined that the material could only be used to replace up to approximately 20% of the asbestos without causing severe degradations in product strength. Finally, research in India has alledged that it is commercially feasible to produce cellulose pulp-cement sheets comparable in strength to asbestos-cement sheets for use in building boards. (17) Other sources have provided information that wood in cement sheet material makes the end product more sawable and nailable, but it is water sensitive and would fail in outside environments. Reportedly, the product would have a limited interior usage.

Wollastinite and mica have also been evaluated as a reinforcing fibers and fillers for cement applications. According to Johns-Manville, compared to asbestos cement, these materials result in reduced strength even at partial substitution. Their singular advantage would be in cost reduction, through materials cost or processing costs.

5.2.4 Competitive Products and Market Structure

The major market for both corrugated and flat cement sheets is in the construction industry as external and/or internal coverings for warehouses and industrial buildings, especially where corrosive vapors are present. As stated previously, other major uses include cooling tower fill sheets, canal liners, laboratory table tops, and electrical switch gear. Table 5.4 indicates the size of these various sub-markets for A/C sheets, competitive products and estimates of market position.

The market for A/C shingles and siding products is highly regionalized and generally limited to New Jersey, Long Island, eastern Pennsylvania, New Orleans and San Antonio. A/C siding is used primarily because it is fireproof and its appearance attractive. Industry sources differ on the total size of the A/C shingle market which is estimated to range between 0.5 and 1.0 million square feet. This market appears to be declining over the past few years as evidenced by the 1967 Census reporting 1.9 million square feet which declined to 1.3 million in 1972. This trend is further borne out by Johns-Manville's decision to stop producing A/C shingles in 1975 and National Gypsum recently closing two asbestos-cement siding plants.

The total size of the A/C siding market is less than 1 million squares per year (one square = 100 square feet) with the total U.S. siding market estimated at 60-80 million squares per year. Brick

Table 5.4: Major A/C Sheet Sub-Markets: Size, Competitive Products, and Market Position

Sub-Market	Size	Competitive Products	Market Position
1. Roofing and Walling for Industrial Buildings.	$13-17 million	Pre-engineered metal panels; pre-cast concrete; aluminum cladding; masonite	A/C sheets used in chemical processing industries, such as fertilizer plants, where A/C sheets resist high moisture content and corrosive fumes in atmosphere. A/C sheets have a fairly stable share of this market.
2. Cooling Tower Fill Sheets	$10-12 million	Glass reinforced plastics; concrete; redwood	A/C sheets have 70% of market with glass reinforced plastics and concrete having a 30% market share. Market heavily dependent on construction of nuclear power plants.
3. Corrugated Bulkheads for Canals		Steel; pre-cast concrete; aluminum	This is a fairly static market prevalent in Florida, the Carolinas, and New Orleans. Environmental controversy over whether canal bank should be natural or not.
4. Laboratory Table Tops	$5-6 million	Stone; molded epoxy resins	A/C sheet currently has 50-60% of the market. A/C sheet costs $5-8/sq.ft. Stone costs $7.50-9.50/sq.ft. Molded epoxy resin costs $10-14/sq.ft. For a $5 table top, the A/C sheet costs $2.50. In 1970 the price for a square foot of A/C sheet was $1.75. A/C sheet prices have been rising at 6-12% per year, while the price of stone and molded epoxy resins have remained at their 1974 and 1975 levels, respectively. The share of market for A/C sheet will probably decline in coming year because of rising prices. The total market for laboratory table tops has been declining since 1968, but now there is the potential for large orders from Arabian countries.
5. Electrical Switching Gear	$2-3 million	Glass; polyester	A/C sheets are used for insulation for switching panels in industrial plants, sub-stations, and generating stations. The alternative material is glass polyester which costs 3 times as much as A/C sheets. Plastics have over 50% of the total market for electrical switching gear, but A/C sheet has a stable 10% share. A/C sheet is generally the only material used in its special market niche.

Source: CONSAD Conversations with Johns-Manville Corp., National Gypsum and Supradar.

has approximately 20% of this market followed by hardboard (Masonite), aluminum, and other forest products. The residential siding market encompasses over half of the total siding market; however, competition from aluminum siding and more recently vinyl siding, has reportedly forced A/C siding from this market. The major applications for A/C siding is now limited to those areas when special fire protection is required or slate-like appearance is desired.

A significant factor which may affect the market for A/C sheet products would be aggressive enforcement of the current 2 fiber/cc asbestos exposure limit and forcing contractors to comply with the other ancillary requirements of the standard. Little exposure is associated with the installation of A/C siding or shingles because factory panels are simply nailed up, bolted on, or screwed in. More exposure is associated with the installation of A/C sheet, which sometimes requires secondary fabrication or cutting at the construction site. This is especially true for flat or corrugated sheets used in roofing and walling for industrial buildings, as opposed to other sub-markets for A/C sheet where almost all cutting and fabrication is done in the shop. A situation could develop where ordinary contractors who only rarely use A/C flat and corrugated sheets, would stop using the product rather than engage in monitoring, medical surveillance, record keeping, etc. However, based on conversations with users of A/C sheets, a select group of contractors could begin to specialize in working with A/C sheets and would be willing to work with A/C sheet and comply with the standards. Current enforcement of the 2 fibers/cc standard may slightly reduce the total demand for A/C sheet. The market for A/C flat sheet architectural panels may decline, however, this is a very small part of the total market for A/C sheets.

5.3 Friction Materials

5.3.1 Background

Friction materials comprise a line of products that rely upon their coefficient of friction with a mating surface to stop or transmit motion. In the case of brakelinings, the most common type of friction material, the function of the lining is to convert the kinetic energy of a moving mass into heat energy. Brake linings are produced in a variety of forms such as segment linings for drum brakes, disc pads for disc brakes and brake blocks. They can be designed to be riveted to a metal backing or bonded with an adhesive.

Other types of friction material include industrial linings for manufacturing equipment and appliances such as washing machines and clutch facings of the molded and spiral wound type.

Asbestos in conjunction with the phenolic resin binder and other additives (commonly called "organic" friction materials) develop the proper coefficient of friction to provide smooth, safe braking action. Asbestos can withstand the high temperatures generated at the braking interface and contributes to the needed dimensional stability of the lining. The fibrous nature and high tensile strength of chrysotile asbestos impart strength to the friction element and allow it to withstand the stresses over a wide temperature range. Asbestos also contributes to the wear characteristics of the lining so that it does not score the mating surface yet provides long life. These same characteristics are important in clutch facings. The general formuiation of asbestos friction materials are:

- Asbestos -- 50-80%
- Binder -- 16-45%
- Friction
- Modifiers -- 5%

In 1974, approximately 55,000 tons of asbestos went into the domestic consumption of friction materials which represented approximately 6% of the total U.S. asbestos consumption. The major submarkets for asbestos friction materials are identified as the automotive original equipment market, the automotive replacement market, and the industrial market.

5.3.2 Technological Feasibility

<u>Review of Process</u>

Bags of asbestos fiber are typically weighed, opened manually, and placed in movable hoppers for in-plant transportation. The hoppers are dumped into mixers, which blend the formulations in either a wet or dry state, depending on product specification. If the type of mixers used are not sufficient to refluff the asbestos, then a fluffing device is also used.

The mix is fed through a compression molder (dry) or an extruder (wet), depending on the required product. Formed strips are cut and bent into various widths and lengths. A mold release compound is added to prevent parts from sticking.

Dry-mixed formulations include a small amount of solvent and are transferred to pressing molds where slabs are formed, sometimes after a preheating step. The slabs are then hot pressed, causing the resin to flow and bind the mixture upon curing. These slabs are next sawed into specific parts and sent to a curing oven.

Following curing, the parts undergo a number of finishing steps needed to produce the final block. These machining operations include sawing, grinding, drilling, blanking, tapping, and boring.

Brake pads may be packaged and sold to a secondary manufacturer or may be applied directly to brake shoes by bonding or riveting.

The asbestos formulations are wet processed where it is practical to meet product specifications. This reduces the potential for asbestos fiber loss in the workplace. Enough solvent is added to form a coherent mass which can be molded or extruded. After drying, the preshaped part is cured.

Control Methods and Work Practices

Centralized local exhaust systems are employed with flexible connections to evacuate dust from individual machine operations, using hoods and enclosures to advantage. Where raw fiber is handled, the plant layout is generally arranged to segregate, if not isolate, this operation from other production areas. Surface dust on the products at intermediate and final stages is a major cause of worker exposure, and many operations undergo a brushing operation to remove latent dust. Manual inspection of parts should be done on down-draft air-exhausting tables to minimize exposure.

Floor cleaning should be conducted nearly continuously, as most plants operate three shifts per day and up to seven days per week at peak periods. Vacuuming is the general housekeeping practice; however, brooms are also used where the spilled material is difficult to vacuum.

Reported Exposure Levels

Continuing correspondence and phone interviews with industry representatives, together with a review of recently-published exposure levels (1, 2, 3) show the time-weighted average (TWA) asbestos exposures in friction materials operations to range widely from 0.1 to > 10 fibers/cc. However, even the lower reported levels have generally been achieved with less-than-full-scale, optimum application of currently available, proven control measures and work practices.

Currently Achievable Exposures

Available, proven control measures and work practices which could be used now to better advantage to assure low exposure levels include the rigorous application of well-known methods, such as:

- Regular performance checks and preventative maintenance on local exhaust systems;

- Immediate clean-up of spillage and floor accumulation of asbestos-containing solids using central vacuum-cleaning systems;

- Floor cleaning at least once per shift with a power-vacuum unit -- preferably combined with wet floor cleaning; and

- Mechanically-supplied, contaminant-free make-up air (tempered relative to ambient conditions) in sufficient volumetric flowrates to balance the combined local exhaust capacity in a given work area.

These measures, together with the consistent, exacting application of control measures described above would, in the contractor's judgment, achieve exposure levels consistently below 0.5 fibers/cc on a time-weighted average basis for friction materials operations.

Future Controls Under Development

Advancing technology for reducing exposure levels in the friction materials operations includes automated product-surface cleaning and more machine-integrated local exhaust, especially the low-volume, high-velocity type of application.

Projected Lowest Achievable Exposures

Table 5.5 shows the projected lowest-achievable exposures that can be attained as a result of the exacting application of control methods mentioned previously and the timely implementation of new technology as it is developed. In summary, the contractor believes that TWA

Table 5.5: Reported and Projected Asbestos Fiber Concentrations
Friction Material

Process-Related Work Areas	TWA Asbestos Exposure Level (fibers/cc)		
	Reported Levels	Currently Achievable	Projected Lowest Achievable
Fiber Receiving & Storage	0.2 - 2.5	0.3	0.2
Fiber Introduction	0.4 - 4.6	0.4	0.2
Mixing	0.2 - 8.0	0.5	0.2
Forming or Rolling	0.5 - 22	0.4	0.2
Curing	0.5 - 3.5	0.4	0.2
Finishing	0.6 - 7.4	0.4	0.2
Adjustment & Printing	0.7 - 1.0	0.4	0.2
Inspection	0.1 - 15	0.5	0.2
Packaging	1.0 - 2.0	0.5	0.2

exposures in the friction materials segment can be maintained consistently below 0.2 fiber/cc within two years.

5.3.3 Potential for Material Substitution

There is presently underway an intense research and development effort to find acceptable substitutes for asbestos in "organic" friction materials. Due to the competitiveness of the business, specific compositions and costs are considered proprietary; therefore, only general statements can be made at this time about these research and develop programs.

Graphite and carbon fibers have been attempted in friction materials and both Goodrich and Goodyear have patents using graphite in aircraft brakes. Additionally, in the USSR; graphite fiber has been introduced into a cerment friction material for a braking gear for aircraft.(18) There has also been research in using carbon and graphite in disc brakes; however, problems were reportedly encountered in processing. Furthermore, these materials are extremely expensive and probably would not constitute an economically feasible substitute for asbestos in the major passenger car brake systems. Raybestos-Manhattan has been attempting several varieties of fibers and materials as asbestos replacements in brake linings. Some of these include fibrous glass, mineral wool, wollastinite, potassium titanate fibers, heat resistant organic mineral fibers, and natural organic fibers such as cotton and sisal. With the exception of wollastinite and the natural organics, the other fibers are all more expensive than asbestos. The less expensive fibers apparently lack the heat resistance and sufficient fiber strength to give good strength to the brake composite material. Another problem is that many of the fibers (e.g., glass, graphite, and mineral wool) tend to break up in the milling process and would require a new coupling agent for use in friction materials. Raybestos has reported that, in general, new or modified processes would have to be developed for manufacture of these asbestos-free friction materials.

In the past, the National Aeronautical and Space Administration (NASA) has investigated new friction materials and their applications outside of the space program. Under NASA's Technology Utilization Office, Stanford Research Institute developed an improved friction material for light weight cars and trucks which utilized potassium titanate fibers (Dupont tradename FYBEX) and other polymer modifications. Commercialization efforts ceased when Dupont withdrew FYBEX from the market due to toxicological effects and other market considerations.(19) (See Appendix C for information on FYBEX.)

In the area of woven clutch facings, some progress is being made in utilizing fibrous glass as a substitute for asbestos. Johns-Manville has a patent for fiberglass clutch facings dated 1973, yet reportedly no license has been issued to date. Raybestos-Manhattan is currently undergoing pilot plant studies to evaluate the performance of a fiber-glass clutch facing they recently developed; however, no futher information is available.

The Bendix Corporation, one of the largest manufacturers of automotive friction materials, is also undergoing an intense research and development effort to find a non-asbestos organic brake drum lining. In conversations with research and development management, they report guarded optimism for a recently developed material. Bendix admits that the subject is still fluid, yet they seem encouraged by the results. For proprietary reasons, no specific information was obtained. In general, though, it was reported that the cost differential between this new material and conventional asbestos brakes was estimated to be in the 10s of percent. Due to the variety of manufacturing processes Bendix uses throughout this country, and the world, some manufacturing processes would have to be changed while other would only have to be slightly modified. Bendix reports that supplies of the raw material for the new brake composition are available, but the exact economics have not yet been worked out. Another point brought out in this conversation is that Bendix has attempted to find a substitute fiber that does not have similar physical characteristics of asbestos (i.e., the fibers would not have the dimensional characteristics that would lodge in the lung). It was further indicated that with a year, Bendix hopes to be able to demonstrate their new composition brake lining as a commercially viable substitute to asbestos in drum brakes.

5.3.4 Other Friction Materials

There exist numerous types of friction materials, different in composition as well as configurations. As discussed previously, these materials generally consist of an asbestos-reinforced polymer filled with various property modifiers and are conventionally called "organic" friction materials. For heavy duty applications such as aircraft, and occasionally race cars, and for certain transmission clutch applications, copper or iron matrix materials, reinforced with steel fiber and reinforced with various ceramic and metallic property modifiers are used. Materials of this type are called cerment friction materials. For application intermediate in duty between organics and cerments, there exist another class of friction materials, i.e., "semi-metallic" which consist of steel fiber reinforced polymer filled with iron and other property modifiers.(20)

The cerment (sometimes called sintered metal) brake linings are used primarily in heavy duty applications where high torque capacities and longer life are required (e.g., aircraft brakes, as noted, earth moving equipment, army tanks and off-highway vehicles. In many of these applications cerment brakes apparently exceed asbestos brakes in overall performance, especially in the aircraft brake market where cerment brakes market share is continuing to grow. Their performance in cold weather is adequate and their noise is comparable with asbestos brakes. However, the price of those brakes range has been estimated to between 3 and 5 times that for asbestos brakes, and probably for that reason, their share of the on-road, truck market is very small, estimated at approximately 5% in conversations with Abex Corporation.

The semimetallic, or sometimes called resin-bonded metallic brake linings are presently being used in heavy duty automotive applications (e.g., police cars and taxi disk brakes and also in semi-tractor-trailer truck brakes). They are reported to be superior to asbestos brakes in performance; however, there are certain aspects of the brake that detract from their use in the passenger car market. The semimetalics have a tendency to perform erratically in different temperatures, they fade and are noisier than conventional asbestos brakes. Furthermore, they are currently 50-60% more expensive than conventional asbestos brakes. Abex Corporation, who manufactures resin-bonded metallic brakes has estimated that under increased production, the cost of these brakes could drop to within 25% of present asbestos brakes.

General Motors has reported using a hybrid disc brake in the mass production of Camaros, Firebirds, and Chevelles. These are disc brakes which consist of one semimetallic and one organic asbestos lining.

The asbestos lining does not actually touch the rotor surface, but acts more to insulate the brake fluid from the heat generated by the friction surface. In effect, utilizing these hybrid brakes reduces the asbestos content of the friction material. They were initially developed to meet higher performance standard for newer model cars. Compared to asbestos disc brakes, they have a higher coefficient of friction, higher heat resistance and will wear longer, yet they are more noisy and more expensive. Precise information on cost were not available for proprietary reasons.

Some industry sources feel that these metallic brakes will gradually take over the market due to its superior performance characteristics. However, other sources believe there may be a trend away from using metallic brakes because of the future emphasis on lower maximum speed limits and lighter weight cars for fuel economy. Both of these factors may indicate less of a need for brake performance. Nonetheless, it is not within the scope or competence of this report to be able to predict the needs of the braking systems of future car markets.

In most of the major friction material markets, the organic asbestos material predominates. On a cost-performance basis, its thermal resistance, mechanical and ability to bind the other materials in the composite has made asbestos friction materials the preferred choice for most of these applications.

Sales of asbestos friction materials totaled $300 million in 1974. The precise breakdown of sales and production for each submarket ((e.g., original equipment automotive, replacement, industrial markets) is not presented due to imprecise information and the complexity of the market structure. However, at present, the non-asbestos friction materials, e.g., cerment and semi-metallics, appear to have only an insignificant share of these markets. Therefore, on a competitive product basis for friction materials asbestos has no peer.

5.4 Vinyl-Asbestos Floor Tile

5.4.1 Background

Vinyl asbestos floor tiles are manufactured from filled polyvinyl chloride polymers or copolymers and produced in squares usually 9-inches x 9-inches or 12-inches x 12-inches with thicknesses varying from 1/32 to 3/32-inches. They have found wide use because of their ease of installation and maintenance, durability and rot resistance. They can be embossed with a variety of colors and patterns or mottled with splashes of different colors. Tiles are fastened down with asphalt based adhesives or a self-sticking adhesive which is put on at the manufacturing facility and covered with a release paper.

In the manufacture of floor tile, asbestos gives a cohesiveness or hot strength to the material that allows it to be processed to the final product. Asbestos imparts indentation resistance, dimensional stability and abrasion resistance to the product in use. Various formulations are:

- Asbestos - 5-20%
- Binder - 15-20%
- Limestone - 53-73%
- Plasticizer - 5%
- Stabilizer - 2%

Asbestos consumption in vinyl asbestos (V/A) floor tile segment was approximately 110,000 tons in 1974 which comprised about 13% of the total U.S. domestic fiber consumption. Next to asbestos paper and cement pipe, floor tile ranks third in overall consumption. V/A floor tile competes in the resiliant flooring market which also includes asphalt tiles, all vinyl tiles, and sheet flooring.

5.4.2 Technological Feasibility

Review of Process

Modern floor-tile manufacturing uses shearing mixers into which opened paper bags or unopened polyethylene bags of asbestos are manually dumped, along with other dry ingredients such as plasticizers, resins, stabilizers, and pigments.

The mixer works the batch mix into an agglomerated, homogenized plastic mass at a temperature of about 300°F. The hot mix, with the asbestos fully bound in the warm plastic, is dumped onto a conveyor and passes to a 2-roll mill.

The mass undergoes final mixing and is formed into a continuous slab during milling. The slab, with an initial thickness of one to two inches, is fed through successive calendar rolls to achieve the desired final-product thickness.

The sheet remains warm and pliable as it is conveyed through embossing, which adds design features and texturing to the surface. After partial cooling and waxing, the sheet is cut into squares by a cutting press, and the tiles are separated from the excess scrap, inspected, and packaged. The scrap and rejected tile are reworked and returned to the mixer for recovery.

Control Methods and Work Practices

Floor-tile manufacturers use a high degree of local exhaust as dust control technology along with routine floor cleaning to minimize worker exposure to asbestos. Because the mixing and forming steps do not cause asbestos fiber loss, the fiber introduction step (for opened bags) and background levels represent the prime concern for controlling exposures to low levels.

Nevertheless, the materials handling equipment, including mixers, are kept under negative pressure with exhaust air directed to a dust-removal system.

Scrap material is conveyed to an isolated or enclosed area where automated choppers process scrap into chips. Worker exposure in scrap recovery is minimal, although this operations is usually exhausted locally.

Reported Exposure Levels

Several plant visits plus continuing correspondence and phone interviews with industry representatives, together with a review of recently-published exposure levels (1, 2, 3) show the time-weighted average (TWA) asbestos exposures in floor tile operations to range widely from < 0.1 to 4.3 fibers/cc. In Clayton's judgment, however, even the lower reported levels have generally been achieved with less-than-full-scale, optimum application of currently-available, proven control measures and work practices.

Currently Achievable Exposures

Available, proven control measures and work practices which could be used now to better advantage to assure low exposure levels include the rigorous application of well-known methods, such as:

- Regular performance checks and preventative maintenance on local exhaust systems;
- Immediate clean-up of spillage and floor accumulation of asbestos-containing solids using central vacuum-cleaning systems;
- Floor cleaning at least once per shift with a power-vacuum unit -- preferably combined with wet floor cleaning; and
- Mechanically-supplied, contaminant-free make-up air (tempered relative to ambient conditions) in sufficient volumetric flowrates to balance the combined local exhaust capacity in a given work area.

These measures, together with the consistent, exacting application of control measures described above would, in the contractor's judgment, achieve exposure levels consistently below 0.4 fiber/cc on a time-weighted average basis for floor tile operations.

Future Control Under Development

No marked technological advances are expected in the floor tile segment for reducing exposures other than timely application of semi-automated bag opening and/or conversion to high-density fiber, together with increasing levels of automation in mixing and forming -- with resultant decrements in worker proximity and exposure.

