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FIBRES IN FRICTION MATERIALS SYMPOSIUM

THE ASBESTOS INSTITUTE

Atlantic City, New Jersey
October 7-8, 1987

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The Asbestos Institute

In cooperation with

SAE The Engineering Society
For Advancing Mobility
Land Sea Air and Space

and the

Friction Materials Standards
Institute

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* These speakers did not submit their paper for publication.

FOREWARD

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The Fibres in Friction Materials Symposium provided an international forum for leading, independent technical experts and scientists to discuss various issues relating to the use of natural and made-man mineral fibres in friction materials applications. Its purpose was to put the facts on the table and provide for open and frank discussion on a number of very complex issues.

When consideration is being given to raw material substitution in technically complex applications where performance is critical to the public interest, it is imperative that any decision taken be of net benefit to society. Analysis must be rigorous and all factors must be taken into account, including those related to relative technical performance of the materials involved, economic aspects, and the relative impact on public and worker health and safety.

The hearings on EPA's proposal to ban and phase-out asbestos demonstrated that the amount of information available on which to base a decision is quite limited and not widely available. EPA has commissioned new studies to help fill the information gaps. It is hoped that this conference will also add to the information base so that informed decisions can be made by government, industry and labour alike.

The organizers of the conference put together a program wich was of very high quality, involving speakers of outstanding reputation. My congratulations go to the Chairpersons who played an integral role in obtaining experts to participate in their respective sessions. I would also like to extend my appreciation to the Society of Automotive Engineers, and the Friction Materials Standards Institute, without whose participation this conference would not have been possible.

SESSION I

FRICTION MATERIALS PERFORMANCE ISSUES

BRAKE SYSTEM PERFORMANCE — EFFECTS OF FIBRE TYPES AND CONCENTRATIONS *

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Abstract — *Fibre reinforced composite friction materials have been highly developed over the past eighty years, largely through trial and error experimentation. For the past ten years, friction material development efforts have emphasized non-asbestos compounds. These generally use a combination of fibrous, acicular, and plate-like reinforcing materials. The processing and performance effects are briefly surveyed for asbestos fibre, aramid fibre and pulp, glass fibre, mineral wool, steel wool, and wollastonite. Appendices are included to provide an introduction to friction materials and brake systems.*

HISTORICAL BACKGROUND

Man did not invent friction, but he did invent frictional devices. The initial materials used were often natural fibre composites, such as wood and leather. Later, metals and metal alloys were added as one or both of the frictional pair. The earliest known frictional brakes were used about 3,500 years ago on Sumerian quarry carts to prevent over-running the oxen during descents from the mountains. These brakes employed bronze chains wrapped around a bronze sleeve on one axle. A wooden lever engaged this self-energizing brake. This brake assembly, while effective in controlling the speed of the cart in descending grades, was noted for its brake squeal.

Based on the squeals heard from today's trucks and buses, we haven't made much progress in brake noise elimination, but we have made significant advances in our brake design and friction material performance.

FRICTION MATERIALS

The first practical, engineered, composite friction materials were developed around the turn of the century by an Englishman named Frood -- founder of Ferodo. Following his lead, many new brake friction materials were developed in the ensuing years. Improved braking performance was required as more efficient automotive engines and drive trains were perfected. This allowed improved stopping capabilities, even with increased vehicle speeds.

Chrysotile asbestos originally was used as a lining constituent and reinforcing agent because of its availability and proven heat resistance. The choice of chrysotile asbestos for reinforcement of most friction materials went unchallenged for many decades. During this time, specific fibre lengths and grades were developed and employed in different combinations to optimize friction material performance in an expanding range of applications.

Largely through intensive trial and error experimentation, the composition and processing of chrysotile asbestos-based brake linings have improved until they far surpassed the performance of their natural composite predecessors. Specialized formulations were developed for different types of brakes and clutches, as well as the differing operating speeds, loadings, and usage environments that these frictional systems might experience. While chrysotile asbestos-based friction materials dominated the market, other types of friction materials were developed and used.

Cast iron alloy friction materials remained in usage, but for a decreasing range of applications, as other materials were developed. For example, railroads used cast iron brake shoes on their wheel brakes until the steam locomotives were replaced by diesel engines. The cast iron could tolerate the steam and oil vapor environment of the early locomotives and was durable and cost effective. Fibre reinforced composition brake shoes presently have replaced about 80 percent of the cast iron shoes used in railroad service.