Projected Lowest Achievable Exposures

Table 5.6 shows the projected lowest-achievable exposures that Clayton believes can be attained as a result of the expecting application of control methods mentioned previously and the timely implementation of new technology as it is developed. In summary, the contractor believes that TWA exposures in the floor tile segment can be maintained consistently below 0.2 fiber/cc within two years.

5.4.3 Potential for Material Substitution

Presently, there is an intense R&D effort in industry to find suitable substitutes for asbestos in floor tile. Armstrong Cork is reported to offer a non-asbestos floor tile using more limestone than conventional V/A tile. In conversations with Johns-Manville, compared to the asbestos tile, it is not nearly as flexible and has a tendency to be friable. Switching to this type of tile would require a heavy capital investment to change the manufacturing process and has been estimated at approximately $100,000 per line. Johns-Manville has reported work with fibrous glass and ball clay in floor tile. They report that the brittleness of glass caused severe degradations in the normal manufacturing process. It was concluded that ball clay could be used as a partial substitute; however, complete substitution was judged to be questionable from a product property standpoint.

Table 5.6: Reported and Projected Asbestos Fiber Concentrations
Floor Tile

Process-Related Work Areas	TWA Asbestos Exposure Level (fibers/cc)		
	Reported Levels	Currently Achievable	Projected Lowest Achievable
Fiber Receiving & Storage	<0.1 - 2.5	0.3	0.2
Fiber Introduction	<0.1 - 4.3	0.4	0.2
Blending	<0.1 - 4.3	0.3	0.2
Banbury Mixer	0.8 - 4.3	0.3	0.2
Milling	-	0.3	0.2
Calendering	-	0.3	0.2
Embossing	-	0.3	0.2
Cutting	-	0.3	0.2
Inspection	-	0.3	0.2
Packing	-	0.3	0.2
Scrap & Rework	-	0.3	0.2

Union Carbide has reported the development of a non-asbestos floor tile. By adjusting the resin formula to include a new petrochemical material, the reinforcing characteristics of asbestos are presumably not needed. Presently, the performance of the new floor tile is being evaluated, and its price is aledged to be competitive to vinyl asbestos floor tile. It was reported, however, that the availability of the substitute petrochemical resin (which is proprietary and not divulged) is not sufficient at this time, if an instant switch to this product were to occur. Union Carbide reports that if a demand were generated for the material, adequate supplies could be probably made available on a large-scale basis.

A great deal of interest has been generated by the development of a natural cellulose fiber, Monsanto Corp., tradename SANTOWEB, which Monsanto claims will prove to be an acceptable substitute for asbestos to reinforce floor tile. It purportedly can be used in existing manufacturing processes and is capable of withstanding 300°F during calendering operations. Presently, the cost of SANTOWEB is $.60/lb vs $.06/lb for asbestos. However, due to its better color clarity and brightness (cream color vs grey asbestos tile), the need for pigments is reduced 75% as compared to asbestos floor tile. Additionally, Monsanto claims that 1 pound of SANTOWEB will replace 5 pounds of asbestos by using other fillers in the process. Therefore, the end price of the tile itself may be comparable to that of V/A tile. Monsanto is currently working with five floor tile companies and by the end of this year, it is believed that final plant trials will have been completed. Because the product has not been commercially produced at this time, no objective evaluation of its performance characteristics was possible.

5.4.4 Flooring Market Structure

Resilient flooring products come in two forms, tile and sheet. Asbestos is mixed with vinyl material to produce a vinyl asbestos tile which is less expensive than an all-vinyl tile, yet retains superior characteristics of attractiveness, durability, and directional stability. The cost reduction and performance characteristics of vinyl asbestos tile has made this type of tile the dominant choice in the resilient tile market.

In 1958 sheet vinyl was introduced into the resilient flooring market in competition with linoleum and by 1974, it has virtually displaced linoleum. Vinyl sheets are customarily installed with a cushioned underlayment with an estimated 81% of all permanent sheet vinyls being cushioned. Asbestos paper is combined with latex to provide an underlayment for such installation, but underlayment composed of organic materials is also available. However, asbestos latex is generally the preferred choice due to its rot resistance, dimensional stability and cushioned effect.

Resilient floor covering is subject to product competition from carpeting and hardwood flooring in many applications. Such competition is conditioned not only by price but also by purchaser preferences. Over the past 15 years there have been dramatic shifts in the shares of the flooring market held by carpeting, resilient flooring and hardwood, with carpeting significantly increasing its share.

Several factors seem to have accounted for the growth in carpeting's share of the flooring market. Over the decade of the sixties prices fell relative to other type of flooring. New home builders began to sell homes with installed carpeting, allowing new home purchasers to finance carpet purchases as part of their mortgage financing. New fibers provided more attractive lower priced carpeting. Carpeting made some penetration into the non-residential market. Finally, rising real estate incomes per capita may have led to some product substitution.

The basic reason for developing asbestos vinyl tile was to substitute a lower cost material for vinyl. Currently, solid vinyl tiles costs 3 to 10 times as much as asbestos vinyl tile. Clearly, there will be significant attempts to find substitute fiber rather than go back to a solid vinyl floor tile. The feasibility and cost of such substitute fibers are discussed in the previous Section 5.4.3.

Vinyl-asbestos floor tile and sheet flooring are the predominant products in the resiliant floor market. In 1975, V/A tile had 38% of the resiliant market while 53% was captured by vinyl sheet. The remainder consisted of asphalts and all-vinyl tile, cushioned and non-cushioned sheet vinyls. For the entire resiliant flooring market, 1975 end-use applications are listed as follows, by percentage:

- New Residential Construction -- 18%
- Residential Replacement -- 42%
- New Commercial Construction -- 19%
- Commercial Replacement -- 21%

The "do-it-yourself" market continued to play as important role in the sales of vinyl asbestos and vinyl tile products.(21)

The Predicasts Research Group out of Cleveland, Ohio has estimated that the growth of resiliant flooring in new and replacement markets will remain static through 1985 with most of the increase in demand being fulfilled by carpeting.(22) However, CONSAD does not have sufficient information to determine the specific demand for vinyl-asbestos floor tile as it relates to either the resiliant, or the total flooring market.

5.5 Reinforced Plastics

5.5.1 Background

The largest uses of asbestos in the plastics industry are for vinyl asbestos floor tile and phenolic molding compounds. It is also used to a much lesser extent in other plastics as polypropylene, polyester, nylon, melamine, epoxy, silicone and vinyl. The most important function of asbestos in plastics are reinforcement, dimensional stability, heat resistance, flow control and general-purpose filling. As noted in the previous section, vinyl asbestos floor tile comprises one of the major primary industry segments of the asbestos industry and is covered under its own section, 5.4. While asbestos is used in many plastic applications, the following discussion will focus only on phenolic molding compounds which predominate as the major user of asbestos in reinforced plastic applications.

The major market for phenolic molding compounds are automotive, household applicances, and electronics. Other markets include wiring devices, communications, and closures. The major competitors phenolics have in these markets are other plastics, such as polypropylene, nylons, polyester, alkyds and polycarbonates. However, it also competes with die cast metals, i.e., aluminum in certain light weight automotive applications. The specific breakdown of shares for phenolics and its competitors for these various markets is not presented due to lack of sufficient information. Nonetheless, demand for phenolics presently is growing. In 1976, industry sources estimated that production of phenolic molding compounds was approximately 350 million lbs, while the production for the past 5-6 years has ranged between ±15% of 300 million pounds.(23) The average selling price for phenolics has been estimated to be approximately \$.50/lb; therefore, the total sales of phenolic molding compounds in 1976 was approximately \$175 million dollars. The portion of total phenolics that were reinforced with asbestos for heat and strength properties is not precisely known. Yet industry sources have estimated the asbestos reinforced contribution at approximately 25%, or about 85 million lbs with total sales in the neighborhood of \$40-45 million dollars.(24)

There is presently a well-defined trend to replace asbestos in phenolic molding compounds, documented both by the literature and in numerous conversations with manufacturers of reinforced phenolics. This movement was initiated in 1972 when General Electric started replacing asbestos in their phenolic products with a new talc-based filler which they called E-Grade.(25) Recently, the Durez Plastics Division of Hooker Chemical Company, who reportedly have 40% of the total reinforced phenolic market, has developed a non-asbestos reinforced product. They report that by July, 1977, their entire line of phenolic molding products (e.g., automotive, appliances, wiring, communications, electronics and electrical switch gear) will be reinforced with this new, non-asbestos material. A crude approximation of the progress of this replacement effort was elicited from various industry sources. A rough consensus developed in that after July 1977 between 50 to 70% of phenolic applications which formally used asbestos as a reinforcement will have switched to non-asbestos substitutes. For this reason, CONSAD judged that the reinforced plastics segment of the primary asbestos industries in most cases, would opt to substitute for asbestos as opposed to expending further capital sums for engineering controls to attain these lower exposure limits. However, there apparently are some specialty products where no feasible asbestos substitute has been found. The Rogers Corporation has reported that the phenolic molding material used in commutators and rotors in the electrical and automotive applications currently are reinforced with asbestos. These products function in a very dynamic environment where temperatures of 350°F and 30,000 RPM are prevelent. Asbestos provides the heat resistance, dimensional stability and moldability necessary for these applications and in their experience, no substitute for asbestos fiber exists for their applications. Nevertheless, the overall trend to replace asbestos in phenolics is evident. More than likely the conversion process will be slow, and in some cases costly as new processing techniques are implemented. It may very well be that asbestos will remain a reinforcement material in specialty applications if exposures can be controlled to within acceptable limits.

However, in view of the general substitution trend the technological feasibility of controlling asbestos exposures to 0.1 fiber/cc was not undertaken. The following discussion focuses on these substitution efforts in more detail.

5.5.2 Substitutes for Asbestos

The material most often identified as replacements for asbestos in phenolic molding compounds are talc, clay, and fibrous glass depending upon the desired end-product properties.

Talc

General Electric's asbestos-free Genal phenolics utilize talc as the major reinforcement materials in conjunction with aluminum, silicates and cellulose fibers.(26) GE claims that this new material has the same basic properties -- including impact strength, dimensional stability and heat resistance -- as their previous asbestos filled products.(27) Its predominate use is for heat resistant phenolic molding compounds in the medium temperature applications with its limit determined at 450°F. GE does report that some minor product strength is sacrificed by using this new material, and that more breakage can be anticipated as compared to asbestos filled phenolics; however, GE suggests that manufacturers can compensate by building thicker-walled products. There is no significant difference in the price between asbestos-filled and the Genal product and GE reports that the same processing equipment can accommodate the new material.

Clay

Although the composition of the non-asbestos phenolic compounds developed by Hooker-Durez is proprietary, it is believed to be of a clay base. It too is reported to maintain an acceptable balance between heat resistance and impact strength that the asbestos-filled phenolics provided. The price of the substitute material is indicated to be comparable to asbestos used in these applications (i.e., \$.10/lb). Additionally, supplies are reported to be readily available. Hooker-Durez maintains that the laboratory development of the substitute took approximately 2½ years, while customer acceptance was achieved in a 1½ year period. Furthermore, no change in the production process is mandated by using the new material.

Fibrous Glass

Fibrous glass is the principal reinforcing material in plastics and is an integral part of most new engineering plastics. In higher temperature reinforced phenolics, glass has been suggested as a possible replacement for asbestos. Glass fibers are on the order 5 times more expensive than asbestos (\$.50/lb vs \$.10/lb) and glass filled phenolics are reportedly harder to manufacture due to the brittleness of the glass than asbestos filled. The Rogers Corporation reports that glass fibers will in many applications provide the bulk and strength needed, but because of their brittleness, are unsuitable for molding applications which their customers use. Another prime consideration in molding of any product is the resin's ability to flow in the mold cavity. In very simple molds, glass fibers are acceptable; however, in complex molds or fine detail requirements, they tend to segregate from the resin binder and fracture.

Finally, the abrasiveness of glass apparently affects the "tool wear", or durability of processing equipment. It has been reported that to use glass instead of asbestos in certain reinforced phenolics would necessitate a change in processing equipment. The extent to which glass is replacing asbestos in certain phenolics molding compounds is not known at this time.

Other Possible Substitutes

Jim Walter Resources Inc. has recently developed a processed mineral fiber made from blast furnace slag and silicates. It is reported to be able to reinforce a variety of plastic materials including phenolics, nylons, polybutalene, epoxys, and polyolifins. Its safety category, as covered by pertinent OSHA regulations, is that of an "inert mineral dust." On a comparative price basis, the material is approximately twice as expensive as asbestos fiber ($.15/lb vs $.06/lb). The material is too new to determine what penetration it is having in reinforcement plastic market; however, Jim Walter reports a growing list of customers in this market. (28, 29)

Although much too expensive to be considered an economic replacement for asbestos, graphite fibers are presently being utilized as a reinforcement in molded phenolics, polyamides, expoxies and polyestus.(30) Like asbestos, they can be used to provide phenolics with resistance to acids, alkalis and solvents suitable up to 150°C.(31)

In 1971 potassium titanate fibers introduced by Dupont, tradename FYBEX, were reported to be a suitable replacement for asbestos in many applications, but were primarily considered to be used as a plastic reinforcement. However, in 1974 Dupont withdrew FYBEX from the market due to unfavorable health hazard potential and slow market growth. (See Appendix C for a further discussion of FYBEX.)

5.6 Paper Products

5.6.1 Background

The asbestos industry classifies asbestos paper products into several product groups. These product classes are differentiated primarily by the raw material content of the product and its end-use. In general, the asbectos fibers impact to these products rot resistance, dimensional stability, and resistance to flame, heat and corrosion. Table 5.7 presents the breakdown of the U.S. paper market, its estimated production by product class. For the entire segment, approximately 330,000 tons of asbestos fibers were consumed in 1974, which represents 38% of total U.S. fiber consumption. Therefore, asbestos paper products rank as the leader in overall U.S. domestic consumption of asbestos. The following subsections present background information for each of these product categories. Many of these product descriptions were taken from a study sponsored by the Government of Quebec on the characterization of the U.S. asbestos paper markets.(32)

<u>Flooring Felts</u>

Asbestos-latex paper for sheet-goods flooring is a felted sheet composed principally of asbestos with moderate amounts of a latex binder. Important properties are surface and caliper uniformity, tensile strength, and resistance to water absorption.

Table 5.7: U.S. Asbestos Paper Market
Estimated Production by Product Class, 1975

Product Class	Production Tons	Percent Share
Flooring Felts	125,000	39
Roofing Felts	120,000	37
Gasket Papers	30,000	9
Pipe Line Wrap	26,000	8
Commercial Paper and Millboard	11,000	3
Specialty Saturating Paper	5,000	2
Corrugated Paper	3,500	1
Muffler Paper	3,000	1
Specialty Papers	Minor	
	323,500	

Source: Arthur D. Little of Canada, Ltd.

The paper is converted to a finished flooring product in a variety of operations which may include rotogravure printing or embossing of a pattern in the polyviny chloride coating that serves as the wearing surface of the sheet. The finished sheet is available in many patterns and is easy to install above or below grade.

Asbestos, the major constituent of this paper, is used to provide rot resistance, dimensional stability, and resilience in combination with the latex. A general formulation would be:

- 85% Asbestos
- 15% Latex

The latex in most cases would be a styrene-butadiene type.

Roofing Felts

Roofing paper is a felted sheet material usually manufactured in weight of 9½ to 15 lbs/100 sq. ft. The material is composed principally of asbestos with varying amounts of cellulose fiber and starch binder. Other materials, such as wet and dry strength polymers, fiber glass, mineral wool, and inorganic fillers are often used. The basic sheet is saturated and/or coated with asphalt and used in the construction of built-up roofs.

The asbestos in the felt resists wicking of moisture into the roofing system, resists decomposition of the roof system with age, and assists the felt in remaining dimensionally stable under changing atmospheric conditions.

Wide variations exist in the formulations for roofing felt. A general formulation would be:

- 85-87% Asbestos
- 8-12% Cellulose
- 3-5% Starch Binder

As mentioned inorganic fibers and fillers and assorted polymers may be added in small amounts to modify various properties of the sheet.

Gasket Paper

Gasketing paper or "beater add" paper should be distinguished from milled or compressed asbestos gaskets, which are not a paper product. Asbestos gasket papers are composed of 60-80% asbestos and 20-40% polymer. The product, in roll form, is die-cut to form gaskets. These gaskets are sold primarily to the automotive industry and have a variety of applications, such as head gaskets and carburetor gaskets. Asbestos paper gaskets are often used in combination with metal gaskets; in this application they serve as a cushioning material. However, much of the discussion on gaskets is contained in Section 5.8 under the packings and gaskets segment of the primary asbestos industry.

Pipe Line Wrap

Pipe line wrap is a rolled asbestos paper product, reinforced with parallel glass strands, and saturated with asphalt or coal tar.

The product is used as a wrapping for underground and submarine pipe lines for corrosion protection.

Commercial Asbestos Paper and Millboard Products

Commercial asbestos paper and millboard products - encompass a broad range of papers which vary primarily in weight and thickness. The product is composed of 95-98% asbestos fiber and 2-5% starch filler. For millboard, the filler can also be cement or other inorganics. The products are sold in rolls (rollboard), sheets, and tapes. The principal end-use of all these products is to provide insulation of minimum thickness against fire, heat and corrosion. Papers are used in electrical insulation, ovens, gas ranges, safes, welding mats and other similar applications. Millboard has an important use as a conveyor material in glass and steel factories.

Specialty Saturating Papers

Specialty saturating papers - are a paper product that is saturated with a thermosetting resin. The paper is wrapped or rolled and then cured to form a hard, heat-resistant substance. It is used principally in high-pressure decorative laminates and in cooling towers.

Corrugated Paper

Corrugated paper is a commercial paper product that is corrugated and cemented to a flat paper backing. It is sometimes laminated with aluminum foil. Because of its lightness and flexibility, the product is used to insulate curved surfaces.

Muffler paper is a waffled or indented asbestos paper product which is used in exhaust emission control systems in automobiles. The product is used primarily as a wrap between the inner and outer skins of a muffler. Another, less common use is as a heat shield between a muffler and the body of the automobile.

Specialty paper products are made to order for numerous specific applications. Some of these products are flame barrier papers (used in aircraft and ships), filter papers (used in pharmaceuticals, beer and wine), electrolytic diaphragms, and high temperature transformer papers.

5.6.2 Technological Feasibility

Review of Process

Production of asbestos paper products begins with introduction of dry asbestos fiber into the process. Individual bags are opened (manually or semi-automatically), and the contents dumped either to a holding hopper and conveyed to the stock preparation area, or directly into the stock-preparation vessel without intermediate storage. "Pulpable" Kraft paper bags containing raw asbestos fibers can be added unopened to the hydropulper or beater without the manual bag-opening and bag-disposal steps.

In the stock preparation step, asbestos, paper stock, binder, and other additives are wet mixed to specified concentrations and consistencies using hydropulpers or beaters. The stock is then pumped into a holding vat and subsequently to the papermaking machine. Asbestos-paper machines for commercial paper and roofing felt include the multi-cylinder and Fourdrinier types which closely resembles machines used in non-asbestos papermaking.

Rotating cylinder molds form the wet plys which are then laminated and press-rolled to remove excess water. Wet paper is routed through a dryer on steam-heated drums to attain desired moisture content. After drying, it passes continuously to a cutting/slitting area to be cut into rolls. The paper product can be packaged directly or rewound. After rewinding on spools, the final product is packaged and wrapped for bulk shipment.

Control Methods and Work Practices

Stock preparation includes fiber introduction -- dumping or whole-bag addition -- to a beater or hydropulper. Such equipment is kept under negative pressure by its inclusion in an exhaust system connected with a larger dust-collection system. When asbestos-containing pulpable bags (Kraft paper) are introduced directly into the stock preparation, this eliminates exposure from bag-opening and bag-disposal.

Housekeeping in the stock preparation area represents a crucial control component for minimizing operator exposure to asbestos. Use of central vacuum-cleaning systems and mechanical floor sweeper-vacuum units should be routine in these operations.

The stock slurry flows into the papermaking machine and forms a "sheet" with solids content less than five percent. Although the moisture content is reduced greatly during transit through the paper machine, the wet nature of the material largely precludes the release of airborne asbestos. Nevertheless, rigorous housekeeping and clean-up measures are critical here as well. Worker exposure in this area can be minimized by preventing spilled material from drying and thus creating a potential dust source.

The steam-heated rolls in the drying section are typically canopy-hooded and exhausted to remove water vapor and heat. This type of hooding and exhaust augments the general ventilation in the area and aids in removing asbestos particulate released during the drying operation.

Local exhausts, area hoods, and exhausts connected to a central collection system represent the normal control measures used to minimize asbestos exposure at the slitting and calendering stages. Housekeeping is also critical here.

The rewinding step involves bulk packaging of paper products on spools, reels, or beams from larger rolls. The operation is completely dry, and area hoods and exhausts typify dust-control measures at these operations. Housekeeping operations in use for this process step are identical to those for stock preparation and papermaking steps.

Currently Achievable Exposures

Available, proven control measures and work practices which could be used now to better advantage to assure low exposure levels include the rigorous application of well-known methods, such as:

- Regular performance checks and preventative maintenance on local exhaust systems;
- Immediate clean-up of spillage and floor accumulation of asbestos-containing solids using central vacuum-cleaning systems;
- Floor cleaning at least once per shift with a power-vacuum unit -- preferably combined with wet floor cleaning; and
- Mechanically-supplied, contaminant-free make-up air (tempered relative to ambient conditions) in sufficient volumetric flowrates to balance the combined local exhaust capacity in a given work area.

These measures, together with the consistent, exacting application of control measures described above would, in Clayton's judgment, achieve exposure levels consistently below 0.4 fiber/cc on a time-weighted average basis for papermaking operations.

Future Controls Under Development

Advancing technology useful for reducing asbestos exposures in asbestos papermaking operations includes more high-automated equipment for greater enclosure and better ventilation. The effect of binder and flocculating agents on fiber release is also an on-going research and development program as it may affect the optimum papermaking stock composition and end-use functionality.

Projected Lowest Achievable Exposures

Table 5.8 shows the projected lowest-achievable exposures that can be attained as a result of the exacting application of control methods mentioned previously and the timely implementation of new technology as it is developed. In summary, the contractor believes that TWA exposures in the papermaking segment can be maintained consistently below 0.2 fiber/cc within two years.

5.6.3 Substitute Materials and Competitive Products

Asbestos imparts to paper characteristics of dimensional stability, durability, resistance to alkali attack, and thermal insulation. As discussed previously, the asbestos market is divided into several major categories. Where information is available, substitution possibilities and competitive products are discussed below for each of the product categories.

Flooring Felts

Flooring felts are used as a base for vinyl sheet flooring or as a underlayment for vinyl tile and carpeting. These materials have competed very successfully with organic, or jute felts in the past. However, development of foam cushion backings and backless flooring will place competitive pressures on asbestos flooring felts. In Europe, fiberglass mats are being used as an underlayment to resilient sheet flooring; however, the dimensional stability is not as good as with

Table 5.8: Reported and Projected Asbestos Fiber Concentrations
Asbestos Paper and Felts

Process-Related Work Areas	TWA Asbestos Exposure Level (fibers/cc)		
	Reported Levels	Currently Achievable	Projected Lowest Achievable
Fiber Receiving & Storage	0.2 - 2.5	0.3	0.2
Fiber Introduction	0.3 - 2.8	0.4	0.2
Stock Preparation	0.1 - 2.7	0.3	0.2
Papermaking	<0.1 - 1.0	0.3	0.2
Drying	0.5 - 1.5	0.3	0.2
Slit and Calendering	<0.1 - 1.6	0.3	0.2
Rewinding	<0.1 - 1.5	0.3	0.2
Splicing	<0.1 - 0.4	0.3	0.2

asbestos flooring felt. Domestic research activities have also tried Dupont's "Nomex" aramid fibers, fiberglass, cellulose fibers; yet no acceptable substitute for asbestos has yet been determined.

Roofing Felts

In the first half of the current decade, the asbestos roofing felt market was one of the fastest growing of the asbestos products markets. After a 1968 American Society for Testing and Materials recommendation, asbestos felt roofing began to make rapid penetration in organic roofing felts' share of the built up roofing market. Its technical advantages over organic systems lie in its rot resistance, dimensional stability and in the fact that it does not require a gravel surface. This last feature makes the roof easier to inspect and repair.

In 1976 built up roofing sales of all types were about 53 million squares. Organic systems had about 45% of the market, asbestos felt 25%, and fiber glass felt 10-15%. Just as asbestos felt made rapid inroads into the organic market share, industry sources believe that fiber glass roofing will reduce both the share of organic and asbestos roofing felts in the built up roofing markets. Fiber glass has the same technical features as asbestos for a roofing product, but it requires less asphalt saturation. Both fiberglass and asbestos systems are inorganic. Inorganic systems have better rot resistance and dimensional stability than organic systems.

With the escalation of petroleum and asbestos fiber prices, fiber glass systems have become less expensive than asbestos felt systems. While prices vary widely across the country, the current average price for a gravel surfaced fiber glass system is $30/square (including labor and materials). This compares with $39-$40/square for an organic system and $46-$47/square for an asbestos system.

Continued expansion of fiber glass capacity can be expected to maintain downward pressure on asbestos roofing felt prices, thus preventing asbestos roofing felt manufacturers from passing on cost increases. According to Arthur D. Little of Canada estimates (32), the free market price of asbestos roofing felt was very close to manufacturing cost in 1975. If their estimate is correct, asbestos felt may be entirely priced out of the market by fiber glass.

Gasket Paper

There is presently very little competitive products or adequate substances for this product category. See also Section 5.8.3, Packings and Gaskets.

Pipe Line Wrap

The coal tar enamel asbestos felt system for oil and gas pipelines is still the most competitive and preferred of all systems. But since 1973 the price of this system has doubled with increased prices for asbestos fiber and increased cost of production for asbestos paper.

This has enabled saturated fiberglass outer wrap to gain a greater share of the market, and become the chief competitor for asbestos felt as a component of the same general system. Alternative systems include epoxy coatings, PVC tape, and PE tape. Continually increasing prices for asbestos pipe line wrap will certainly decrease its share of market in this competitive field.

Commercial Asbestos Paper and Millboard Products

Domestic research for substitutes have centered on fiber glass, cellulose, "Nomex" and "Kevlar" fibers.* Johns-Manville reported on research with glass fiber which resulted in a weak, brittle, more expensive product that required a new forming system for manufacture. Other industry sources have quoted a glass paper developed for thermal applications costing approximately $2/lb as compared to $.35/lb for asbestos commercial paper. Cellulose papers lack the temperature resistance of asbestos paper and they do not have equivalent dimensional stability under relatively high humidity and temperature. For electrical insulation applications, Dupont has marketed a "Nomex" paper which is thermally stable, flame resistant, moisture resistant and has excellent electrical properties. (33) It has been approved by Under-

*See Section 5.9.3 for more discussion on Nomex and Kevlar fibers.

writers Laboratory for temperatures up to 220°C. The cost of Nomex papers varies from \$6-\$7.75/lb depending upon its thickness and density. The extent to which Nomex paper has competed with asbestos commercial papers has not been determined.

Ceramic mineral fibers, "Kaowool" by Babcock and Wilcock, Inc. and Carborundum's "Fiberfax" have seen applications recently in millboard and rollboard in which the asbestos has been replaced. These materials have very good temperature resistance up to 2300°F, but do not have the reinforcing capabilities of asbestos. Ceramic papers are also a great deal more expensive than their asbestos counterparts with prices ranging from \$5-\$10/lb as compared to \$.35/lb for commercial asbestos papers. Due to this price differential, ceramic papers cannot be considered as an economically direct replacement for asbestos in all paper applications.

Muffler paper has been one of the fastest growing products in the asbestos paper industry due to their use in catalytic converters in emission control systems. Nevertheless, industry sources have revealed that the automobile industry is currently looking for a replacement for asbestos in these applications, presumably to glass, or ceramic papers.

Other Applications

In the specialty paper market which includes asbestos filters and diaphrams, some progress has been reported in replacing asbestos.

The Durez Division of Hooker Chemical Company has developed a new membrane made from perflurosulfionic acid resins for use in chlorine-caustic production. They claim that this new material, tradename NAFION, represents an improvement over asbestos diaphrams and is less expensive. However, they do report that the membrane is not as efficient electrically as asbestos diaphrams. (34) Saffil alumina fibers by ICI in England show promise as high temperature and chemical resistant filtration medium. They have demonstrated to be an effective replacement for asbestos filters in breweries. (35, 36)

5.7 Gaskets, Seals and Packings

5.7.1 Background

Asbestos is the most widely used material for gaskets and packing because of its resilience, strength, chemical inertness, and heat resistance. These asbestos materials are used in nearly every industry, household, machine, and transportation vehicle.

A wide variety of products are manufactured using raw asbestos fiber, textiles, and asbestos paper. The asbestos may be bonded under heat and pressure with materials such as nitril rubber or chloroprene for resistance to oil and solvents. In fact, a wide range of materials is used in compounds with asbestos to engineer a product of highly specialized properties. Although some dry asbestos packing is used to seal furnace doors, rotary kins and high-temperature refractory equipment, packing generally incorporates a lubricant and is typically made by braiding asbestos yarns which are impregnated with a grease-base lubricant.

As a distinct industry segment, packings and gaskets consumes approximately 50,000 tons of fiber per year based on 1974 estimates. However, this figure may be misleading by itself because of those 50,000 tons is included 21,000 tons of fibers used in beater-add gaskets, a paper product. Therefore, not counting beater-add gaskets, 29,000 tons of fibers went into this segment and represent about 3% of the total U.S. asbestos consumption.

This segment of the primary asbestos industry is further complicated by the fact that the materials used as packing are in actuality asbestos textiles. Therefore, the gasket, seals and packing segments described in this section also includes materials from the paper and textile segments. For example, manufacturers of sheet and beater-add gaskets sell pressed gasket material to gasket manufacturers (numbering around 40 establishments nationwide). These firms may then sell to gasket cutters, numbering between 200 to 300 establishments, or they may go directly to end-users. For consistancy in the discussion on substitutes and competitive products, there exist six major product lines of packing and gaskets which contain asbestos. There are:

- Compression Packings
- Molded Packings
- Sheet Gaskets
- Beater-Add Gaskets
- Spiral-Wound Gaskets
- Metal-Clad Asbestos Gaskets

5.7.2 Technological Feasibility

<u>Review of Process</u>

<u>Gaskets</u>. Asbestos bags are opened manually and dumped into a mixing tank or a conveyor leading to the mixer. In some cases, the compressed raw asbestos is dumped into a fluffer for fiber opening before the mix step. Fillers and bonding materials are also added to the mixer, and the mixture is blended. Mixing may be in a dry or wet state, according to the product requirements; multiple production lines may be employed.

The formulation from the mixer is calender-rolled into sheeting. The sheeting may be packaged and sold to secondary manufacturers for further processing, such as gasket cutters. The sheeting could also be sold in sheet form to distributors serving the maintenance market.

Packings. Asbestos-based packing can be manufactured by a number of processes. The most common method is to impregnate dry yarn with lubricants, which coat the fibers. These yarns are then braided into a continuous length of packing, and then calendered to specific sizes and cross-sectional shapes. The sized braid may then be coiled, boxed, and sold to the maintenance trade, or it may be cut and die-formed to manufacturer's specifications.

A variation of braided packing can be produced by first extruding a mixture of asbestos fiber, binder, and lubricants, and then braiding lubricated asbestos yarns over the extrusion.

Control Methods and Work Practices

The greatest fiber exposure potential for the gaskets and packings segment is associated with the manual handling, opening, dumping, and mixing of raw asbestos from bags as well as bag disposal. These exposures are controlled by local exhaust ventilation and floor cleaning. Where mixing is accomplished with a wetted compound, fiber evolution is low. Fiber exposure during braiding and twisting of treated asbestos yarn can likely be controlled adequately by local exhaust supplemented by general control measures, including dilution, ventilation, and systematic cleaning.

Reported Exposure Levels

Several plant visits plus continuing correspondence and phone interviews with industry representatives, together with a review of recently-published exposure levels, show the time-weighted average (TWA) asbestos exposures in the gaskets and packings segment to range widely from 0.1 to 2.5 fibers/cc. However, even the lower reported levels have generally been achieved with less-than-full-scale, optimum application of currently-available, proven control measures and work practices.

Currently-Achievable Exposures

Available, proven control measures and work practices which could be used now to better advantage to assure low exposure levels include the rigorous application of well-known methods, such as:

1. Regular performance checks and preventative maintenance on local exhaust systems;
2. Immediate clean-up of spillage and floor accumulation of asbestos-containing solids using central vacuum-cleaning systems;
3. Floor cleaning at least once per shift with a power-vacuum unit - preferably combined with wet floor cleaning; and

4. Mechanically-supplied, contaminant-free make-up air (tempered relative to ambient conditions) in sufficient volumetric flowrates to balance the combined local exhaust capacity in a given work area.

These measures, together with the consistent, exacting application of control measures described above would, in Clayton's judgement, achieve exposure levels consistently below 0.4 fiber/cc on a time-weighted average basis for the packings and gaskets segment.

Future Controls Under Development

New control techniques for the gasket and packings segment relate almost exclusively to fiber receipt and dumping, including improved packaging of raw asbestos and the ultimate conversion to semi-automated dumping and use of more densified raw fiber.

Projected Lowest-Achievable Exposures

Table 5.9 shows the projected lowest-achievable exposures that we believe can be attained as a result of the exacting application of control methods mentioned previously and the timely implementation of new technology as it is developed. In summary, the contractor believes that TWA exposures in the gasket and packings segment can be maintained consistently below 0.2 fiber/cc within two years.

TABLE 5.9

REPORTED AND PROJECTED ASBESTOS FIBER CONCENTRATIONS

GASKETS AND PACKINGS

Process-Related Work Areas	TWA Asbestos Exposure Level (fibers/cc)		
	Reported	Currently Achievable	Projected Lowest Achievable
Fiber Receiving & Storage	0.2 - 2.5	0.3	0.2
Fiber Introduction	0.5 - 2.5	0.4	0.2
Mixing	<0.1 - 1.0	0.3	0.2
Braiding and Twisting (damp process)	0.1 - 1.6	0.4	0.2
Sheet Formation	0.2 - 0.3	0.3	0.2
Cutting/Packaging	0.1 - 0.5	0.3	0.2

5.7.3 Substitutes and Competitive Products

Table 5.10 presents the various sub-markets for asbestos packings and gaskets. It also includes size and share of these markets in addition to major competitive products for each major line.

Compression Packings

Compression packings are also known as mechanical and braided packings. These materials are actually asbestos textiles that have been braided for flexibility and resiliance. The asbestos also acts as a reinforcement for longer wear, heat and chemical resistance and has the ability to hold a lubricant, then discharge it under pressure. Cotton, jute and flax packings work well in cold environments (below 0° C) and cotton is acceptable at room temperature for water pump applications (38). However, these materials will not function at elevated temperatures. TFE*, Dupont trade name TEFLON, yard can be used in applications up to 500° F and has the chemical resistance of asbestos in the extreme ph ranges, 1-2 ph for strong acids, and 13-14 for very caustic material. In a conversations with SEPCO Company, it was found that TFE filament yarn is 8 times more expensive than woven asbestos ($10 to $12 lb. vs. $1.50-$1/75/lb. for asbestos) and would increase the selling price of the

*tetrafluroethylene

TABLE 5.10

Packings and Gaskets - Sub-Markets

	Estimates of Annual Sales	Competitive Products	Market Position
Compression Packings (mechanical or braided packings)	$75-$100 million	TFE Filament Yarn (Teflon) Graphite Filament Yarn	Total Market - Asbestos 75% Excluding cold water gaskets Asbestos 90%, TFE & Graphite 10%
Molded Packings (hydraulic, pneumatic)	$10-$15 million	Grafoil	Asbestos less than 10% of market
Sheet Gaskets	$50 million	Neoprene, STR Teflon mixed with Fillers	Insufficient information to evaluate market shares
Beater Add Gaskets	$100 million	Neoprene, STR Teflon mixed with Fillers	Entire Market Asbestos
Spiral Wound Gaskets	$15-$20 million	Teflon Strip Grafoil	Asbestos 90%
Metal Clad Asbestos Gaskets	$10-$15 million	No competitive Productive	Entire Market Asbestos

Source: Conversations with Industry Representatives

CRMC-M&S-002863

packing 4 to 5 time over the asbestos packings. Furthermore, TFE packings will not hold lubricants like the asbestos packings, thus decreasing their overall acceptance.

Graphite filament yarn is presently being used in packing applications where extremely high heat and chemical resistance are required. It is able to withstand temperature up to 1500° F; however, because of its poor tensile strength it is difficult to process. Compared to asbestos packings, graphite packings are extremely expensive ($30-$35/lb.), and yet its popularity is growing due to its increased resistance to heat and chemicals which add significant product life over conventional asbestos packings.

A third high-priced substitute for asbestos packing is ceramic yarn which costs approximately 10 times that of asbestos. It has good chemical and temperature resistance, but is also has poor tensile strength and is extremely abrasive.

As is evident, there do exist substitutes for asbestos mechanical packings, but no one material will be adequate for all the different applications which asbestos enjoys. With no economic considerations, asbestos could be replaced with some performance penalty. However, the raw material cost would be an order of magnitude greater than asbestos.

Molded Packing

Molded packings use asbestos and rubber in a compression packing to be used as a seal around rotating shafts. There are presently substitutes available especially in low temperature applications organic such as cotton or jute could be utilized. Canvas molded packings are also in use today and as less expensive than similar types of asbestos packings. In higher temperature applications, glass textiles could be utilized. The cost of these glass packings would be slightly higher than comparable asbestos packings. Additionally, Grafoil, a graphite molded packing manufactured by Union Carbide can withstand temperatures of 3000 F and could replace asbestos in many high temperature applications. However, it is much more expensive.

Sheet Gaskets

The asbestos sheet gaskets impart dimensional stability, reinforcement, heat and chemical resistance, and resiliance to stress and relaxation. Approximately 75 to 80% of the sheet gasket applications are to seal flanges at temperatures below 500 F. The organics, cotton and jute, do not have the temperature resistance for these applications. Fibrous glass is brittle and subject to chemical attach. Dupont's Teflon mixed with fillers is being used for sheet gaskets at temperatures up to 500 F; however, it is significantly more expensive than asbestos ($3.50-$4.00/lb. with glass fiber filler vs. $1/lb. asbestos). Other performance penalties are that the teflon will squeeze out of the gasket under extremely heavy mechanical loads, i.e., 2000 psi. Additionally, under a heavy load the gasket will deform over time. Dupont sources indicate that Teflon filler mixed with carbon or graphite improves the performance characteristics greatly, but also adds significantly to the cost.

<u>Beater-Add Gaskets</u>

Beater-add gaskets are actually a paper product made from the same machine as used for latex sheet underlayment for vinyl sheet flooring. Property characteristics have already been discussed in Section 5.6 for the paper segment of the asbestos industry. At present, no suitable substitutes have been found for the asbestos beater-add gaskets. Furthermore, in applications that are not both critically sensitive to high heat and pressures, these gaskets are taking over a greater share of the gasket market.

<u>Spiral-Wound Gaskets</u>

These metal gaskets utilize asbestos paper and are found primarily in high temperatures. Asbestos spiral wound gaskets have approximately 90% of the market. Teflon may be used when greater chemical resistance is needed, and Grafoil, a graphite material, is utilized where very high temperatures are present.

Metal Clad Asbestos Gaskets

These gaskets use asbestos as a filler in a metal sandwich and find use in heat exchangers in industry. Apparently, no competitive products exist for this asbestos application.

Common Problems Associated with Non-Asbestos Gaskets

As has been shown, there do exist many varieties of substitutes and competitive products that could replace asbestos. However, there is not one single substance that is compatible with all of the asbestos gasket applications. From a practical standpoint, if industry were forced to switch to non-asbestos gaskets, many different types of gaskets would have to be stocked and problems may result from improper selection. Additionally, for varying temperature and chemical applications, asbestos gaskets have proven to be an excellent performer. not only on a technical basis, but also on cost. Other materials are invariably more expensive, and in many instances, there may be a performance penalty in switching to a non-asbestos gasket.

5.8 Paints, Coatings and Sealants

5.8.1 Background

The primary constituent of this industry segment is asphalt coatings which represent a line of products which have a variety of end uses in the industrial, automotive, and construction industries. They are produced for such varied uses as protective coatings for metals and tanks, insulation for pipes and tanks, sound deadeners, sealants and undercoatings for automobiles and roof coatings, flashing cements and tile cements in construction. One type is made from an asphalt cut back with kerosene or mineral spirits used as a solvent and the other with an asphalt emulsion in water.

The primary purpose of asbestos in coatings is to enhance the rheology of the system and especially the thixotropic characteristics. Since many of the uses involve outdoor exposure the excellent weathering resistance imparted to the coating by asbestos is essential and its fibrous nature provides the desired viscosity characteristics. The low cost of asbestos in relation to the value added is essential in these low cost products.

Because of the variety of products and the number of producers there are unlimited formulations. The major components are:

Cutback Products

Cutback Asphalt	30-80%
Asbestos	10-15%
Limestone and Slate Fluor	15-30%
Disperant	1%

Emulsion Products

Emulsion Asphalt	55-80%
Asbestos	10-15%
Limestone	5-15%
Dispersant	1%

Asphalt coatings and sealants consume approximately 65,000 tons of asbestos annually, representing around 7% of the total U.S. fiber consumption. For this report, joint cement compounds is included under this general coatings and sealants heading. In 1974, 13,000 tons of asbestos were used in joints cements; however, this figure is reported to be drastically reduced for 1976 consumption due to substitution efforts in anticipation of the ban on dry-wall spackling compounds by the U.S. Consumer Products Safety Commission.

The major products applications that will be discussed in the subsequent section of substitutes and competitive products include:

Asphalt roof coatings	35,000 tons of asbestos
Automobile underbody coatings	8,000 tons of asbestos
Adhesives and sealants	insufficient data on consumption

5.8.2 Technological Feasibility

Review of Process

The paints, coatings, and sealants manufacturing operations are characterized by two key operations: mixing and packaging. Fiber introduction in this segment represents the critical phase with regard to worker exposure. Fiber fluffing must be used to convert the compressed fibers to an open, free condition to assure dispersion and encapsulation during asphalt mixing.

Fluffed asbestos fiber is transferred to hoppers or directly to a batch mixing tank. Either horizontal, helical type mixers or paddle-blade type mixers are used to provide homogeneous dispersion. Fiber transfer takes place pneumatically, by mechanical conveyor, or manually. Pneumatic transfer systems are enclosed and exhausted through fibric filters. Conveyors are generally enclosed. Manual transfer may be employed for small batch operations or for specialized, low-volume requirements.

The fluffed fiber and other dry materials are mixed with asphalt (and solvents as required) in a batch tank; in some cases, mixing order is reversed and only dry materials are mixed initially. The batch is mixed sufficiently to achieve uniform dispersion. The batch is mixed sufficiently to achieve uniform dispersion. The batch mixing tanks are normally exhausted to prevent fiber dispersion. After a short mixing time, the asbestos fiber is bound in the asphalt. Upon completion of mixing, the asbestos is encapsulated in the asphalt with little chance for fiber dust exposure. When the batch is finished, the material is pumped to the packaging operation.

The predominant packaging for coatings is 5-gallon cans with sealed lids. Special orders are filled occassionally with drum containers, and bulk shipments occur rarely.

Control Methods and Work Practices

The need to achieve a high degree of fiber opening for the paints, coatings, and sealants applications has led to the use of a high-speed fluffer which can create a backdraft that tends to offset the control velocity achieved within the fiber dumping hood at the fiber introduction station. This is offset in part by the fact that the typical fiber introduction operation is very intermittent, lasting only a small fraction of the work day. Nevertheless, this operation needs to be redesigned or modified to achieve and maintain inlet velocities of at least 250 feet per minute even when the fluffer is activated.

No control equipment is installed or believed required from the mixing through packaging stages of processing in this segment.

Reported Exposure Levels

Recent plant visits plus continuing correspondence and phone interviews with industry representatives, together with a review of recently-published exposure levels (1, 2, 3), show the time-weighted average (TWA) asbestos exposures in paints, coatings, and sealants to range widely from 0.1 to 8.0 fibers/cc. However, even the lower reported levels have generally been achieved with less-than-full-scale, optimum application of currently-available, proven control measures and work practices.