Solid state sintered ferrous and copper-based friction materials were developed for some high unit load and high environmental temperature applications. These included aircraft and race car brakes, as well as many industrial brakes and clutches.

During World War II, resin-bonded metallic brake linings were conceived in Germany to circumvent a shortage of chrysotile asbestos. These steel wool based friction materials were the forerunner of some of today's non-asbestos brake linings, including semimetallic (or semimet) linings that are used on many automotive disc brakes.

In the wet friction area, those operating in an oil-lubricated environment, cork and cork-rubber composites were used, later to be replaced by cellulosic paper-based wet friction materials in most applications. Often the paper-based materials contained amphibole fibres for added strength, heat resistance, and static friction enhancement. Some sintered metallic, usually copper-based, wet friction materials were developed for severe loading applications. In most cases, these too were replaced by improved paper-based wet friction materials.

Starting in the early 1970's, there was a sharp increase in the development effort for non-asbestos friction material formulations. This resulted primarily from the growing concern about asbestos dust in the work place and the uncertainty of chrysotile asbestos toxicity, compared with that of the amphibole asbestos forms. During the ensuing period, over a thousand fibrous, acicular, and platelike substitute reinforcements were evaluated. Of these, only a comparative few have been used in production friction materials. The most used of the structurally significant substitutes were aramid (e.g. DuPont's Kevlar), fibrous glass, mineral wool (and other man-made glass fibres), steel wool, and wollastonite.

None of the above fibrous materials, singularly, was acceptable as an asbestos substitute for any significant friction material application. Consequently, a combination of fibres was used and/or a totally different lining formulation was developed. Since most of these friction materials contain a "fibre cocktail" of reinforcements, it is not correct to categorize them on the basis of a single fibre constituent nor is it easy to classify them accurately. In many cases, the friction material manufacturer will not disclose what fibres are used in a given formulation.

FRICTIONAL MATERIAL TYPES

Friction materials which contain fibres may be classified into generic types, such as:

Asbestos — Materials (also known as "organic linings") form a large family that contain from 8% to 65% (typically 35-55%) of chrysotile asbestos, but many also contain other fibrous or acicular reinforcing agents;

NAO — Non-asbestos Organic materials (named for what they do not contain) use an organic resin binder and generally a blend of reinforcing fibres, in conjunction with various fillers and friction modifiers;

Semimet	Semimetallic brake linings typically contain chopped steel wool, iron powder, graphite, and other materials in a porous composite form, using an organic binder system;
Carbon-Carbon	Carbon (graphitic) fibre composite that uses an amorphous carbon binder, formed in place by a slow and costly manufacturing process. This material, unlike the others, usually is rubbed against another carbon-carbon element in a full disc brake or clutch configuration;
Paper	Cellulosic (e.g. cotton) fibres and other constituents are made into a base paper that is subsequently saturated with a binder resin to produce a thin porous friction paper that is used for many wet friction system applications. Paper friction materials may contain an amphibole and chrysotile asbestos. Asbestos-free paper materials now include other fibre types, such as aramid or glass.

FRICTIONAL SYSTEMS

Probably the most complex and the best known frictional systems are those in automotive use. For simplicity, only automotive brake development will be highlighted. Appendix 1 contains an introduction to brake systems, for those who wish additional background on this topic.

Early automotive brakes were on the rear wheels only, were mechanically applied, and of an external-contracting band brake design. Contamination by water and dirt provided inconsistent brake torque output as well as high wear rates for the linings and drum. Later internal-expanding drum brakes employed curved beams as brake shoes, to which the friction materials were attached by rivets or bolts. This permitted the brake to be enclosed for less particulate contamination problems, but it still was sensitive to loss of output torque from water contamination.

The mechanically actuated internal-expanding drum brake eventually was used on all four wheels, and further improved by hydraulic actuation. As vehicles grew heavier and faster, the brake pedal force requirements to stop the vehicle were kept down by friction material and brake design changes to increase the self-energization effect. The duo-servo drum brake design became popular, and remains so even today, because of its high overall effectiveness (the ratio of brake-torque-output to apply-force-input). This high self-actuation characteristic makes the duo-servo drum brake sensitive to brake lining frictional and dimensional changes.