Currently-Achievable Exposures

Available, proven control measures and work practices which could be used now to better advantage to assure low exposure levels include the rigorous application of well-known methods, such as:

1. Regular performance checks and preventative maintenance on local exhaust systems;
2. Immediate clean-up of spillage and floor accumulation of asbestos-containing solids using central vacuum-cleaning systems;
3. Floor cleaning at least once per shift with a power-vacuum unit - perferably combined with wet floor cleaning; and
4. Mechanically-supplied, contaminant-free make-up air (tempered relative to ambient conditions) in sufficient volumetric flowrates to balance the combined local exhaust capacity in a given work area.

These measures, together with the consistent, exacting application of control measures described above would, in Clayton's judgement, achieve exposure levels consistently below 0.4 fiber/cc on a time-weighted average basis for paints, coatings, and sealants.

Future Controls Under Development

Ongoing technological improvements for control of asbestos exposures in this segment of the primary industries relate primarily to fiber receipt, storage, and bag-opening developments discussed earlier in the report. Particular attention needs to be given, and is being given, to the develolment of adequate exhaust hooding for manual fiber dumping because of the importance in these operations to open and fluff the compressed fiber prior to mixing. This high-speed fluffing can create back-draft windage, and this needs to be overcome by adequately-designed local exhaust in order to control exposures in the fiber-introduction phase of the operations.

Projected Lowest-Achievable Exposures

Table 5.11 shows the projected lowest-achievable exposures that can be attained as a result of the exacting application of control methods mentioned previously and the timely implementation of new technology as it is developed. In summary, the contractor believes that TWA exposures in the paints, coatings, and sealants segment can be maintained consistently below 0.2 fiber/cc within two years.

TABLE 5.11

REPORTED AND PROJECTED ASBESTOS FIBER CONCENTRATIONS

PAINTS, COATINGS, AND SEALANTS

Process-Related Work Areas	TWA Asbestos Exposure Level (fibers/cc)		
	Reported Levels	Currently Achievable	Projected Lowest Achievable
Fiber Receiving & Storage	0.2 - 2.5	0.3	0.2
Fiber Introduction	1.5 - 8.0	0.4	0.2
Mixing/Compounding/Packaging	<0.1	0.2	0.1

5.8.3 Substitutes and Competitive Products

Asbestos is mixed with asphalt and other fillers to give sealants and coatings dimensional stability. The advantage of using asbestos in asphalt is in the electrical and capillary affinity between the two materials that strengthens the bond between the filler and base.

Roof Coatings

For roof coating applications, asbestos contributes to the viscosity of the fluid, increase the tensile strength through reinforcement, and provides stability in can storage. The amount of asbestos in this material ranges between 15-20%. TREMCO, Inc., one of the largest producers of roof coatings has tried polyethylenes, polyproylenes, polyesters, and acrylics as a substitute for asbestos. They have developed a proprietary substitute with acceptable characteristics in this application, but its cost is 8 times that of asbestos. Furthermore, it is reported that a change in the manufacturing process would be required if these materials were produced commercially. Some success has been achieved utilizing fiberglass as an asbestos substitute in roof coatings. The glass provides reinforcement, but does not contribute to the viscosity of the coating. It also lacks the chemical affinity for asphalt that asbestos fibers apparently have. Fibrous glass used in these applications are on the order 7 times more expensive than asbestos ($.50/lb. vs $.06-$.10/lb. for asbestos) and apparently would require a change in the manufacturing process.

The market for roof coatings is divided into fibrated and non-fibrated coatings representing 60% and 40% of the total market respectively. To date, the fibrated coatings are almost completely asbestos filled; however, as reported above, substitute materials may become a factor in the future. The non-fibraded roof coating are generally used for maintenance and repair work. Furthermore, they cannot be used on steep, or vertical surfaces because they will slide off. Asbestos roof coatings offer the advantages of better weather resistance and a better fire rating.

Automotive Underbody Coatings

In automotive underbody coatings, the asbestos-asphalt material provides a sound deadener and corrosion resistance. Johns-Manville reports that other materials have not been found to be as effective on a cost/performance basis as asbestos in this application. There do exist others that achieve the same effect of resisting corrosion (i.e., zinc-processing to rust-proof automobiles), but they do not significantly deaden sound.

Adhesives and Sealants

Asbestos used in adhesives and sealants provide reinforcement, weather resistance and temperature resistance. This market is primarily in automobile, mobile home and industrial applications. Many sealants for household use do not contain asbestos, but without asbestos as a fiber, they are more expensive. A fumed silica (high purity silica oxide) material manufactured by the Cabot Corporation, trade name Cab-o-Sil, is reported to be an asbestos substitute in decorative coatings and wood ashesives. Its cost is $1.20 to $3/lb. compared to $.15/lb. for asbestos; nonetheless, because of the high selling price of many sealants, Cab-o-Sil can be used as an asbestos replacement. Percipitated silicas are also reported being used as a substitute for asbestos in sealants.

Joint compounds used as dry-wall spackling compounds may not be considered sealants or coatings in a traditional sense; however, for consistency they will be discussed under this heading. Over the past few months, there has been a consistent trend to substitute for the asbestos in this product due primarily to the dust problems encountered in using the product. In April 1977, the Consumer Product Safety Commission decided to propose a ban on the use of asbestos in these products.* Therefore, asbestos will continue to be replaced in this application. An asbestos-free dry-wall joint compount was developed by National Gypsum and utilizes attapulgite clay as an asbestos substitute. It is reported that these asbestos-free compounds have good plasticity, water retention, cohesiveness and viscosity stability (37). The construction industry has estimated that to substitute the asbestos in dry-wall joint compounds would increase the price of the compound approximately 12 to 13%.

*No specific proposal has been published to date.

5.9 Asbestos Textiles

5.9.1 Background

Asbestos fibers, when worked into textile form, provide a material which is incombustible and retains its physical properties at high temperatures. Asbestos textiles are manufactured in several different forms:

- Lap - used as insulation for electrical conducters;
- Roving - used as insulation for heater cards, twisted to form yarn;
- Yarn - woven into textiles;
- Cord - used for seals, packing, insulation;
- Cloth - used for curtains, blankets, safety clothing;
- Tubing - used for sleeving for electrical conducters;
- Wick - used as packing and sealings;
- Tape - used for electrical insulation.

Typical formulation for those textile products are 75-100% chrysotile asbestos and 0-25% organic fibers.

The U.S. asbestos textile market consumed approximately 12,000 tons of asbestos in 1974 which accounted for approximately 1% of total U.S. fiber consumption. The primary end uses for asbestos textiles are in friction materials, packings and sealings, protective clothing and thermal and electrical insulation.

5.9.2 Technological Feasibility

Review of Process

Asbestos textile manufacturing operations comprise two basic process variations: conventional and wet. The conventional operation can be subdivided into "dry-woven" and "damp" processes. The dry and damp processes differ only with respect to moisture applied to the yarn by contact with water on a roller or a mist spray. The dry-woven process yields highly specialized yarn without any water contact. Dust release in dry processing is much greater than in damp processing.

The newly-developed wet process produces yarn by extruding a chemically-dispersed slurry into a chemical coagulant. The wet-process yarn so formed is dense and tends to hold asbestos fibers better than yarn produced by the conventional process. This has a beneficial effect, resulting in smaller amounts of fibers released to the work environment. Major disadvantages with yarn produced by the wet process include reduced absorption and impregnation characteristics.

Textile plants typically produce several products, and thousands of operations occur simultaneously as hundreds of strands are wound, rewound, spun, twisted, braided, and woven. Because of the replicated operations and the continuous, high-speed movement of final and intermediate yarn products, hundreds of point sources of asbestos fiber are present in any given area.

Conventional Process

The raw asbestos grades and other ingredients are weighed and dumped into several blending machines. The blending machines are operated continuously to gently mix the components of the formulation. The mixing takes place as the asbestos slowly moves toward the rear of the machine, is drawn up an incline, and tumbles back to the bottom. Part of the mix is carried over the incline and falls into a hopper. The rear of the blending machine is enclosed and hooded to minimize fiber evolution. As the hoppers are filled with the blended fibers, they are transferred to the carding machines.

The carding operation combs the fiber mix into a paralleled (oriented) fiber mat. This mat is pressed mechanically and layered into a lap. At the finishing card, the lap is separated into thin continuous strips of fiber known as "roving". At this point, cotton or rayon or other materials may be added to the roving to impart strength and other characteristics. The lap, matting, or roving may be packaged and sold to secondary industries. Otherwise, the roving procedes to the spinning operations.

The roving is spun by twisting to the specified number of turns per inch to give it strength. In the damp process, the roving is moistened via wet rollers before spinning. This dampening process is employed to reduce fibrous dust during subsequent processing. In some cases, for reasons of product quality, the roving is not wetted.

During spinning and further processing, many of the strands will break, releasing fibrous dust as ends whip around the spindles. During this high-speed processing, strands break repeatedly and are repaired manually.

Spun roving, known as "single yarn", can be twisted with other single yarn, or other material to produce "plied yarns". Plied yarns can be coated to produce thread or treated yarns, or be woven to produce tapes, cloth, or woven tubing. It can also be braided to produce cord, rope, or braided tubing. Spun yarn can be processed without twisting to produce woven, braided, and otherwise-treated products.

At the weaving operations, the yarn is first put on a beam or creel, which handles a large number of strands to feed a loom. A "damp" or "dry" loom can be used to create cloths of different characteristics.

Wet Process

The wet process differs from the conventional processes in that the raw asbestos is dumped directly into a slurrying tank with water and chemicals. The resulting slurry is extruded directly into strands. These strands proceed to the spinning and subsequent operations similar to conventional processing. The wet process thus produces the blending and carding operations which, in the conventional process, generates substantial amounts of asbestos dust. Wet-processed textiles possess quite different characteristics than the conventionally-woven products; and therefore, secondary manufacturers must adapt production techniques to compensate for the altered processability and final-product characteristics.

Control Methods and Work Practices

Hoods and local exhause are generally employed where raw fiber is dumped from the bags. The blending machines are normally enclosed partially and evacuated to minimize worker exposure to asbestos. Blended asbestos fiber is often transported manually to the carding machine, and plastic sheet is used to cover hoppers during this transfer.

To eliminate dust in asbestos textile operations, many of the processes such as carding need to be completely enclosed, coupled, and exhausted with well-designed ventilation systems. When asbestos textiles are processed in a damp or wet state, or otherwise are treated, little, if any, dust is generated during handling.

In dry processing, fiber introduction, blending, transporting, and carding are high exposure areas because of the manual handling of raw fiber.

Spinning, twisting, weaving, and braiding are expansive operations and, although highly mechanized, require constant worker attendance to repair broken strands and to make equipment adjustments. The continuous high speed working of the yarn (spindling, spinning, twisting, and weaving) constantly emits asbestos fiber into the air. Since thousands of strands undergo replicated processing in large work areas, isolation of point sources is not feasible.

In general, enclosures, hoods, and exhaust ventilation are applied for raw-asbestos-handling operations such as bag opening, blending, wet mixing, and conveying of bulk fiber. Fixed and portable vacuum systems help to control spillage and can be used to keep floors and other surface areas relatively clean.

Repetitive wetting of strands is used to control fiber levels. Although spindles have been designed to stop rotating when a strand breaks, this impedes spinning and twisting speeds and retards production rates.

Reported Exposure Levels

Several plant visits, plus continuing correspondence and phone interviews with industry representatives, together with a review of recently-published exposure levels (1,2,3) show the time-weighted average (TWA) asbestos exposures in asbestos textiles to range widely from 0.1 to 10 fibers/cc. However, even the lower reported levels have generally been achieved with less-than-full-scale, optimum application of currently-available, proven control measures and work practices.

Currently-Achievable Exposures

Available, proven control measures and work practices which could be used now to better advantage to assure low exposure levels include the rigorous application of well-known methods, such as:

1. Regular performance checks and preventative maintenance on local exhaust systems;
2. Immediate clean-up of spillage and floor accumulation of asbestos-containing solids using central vacuum-cleaning systems;
3. Floor cleaning at least once per shift with a power-vacuum unit - preferably combined with wet floor cleaning; and
4. Mechanically-supplied, contaminant-free make-up air (tempered relative to ambient conditions) in sufficient volumetric flowrates to balance the combined local exhausc capacity in in given work area.

These measures, together with the consistent, exacting application of control measures described above would, in Clayton's judgement, achieve exposure levels consistently below 1.5 fiber/cc on a time-weighted average basis for asbestos textiles.

Future Controls Under Development

Damp processing and conversion to the newly-developed wet process represents the only real technological advance for controlling worker exposures to TWA levels consistently below 1.0 fiber/cc. This will require developmental time. Furthermore, all current markets cannot be served with the wet-processed yarn.

Projected Lowest-Achievable Exposures

Tables 5.12 and 5.13 show the projected lowest-achievable exposures that we believe can be attained in conventional and wet processing, respectively, as a result of the exacting application of control methods mentioned previously and the timely implementation of new technology as it is developed. In summary, Clayton believes that TWA exposures in the conventionally-processed textile operations can be maintained consistently below 1.0 fiber/cc within two years. Similarly, the contractor believes that after the same period, TWA exposures in the wet-processed textile operations can be maintained consistently below 0.2 fiber/cc.

TABLE 5.12

REPORTED AND PROJECTED ASBESTOS FIBER CONCENTRATIONS

ASBESTOS TEXTILES — CONVENTIONAL PROCESSING

Process-Related Work Areas	TWA Asbestos Exposure Level (fibers/cc)		
	Reported Levels	Currently Achievable	Projected Lowest Achievable
Fiber Receiving & Storage	0.2 - 2.5	0.3	0.2
Fiber Introduction	2.0 - 10	0.8	0.5
Mixing and Blending	2.0 - 10	1.0	0.8
Carding	2.0 - 10	1.5	1.0
Spinning	2.0 - 10	1.5	1.0
Twisting	4.0 - 10	1.5	1.0
Weaving	1.0 - 4.0	1.0	0.8
Braiding	2.0 - 5.0	1.5	1.0

TABLE 5.13

REPORTED AND PROJECTED ASBESTOS FIBER CONCENTRATIONS

ASBESTOS TEXTILES — WET PROCESSING

Process-Related Work Areas	TWA Asbestos Exposure Level (fibers/cc)		
	Reported Levels	Currently Achievable	Projected Lowest Achievable
Fiber Receiving & Storage	0.2 - 2.5	0.3	0.2
Fiber Introduction	0.1 - 4.8	0.4	0.2
Spinning	2.0	0.3	0.2
Twisting	2.0	0.3	0.2
Weaving	1.0	0.3	0.2
Braiding	1.0	0.3	0.2

5.9.3 Competitive Products

Asbestos fibers, spun and woven into textile forms, are incombustible and resistant to heat, corrosion and biological attack. At service temperature above 400° F, asbestos products are presently the undisputed leader on a cost/performance basis.

At temperatures below 400° F and occasionally at higher service temperatures where short exposure times are expected, there are a number of fibrous materials which compete for asbestos textile markets. In most cases these competitive materials are more expensive than asbestos but are usually stronger (in yarn form), lighter and have a more textile-like feel and appearance.

Each of these competitive products are discussed individually below. Much of this information has been taken from a 1976 Arthur D. Little of Canada study conducted for the Quebec government, Ministry of Industry and Commerce. (39) In reviewing this list of competitive products, it should be kept in mind that, with the exception of glass fibers, none of these materials were commercially available fifteen years ago.

<u>Glass</u>

Advances in the technology of glass fiber manufacture have been rapid particularly in the last ten years. Glass fibers have about the same density as asbestos but glass yarns are stronger and cheaper than asbestos yarns of similar size. (glass fibers cost approximately

\$.75/lb vs \$1.00/lb for asbestos spinning grade fiber.) Glass competes directly with asbestos fibers in thermal and electrical insulation applications where ultra-high temperature resistance is not required. In addition, glass fiber competes with asbestos fiber in applications where an inert substrate is required for plastic coatings. The total market for glass fiber in the United States is approximately ten times that of the asbestos fiber market and glass fiber applications, particularly in industrial areas, are expected to continue to grow at least as fast as the growth in real GNP and will continue to compete for asbestos fiber markets.

Quartz

The market for quartz fibers in the United States is extremely small and restricted almost entirely to military applications. Quartz fibers are manufactured as a continuous filament material and are used in areas where high strength, high thermal stability, and low electrical conductivity are required. Because of the very high cost of quartz fibers, they do not represent a serious threat to asbestos textile markets.

"Nomex"

The term "Nomex" is a registered trademark of the Du Pont Company for an aromatic polyamide which is manufactured by condensing meta-phenylenediamine with isophthaloyl chloride. The product is manufactured as a staple fiber, a continuous filament, and as short fibers (fibrids) for use in paper applications. About 25 million pounds of all "Nomex" products are currently sold in the U.S. market principally for electrical insulation applications and for protective clothing applications such as flight suits, where high temperature resistance for short periods of time is required. Other applications includes dryer felts, laundry press fabrics and high temperature filters. The price for "Nomex" ranges from $5. to $5.50/lb for raw fiber and $6.50 to $10/lb for continuous filaments as compared to $1/lb for asbestos fiber. "Nomex" is and will continue to be a serious competitor for asbestos textiles.

"Durette"

This is a product which is manufactured by chlorinating woven fabrics of "Nomex". "Durette" was originally developed by Monsanto, but the rights to the process have been recently sold to a third party. This product has substantially better heat stability than "Nomex" but because of its high cost has found only limited usage in protective clothing applications. "Durette" fabrics are not perceived as a serious competitive threat to asbestos textiles.

"Kevlar"

The term "Kevlar" is also a registred trademark of the Du Pont Company. "Kevlar" is an aromatic polyamide made by reacting paraphenylenediamine with phtahaloyl chloride. At the present time, "Kevlar" is manufactured only in continuous filament form and its current principal use and potential for the future is in tire cord. "Kevlar" has outstanding thermal stability for an organic material having reasonable physical properties up to 500° F. It is stronger and has a higher modulus of elasticity than steel, and has excellent flexural properties. The Du Pont Company presently has approximately 6 million pounds of "Kevlar" manufacturing capacity and has announced plans to expand this by an additional 50 million pounds before 1980. Within the past two years significant quantities of "Kevlar", up to 2 million pounds, have found their way into applications where it is used as a substrate for plastic coating. The high strength and stiffness coupled with good thermal resistance and good electrical insulation properties should allow this product to compete with increasing success in the high temperature fiber field. In the longer term, "Kevlar" fibers and fabrics will represent a more serious threat to asbestos textiles than "Nomex."

"Teflon"

"Teflon" is a registered trademark of the Du Pont Company. "Teflon" is a perfluorinated polyethylene manufactured by polymerizing tetrafluoroethylene in a proprietary process. "Teflon" fibers are manufactured by dispersing "Teflon" particles in a viscous (rayon) dope and extruding the "Teflon" particles in a matrix of rayon. The rayon is then burned off leaving a contiguous "Teflon" filament. "Teflon" filament products are used in applications where high temperature resistance is required such as in the filtration of hot gases. "Teflon" fabrics are also used in areas such as bearing joints where their high temperature resistance and unusually low surface frictional properties are required. About 5 million pounds of "Teflon" fiber is currently being used in the United States. Less than 10% of this competes directly with asbestos.

"Kynol"

The term "Kynol" is a registered trademark of the Carborundum Corporation. "Kynol" is a phenol formaldehyde polymer which is formed in the staple fibers in the novelac stage and subsequently cross-linked. "Kynol" fibers have remarkable high temperature stability and find applications where lightweight thermal barriers are required. The principal limitation of "Kynol" is the fact that while it is inert at elevated temperature, it suffers from extreme losses of strength thus limiting its use to fairly heavy textile structures where little or no stress is applied. The total market for "Kynol" in the United States is currently less than 1 million pounds. While it represents a direct threat to asbestos, because of the high cost of producing "Kynol" fibers the total impact will be small. On a comparative cost basis, "Kynol" fibers are priced at $3.60/lb verses $1/lb for asbestos.

Carbon

Carbon fibers are manufactured by sintering either fibers of rayon or polyacrylonitrile. The resulting fibers are extremely strong, have a high flexural modulus, are light in weight and have superb retention of properties at elevated temperatures. Most of the applications for carbon fibers which utilize their high thermal stability are in the military area; however, because of the unusual combination of properties of carbon fibers, a great deal of research has been devoted toward manufacturing technology which would lower the cost of the material. Carbon fibers are now being produced experimentally by direct spinning processes which have the potential of reducing carbon fiber prices to the range of $1-2 per pound. Should these developments become commercial, carbon fibers would be a serious competitor for asbestos fibers in many applications including gasketing material, thermal insulation, and possibly in some friction applications.

Ceramic Fibers

A new process has been developed by the 3M Company to manufacture continuous ceramic filaments into tapes, cloths and ropes. These materials are characterized by high tensile strength, flexibility and heat resistance up to 2600° F. Potential applications include conveyor belts, furnace curtains, cable and hose coverings for furnace applications. Electrical applications are wire and cable fire protection, heating element insulation and braided sleeving rope for heater insulation. These materials are very expensive compared to asbestos and are currently priced from $30-$32.50/lb.

Another ceramic textile currently in the high temperature market is "Refrasil" developed by the HITCO Company. It is a pure regenerated glass capable of withstanding temperature of 2200 C and used primarily as welder's curtain drop cloths, furnace curtain, refractory door and hose coverings. Its price is approximately $9/lb. for the fibers, $28/lb. spun into strands. Both the "3M Brand" and "Refrasil" ceramic textiles are capable of replacing asbestos on a performance basis. However, their cost would tend to minimize complete replacement of asbestos in high temperature. Furthermore, some of their furnace applications approaching 2000 C are beyond the useful temperature limit for asbestos; therefore, these new ceramics should not be considered as a feasible replacement for asbestos textile except in very specialized refractory applications.

In addition to the list of competitive products discussed above, asbestos fibers are confronted with increasing competition from polyester and nylon monofilaments in the dryer felt area. The decline in the use of asbestos fibers in dryer felts is directly attributed to competition from these materials which provide higher strength and abrasion resistance, better filtration properties, and, despite lower thermal resistance from both polyester and nylon, longer life.