High speed effectiveness, fade resistance, cooling rates, and other functional considerations led to the redevelopment of the disc brake (originally patented in 1902) during the mid 1950's and early 1960's. Since the typical automotive disc brake was not self-energized, it required a power brake system to keep the brake pedal application forces in the expected range. The disc brake's effectiveness, although lower, was clearly more consistent than that of the drum brakes, and especially the duo-servo type. Cooling was superior on the front disc brakes, particularly with ventillated rotor designs. But rear disc brakes provided design difficulties with parking brakes, contamination control, parasitic drag, and cooling. Thus most passenger cars and light trucks came to use disc brakes on the more heavily loaded front wheels and drum brakes on the rear wheels, with all but the lightest vehicles using power brake boosters.

Frictional Material Applications

Most people think of automotive brakes when they think of friction material usage, but friction materials are used in many non-automotive brake applications as well as a range of clutch service. Brakes and clutches are similar, from a friction material standpoint, but differ primarily in how they are used. Brakes are used to control motion with respect to a fixed frame of reference, while clutches are used to control motion between rotating shafts. Both brakes and clutches may be designed to operate dry or wet (i.e. in a liquid cooled/lubricated) environment.

Wet Friction Material Applications usually involve an oil or oil mist environment, such as in an automatic transmission. Several wet clutches and band brake assemblies are usually used to produce gear changes in a fraction of a second. Other wet clutches may operate for much longer periods, some even continuously. In electrical power generation, for example, large wet clutches with paper friction elements may be located between water turbines and electric power generators to transmit torque and control generator speed. These wet clutches slip on a continuous basis for months or even years without service. At the other extreme, some safety clutches and brakes only operate if triggered by a component failure. These require dependable operation, even after extended periods without usage.

Depending on the application, friction elements may be as small as a centimeter, or as large as a meter in size. Applications range from miniature instrument dampers to drivetrain clutches or brakes in gigantic earthmoving equipment.

Wet friction material applications may employ paper-based, sintered metallic, cork-based, molded, graphitic, or resilient materials. The countersurface metal that is rubbed against wet friction materials commonly is a low carbon steel or a cast iron. Wear is generally low, since a large amount of the frictional work is dissipated through the viscous shearing of the thin, elastohydrodynamic films of the lubricant/coolant. The mechanical work done in these frictional devices usually has an associated wear coefficient that is quite small, due to low operating temperatures.

DRY FRICTION MATERIAL APPLICATIONS are those that operate without intentional usage of cooling or lubricating liquids at the rubbing interface. The majority of automotive and industrial brakes and clutches are of this type. Since these generally do not have totally enclosed and sealed housings, the wear debris of these devices typically is emitted to the surroundings. In a simililar vein, external contanimants such as water, oil, dust, rust, and other particulates may enter the rubbing interface and alter friction, wear, or both.

The most commonly used countersurfaces for rubbing against dry friction materials are iron/steel alloys. Virtually all of the automotive disc brake rotors and brake drums are of cast iron, or use cast iron inserts for the actual braking surfaces. Dry clutches use both grey or nodular iron, with nodular iron most used for the pressure plates. Other applications use steel alloys or other cast ferrous materials for the rubbing countersurface. One consequence of the predominance of ferrous countersurfaces is the influence these materials have on peak interfacial temperatures.

Research has shown that ferrous materials have limiting asperity temperatures between 1000 and 1125 degrees Celcius. Rubbing speeds above 3 meters per second are required to reach such limiting values. These "flash" temperature values, together with the hardness of ferrous materials at high temperatures, help determine the choice of fibre and inorganic friction material additives.

An immense range of applications for dry friction materials exists, from stopping a bicycle to braking a mile-long train, and from controlling the vibrations of a washing machine drum in the laundry to controlling the deployment of a satellite antenna in earth orbit.

The most critical applications of friction materials, and especially brake linings, are found in the automotive applications — cars, trucks, buses, rail cars, motorcycles, and aircraft. In these applications many critical performance-related issues result from:

- extremely wide range of operating conditions
- large range of environmental conditions
- complex safety considerations
- duralibity/maintainability/economic issues

A new automobile or light truck brake system probably will have a million miles or more accumulated during the development and durability testing before it is released. The OEM (original equipment manufacturer) brake components will have undergone qualification testing for all combinations of powertrain, tire, wheel, and body options on the Federal Vehicle Safety Standard 105-75 as well as other governmental and manufacturer performance and duralibity tests. Surprisingly, after the vehicle is sold, replacement brake components are virtually unregulated. No brake performance or durability standards are required.