As technology for the production of synthetic fibrous materials with high temperature properties advances, competition from asbestos fiber markets can be expected to increase.

5.9.4 Effect of Imports on Domestic Asbestos Asbestos Textiles

Domestic producers of asbestos textile products have faced increasing competition from competitive products and from imports over the past several years. On a poundage basis, imports have more than doubled since 1970 while domestic shipments have declined from 35.6 million lbs in 1972 to 31 million lbs in 1976. Imports have made their most significant gains with respect to the markets for yarn and cloth. A significant percentage of the yarn which is woven into textiles for friction material is now being imported according to a major manufacturer of friction materials. Associated with this phenomenon are recent production and investment decisions by domestic producers. Garlock has shut down its domestic yarn facility and imports yarn from Canada. Johns-Mansville has also curtailed domestic yarn production.

Significant increases in imports have come recently from Mexico, where Amatex has a minority interest in Hiladosy Tegidos de Asbestos S.A., and from Venezuela, where Raybestos Manhattan has a 47% interest in Manufactures Multiples.

Imports have penetrated the American market by selling at a discount relative to domestic products. As in the production of organic fiber textiles, labor represents a significant cost component, and labor cost differentials have undoubtedly contributed to the penetration of imports. In addition, the required investment for exposure control mandated by the 1972 emergency standards and the 1976 2 fiber/cc exposure limit standard appear to have increased the spread between domestic and foreign prices. The maintenance of such a cost differential will undoubtedly increase imports share of the asbestos textile market.

The continued penetration of imports and product substitutions in lines where asbestos textiles were once dominant presents a pattern of stagnation and possibly absolute decline for the asbestos textile industry.

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6.0 IMPLICATIONS OF A 0.1 FIBER/CC EXPOSURE LIMIT

Further reducing the asbestos exposure limit to 0.1 fiber/cc will definitely have certain implications for the asbestos industry in both the primary segments (i.e., the producers of asbestos products) and the users of asbestos containing products. Depending upon each industry's perspective, there are certain options that affected firms may choose as a result of the recommended exposure limit of 0.1 fiber/cc. Such possibilities include:

- Reduce exposures through engineering controls to the lowest level achievable;
- Substitute for asbestos in the manufacturing process by using another material;
- Switch to competitive products; and
- Abandon the asbestos product line.

It is not the contractor's intent to be able to categorically predict how the major segments in the asbestos industry will react to the new exposure limit, nor which industries will actually choose one of the options outlined above. However, based to a major extent on information presented in Chapter 5.0, general trends were observed and some judgments can be made. It should be stressed, however, that the possibilities outlined above are closely interdependent. Many firms have already, or are in the process of evaluating the future of asbestos containing products and their own market position.

6.1 Option 1: Reduce Exposure Through Engineering and Work Practices

For reasons outlined in Chapter 5.0, it was concluded that for each major product segment of the asbestos industry, it is not technologically feasible for industry to consistently maintain fiber exposure levels below 0.1 fibers/cc TWA. Therefore, according to the ancillary requirements set forth in the October 15, 1975 proposal for 0.5 fibers/cc, non-compliance with the permissible exposure limit would necessitate employers in all affected industries to provide respirators, protective clothing and shower facilities for employees. Additionally, all working areas would have to be designated as restricted areas. Using the costs in the previous TFA/IIS for the 0.5 fiber/cc limit which were developed on a per employee basis, the additional cost to the primary segments of the asbestos industry is approximately $30 million, annually, computed as follows:

Respirators	$ 180/man/year
Protective Clothing	175/man/year
Showers Facilities	100/man/year*
Productivity Loss	1045/man/year
	$1500/man/year (x) 20,000 employees (approximately)

Conceivably, these may be over estimated, for it may be possible for some operations within a process to maintain a 0.1 fiber/cc exposure limit. However, the contractor does not believe that the

*Based on total capital cost of $760/man and annualized to reflect a 15 year life at 10% interest.

entire process can achieve this lower exposure limit due to the ubiquitous nature of asbestos in such facilities. Therefore, all employees actively working in the process would be at risk.

Clayton Environmental Consultants did conclude that 0.2 fiber/cc was generally achievable for the primary manufacturers of asbestos products through implementation of "best technology" and strict work practice. The single exception to this judgment is for dry-woven asbestos textiles where an exposure limit of 1.0 fiber/cc is considered to be the lowest level achievable. The costs to achieve these levels has already been computed in the TFA/IIS the contractor submitted for the 0.5 fibers/cc exposure limit. However, in light of updated information and recent on-site investigation of the progress in achieving lower asbestos exposure levels, these cost estimates will have to be modified. Such changes have not been done to date, but the contractor fully intends to do so in the near future. Therefore, to prevent misinterpretation, the costs to achieve 0.2 fibers/cc as determined from the previous TFA/IIS will not be presented in this report.

With respect to plant size and a firm's ability to achieve increasingly lower asbestos exposure limits, Clayton concludes that the control technology is highly transferrable from one firm to another as it relates to asbestos fiber control measures. This is true primarily because the most effective measures are those techniques which have been tried, developed, proven and refined over several years. In addition, the projected lowest-achievable fiber exposure, 0.2 fibers/cc, is actually higher than many of the reported exposure levels indicated in the contractors recent on-site investigations. Such observation indicated a commendable, yet generally less than best, application of available control techniques. Therefore, Clayton concludes that any major differences due to resource limitations among the industries with respect to the timing or the extent of implementing controls will be offset in part, by an exposure level slightly greater than what conservative judgment may indicate.

Finally, it is also concluded that many secondary users of asbestos-containing products will not be able to achieve a 0.1 fiber/cc exposure limit. The refacing sector of the aftermarket will not be able to attain a 0.1 fiber/cc exposure limit, but it would be possible to control to 0.2 fiber/cc. It is believed that the repackaging sector will be able to maintain a 0.1 fiber/cc TWA, but that general maintenance and repair shops would have trouble with a peak exposure limit between 0.1 and 1.0 fiber/cc due to the practice of blowing out brake drums. For the secondary fabricators of asbestos reinforced plastics, paper, packings and gaskets, a 0.1 fiber/cc exposure limit is determined to be feasible, yet the associated peak exposure limit of 0.5 fiber/cc may be exceeded for the fabrication of textiles and cement sheets. Clayton concludes that a 0.1 fiber/cc exposure limit will not be feasible nor is it clear that any integrated TWA exposure below 0.5 will be feasible because of the machining and fabriction of these products. In all of the above cases where 0.1 fiber/cc TWA, or the peak exposure limit of 0.5 fiber/cc cannot be achieved, the employers will have to provide respirators, protective clothing and shower facilities.

6.2 Option 2: Substitute for Asbestos

Chapter 5.0 and Appendix B cover in detail the extent of the research and development efforts to find a suitable replacement for asbestos in various product lines. However, for this discussion, it is important to make a distinction between substitute materials for asbestos in a manufacturing process and a product which competes with an asbestos-containing product in the market. Competitive products will be discussed in more detail in Section 6.3. Almost without exception, substitute materials have been evaluated for most of the primary asbestos product lines, with varying degrees of success achieved. The most pronounced trend to replace asbestos was found in phenolic molding compounds where it was estimated that between 50-70% of compounds previously using asbestos have now switched to other materials such as talc, clay or fiberglass. A second promising area is in floor tile where substitutes are currently undergoing manufacturing trials in industry to determine the correct formulations. Reported materials are cellulose fibers and a proprietary petrochemical. It is still too early to tell whether these materials will perform adequately as an asbestos replacement.

Asbestos usage in friction materials is contingent upon the success of a significant research and development undertaking by most of the major producers of friction materials to find a suitable replacement for asbestos. This work is in progress and some success has been reported, especially with regard to "organic" brake linings and woven clutch facings. However, it would be premature for CONSAD to conclude that a substitute for asbestos has been found for friction materials. Promising materials are on the horizon, yet a determination of when both a technically and economically feasible substitute will be available for the market cannot be made based on information obtained to date.

As related in Chapter 5.0, there has been extensive research centered on fiber reinforcement for cement products which would include both cement pipe and sheets. Development of an alkali-resistant glass to be used in these applications has generated enthusiasm in some parts of the cement industry, especially in England where this materials is presently being used to replace asbestos in cement sheets. However, there has been little interest in this country beyond the research phase for alkali-resistant glass to replace asbestos in cement products. From the literature and conversations with industry sources, there was no reporting of alkali-resistant glass presently being used in actual cement product applications as a reinforcement. Therefore, there is uncertainty with regard to using this material as a replacement for asbestos in these product lines.

Fibrous glass is the material most often identified as a substance that could replace asbestos in many of its product applications. Fiberglass used in roofing felts and pipeline felts are at present strongly competing with asbestos papers in these applications. Additionally, it may also have further applications in certain asphalt coatings which presently use asbestos, however, it is premature to judge the extent to which such substituion may take place.

Ceramic fibers have also been mentioned as possible replacements for asbestos in paper applications, such as millboard and muffler paper. There are currently ceramic boards on the market which are penetrating the conveyor applications of millboard in the glass and steel industries. Replacing asbestos paper with ceramic paper in muffler application has only been reported in the research and development stages at this time.

Asbestos-free sealants have been marketed recently and are penetrating some of the markets asbestos sealants have previously had.

However, the extent of this trend is not known at this time. In the packings and gaskets applications, there do exist substitute materials that can replace asbestos without a substantial performance penalty in specific applications. However, there is not one material that will suffice for all the various asbestos uses in packings and gaskets. Furthermore, these materials are significantly more expensive than asbestos. Therefore, there has not been a siginificant switch to non-asbestos gaskets, nor is there any indication that such will happen in the near future.

For the most part, materials being considered as a replacement for asbestos are significantly more expensive than asbestos fibers. There are some exceptions, such as other inorganic materials including talc, mineral wool, clay and wollastinite. Fibrous glass in the majority of applications where it is considered as a substitute are on the order of 2-5 times as expensive as the asbestos fibers used in these applications. There are also the "high-priced" materials such as ceramic fibers and graphite which range from 10 to 100 times more expensive than asbestos on a comparative basis. Of course, raw material costs make up only a part of the end-product price. Nonetheless, it is fair to state that by substituting for asbestos in most applications, the end price of the product will be increased.

Another major concern in evaluating the potential to substitute for asbestos is the availability of obtaining sufficient quantities of alternative materials. A case in point in exemplified by fiberglass which was noted as a possible replacement for asbestos in certain applications. Due to the recent emphasis on energy conservation by the President's Energy Plant, which stressed the need for home insulation, the demand for fiberglass apparently will increase substantially in the coming months. Some industry sources question the ability of the fiberglass manufacturers to keep up with demand, especially if fiberglass continues its penetration into the roofing felt and pipeline felt markets. CONSAD does not have any specific data to support this contention; however, it is possible to concede that in the short-run, a scarcity of fiberglass could develop. In the long-run, the economics of supply and demand would probably ensure that a sufficient supply of fiberglass could be made available.

A final note on substitutes should be made. The use of asbestos in insulation has almost ceased to exist. The health hazard studies by Selikoff in the 1960's pointed up the problems associated with asbestos in these applications. The makers of these insulation products began research and development efforts to find a suitable replacement for asbestos. Appendix A, as noted previously, presents a case study of Johns-Manville's effort to replace asbestos in their molded calcium silicate insulation products. Fiberglass has been utilized in other insulating applications, thus reducing the asbestos consumption for these products. Furthermore, the Environmental Protection Agency has banned the use of asbestos in spray-on insulation applications. Therefore, for all purposes, asbestos is not to be found in most insulation materials.

6.3 Option 3: Switch to Competitive Products

A 0.1 fiber/cc exposure limit would also impact the users of asbestos-containing products by requiring engineering to control exposures, monitoring, medical surveillance and other ancillary requirements. As a general rule, where a non-asbestos product competes on a comparable cost/performance basis with an asbestos product, it will gain increasing share of the market. Several cases point this out. With respect to sewer pipe, polyvinyl chloride pipe has demonstrated good performance and low cost especially in the smaller diameter pipe size. It has gained widespread acceptance in this market at the expense of the other pipes, including A/C pipe. In another instance, fiberglass roofing felts are penetrating the build-up roofing market in which both organic and asbestos felts have been competing in recent years. Because installation of fiberglass roofing is cheaper than comparable asbestos installations and the performance characteristics are similar, it is anticipated that asbestos felts will lose some of its market share to fiberglass. Additionally, fiberglass felts are also a strong competitor to asbestos pipeline felts.

Over the last few years, asbestos textile products have been losing their share of the market in dryer felts and protective clothing and maintenance cloths. Synthetic fabrics, such as nylons and the new aramid fibers, "Nomex" are the major causes for this shift. With implementation of a 0.1 fiber/cc exposure limit for asbestos-containing products, this trend may be exaggerated. The replacement of asbestos textiles in friction materials (e.g., woven brakes, clutch facings) is contingent upon the research and development effort currently underway in this segment of the industry, as described in the previous section.

The major end-use for asbestos-containing products is the construction industry which accounts for approximately 70% of the total U.S. asbestos applications. Even under strict enforcement of the current 2 fiber/cc exposure limit, certain asbestos products that release dust during fabrication or installation may find less acceptance in certain areas. Compliance with the various ancillary requirements (e.g., monitoring, medical surveillance, record keeping, etc.) may prove to be costly to construaction contractors and may force some of them to switch to non-asbestos products. Of course, there are certain asbestos-containing products that do not release significant amounts of asbestos fibers and thus, would not be affected. These are: vinyl-asbestos floor tile, resiliant sheet flooring, and fibrated asphlat coatings. Little asbestos exposure is observed for A/C siding or shingles, since these products are usually pre-cut at the factory and simply nailed-up, bolted, or screwed into place.

However, other asbestos products that do release fibers upon installation would probably be affected. These include: asbestos cement sheets, roofing felts, and probably A/C pipe. For example, asbestos-cement sheets are now used as wall or roof panels around chemical processes where resistance to corrosive vapors is required. Some fibers are released in field installation because of the necessity to cut the panels to size. However, the product is so unique in this application that there apparently would be contractors who would choose to control exposures and comply with the various requirements concerning the use of asbestos products. The situation is not the same with regard to decorative A/C sheets which compete with many other types of paneling. Release of fibers during installation and the associated OSHA requirements may indeed force most contractors to switch to other materials, thus avoiding the "hassle" accompanying the asbestos product. Therefore, it could be anticipated that the market for A/C sheets would decline under enforcement of the current standard with the trend being exaccrabated by lower exposure limits of 0.5 or 0.1 fiber/cc. A similar situation could exist in the built-up roofing market, if contractors had to comply with the ancillary requirements of OSHA standards for handling these asbestos products. This circumstance may accelerate the trend towards fiberglass built-up roofs.

6.4 Option 4: Abandon Asbestos Product Line

This last option, to abandon the asbestos product line, represents the most extreme measure that various manufacturers of asbestos products could take. It is very difficult, if not impossible, for CONSAD to predict which products may be abandoned as a result of further reducing asbestos exposures. Individual firms have made this choice in the past due to the uncertainty of their market, profitability and other considerations. The asbestos textile industry represents a case in point in which only three domestic producers of asbestos textiles remain. Lower priced foreign imports have under cut domestic made asbestos textiles which find it increasingly hard to compete. In 1975 National Gypsum closed two asbestos-cement sheet plants presumably due to an inability to justify further expenditures for asbestos dust control equipment. The advent of fiberglass roofing felts may so seriously erode asbestos felt roofs that some firms may opt to terminate making asbestos products and switch to fiberglass. However, this transformation involves a completely new change in process and is very capital intensive. Finally, if the present trend towards PVC small diameter sewer pipe continues, A/C pipe along with the other competitors (i.e., vitrified clay and concrete pipe) may find their markets declining. This may force a cut-back in A/C pipe for sewer applications. Both Johns-Manville and Certain-teed make A/C and PVC pipe, so that a decrease in production of A/C sewer pipe may be compensated by increasing PVC pipe orders. However, of the four A/C pipe producers reported in last years TFA/IIS for asbestos, only Johns-Manville, Certain-teed and CAPCO remain. Flintkote will close its A/C pipe plant at Ravenna, Ohio if no one buys it.

7.0 FEASIBILITY OF MONITORING ASBESTOS IN THE WORKPLACE ENVIRONMENT IN THE 0.1 - 1.0 FIBER/CC RANGE

7.1 Background and Objective

In October, 1975, the Occupational Safety and Health Administration (OSHA) proposed a reduction in the permissible limit for asbestos exposure to 0.5 fiber/cc for an 8-hour time-weighted average exposure (fibers > 5 μm in length). The proposal also included a corresponding reduction in the ceiling exposure limit from ten to five fibers/cc as determined over a period of up to 15 minutes.

In December, 1976, the National Institute for Occupational Safety and Health (NIOSH) recommended to OSHA that no worker be exposed to an airborne concentration of asbestos in excess of 0.1 fiber/cc on an 8-hour time-weighted average basis and further, that no worker be exposed to peak concentrations in excess of 0.5 fiber/cc based on 15-minute sampling periods.

An extremely important aspect of these proposals concerns the feasibility of monitoring asbestos exposures in the workplace at airborne concentrations below one fiber/cc. The suitability of any monitoring method associated with and incorporated within an exposure standard is fundamental in at least two basic respects. First, an environmental standard has meaning only if airborne concentrations can be measured reliably so that quantitative indices of exposure have a common, widely-accepted, well-understood meaning to all interested parties -- health agencies, industry, the work force at risk, indeed the general scientific community. This is a fundamental concept that applies in the promulgation and application of any standardized measuring method, and it certainly applies in the case of the sampling and analytical methodology used to document worker exposures to airborne asbestos in the occupational setting.

Secondly, in the context of this study, the asbestos monitoring method has special meaning as it relates to the technological feasibility and economic impact of the proposed exposure limits. Technological feasibility and economic impact are closely related in this sense, especially with respect to the number of samples to be taken and the length of sampling and analytical times associated with measuring the workplace environment to (a) judge compliance with the proposed standard and (b) fulfill the on-going monitoring requirements set forth explicitly in the proposed rulemaking.

7.1.1 The Role of Monitoring

The Occupational Safety and Health Administration's notice of proposed rulemaking in the Federal Register of October 9, 1975, states in Paragraph E... "The purpose of all monitoring required by this paragraph is to measure accurately the airborne concentrations of asbestos fibers in a workplace to which employees would be exposed if they worked in the area without use of personal protective equipment such as respirators. Monitoring shall be performed in a manner reasonably calculated to satisfy this purpose."

The proposal also specifies initial monitoring by every employer where asbestos fibers may be released, and, in those cases where exposures exceed the limits proposed, monitoring must be repeated every month except where two consecutive monitorings made at least five days (but not more than three months) apart show employees' exposures to be below both limits. In this instance, monitoring need not be repeated except for those operations where modifications in production, process controls, or other relevant factors would "lead the employer to believe" that an employee's level of exposure may be above the limits prescribed.

The recommended sampling and analytical method set forth in the proposal is the "USPHS/NIOSH Membrane Filter Method for Evaluating Airborne Asbestos Fibers", a draft report by Nelson A. Liedel, Stephen O. Bayer, Ralph D. Zumwalde, and Kenneth A. Busch, investigators within NIOSH.[1]

7.1.2 Criteria for a Monitoring Method

The basic requirements for any monitoring method used to document environmental exposure include the following:

- Specificity - the extent to which the method can specifically identify the material of interest - in this case, asbestiform fibers.

- Sensitivity - the degree to which the method can be used to characterize very low concentrations of fibers in air and, in that sense, the lowest feasible concentration of fibers which can be documented reliably with the procedure.

- Accuracy - the extent to which the method provides a true estimate of the concentration of asbestiform fibers of the diameter and aspect ratio of interest present in the air and represented by the sample.

- Precision - the extent to which the measurement can be reproduced with reference to a single investigator and different investigators analyzing the same sample.

These criteria have special meaning in the case of asbestos because of the evolution of a monitoring method -- namely the NIOSH method -- where serious concern has been expressed with respect to all of the criteria identified above. These concerns will surface throughout this report and to that extent, they can be used as a thread of continuity relating this disucssion to the technological feasibility and economic impact of the monitoring aspects of the proposed rulemaking.

7.1.3 Purpose

The purpose of this analysis is to examine the feasibility of monitoring airborne asbestos in the workplace environment in the 0.1 - 1.0 fiber/cc range. This examination includes a critical review of current monitoring practices as they relate to those procedures associated with the proposed standard and a discussion of critical issues yet unresolved with respect to the specficity, sensitivity, accuracy, and precision of alternative sampling and analytical methods, generally, and the NIOSH monitoring method stipulated in the rulemaking, specifically.

7.2 Summary and Conclusions

With all its shortcomings, the NIOSH phase-contrast method is the only monitoring technique for asbestos that can be used routinely and widely at a reasonable cost. Despite its limitations in specificity, sensitivity and precision, this method has been used in conjunction with the more recent epidemiological studies on occupational exposure to asbestos. Any change in the method for monitoring asbestos must be coupled with a corresponding review and reevaluation of the epidemiological data base.

The NIOSH monitoring method can be used to measure asbestos concentrations at or below those levels stipulated in the proposed rule-making. Nevertheless, only a certain combination of sampling pumps and microscopes can be used to achieve an acceptable range of surface fiber density on filter samples.

The precision of the NIOSH method has not been defined adequately -- qualitatively or quantitatively -- so as to include the random errors associated with all components of the total sampling and analytical process. The published NIOSH assertions concerning precision of the method are not consistent with the "total coefficient of variation" for other NIOSH monitoring methods. It is our judgment that they underestimate the coefficient of variation in a likely-significant, still-undetermined manner.

The relatively large confidence interval associated with measured airborne concentrations detracts from the meaning and conclusiveness of estimated exposures at low levels. This relative imprecision becomes increasingly important at decreasing concentrations. The magnitude and impact of this problem cannot be measured exactly until the relationship between fiber counts on a given filter and coefficient of variation (CV) is defined empirically in a rigorous manner. Based upon our best estimate of the precision of the NIOSH monitoring method at concentrations at or below 0.5 fiber/cc, the determination of compliance or noncompliance with a standard in this range will be difficult and will likely require counting large numbers of fibers on samples with low surface fiber densities. Even under such conditions, the conclusiveness of exposure estimates in this range of concentrations must be qualified due to the high degree of statistical uncertainty.