For those wishing more information in this area, Appendix 2 contains background information about methods used to evaluate the performance of automotive brake linings. Appendix 3 provides information about the performance characteristics of automotive brake linings.

FIBRES IN FRICTION MATERIALS

The processability and performance of the finished friction materials are highly dependent upon the constituent fibre types and their concentrations. Some composite friction materials are natural, such as leather, cork, or wood; but most are man-made composites. Commercial brake linings are not compounded using scientific formulas. Rather they evolve, more by art than science, since little is known about most fundamental friction and wear processes. Fibres provide strength and control dimensional changes, so fibre morphology and distribution affects brake lining performance. Furthermore, different manufacturing processes may provide different end product performance, even with the same nominal formulation. The processability and uniformity of the friction materials are dependent upon the manufacturing process techniques used. Thus precise compositions and manufacturing processes of brake linings and clutch facings are held as closely guarded proprietary secrets. Which raw materials that are used in the industry is generally known. Specific fibres and other constituents that are used in friction materials are generally known. What is not known are the detailed compositions and processing procedures used for particular friction material formulations.

The fibres used in a friction material affect many characteristics in the manufacturing process. For example, the bridging or interconnecting of fibres during the mixing operation can have a major influence on the retention of powders and granular material within the mix. Without this bridging, many friction materials would have serious segregation problems before being molded into individual pieces. Some reinforcing fibres, such as chrysotile asbestos and aramid pulp, change form during the mixing process, as the fibre bundles or pulped material "opens" due to the mechanical action in the mixer. This makes the time of mixing and the intensity of the shearing and beating action important in obtaining a proper mix. Even with the simplified situation presented thus far, the order of the mixing, size of the mix, size of the mixer, and more may be recognized as affecting both mixing process and the performance of the end product.

Prior to the time that the binder resin "crosslinks" to provide a structurally sound final product, fibres provide much of the "green strength" needed for processing. For "dry" mixes, those that use powdered binder resins, the mixing process can generate strong electrostatic charges, making humidity, water content, and apparatus grounding conditions quite critical. Some material shape and density factors can lead to "demixing" conditions in dry mixing. In this case, the mixing process reaches an optimum level at some specific time. Thereafter, additional mixing time leads to a loss of mix uniformity and can lead to a nearly total segregation of certain constituents.

These, and other processing considerations, provide some limitations on the amount and types of fibres that can effectively be used in the mixing process. Friction material performance considerations provide additional bounds for the fibres used. Only when these processing and performance bounds overlap by a significant amount can a friction material be said to be production feasible. More than one friction material has been formulated that could be made on small laboratory apparatus and perform acceptably, yet not on production equipment. Other materials can be made into some physical sizes, but not into all of the desired thicknesses, widths, or other dimensions.

Art, creativity, and ingenuity are required to compound a friction material that can be manufactured with low scrap losses, and with consistent performance characteristics as a finished product. Technology does not yet exist to allow *a priori* design of a new friction material. Most lining formulations involve evolutionary processes, since compounders prefer to build from established data bases.

CHRYSOTILE ASBESTOS has been used in more successful brake lining and clutch formulations than any other fibre, not only because of the time that has been devoted to development of asbestos-based friction materials, but also because this material has many desirable inherent characteristics for usage in frictional applications. The ultimate chrysotile fibre, called a fibril, is only about 0.03 micro meters in diameter (just over 1 micro inch), but the typical asbestos fibre is a much larger bundle of fibrils. For example, a fibre the diameter of human hair will contain about a million fibrils. These fibre bundles are much like an old rope, with frayed strands. During the mixing phase, the fibre bundles "open" to provide an irregular and branched network that readily holds other lining constituents and provides significant green strength.

When pressed, rolled, or otherwise formed into lining preforms, the larger particles in the brake lining matrix will cause nearby asbestos bundles to bend into more irregular, often branched forms. This branching contributes to substantial structural reinforcement through the lining thickness, both for strength and stiffness. Asbestos thus can provide friction materials with a composite structure that has less directional variation (orthotropy) than materials made with other reinforcing fibres.