7.3 Alternative Analytical Methods

The following paragraphs present brief summary comparisons of the various analytical methods used to measure asbestos. For more detailed information, reference is made to the latest NIOSH release on the subject "Revised Recommended Asbestos Standard," NIOSH Publication Number 77-169, December 1976.

7.3.1 Light Microscopy

The current, standard asbestos monitoring method -- that endorsed by NIOSH -- for quantifying occupational exposures is the visual counting of fibers on membrane filters using phase-contract microscopy. The air to be sampled is drawn through a cellulose acetate membrane filter at a known flowrate and sampling duration. The filter is then sectioned, placed on a microscope slide, and rendered transparent by an ester-based mounting medium. The sample is examined at a magnification of 400 to 450X using phase-contrast illumination and a standard reticle. The number of fields of the reticle to be evaluated varies from 20 to 100 or more for each sample, depending upon the dust loading. The technique requires considerable training, skill, and patience, and is thus subject to operator error.

In comparative evaluations of possible alternative methods, specificity is a glaring weakness of the phase-contrast method and a distinct advantage for most other techniques such as X-ray diffraction and electron microscopy.

It is virtually impossible to assess the "accuracy" of the phase-contrast method, that is, its capability to estimate or measure at or very near the "actual" level, because of the extreme difficulty in generating known concentrations of asbestos fiber for "calibration" purposes.

7.3.2 Electron Microscopy

Electron microscopy has great advantages over light microscopy in terms of higher resolution. This permits derivation of morphological information which can be used for positive identification of asbestos. For instance, chrysotile fibers exhibit characteristic center channels, and most asbestos fibers break in a manner such that the ends are fairly characteristic. However, these effects are not sufficiently specific to provide positive identification in all cases, making additional characterization necessary. This may include X-ray fluorescence and selected area electron diffraction techniques.

In scanning electron microscope (SEM) analysis, filters are first vacuum coated to make them conductive. The frequency of fibers that display X-ray fluorescence characteristic of asbestos are then measured against standards.

The transmission electron microscope (TEM) coupled with selected area electron diffraction (SAED) represents a powerful analytical tool for asbestos determination. In cases where diameters of the fibers can vary over a wide range, SEM is preferable. The TEM is unable to cope satisfactorily with a wide range of diameters.

Although electron microscopy offers the advantage of achieving positive, accurate identification of any crystalline fiber by its electron diffraction pattern, with good sensitivity, the analysis time is relatively long. Processing time typically exceeds four person-hours per sample. The required instrumentation is also prohibitively costly for widespread, routine usage.*

7.3.3 <u>Infrared Spectrometry</u>

A technique based on the absorption of infrared radiation (IR) at 2.72 μm wavelength has been reported in the literature.[2] This absorption is associated with the stretching vibration of hydroxyl groups bound to the silicate structure and is well separated from the absorption bands that are due to water. Although water does not interfere in the analysis, a large number of common minerals such as

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*Electron microscopy instrumentation with elemental analysis capability cost roughly $250,000 as compared to $1,000 for the phase contrast method instruments.

nonfibrous serpentines, clays, micas, and talc can be expected to give false positive signals and may mask the chrysotile peak. The infrared technique is fairly sensitive, and may be useful in certain low-interference environments. It also has the advantage of being relatively simple and rapid.

7.3.4 X-ray Diffraction

Dust samples collected on a filter or impaction surface can be identified and quantified by characteristic diffraction patterns which result from X-ray scattering by the crystalline compounds in the sample. Diffraction angle and intensity, respectively, can be used to identify and quantify the asbestos in the dust sample. Sensitivity is marginal, and morphological information is virtually nonexistent. Notwithstanding its sensitivity, the lack of interferences and the adaptability to automated operation make this method attractive.

7.3.5 Dispersion Staining

It has been proposed that the outer $Mg(OH)_2$ surface of the asbestos fibers might be stained with a selective dye after sample collection and the asbestos then be estimated by spectrophotometry or, alternatively, be more easily counted optically because of the enhanced contrast.

Dispersion staining is one of the most promising techniques for fiber analysis. It is not significantly more expensive than the phase contract microscopy, but offers the advantage of specificity. The equipment is not much different than that used for phase contrast methods, however, this technique requires somewhat more operator training.

7.3.6 Thermoluminescence

Thermoluminescence (TL) is the characteristic luminescence emitted by a stressed material as it relaxes when heated. X or gamma radiation is most often the energy source used for including the stress. Subsequent heating of the material releases some of the absorbed energy in the form of ultraviolet or visible light. TL data are commonly presented in the form of a glow curve with luminescent intensity exposed as a function of temperature. Temperatures at which peaks occur in the glow curve and the wavelength of the luminescence are related to structural imperfections in the material. If sufficiently characteristic, the glow peaks can be used to identify the material. Differential thermal analysis has not been used for environmental samples as lower limits of mass detection are extremely poor. This technique, like X-ray diffraction, is not capable of differentiating between asbestos fibers and their nonfibrous mineralogic polymorphs.

7.4 NIOSH Asbestos Monitoring Method

7.4.1 Historical Development

The first published version of the membrane filter method, as used by the former Division of Occupational Health (USPHS), was that of Edwards and Lynch in 1968.[3] Bayer and Zumwalde of NIOSH assembled a more detailed version of the membrane filtercount method in 1972 based on material prepared for use in a NIOSH training course covering sampling and analysis of airborne asbestos dust.[4] Leidel, Bayer, and Zumwalde prepared a more detailed version of the method in 1973 for submittal to the American Society for Testing and Materials Committee D22.04.[5] This report was also used in NIOSH training courses, but was never formally published by NIOSH. The 1973 report contained the first NIOSH estimate of the method's precision on the basis of a limited study published by Conway and Holland in February, 1973.[6]

Several subsequent draft versions of the NIOSH in-house report have been circulated informally, although no final report has been published to date. In late 1975, after the publication of the OSHA-proposed reduction in the asbestos standard, Leidel et al. of NIOSH once again revised the asbestos-count method.[7] The latest in-house draft of the NIOSH method known to CONSAD/Clayton is that dated June, 1977.[8]

7.4.2 Scope and Summary of NIOSH Method

Samples are collected by drawing air through a cellulose-ester membrane filter by means of a battery-powered personal sampling pump. After sampling, the filter is transformed from an opaque, solid membrane to a transparent, optically homogenous gel. The fibers are sized and counted by phase-contrast microscopy at 400 - 450X magnification.

This method considers only fibers with a length to width ratio of 3-to-1 or greater and a length greater than five micrometers. Thus, it is intended to give an index of exposure to airborne asbestos fibers of specific, yet limited, dimensional characteristics.

The method has been successfully applied using 37-mm Millipore AA filters and small battery-operated personal sampling pumps at flowrates of 1.0 to 2.5 liters per minute (lpm) for time periods of a few minutes to 150 minutes over a concentration range of 1 to 20 fibers/cc. Large deviations from these conditions can result in samples with either too few or too many fibers, which can yield air concentration estimates of low statistical precision and accuracy.

7.4.3 Application of NIOSH Method at Low Concentrations

The feasibility of monitoring airborne asbestos levels in the workplace at very low concentrations (below 1.0 fiber/cc) depends heavily on two important characteristics of the sampling and analytical method: sensitivity and precision. Sensitivity relates to the sampling time, pump flowrate, and counting procedure needed to determine fiber concentrations at or below the prescribed concentration limit, whether it be 0.1, 0.2, 0.5, or some higher level. The certainty of decisions resulting from a comparison of measured concentrations with the presceibed limit is reflected in the variation or precision of the sampling and analytical method based on its random errors.

The empirical precision of the phase contrast method presents the crux of the problem with the NIOSH monitoring method. The confidence level attached to an environmental measurement, including asbestos concentrations, depends greatly upon the ability of an investigator using a standard method to obtain reproducible results. In general, this question has been overlooked to a great extent until the recent past when the question of compliance and/or noncompliance has become more important. Such determinations now must be tested in a legal sense with the result that methodology and analyses must become more defendable, and therefore, more rigorous. Phase contrast counting of asbestos fibers is notoriously troublesome with respect to reproducibility, and in the heightened concern over the movement toward a reduction in the asbestos fiber standard, the precision (or imprecision) of the sampling and analytical techniques as a whole must be recognized fully.

In recent years, NIOSH has conducted and published statistical research on the types of variation affecting occupational health related environmental monitoring methods. Leidel and Busch have developed procedures that describe the calculation of confidence limits for the true airborne concentration of a contaminant.[9] In 1975, these investigators published recommended procedures in a NIOSH report for the collection and evaluation of sample results to determine if the state of noncompliance with an occupational health standard exists.[10]

The NIOSH monitoring method is best suited for a filter surface fiber density in the optimum zone of one to five fibers/field. For typical conditions, with an exposed filter area of 855 mm^2 and a field area of about 0.003 mm^2, this means that the optimum sampling arrangement would yield at least 285,000 fibers during the sampling period. If the true airborne fiber concentration were 0.2 fiber/cc, this means that an optimum sample volume would be about 1425 liters. At a typical flowrate of 2.0 liters per minute, this corresponds to a sampling time of about 700 minutes. Therefore, by NIOSH's own description of the procedure, the method must be modified to extend the "optimum" surface fiber density range below one fiber per field to be compatible with even full-shift (8-hour) sampling using conventional sampling equipment.

The NIOSH draft method of November, 1975 (that published just after OSHA proposed a reduction in the standards) states "the optimum fiber density should be one to five fibers per microscope counting field."[7] In the latest draft method (June, 1977) the acceptable range of surface fiber density has been extended, but without any rational or documentation to support such an extension. The latest draft states "feasible counting conditions may extend down to about 0.1 fiber/field and up to 5.0 fibers/field."[8] The impression is given that the range was extended downward to 0.1 fiber/field to accommodate the proposed reductions in the standard to 0.5 fiber/cc and below.

7.5 Statistical Interpretation of Monitoring Results

7.5.1 Sources of Error and Measures of Precision

The latest draft of the NIOSH method presents the NIOSH interpretation of the major sources of variation in the procedure.[8] The following table summarizes that interpretation.

The relative variation or dispersion of a normally distribution data set (such as the random variations in a sampling and analytical procedure) is commonly measured by the "coefficient of variation (CV)". The CV is also known as the relative standard deviation. It is calculated by dividing the standard deviation of the data by the arithmetic average. The CV is a useful parameter of dispersion in that limits

Source of Variation	Possible Causes and Nature
1. Intrafilter (consisting of interfield within a wedge and interwedge within a filter)	The counting procedure only "samples" and estimates the filter surface fiber density. Random variations with some likelihood of small systematic biases between wedges which can be treated as random.
2. Intercounter	Some random variations exist, but differences are primarily systematic due to improper training, lack of experience, attitude, poor visual acuity, or no quality control programs.
3. Interfilter (within simultaneous samples)	Random variations due to random fluctuations in pump flowrate. Systematic biases due to improper pump calibration.
4. Interlaboratory	Systematic variations due to differences in microscope quality and specifications, improper microscope adjustment, counter training, or improper application of the method.
5. Environmental	Both random variations and systematic biases due to concentration changes in time and space.

consisting of the true mean of a data set, plus or minus 1.645 the standard deviation, will contain about 90 percent of the data measurements. This is a rough approximation that depends on the number of data values from which the mean and standard deviation were calculated. Correspondingly, if an analytical procedure with a known CV of 0.20 were used to measure repeatedly some fixed physical property, then about 95 percent of the measurements would fall within plus or minus 40 percent (twice the CV) of the true concentration, assuming an unbiased measuring procedure.

The most critical issues in the feasibility analysis for the NIOSH monitoring method and its intended application are (1) the definition of "coefficient of variation" as it relates to the monitoring method for asbestos, and (2) the value of CV for the method as it affects sampling and analytical time and the corresponding expenditure of resources.

For some -- yet unexplained -- reason, it is NIOSH's position that the CV for the asbestos count method should measure and include only the net variation associated with the sources of a random error described above. Obviously, however, the coefficient of variation claimed by NIOSH is based on only some of the random errors encountered during the analytical method. Other NIOSH methods included in the Standards Completion Projects, for example, include methods for which the coefficients of variation have been based upon sampling and analytical errors.

NIOSH has maintained consistently, throughout its reports and in the record, that its recommended asbestos monitoring procedures can "adequately and confidently" monitor and describe compliance with the OSHA-proposed asbestos standard of 0.5 fiber/cc and the NIOSH-recommended level of 0.1 fiber/cc. Based upon the evidence and the record, however, it seems clear at this point that the coefficient of variation for the asbestos monitoring method using the NIOSH-proposed technique has not been evaluated in a rigorous way that can be supported by even the various, semi-objective scientific interests that surround this issue. Further, it is Clayton's judgment that the NIOSH coefficient of variation estimate of 0.24 is too low because it is incomplete.

The resolution of this question will depend upon: (1) agreement concerning the definition of coefficient of variation as it relates to the asbestos monitoring method, and (2) the timing and quality of a carefully designed study that will measure the various relevant components of variation in the total sampling and analytical process. It does seem reasonable, in the meantime, that as a minimum consideration, the definition of CV be consistent with the definition used in the development of other sampling and analytical methods, specifically the definition of coefficient of variation associated with other NIOSH-proposed sampling and analytical methods.

7.5.2 Determining Compliance and Noncompliance

NIOSH has proposed a procedure for determining compliance or noncompliance with exposure limits using workplace sampling schemes of the following variations: (1) single eight-hour sample; (2) several consecutive samples totaling eight hours; (3) several consecutive samples totaling less than eight hours; and (4) grab samples.[9] The calculational procedures useful for determining compliance in the simplest of these sampling schemes are described briefly below, to illustrate the critical nature of the coefficient of variation of the sampling and analytical method.

Terms and Abbreviations

The airborne asbestos fiber concentration estimated by counting one wedge of the filter sample is calculated as follows:

$$AC = \frac{[(FB/FL) - (BFB/BFL)] \quad (ECA)}{1000 \quad (FR) \quad (\Delta T) \quad (MFA)}$$

where:

AC = Airborne fiber concentration, (fibers > 5 μm)/cc.

BFB = Total number of fibers counted in the BFL fields of the blank (control) filters, fibers > 5 μm.

BFL = Total number of fields counted on the blank (control) filters.

ECA = Effective collecting area of filter, mm^2.

FR = Pump flowrate, liters/min (lpm).

FB = Total number of fibers counted in the FL fields, fibers > 5 μm.

FL = Total number of fields counted on the filter.

MFA = Microscope count field area, mm^2 (generally 0.003 to 0.006).

ΔT = Sample collection time, minutes.

Other terms useful in describing the statistical methodology include:

CV = Coefficient of variation for a sampling and analytical method at conditions characteristic of a given measurement.

LCL = Lower confidence level for AC (normally at 95% significance with statistical coefficient of 1.645), fibers > 5 μm)/cc.

SE = Standard error of TWA = ($\sqrt{V}$)

STD = Exposure standard, (fibers > 5 μm)/cc.

TWA = Time-weighted average fiber concentration, (fibers > 5 μm)/cc.

UCL = Upper confidence level for AC (normally at 95% significance with statistical coefficient at 1.645), (fibers > 5 μm)/cc.

V = TWA variance based on N samples (SE^2).

<u>Procedure for Single, Full-Shift Sampling</u>

1. Obtain AC and CV. AC is the estimate of the airborne fiber concentration (f/cc) calculated from the total fiber count (FB). CV is a function of total fibers counted (FB). Because values of CV are not defined adequately, reference is made to the general expression:

$$CV = f\,(FB)$$

2. Calculate LCL or UCL:

   - Compliance officer's test for noncompliance.
     LCL (95%) = AC - 1.645 (CV) (STD)

   - Employer's test for compliance.
     UCL (95%) = AC + 1.645 (CV) (STD)

3. Classify exposure estimate:

   - Compliance officer's test for noncompliance.
     If LCL > STD, conclude "noncompliance"
     If AC > STD and LCL < STD, conclude "possible noncompliance"
     If AC < STD, no statistical test for noncompliance is needed

   - Employer's test for compliance.
     If UCL < STD, conclude "compliance"
     If UCL > STD, conclude "possible noncompliance"

Example:

1. An airborne asbestos fiber level of about 0.2 f/cc was suspected. A phase-contrast microscope with a count field area of 0.003 mm^2 and a pump calibrated for 2.0 lpm are available. When a filter wedge was counted, the total fibers counted in 100 fields was 58. No fibers were found on the blank filters. Assume (for purposes of illustration) that CV = 0.4 for 58 fibers and STD = 0.2.

$$AC = \frac{58/100)\ (855)}{(1000)\ (2)\ (480)\ (0.003)} = 0.17 \text{ f/cc}$$

2. LCL (95%) = 0.17 - (1.645) (0.4) (0.2) = 0.04
UCL (95%) = 0.17 + (1.645) (0.4) (0.2) = 0.30

3. Since AC = 0.17 is less than 0.2, a conclusion of "noncompliance" is not warranted.

Since 0.30 (UCL) exceeds STD, an employer should conclude "possible noncompliance".

Although these calculational procedures are similar, yet somewhat more complicated for other sampling schemes, such as consecutive sampling and grab sampling, the parameter CV remains a crucial aspect of the statistical interpretation of monitoring results.

7.6 Feasibility Analysis

Both the technical feasibility and costs of monitoring airborne asbestos in the workplace with reference to very low exposure limits (<1.0 fiber/cc) depend on the incremental and overall feasibility of each stage in the sampling and analytical procedure. Two basic characteristics determine such feasibility, however, the sensitivity and precision of the monitoring method.

7.6.1 Sensitivity

The importance of sensitivity in this context can be examined by looking at the logistical and calculational steps needed to sample, count, and compute fiber-concentration estimates at or below the prescribed exposure limits. Minimum detectable fiber concentrations derived from phase-contrast microscopy depend directly on sample volume, microscope field area (MFA), number of fields counted, and the presence of absence of nonfibrous particles. Theoretical minimum detectable concentrations can be computed by assuming one fiber > 5 μm in length is observed in 100 counting fields. At a sampling flow-rate of 2.0 lpm (FR), using an exposed filter area of 855 mm^2 (ECA), these data can be expressed as follows:

Sampling Period (minutes)	Minimum Detectable Fiber Concentration (fibers > 5μm)/cc		
	MFA = 0.003 mm^2	MFA = 0.005 mm^2	MFA = 0.007 mm^2
15	0.10	0.06	0.04
30	0.05	0.03	0.02
60	0.02	0.01	0.01
90	0.02	0.01	0.007
120	0.01	0.007	0.005
240	0.006	0.004	0.003
360	0.004	0.002	0.002
480	0.003	0.002	0.001

The NIOSH method, however, calls for the analyst to count no less than 10 fibers or no less than 20 fields. At very low concentrations, therefore, the route to adequate sensitivity using the NIOSH method is to count enough fields to reveal at least 10 fibers after discounting the control sample. This can be done at a higher time expenditure, only if enough fibers have been collected on the filter sample.

Today's state-of-the-art in personal sampling equipment for documenting workplace exposures provides wide access to sampling equipment which operates in the range of 1.5 to 2.5 liters per minute. Because the membrane filter used for sample collection in the NIOSH method has a relatively large resistance (pressure drop), sampling pumps typically run at a rate of 1.5 to 2.0 liters per minute, although some configurations may be available at higher rates, such as 2.5 liters per minute.

Suppose a peak exposure of 0.5 fiber/cc or more is suspected for short periods up to 15 minutes. Using a calibrated pump at 2.0 lpm, an industrial hygienist samples the breathing zone of the worker for 15 minutes using a 37-mm membrane filter. Assume this laboratory uses a phase-contrast microscope with MFA = 0.004 mm^2. The filter collection area (855 mm^2) contains about 214,000 fields. The 30-liter air sample will contain 15,000 fibers if the concentration (AC) is 0.5 fiber/cc. The surface density of fibers in the sample will be 0.07 fiber/field, however, somewhat less than the lower bound of the acceptable range, 0.1.

The following table shows the surface fiber density achieveable using various sampling/analytical configurations for a 37-mm filter and a 15-minute sampling period and airborne fiber concentration of 0.5 fiber/cc.

Flowrate (lpm)	Surface Fiber Density Achievable (FB/FL)				
	MFA (mm^2)				
	0.003	0.004	0.005	0.006	0.007
1.5	0.04	0.05	0.07	0.08	0.09
2.0	0.05	0.07	0.09	0.11	0.12
2.5	0.07	0.09	0.11	0.13	0.15
3.0	0.08	0.11	0.13	0.16	0.18
3.5	0.09	0.12	0.15	0.18	0.21

This table shows clearly that only a certain combination of sampling (pump) and analytical (microscope) instruments can be used to achieve a minimum surface fiber-density of 0.1 fiber/field for 15-minute sampling with reference to the NIOSH-proposed ceiling concentration of 0.5 fiber/cc. Thus, economic costs of monitoring asbestos, based on sensitivity considerations only, relate to the limited configuration of instrumentation acceptable as well as the costs of preparing and counting filter samples. The requirement and advantage of higher flowrate pumps with regard to sensitivity suggest that a new generation of sampling equipment will be necessary to conform to the requirements implicit in the 0.1 fiber/cc (8-hour TWA) and 0.5 fiber/cc (15-minute peak) NIOSH proposal.

The surface fiber density estimates must also be considered in light of the fact that the method requires each filter prepared for counting to be relatively free of other background particulates. In many industrial applications, even within the primary asbestos industry, other dusts -- fibrous and nonfibrous -- will be present. In effect, therefore, longer sampling times such as those lasting several hours are not necessarily consistent with the NIOSH method because of the likelihood of overloading the filters with background particulate that will interfere in the counting procedure.