The larger chrysotile asbestos fibre bundles, called crudes, also serve as pipelines for the release of gaseous products released during the curing and baking cycles. Water, ammonia, and some low molecular weight hydrocarbons are evolved as the binder resins crosslink. This evolution provides processing limitations for most brake linings, since it can cause blisters, cracks, or low density regions. Chrysotile fibres provide paths for release of these volatiles from the interior of the friction material, both during processing of the brake lining and during hard braking with the finished product.

Many brake and clutch formulations use a combination of asbestos fibre grades to obtain the best combination of cost, processing, and end product performance. Chrysotile asbestos is processed into a multitude of grades that provide different fibre lengths, length distributions, and degrees of fibre bundle "openness" or "crudiness". Fibre from different mine sources may have different types and amounts of impurities, such as talc or quartz, that can affect friction material performance. This is one of the characteristics of a natural product that can be either an advantage or a shortcoming, depending on the initial selection and subsequent quality control of the fibre for a particular formulation.

Chrysotile asbestos has been used in friction materials from under 10 weight percent, in railroad brake shoes, to over 60 percent, in some passenger car drum brake lining segments. Typical asbestos usage is between 35 and 55 percent. Blends of an "open" asbestos and a "crudy" fibre of a different length often were found to give best processing and end-product performance. The substantial water content of chrysotile asbestos tends to provide a "green fade" to friction materials. That is, they may provide lower frictional output the first time the friction material is heated significantly. This is more noticeable with higher asbestos concentrations, with more opened fibres, and with more dense friction materials.

In use, the chrysotile asbestos fibres near the rubbing interface will dehydroxylate around 650°C, losing about 14 weight percent as this water is lost. At higher temperatures, the chrysotile thermally decomposes, in an exothermic reaction, producing Forsterite or related glassy material. This decomposition product fractures upon cooling into a fine powdered substance. Laboratory studies show the transformation to occur quickly at around 830°C, with conversion over much longer time periods at lower temperatures. Since asperity temperatures will be over 1000 degrees Celcius for most rubbing speeds, the surface conversion of chrysotile asbestos is virtually assured.

Several studies of airborne emissions from asbestos brake linings have indicated that over 99.9 percent of the asbestos is converted to non-fibrous material. Larger, non-respirable, wear particulates may contain up to 1 percent asbestos fibre. Since these particles do not appear to have been exposed to high interfacial temperatures, the fibres are believed to originate from edge fractures and extrusion of material from the lining edges during a brake application. This is consistent with the observation that asbestos emissions are lower from friction materials that have molded edge surfaces, where the resin "skin" can better retain edge fibres.

OTHER ASBESTOS TYPES AND FORMS have been used, but to a lesser extent. Wet friction materials of the paper type may contain amphibole asbestos fibres. Some special frictional applications have contained amphibole asbestos, amosite and crocidolite, presumably for their acid resistance. Presently, there is no known usage of amphibole asbestos fibre in US OEM friction materials.

Hedmonite, a serpentine lizardite, is used in some friction materials. There is some chrysotile asbestos fibre content to this material, with perhaps 1 weight percent being above 5 microns in length. Hedmonite is believed to be used principally in conjunction with other fibrous materials and has been detected in brake linings that were advertised as "non-asbestos".

NON-ASBESTOS FIBRES— Friction materials are known to be of certain classes or types, for example, resin-bonded (usually solid state), cast metallic, or carbon-carbon. Of the non-asbestos friction materials, the largest number are called non-asbestos organics (NAO). These employ one or more organic binder resins to form a matrix structure with one or more fibres and larger number of fillers and friction modifiers. Usually the NAO materials contain several fibres, but may be classified by a single fibre type. Thus there may be reference to fibreglass based linings or Kevlar based linings, but most friction materials will contain a "cocktail" of reinforcing fibres, acicular materials, and platelike powders. The following describes some characteristics of individual fibre types. Combinations of several fibres often, but not always, provide characteristics that would be expected, based on the properties of the constituent fibres used. Little information is available about fibre combination effects, even those that have been found to be unsuited for commercial friction products. The friction materials industry penchant for secrecy, coupled with a limited data base on non-asbestos friction materials, appears to have hampered development and increased costs for improved non-asbestos friction products.

ARAMID (e.g. KEVLAR OR TWARON) fibres are man-made, both in the fibrous and pulped forms. The pulped form is the most useful for friction material applications. This material, like asbestos, is multifunctional. It provides the bridging action that helps hold the dry materials together and which help prevent segregation. It also adds significantly to the "green" strength of both dry and wet preforms. In the finished product, aramid not only provides structural benefits, but also adds to the wear life of the product. This wear enhancement is believed to result from surface softening of the aramid, which then adheres to powdered wear debris. The surface softening thus provides a means for reutilization, or recycling, of the brake lining wear debris, providing greater wear life. Wear improvement appears to be greatest in the 250 to 350 degrees Celcius temperature region, where many production friction materials begin to wear at a rapid rate.

Aramid content provides the above performance benefits with increasing concentrations, up to about a 3 weight percent addition level. Then cost and negative perfomance factors may appear, while benefits are obtained with diminishing returns. The optimal concentration of aramid depends on the specific friction material application, as well as the usage that the material is expected to experience. Since most aramid applications for friction materials use less than a 5 weight percent loading, other reinforcing agents generally must be employed to achieve the desired stiffness and strength characteristics.

Optimal usage of aramid fibre types usually requires changes to the mixing apparatus and to the mixing techniques employed. In dry mixing, there is a very high "bulking" of the aramid fibre. This, and other considerations often limits both the upper and lower bounds of mix size and weight for a given mixer. Trimming mold "flash" from aramid-containing products may offer some difficulties due to their high strength and toughness. Technology has advanced rapidly for mixing and mold "flash" trimming of aramid composites, largely due to research on friction material applications and technical assistance from the aramid fibre supplier.

GLASS FIBRES are currently used in several friction materials, both as the primary reinforcement and as part of a fibre "cocktail". An E glass fibre of 3 to 6 millimeter (1/8 to 1/4 inch) length often is used. A silane surface coating helps provide good coupling to the resin binders. Glass fibre is not easily mixed, due to bulking and fibre bundle opening factors, and requires both mixing and formulation expertise to obtain good friction and wear properties. Friction materials made only with glass fibres tend to have highly orthotropic thermal expansion and mechanical strength characteristics. This has adversely affected friction stability in some drum brake applications and has made lining attachment by riveting a more critical operation.

Glass fibres either bend elastically or they break. There is no plastic behavior at normal temperatures. Thus the fibres tend to lay in the plane of the friction material, or be bent elastically into forms that approximate the plane of formation. Glass fibre friction materials, especially when thick, tend to exhibit very small thermal expansion rates at low temperatures. However, at higher temperatures such materials may provide unexpectedly large thickness changes, called lining growth, upon initial heating to temperatures above the curing or baking temperature of the friction material. This expansion can cause drum and disc brakes to develop significant parasitic drag torques, with resultant overheating of the brake linings.

MINERAL WOOL is a type of glass, made by one of several processes that generates short fibres, not continuous filaments. Typical fibres are around 4 micrometers in diameter and 200 to 800 micrometers in length. These fibres are of the calcium-alumino silicate family, made from such raw materials as slag or basalt. This provides a higher softening temperature and differing dimensional attributes than glass fibre. Like glass fibre, silane and other surface treatments can be used to improve coupling with the binder resins. Although not as effective as glass fibres in providing longitudinal and lateral stiffness and strength, mineral wool can provide significant performance benefits, when properly compounded with other fibre types.

Different manufacturing processes provide varying values of fibre diameter, length, and amount of "shot". Shot is the term for the globular ends that are inherent with generation of mineral wool. Some nearly shot-free fibre has been produced. While certain friction material applications may benefit from a limited, controlled quantity of such shot, it can increase the wear of the mixing apparatus and generally is to be avoided.

CERAMIC FIBRES are usually man-made alumina-silica fibres, from 2 to 4 micrometers in diameter. These fibres also may have a significant shot content. With a higher softening and melting temperature than the mineral wools, this shot can provide strong abrasive characteristics to friction materials. This raises lining friction levels, but at a significant cost in terms of cast iron countersurface wear and scoring. Consequently, ceramic fibre must not be used in high concentrations, unless virtually shot-free. Truck brake blocks and other friction materials requiring high friction levels and high operating temperatures have used ceramic fibre as one of the reinforcing constituents.