7.6.2 Precision

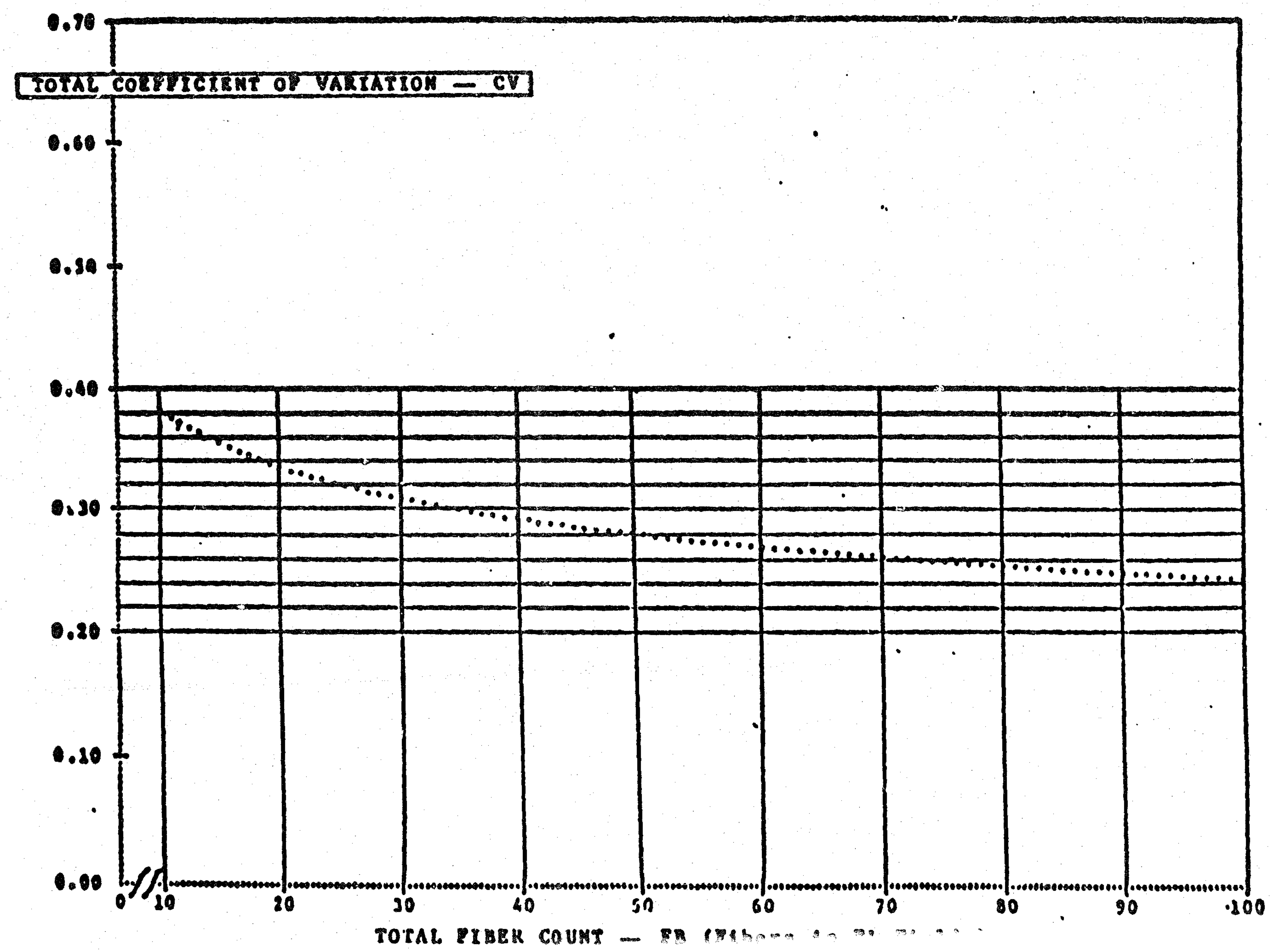
Section 7.6.1 discussed technical feasibility of monitoring airborne asbestos in terms of minimum detectable concentrations (sensitivity) and conditions conducive to collection of minimum required numbers of fibers in given sampling schemes. "Precision" represents another extremely pertinent characteristic of the NIOSH phase-contrast monitoring method in the context of technical feasibility. The confidence interval associated with a given estimate of fiber concentration dictates the extent and conclusiveness with which comparisons with permissible exposure levels can be made and, moreover, the cost-benefit of resource expenditures needed to narrow the confidence levels (strengthen the conclusiveness) of exposure estimates by improving the precision of the monitoring method in any given application.

The most critical issue here, as explained in Section 7.5, is the definition -- quantitative and qualitative -- of the variability in the method from random errors, i.e., the coefficient of variation (CV). NIOSH has conceded, on the basis of its latest in-house draft of the monitoring method report that CV is not a fixed value (formerly asserted to be 0.22), but a function of total fiber count, FB (see Figure VII-1).[8]

Theoretical and empirical considerations suggest that CV decreases for larger numbers of fibers counted and increases for counts (FB) of smaller magnitude. It is our judgment that, as of this time, no adequate research has defined CV for the phase-contrast method as to include the random errors associated with the entire sampling and analytical procedure. Clearly, the NIOSH estimates to date are incomplete and very likely too low. (See Section 7.5.2)

For purposes of illustration, however, various levels of CV can be assumed so as to demonstrate the importance of this parameter in the context of feasibility. Because no one has yet, in our judgment, rigorously determined the coefficient of variation of the NIOSH method

Figure VII-1: Total Coefficient of Variation as a Function of Total Fiber Count[8]



by a well-designed empirical process, one must discuss feasibility at this stage in terms of assumed levels of CV. It appears likely from our analysis of the literature and various positions of advocates of one cause or another in these circumstances, that a range of 0.3 to 1.2 will likely bracket the "true" CV, at least for fiber counts of 20 or greater. A relationship CV = f (FB) will undoubtedly be determined ultimately, and after peer review and comment in the scientific literature, be accepted as an estimate derived by a consistent, rational approach.

Suppose a sample of air is drawn at 2.0 lpm for a full-shift (480 minutes) sample for comparison of the measured exposure with the permissible TWA. Assume the FB/FL ratio is 0.40 (for example, 50 fibers in 125 fields). Assume, (from a yet uncompleted, definitive study) that CV = 0.6 at FB = 50. From Section 7.5.2, assuming BFB/BFL = 0, ECA = 855 mm^2, and MFA = 0.006 mm^2,

$$AC = \frac{(0.4)\ (855)}{(1000)\ (480)\ (2)\ (0.006)} = 0.06 \text{ fiber/cc}$$

then,

$$\text{LCL} = 0.06 - 1.645\ (0.6) = \text{"}-0.93\text{" fiber/cc}$$
$$\text{UCL} = 0.06 + 1.645\ (0.6) = 1.0 \text{ fiber/cc}$$

The 95% confidence interval associated with this exposure estimate of 0.06 fiber/cc thus ranges from 0 to 1.0 fiber/cc. Clearly, an employer could not form a definitive conclusion on the magnitude of the exposure relative to a TWA permissible limit less than one fiber/cc. The only alternative to strengthen the conclusion is to minimize CV within the constraints governing the collection and analysis of that sample; this can only be done by counting more fibers.

The importance of CV for the case of shorter than full-shift sampling periods is illustrated in the following example where several consecutive samples cover a full-shift (eight hours).

An industrial hygienist whose laboratory has a microscope with MFA = 0.006 mm^2 samples a worker's asbestos exposure with a pump calibrated at 1.9 lpm and filters with ECA = 855 mm^2. Results are as follows:

ΔT_i minutes	FB_i	FL_i	FB_i/FL_i	AC_i (f/cc)	CV_i*
110	40	120	0.33	0.23	0.62
125	45	100	0.45	0.28	0.59
130	65	130	0.50	0.38	0.51
115	55	110	0.50	0.31	0.55

*Values assumed for purposes of illustration

$$TWA = \frac{(110)(0.23)+(125)(0.28)+(130)(0.38)+(115)(0.31)}{480} = 0.30 \text{ f/cc}$$

$$V = \text{TWA variance} = \sum_{i=1}^{4}\left[\frac{(\Delta T_i)(AC_i)(CV_i)}{480}\right]^2$$

$$V = 0.001068 + 0.001851 + 0.002755 + 0.001669 = 0.007342$$

$$SE = \text{Standard error of TWA} = \sqrt{V} = 0.086 \text{ f/cc}$$

$$LCL(95\%) = 0.30 - 1.645\ (0.086) = 0.16 \text{ f/cc}$$

$$UCL(95\%) = 0.30 + 1.645\ (0.086) = 0.44 \text{ f/cc}$$

Therefore, it is obvious that the range confidence interval of the method must be taken into account in determining the compliance, or non-compliance of a workplace environment.

7.7 Questions Concerning the NIOSH Phase Contrast Method

Several questions remain as to the rationale for the NIOSH insistence that CV is adequately defined for the method on the basis of Figure VII-1.

NIOSH has stated that the coefficient of variation (CV) for the asbestos count method should include (measure) only random intra-filter variations (inter-field within a wedge and interwedge within a filter), random inter-counter variations, and random pump flowrate variations.(8) Is this "definition" of a "total coefficient of variation" really consistent with other NIOSH-recommended monitoring methods? For example, is this definition consistent with that used in the SRI Standards Completion Project Contract (CDC-99-74-45)?

Why does the NIOSH definition of "total coefficient of variation" for the asbestos method not include random errors associated with filter preparation (loading and unloading) and filter wedge mounting after sampling but prior to counting?

Because the coefficient of variation estimated by $s/\bar{x}$ inherently underestimates the true value of σ/μ (the mean value of a ratio is less than the ratio of the true means), why haven't the NIOSH investigators corrected for this bias in estimating CV?

7.8 References

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APPENDIX A: Case History of Substitution for Asbestos Products - Calcium Silicate Molded Insulation*

Thermobestos was Johns-Manville's tradename for its molded insulation, a calcium silicate product reinforced with asbestos and capable of insulating up to 1200 F. Its application was widespread both in the general industry and shipboard applications as molded insulation that could be cut and fabricated in the field to fit a variety of high temperature applications. The manufacturing process involved blending the raw materials, (i.e., lime, silica

ing the shapes, and autoclaving under heat and pressure which caused a hydrothermal reaction forming the hard calcium silicate product. The health hazards associated with using these products first surfaced in 1964 as a result of Selikoff's studies on insulation workers. Subsequently, work practices were determined not to be effective to control the dust problems associated with field fabrication. Therefore, in mid-1960's Johns-Manville initiated research and development effort to which was intensified in 1968 to find a suitable substitute for asbestos, in calcium silicate insulation.

As reported by Johns-Manville, several process considerations had to be taken into account when considering substitution. The raw

*The information for this case history was based on on-site interviews and follow-up correspondence with research and development personnel of Johns-Manville Corporation, Denver, Colorado.

materials must be easily dispersed and maintain their fluidity until molding. The material must have the property of good filterability to extract the excess water before autoclaving; the product must have sufficient independent strength to hold its form before autoclaving; and, the drying time of the product must be relatively short to conserve energy. Finally, the manufacturing process must be able to maintain a high production rate to justify the economics of the product. With respect to the properties of the finished product, the new material must have "good shipability" i.e., a light weight product for lower shipping cost, resistance to breakage. For application in the field, the product must have abraision resistance to withstand fabrication handling and have high transverse strength. Furthermore, from a marketing standpoint, the product must be able to perform adequately and sell competitively.

Johns-Manville first attempted to remove the asbestos fiber from the product. This resulted in failure due to lack of strength. A second attempt was to keep the same manufacturing process, but try alternative fibers. These investigations included such materials as:

organic fibers	inorganic fibers
rayon, cuthen linten	glass
polyester, flax	mineral wool
sisal, cellulose products	

All of these trials failed because the fibers were destroyed by alkali or thermal attack during the hydrothermal reaction in the autoclaving process. The third major research effort was to change the process to adapt to characteristics of new raw materials. In this case, a pre-autoclave process was utilized by first blending the raw materials of lime and silicates and then autoclaving to form a calcium silicate slurry. The new reinforcement fibers were subsequently added to provide strength. This approach met with success by using a combination of polyester fibers for wet strength applications and fiberglass for temperature resistance as the reinforcing fibers. The time involved for this phase of research was approximately two years from early 1969 to late 1971 and involved approximately $250,000 in direct labor costs.

Johns-Manville then moved into the development phase in starting-up the actual manufacturing process for their new asbestos-free product, now called Thermo-12. The calcium-silicate slurry was found to be extremely abraisive and destroyed the original piping in the process. Therefore, a complete re-design of piping and valving was required. Additionally, the process for Thermo-12 required higher temperatures and pressures than those for Thermobestos, so that pressure vessels had to be modified. There was a problem involving quality control of raw materials due to the sensitivity of the process and the fluctuations in material quality. It also has been determined that the maintenance costs for this new process has increased approximately 10% because of the corrosiveness of the intermediate materials. The initial start-up of the new product line was in July 1972 with modifications and re-design continuing through 1973.

Johns-Manville provided CONSAD with research and development costs for converting Thermobestos to Thermo-12 as follows:

Approximate Costs Associated with
Conversion from Thermobestos to Thermo-12*

Capital Expenditures	$ 5,800,000
Start-up, overruns, production losses	6,100,000
Loss of profits on sales	3,100,000
Technical and engineering personnel expenses	350,000
Research Costs	1,774,600**
Total	$17,124,600***

A review of the Thermobestos/Thermo-12 sales as reported by Johns-Manville is presented as follows:

1970	$ 7,500,000	
1971	9,650,000	
1972	11,240,000	
1973	7,258,000	Year of Conversion
1974	11,545,000	
1975	13,670,000	Production capacity doubled.
1976	20,000,000	

Total industry sales were approximately $45 million in 1976.

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*Cost figures cover the period 1973-1976, which is essentially the span of conversion.

**Research costs span the period 1969-1976.

***The above figures do not include corporate-division taskforce expenses, nor management time.

Price increases during this period were in the 5-7% range. No significant price increases were instituted by Johns-Manville or its competitors (Owens-Corning, Fiberboard Corporation) as a result of new product formulations. For competitive reasons, no attempt was made to recoup any significant portion of these conversion costs.

As is evident from the above discussion of research process changes and costs, the effort to replace asbestos in this application was both difficult and costly. This example has been cited to illustrate some of the complexities involved in replacing asbestos in various product applications. Even though much experience was gained through this experience by the manufacturer, it is not necessarily transferrable to other product applications. It may be fair to say that research and development efforts to find substitute for asbestos will be as unique as the individual production and product/performance requirements.

APPENDIX B: Materials Evaluated as Potential Asbestos Substitutes

This appendix is arranged in tabular form to present materials evaluated as potential substitutes for asbestos as identified in the literature and through conversations with industry sources. For each material is listed the product applications where research has been undertaken to evaluate its substitution potential. Information is given comparing the cost of the material to asbestos used in that specific product application. Additionally, general performance characteristics and pertinent comments for these materials is briefly outlined for each application. This listing is in on way intended to be comprehensive to include all research and development in the present efforts to replace asbestos. However, it should provide significant background information to demonstrate the scope of these present R & D measures.

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
Fibrous Glass	Cement - Reinforcement	46-52¢/lb. vs. 13-25¢/lb asbestos	Provide flexural and impact strength; product weak, attacked by alkali; formation and dispersion problems.	(1)(2)
	Asbestos Papers	50-75¢/lb. vs. 12-24¢/lb. asbestos	Different product obtained; more brittle and higher cost; glass can be used in small percentage with asbestos, but not as complete replacement; requires different forming system.	(2)
	Reinforced Phenolic Plastics	75¢/lb. vs 55¢/lb. long fiber asbestos; 50¢/lb. vs. 10¢/lb. short fiber asbestos	May be used for higher temperature applications; problems with abrasiveness of glass wearing out processing equipment; process change probable.	(3)(4)(7)
	Textiles, Pipe, Wrap and Lagging	50-75¢/lb. vs. $1.00	Flame resistant; weight comparable to asbestos; better able to automate manufacturing process; not as durable as asbestos; lower temperature resistance than asbestos textiles.	(5)
	Friction Materials - Clutch Facing	50-75¢/lb. vs. 5-15¢/lb. asbestos	Research in progress; brittleness requires different process; cost and performance unknown.	(2)(6)
	Vinyl Floor Tile	50-75¢/lb. vs. 5-10¢/lb. asbestos	Brittleness caused degradation in normal process.	(2)
	Packings	50-75¢/lb. vs. 50¢-$1/lb. asbestos	Brittleness of glass requires different processing; might be used for specific products and usages; glass can be used in high temperature packings.	(2)
	Roof Coatings	40¢/lb. vs. 5-10¢/lb. asbestos	Glass does not absorb asphalt as well as asbestos; glass has reinforcement properties but lacks viscosity in coating materials.	(9)(2)

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
Alkali-Resistant Glass Cem-Fil Pilkington Bros. Ltd.	Cement Reinforcement (pipe, sheets)	95¢-$1.25/lb. vs. 13-25¢/lb. asbestos	Capable of reinforcing portland cement; improve impacts and tensile strength; reduced strength compared to asbestos product; formation difficult on existing equipment; product loses strength with time; research effort in U.S. with Owens-Corning; presently not a commercially acceptable substitute.	(2)(8)(42)
Mineral Wool	Cement Reinforcement	16¢/lb. vs. 13-25¢/lb. asbestos	Weak product; attacked by alkali in portland cement; difficult to disperse; poor formation; brittle fiber; experimental work using mineral wool to build up composite cement sheet.	(2)(10)
	Reinforced Plastics (Filler)	18¢/lb. vs. 8-10¢/lb. asbestos	Processed mineral fiber developed by Jim Walter Resources, Inc. Pilot Plant Operation; made from blast furnace slag and silicates; purported to be replacement for asbestos in phenolic molding compounds.	(11)
Potassium Titanate Fibers Dupont - FYBEX	Reinforced Plastics Friction Materials Asbestos Cement	$1-1.25/lb. vs. 6¢/lb. asbestos $1-1.25/lb. vs. 6¢/lb. asbestos $1-1.25/lb. vs. 13-25¢/lb. asbestos	Weak cement product; NASA developed FYBEX brake composition; used as additive to asbestos in car brakes to cut down fade and improve coefficient of friction; Dupont removed from market due to health hazard evaluation and slow market growth.	(2)(12)
Steel Fibers	Cement Reinforcement	20¢/lb. vs. 13-25¢/lb. asbestos	Very good reinforcement; high impact strength; resistant to alkali attack; difficult to keep dispersed; problems with machining and cutting; problems with rust.	(2)
	Semi-metallic Friction Materials	Price information proprietary	Good brake performance but faster wear; good friction at high temperature; poor at low temperature; completely different product than conventional asbestos brake lining; applicable only to disc brakes.	(2)

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
MICA (Suzorite)	Cement Reinforcement	5¢/lb. vs. 13-25¢/lb. asbestos	Reduced strength even at partial substitution	(2)
	Reinforced Plastics	d. o.	Adds dimensional stability and increases strength of plastics; high-aspect-ratio mica purported to provide middle ground in cost-performance between inorganic particulate fillers and fiber reinforcement.	(13)(18)
Graphite-Carbon Fibers	Cement Sheets	$10-$12/lb. vs. 13-25¢/lb. asbestos	Increases modular strength of portland cement; resistant to alkali attack; no increase in impact strength; very expensive.	(8)
	Reinforced Plastics	$10-$12/lb. vs. 5-10¢/lb. asbestos	For high strength applications; increases acid resistance in phenolics; also used as filler for thermoset plastics; high heat resistance; specialty applications only.	(15)
	Friction Materials	$10-$12/lb. vs. 10-15¢/lb. asbestos	Primary application in aircraft brakes; research in disc brakes; very expensive.	(16)(17)
	Packings	$10-$12/lb. vs 50¢-$1/lb. asbestos	Graphite filament yard; great heat and chemical resistance; used in application over 500°F; provides longer life than asbestos packings; degrades processing equipment; does not hold lubricants like asbestos	(18)(43)
Basalt	Cement Reinforcement	No Data	Research effort in development of "A" fiber from basalt as possible replacement for asbestos; properties demonstrate good alkalinity; not considered as a complete asbestos substitute; could be used up to 20% of asbestos content without causing degradation in product strength; USSR research developed experimental basalt fiberboard purportedly found to be superior to asbestos slabs.	(21)(22)
Talc	Reinforced Plastics	6¢/lb. vs 5-10¢/lb. asbestos	Loss of strength but can compensate by making thicker walled product presently utilized as asbestos substitute; is not applicable to high temperature applications	(7)(23)

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
Talc	Roof Coatings		No reinforcement value and no significant increase in viscosity.	(9)
Carbonate Clay	Floor Tile	4-8¢/lb. vs. 5-10¢/lb. asbestos	Used as filler, no reinforcement; can be used as partial asbestos substitute.	(2)
	Reinforced Plastics		Proprietary information.	(4)
Attapulgite Clay	Joint Compounds	no data on cost	Presently used as asbestos substitute in spackling compounds; no process charge required; purported to increase price over asbestos joint cement by 12-13%.	(24)
Ceramic Fibers	Cement Reinforcement (Alumina Fibers (Saffil)	$8/lb. vs. 15-25¢/lb. asbestos	Reduced plasticity; reduced strength at partial substition compared to asbestos; high cost; difficulty in processing.	(2)
	Textiles - Alumina-Boria (3M) Alumina-Chromia (3M)	$30-$32/lb. vs. $1/lb. asbestos	For use in extremely high temperature (over 1000°F) applications, e.g., high temperature blankets; not an economic substitute for asbestos; also for high temperature electrical and furnace applications.	(25)
	Silica (Refrasil)	$8.80/lb. vs. $1/lb. asbestos	High heat resistance; low abrasion; brittle material.	(26)
	Packings	$10/lb. vs. $1/lb. asbestos	Very good chemical and heat resistance; poor tensile strength; abrasive material; does not hold lubricant like asbestos.	(18)
	Cermet Friction Materials	no data	Cermet friction materials use copper iron matrix materials reinforced with steel fiber with various ceramic and metallic property modifiers; used in heavy duty applications such as aircraft and racing cars; friction coefficient increases with increasing hardness of ceramic.	(27)

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
Ceramic Fibers	Paper Millboard Rollboard Muffler Paper	Alumina Silicates @ $1/lb. vs. 12-24¢/lb. asbestos	Not used as reinforcing material, but for thermal applications; specific use to replace asbestos in muffler paper.	(2)(29)
	Filters	Alumina (Saffil) @ $8/lb. vs. 12-24¢/lb. asbestos	Saffil fibers shown to be effective replacement for asbestos filters in breweries; show high promise as high temperature chemical resistant filtration medium.	(29)(30)
Aramid Fibers	Asbestos Cement	Dupont Kevlar $6-8/lb. vs. 13-25¢/lb. asbestos	Does not compare with flexural or physical strength of asbestos; product in research stage only; fibers not easily dispersed and tend to clump together; not intended to be total replacement for asbestos; Kevlar loses strength in concentrated caustic solution but is resistant to alkali at room temperature.	(2)(31)
	Friction Materials Clutch Facings	Kevlar $6-8/lb. vs. 5-10¢/lb. asbestos	Research and development in high performance clutch facings, off-road trucks and on-road trucks with automatic transmissions.	(32)
	Reinforced Plastics	Dupon Nomex $5-6/lb. vs. 5-10¢/lb. asbestos	Use in specialty plastic reinforcements; too expensive for asbestos replacement in phenolic molding compounds.	
	Protective Clothing Dryer Felts Laundry Press Fabrics High Temperature Filtration	Dupont Nomex $5-6/lb. vs. $1/lb. asbestos	Best heat resistance of organics; not applicable over 500 F; strong material and abrasion resistant.	(32)(33)(34)
	Paper Electrical Insulation	Nomex - $5-6/lb. vs. 12-24¢/lb. asbestos	Low sensitivity to moisture and resistant to common solvents and chemicals; not degraded by molds and mildews; approved for temperatures up to 220 C; can be used as replacement for asbestos in high temperature applications; cost of paper ranges from $1-9/square yard or $6.50-$800/lb. depending upon thickness.	(35)(36)

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
Nylon	Cement Reinforcement	60¢/lb. vs. 13-25¢/lb. asbestos	Provides impact strength; but no reinforcement.	(2)
Polypropylene	Cement Reinforcement	35¢/lb. vs. 13-25¢/lb. asbestos	Provides impact strength; but no reinforcement; presently used in short-segmented concrete pilings.	(2)(8)
Tetrafluoroethylene (TFE) fibers	Mechanical Packings Packings	$10-12/lb. Dupont teflon yard @ vs. $1.50-1.75/lb. asbestos yarn	TFE filament yard has chemical resistance, strength, and heat resistance of asbestos; has superior chemical resistance for strong acids and caustic materials in the pH range 1-2 and 13-14; can be used in applications up to 500°F; disadvantages - cannot impregnate TFE with resin; not as resiliant as asbestos; using TFE in place of asbestos increases price of packings 4 to 5 times.	(18)
	Sheet Gaskets	Dupon Teflon $8/lb. mixed w/fillers vs. $1/lb. asbestos	Applicable in applications under 500°F; cannot withstand heavy mechanical load; under pressure gasket will deform over time; upper temperature limit 350 F under continuous pressure.	(38)(39)
Phenolic Fiber	Textiles Protective Clothing Fire-Resistant Draperies	Carborundum Kynol @ $3.60/lb. vs. $1/lb. asbestos	Good insulation properties up to 800 F; does not have good abraision resistance.	(9)
Phenolic Fiber PBI (Polyben	Protective Clothing Air Force Flight Suits	No data	Reported to offer better thermal protective capabilities than NOMEX aramid textiles; provides both comfort and thermal resistant characteristics.	(40)(42)
Cellulose Fibers	Cement Sheet	No data	Wood fibers added to cement sheets to make them more sawable and nailable; water sensitive and fails in outside environment; has limited interior usage; indian research experimenting with cellulose pulp as replacement for asbestos.	(2)(19)

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
	Asbestos Papers	6-60¢/lb. vs. 5-14¢/lb. asbestos	Lacks temperature resistance; does not have equivalent dimensional stability under changing humidity and temperature compared to asbestos papers; will rot and burn.	(2)
	Floor Tile	60¢/lb. vs. 5-14¢/lb. asbestos	Monsanto Santoweb[R] fiber; purported to have better color clarity and brightness in floor tiles compared to asbestos floor tile; reduce need for pigment by 75% thus making price of end product comparable to asbestos tile; 1 pound of Santoweb takes the place of 5 pounds of asbestos by using filler (i.e., limestone).	(26)
Cotton, flax	Braided Mechanical Packings	50¢-$1/lb. asbestos	Packings work well in extremely cold applications (-300 F) and are good water seals at room temperature; is not applicable in higher temperature applications.	(38)
Cotton Linters	Friction Materials	20¢/lb. vs. 5-15¢/lb. asbestos	For specific applications depending upon performance requirements.	(2)

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APPENDIX C: Case Study of Potassium Titanate Fibers as a Substitute for Asbestos*

Dupont developed a potassium titanate fiber in 1966 to be used primarily as premium pigment for high brightness paper. In 1972 Dupont introduced this material as "FYBEX", an inorganic reinforcing titanate which was attractive for their reinforcement potential and their resistance to alkali attack. The primary use was intended to be in reinforcing plasticis, and in some cases was purported to be an adequate substitute for asbestos. Other applications included premium and decorative pigments, friction materials, insulation and battery separators. The National Aeronautical and Space Administration (NASA) developed a brake composition material with FYBEX replacing asbestos and conducted studies to determine the market for such a material.

Limited testing of these titanate by Dupont to determine their health effects had taken place prior to 1966. These tests indicated that FYBEX should be heated like asbestos. With the concern surrounding the health hazards of asbestos in 1971 and 1972 and the permissible exposure levels for asbestos being reduced, Dupont recommended that an exposure limit of 2 fibers/cc be set for FYBEX. There was concern that FYBEX would later prove to be carcinogenic, although the necessary tests were not done.

*Information on FYBEX was obtained through correspondence with the Pigments Department, E.I. Dupont DeNemours & Co., Inc. Wilmington, Delaware.

In September 1974, Dupont announced the withdrawal of FYBEX from the market, effective in December of that year. The potential health hazards of FYBEX were obviously a major factor in this discussion. However, Dupont reported that equally important was FYBEX's slow market growth and the anticipation that it would become a low volume, specialty market were conditions that also prompted the withdrawal decision. Dupont customers of FYBEX with difficult substitution problems were phased out in 1975. Additionally, NASA had to discontinue its efforts to develop a commercially viable non-asbestos brake lining.

As reported by Dupont, many toxicologists hold the view that any fine durable mineral fiber in the same size range as asbestos will be found fibrogenic and carcinogenic. To evaluate the toxicity of substitutes for asbestos, long term inhalation tests are necessary which compare animals exposed to varying concentrations of the materials. Dupont reports that these inhalation tests may take two to three years and can cost in the range of $200,000 to $500,000. Intra-trachial tests inject materials in suspension directly into the lung area of animals. These are shorter, less costly tests than the inhalation studies, but are also less reliable.

There is a real concern among industry that by substituting for asbestos, they may be trading one health hazard for another. If it is true that all fine durable fibers in the asbestos size range prove to be fibrogenic and carcinogenic, independent of chemical composition, then the chances of finding a non-toxic substitute fiber for asbestos may be low. An excellent example of this situation is NIOSH's recent criteria document for fibrous glass in which they recommend an exposure limit of 3 fibers/cc, 8-hour time weighted average. The toxicological data on other possible substitutes was not part of CONSAD's charge for this study. However, there are serioud questions concerning the difference in toxicity between asbestos and possible substitutes that remain unanswered.

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
Fibrous Glass	Cement - Reinforcement	46-52¢/lb. vs. 13-25¢/lb asbestos	Provide flexural and impact strength; product weak, attacked by alkali; formation and dispersion problems.	(1)(2)
	Asbestos Papers	50-75¢/lb. vs. 12-24¢/lb. asbestos	Different product obtained; more brittle and higher cost; glass can be used in small percentage with asbestos, but not as complete replacement; requires different forming system.	(2)
	Reinforced Phenolic Plastics	75¢/lb. vs 55¢/lb. long fiber asbestos; 50¢/lb. vs. 10¢/lb. short fiber asbestos	May be used for higher temperature applications; problems with abrasiveness of glass wearing out processing equipment; process change probable.	(3)(4)(7)
	Textiles, Pipe, Wrap and Lagging	50-75¢/lb. vs. $1.00	Flame resistant; weight comparable to asbestos; better able to automate manufacturing process; not as durable as asbestos; lower temperature resistance than asbestos textiles.	(5)
	Friction Materials - Clutch Facing	50-75¢/lb. vs. 5-15¢/lb. asbestos	Research in progress; brittleness requires different process; cost and performance unknown.	(2)(6)
	Vinyl Floor Tile	50-75¢/lb. vs. 5-10¢/lb. asbestos	Brittleness caused degradation in normal process.	(2)
	Packings	50-75¢/lb. vs. 50¢-$1/lb. asbestos	Brittleness of glass requires different processing; might be used for specific products and usages; glass can be used in high temperature packings.	(2)
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Mineral Wool	Cement Reinforcement	16¢/lb. vs. 13-25¢/lb. asbestos	Weak product; attacked by alkali in portland cement; difficult to disperse; poor formation; brittle fiber; experimental work using mineral wool to build up composite cement sheet.	(2)(10)
	Reinforced Plastics (Filler)	15¢/lb. vs. 5-10¢/lb. asbestos	Processed mineral fiber developed by Jim Walter Resources, Inc. Pilot Plant Operation; made from blast furnace slag and silicates; purported to be replacement for asbestos in phenolic molding compounds.	(11)
Potassium Titanate Fibers Dupont - FYBEX	Reinforced Plastics	$1-1.25/lb. vs. 6¢/lb. asbestos	Weak cement product; NASA developed FYBEX brake composition; used as additive to asbestos in car brakes to cut down fade and improve coefficient of friction; Dupont removed from market due to health hazard evaluation and slow market growth.	(2)(12)
	Friction Materials	$1-1.25/lb. vs. 6¢/lb. asbestos		
	Asbestos Cement	$1-1.25/lb. vs. 13-25¢/lb. asbestos		
Steel Fibers	Cement Reinforcement	20¢/lb. vs. 13-25¢/lb. asbestos	Very good reinforcement; high impact strength; resistant to alkali attack; difficult to keep dispersed; problems with machining and cutting; problems with rust.	(2)
	Semi-metallic Friction Materials	Price information proprietary	Good brake performance but faster wear; good friction at high temperature; poor at low temperature; completely different product than conventional asbestos brake lining; applicable only to disc brakes.	(2)

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
MICA (Suzorite)	Cement Reinforcement	5¢/lb. vs. 13-25¢/lb. asbestos	Reduced strength even at partial substitution	(2)
	Reinforced Plastics	d. o.	Adds dimensional stability and increases strength of plastics; high-aspect-ratio mica purported to provide middle ground in cost-performance between inorganic particulate fillers and fiber reinforcement.	(13)(18)
Graphite-Carbon Fibers	Cement Sheets	$10-$12/lb. vs. 13-25¢/lb. asbestos	Increases modular strength of portland cement; resistant to alkali attack; no increase in impact strength; very expensive.	(8)
	Reinforced Plastics	$10-$12/lb. vs. 5-10¢/lb. asbestos	For high strength applications; increases acid resistance in phenolics; also used as filler for thermoset plastics; high heat resistance; specialty applications only.	(19)
	Friction Materials	$10-$12/lb. vs. 10-15¢/lb. asbestos	Primary application in aircraft brakes; research in disc brakes; very expensive.	(16)(17)
	Packings	$10-$12/lb. vs 50¢-$1/lb. asbestos	Graphite filament yard; great heat and chemical resistance; used in application over 500°F; provides longer life than asbestos packings; degrades processing equipment; does not hold lubricants like asbestos	(18)(43)
Basalt	Cement Reinforcement	No Data	Research effort in development of "A" fiber from basalt as possible replacement for asbestos; properties demonstrate good alkalinity; not considered as a complete asbestos substitute; could be used up to 20% of asbestos content without causing degradation in product strength; USSR research developed experimental basalt fiberboard purportedly found to be superior to asbestos slabs.	(21)(22)
Talc	Reinforced Plastics	6¢/lb. vs 5-10¢/lb. asbestos	Loss of strength but can compensate by making thicker walled product; presently utilized as asbestos substitute; is not applicable to high temperature applications	(7)(23)

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
Talc	Roof Coatings		No reinforcement value and no significant increase in viscosity.	(9)
Carbonate Clay	Floor Tile	4-8¢/lb. vs. 8-10¢/lb. asbestos	Used as filler, no reinforcement; can be used as partial asbestos substitute.	(2)
	Reinforced Plastics		Proprietary information.	(4)
Attapulgite Clay	Joint Compounds	no data on cost	Presently used as asbestos substitute in spackling compounds; no process change required; purported to increase price over asbestos joint cement by 12-13%.	(24)
Ceramic Fibers	Cement Reinforcement (Alumina Fibers (Saffil))	$8/lb. vs. 13-25¢/lb. asbestos	Reduced plasticity; reduced strength at partial substition compared to asbestos; high cost; difficulty in processing.	(2)
	Textiles - Alumina-Boria (3M) Alumina-Chromia (3M)	$30-$32/lb. vs. $1/lb. asbestos	For use in extremely high temperature (over 1000°F) applications, e.g., high temperature blankets; not an economic substitute for asbestos; also for high temperature electrical and furnace applications.	(24)
	Silica (Refrasil)	$8.80/lb. vs. $1/lb. asbestos	High heat resistance; low abrasion; brittle material.	(24)
	Packings	$10/lb. vs. $1/lb. asbestos	Very good chemical and heat resistance; poor tensile strength; abrasive material; does not hold lubricant like asbestos.	(15)
	Cermet Friction Materials	no data	Cermet friction materials use copper iron matrix materials reinforced with steel fiber with various ceramic and metallic property modifiers. used in heavy duty applications such as aircraft and racing cars; friction coefficient increases with increasing hardness of ceramic.	(27)

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
Ceramic Fibers	Paper Millboard Rollboard Muffler Paper	Alumina Silicates @ $1/lb. vs. 12-24¢/lb. asbestos	Not used as reinforcing material, but for thermal applications; specific use to replace asbestos in muffler paper.	(2)(29)
	Filters	Aluminas (Saffil) @ $8/lb. vs. 12-24¢/lb. asbestos	Saffil fibers shown to be effective replacement for asbestos filters in breweries; show high promise as high temperature chemical resistant filtration medium.	(29)(30)
Aramid Fibers	Asbestos Cement	Dupont Kevlar $6-8/lb. vs. 13-25¢/lb. asbestos	Does not compare with flexural or physical strength of asbestos; product in research stage only; fibers not easily dispersed and tend to clump together; not intended to be total replacement for asbestos; Kevlar loses strength in concentrated caustic solution but is resistant to alkali at room temperature.	(2)(31)
	Friction Materials Clutch Facings	Kevlar $6-8/lb. vs. 5-10¢/lb. asbestos	Research and development in high performance clutch facings, off-road trucks and on-road trucks with automatic transmissions.	(32)
	Reinforced Plastics	Dupon Nomex $5-6/lb. vs. 5-10¢/lb. asbestos	Use in specialty plastic reinforcements; too expensive for asbestos replacement in phenolic molding compounds.	
	Protective Clothing Dryer Felts Laundry Press Fabrics High Temperature Filtration	Dupont Nomex $5-6/lb. vs. $1/lb. asbestos	Best heat resistance of organics; not applicable over 500 F; strong material and abrasion resistant.	(32)(33)(34)
	Paper Electrical Insulation	Nomex - $5-6/lb. vs. 12-24¢/lb. asbestos	Low sensitivity to moisture and resistant to common solvents and chemicals; not degraded by molds and mildews; approved for temperatures up to 220 C; can be used as replacement for asbestos in high temperature applications; cost of paper ranges from $1-9/square yard or $6.50-$800/lb. depending upon thickness.	(15)(3?)

Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
Nylon	Cement Reinforcement	60¢/lb. vs. 13-25¢/lb. asbestos	Provides impact strength; but no reinforcement.	(2)
Polypropylene	Cement Reinforcement	35¢/lb. vs. 13-25¢/lb. asbestos	Provides impact strength; but no reinforcement; presently used in short-segmented concrete pilings.	(2)([illegible])
Tetrafluoroethylene (TFE) fiber	Mechanical Packing Packings	$10-13/lb. Dupont teflon yard [illegible] vs. $1.50-1.75/lb. asbestos yarn	TFE filament yard has chemical resistance, strength, and heat resistance of asbestos; has superior chemical resistance for strong acids and caustic materials in the pH range 1-2 and 13-14; can be used in applications up to 500°F; disadvantages - cannot impregnate TFE with resin; not as resiliant as asbestos; using TFE in place of asbestos increases price of packings 4 to 5 times.	(1[illegible])
	Sheet Gaskets	Dupon Teflon $8/lb. mixed w/filler vs. $1/lb. asbestos	Applicable in applications under 500°F; cannot withstand heavy mechanical load; under pressure gasket will deform over time; upper temperature limit 350 F under continuous pressure.	(3[illegible])(39)
Phenolic Fiber	Textiles Protective Clothing Fire-Resistant Draperies	Carborundum Kynol @ $3.60/lb., vs. $1/lb. asbestos	Good insulation properties up to 800 F; does not have good abrasion resistance.	(5)
Phenolic Fiber P31 (Polyben	Protective Clothing Air Force Flight Suits	No data	Reported to offer better thermal protective capabilities than NOMEX aramid textiles; provides both comfort and thermal resistant characteristics.	(40)(42)
Cellulose Fibers	Cement Sheet	No data	Wood fibers added to cement sheets to make them more sawable and nailable; water sensitive and fails in outside environment; has limited interior usage; Indian research experimenting with cellulose pulp as replacement for asbestos.	(2)([illegible])

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Substitute Material	Product Application	Price Compared to Asbestos	Performance and Comments	References
	Asbestos Papers	6-60¢/lb. vs. 5-14¢/lb. asbestos	Lacks temperature resistance; does not have equivalent dimensional stability under changing humidity and temperature compared to asbestos papers; will rot and burn.	(2)
	Floor Tile	60¢/lb. vs. 5-14¢/lb. asbestos	Monsanto Santoweb[R] fiber; purported to have better color clarity and brightness in floor tiles compared to asbestos floor tile; reduce need for pigment by 75% thus making price of end product comparable to asbestos tile; 1 pound of Santoweb takes the place of 5 pounds of asbestos by using filler (i.e., limestone).	(20)
Cotton, flax	Braided Mechanical Packings	50¢-$1/lb. asbestos	Packings work well in extremely cold applications (-300 F) and are good water seals at room temperature; is not applicable in higher temperature applications.	(38)
Cotton Linters	Friction Materials	20¢/lb. vs. 5-15¢/lb. asbestos	For specific applications depending upon performance requirements.	(2)

Table : Major A/C Sheet Sub-Markets: Size, Competitive Products, and Market Position

Sub-Market	Size	Competitive Products	Market Position
1. Roofing and Walling for Industrial Buildings.	$13-17 million	Pre-engineered metal panels; pre-cast concrete; aluminum cladding; masonite	A/C sheets used in chemical processing industries, such as fertilizer plants, where A/C sheets resist high moisture content and corrosive fumes in atmosphere. A/C sheets have a fairly stable share of this market.
2. Cooling Tower Fill Sheets	$10-12 million	Glass reinforced plastics; concrete; redwood	A/C sheets have 70% of market with glass reinforced plastics and concrete having a 30% market share. Market heavily dependent on construction of nuclear power plants.
3. Corrugated Bulkheads for Canals		Steel; pre-cast concrete; aluminum	This is a fairly static market prevalent in Florida, the Carolinas, and New Orleans. Environmental controversy over whether canal bank should be natural or not.
4. Laboratory Table Tops	$5-6 million	Stone; molded epoxy resins	A/C sheet currently has 50-60% of the market. A/C sheet costs $5-8/sq.ft. Stone costs $7.50-9.50/sq.ft. Molded epoxy resin costs $10-14/sq.ft. For a $5 table top, the A/C sheet costs $2.50. In 1970 the price for a square foot of A/C sheet was $1.75. A/C sheet prices have been rising at 6-12% per year, while the price of stone and molded epoxy resins have remained at their 1974 and 1975 levels, respectively. The share of market for A/C sheet will probably decline in coming year because of rising prices. The total market for laboratory table tops has been declining since 1968, but now there is the potential for large orders from Arabian countries.
5. Electrical Switching Gear	$2-3 million	Glass; polyester	A/C sheets are used for insulation for switching panels in industrial plants, sub-stations, and generating stations. The alternative material is glass polyester which costs 3 times as much as A/C sheets. Plastics have over 50% of the total market for electrical switching gear, but A/C sheet has a stable 10% share. A/C sheet is generally the only material used in its special market niche.

TABLE 5.2: Water and Sanitary Sewer Pipe Price and Market Estimates

Water Pipe Market (pressure pipe)	Price (8" Standard Size) 6"	12"	Market Share (Estimates) Rural (4" - 6")	Suburban Middle-Sized Cities	Big Cities (6" - 12")
Ductal Iron	$4.47/Ft. (Los Angeles)	$10.19/Ft. (Los Angeles)	?	10%	50%
A/C	$2.49/Ft. (Los Angeles)	$7.38/Ft. (Los Angeles)	20%	50-60%	30%
PVC	$3.94/Ft. (Thick Wall) (Oakland, Cal.) $1.87/Ft. (Thin Wall) (Texas)	$9 - 10/Ft. (Thick Wall) (Johns-Manville)	70% (Thin Wall)	30-40%	5%
Sanitary Sewer Market (Gravity Flow)				Standard 8" Diameter	
Clay	$1.50/Ft. (Western Pa.)			45%	
PVC	$1.65/Ft. (Western Pa.)			20%	
A.B.S. Truss Pipe	$1.65/Ft. (Western Pa.)			20%	
A/C	$1.50/Ft. (Western Pa.)			10%	
Concrete				--*	

*(C[illegible] greater than 24", rather than the standard 8" size for sanitary sewer pipe.)

Source: CONSAD estimates based on conversations with ARMCO Steel Corp., Johns-Manville Corp., Los Angeles Water and Power Company, East Bay Municipal Utility District, Trans-Tex Supply, and UNIBELL.