STEEL WOOL is made by scraping a shaped tool against moving steel wire and subsequently chopped into appropriate lengths. Fibres are generally rounded triangles in cross section and are curved. This helps provide a three dimensional reinforcement to the friction materials that use them. Semimetallic brake linings may contain from 12 to 25 percent steel wool by weight. Other non-asbestos linings generally contain smaller amounts, in conjunction with other fibrous material. Graphite may be needed as the steel wool content is increased. Since graphite tends to provide low friction at ambient temperature, the amount of steel wool used is often limited by the need to maintain cold friction levels.

Most steel wool is made from low carbon steel and is cut with a water-oil coolant. The finished product then has about a micrometer film of residual oil on the fibre surface. Other steel wool is said to be cut dry, and is free of this oil film. Good friction material composites can be made from either type, but may require different choices of binder resins and mixing conditions.

WOLLASTONITE is not a true fibre, but is a naturally occuring calcium metasilicate mineral that fractures into acicular needles upon processing.

Maximum lengths are about 25 micrometers, so wollastonite is limited to a secondary reinforcement role in most friction material applications. Strength of the friction material composite can be enhanced by using a surface modified form of wollastonite. The high softening and melting temperatures of this material, coupled with some needle geometries, can lead to abrasive action against the typical grey cast iron countersurface.

Optimum Friction Material Fibre System

Friction material performance, in a given application and environment, can be rated by: friction level, friction stability, lining wear life, countersurface durability, environmental stability, thermoelastic stability, thermomechanical properties, mechanical strength, elastic properties, and processability. All of these are affected to some extent by the type, amount, and orientation of the constituent fibres. If only these functional issues are considered, the following would most likely be optimum ranges for car and truck brake linings:

FIBRE MATERIAL	FIBRE FORM	WEIGHT PERCENT
° aramid	pulped fibre	2 - 3.5
° ceramic	fine, shot free	0 - 4
° chrysotile asbestos	mixed fibre openness	22 - 28
° mineral wool	application variable	5 - 20
° steel wool	low oil chopped	0 - 2
° wollastonite	application variable	0 - 25

Regretably, there is no single ideal friction material for all applications. Depending on the application and usage severity, along with the type of brake lining (drum segments, disc pads, or truck blocks), the optimum fibre cocktail would vary.

Similar tables could be generated for dry and wet clutch friction materials, as well as the industrial, aircraft, and other applications. Glass, cellulose, and carbon fibres would then be added to the list, and differing optimum percentage ranges would result.

Concluding Comments

It is hoped that this introductory survey of friction materials and their constituent fibres has provided a better understanding of the complex issues surrounding their formulation, development and application. Development of new friction materials is a slow and costly process, even using known materials. New fibres are being introduced into the market at a rapid pace, some to be removed before they are released for production. Existing fibres may be banned, have changes of regulations, or incur insurance costs that effectively prevent their use.

Difficult judgements need to be made, judgements that will have far-reaching consequences to the friction materials industry and to our entire population. Much has been written about fibre toxicity, usually based on unknown or poorly understood mechanisms. Human dose-response relationships to different types and sizes of fibres often appear to be based on incomplete data sets. The decisions of governments, original equipment manufacturers, friction material vendors, and fibre suppliers have in the past, and will in the future, affect the choice and availability of different friction materials. However, we must consider the above uncertainties in the light of human safety considerations from frictional systems affected by these decisions.

These decisions can not be made without a clear and informed view of the complete picture. Hopefully this symposium, with its multifaceted view of friction material fibres, will help to provide an enhanced perspective.

APPENDIX 1

REVIEW OF VEHICLE BRAKING SYSTEMS

BRAKE PERFORMANCE REQUIREMENTS

The primary requirement of a vehicle brake system is to provide the capability to decelerate the vehicle in a predictable and dependable manner, over the full range of in-service operating and environmental conditions, with acceptable brake pedal input forces. The brake system must provide consistent and dependable frictional behavior for all reasonable usage conditions. These vehicle service usage conditions are affected by the environmental conditions, such as weather, water, road surface, traffic, and contamination level as well as the operating conditions, such as vehicle speed, wheel/tire condition, brake system component temperatures, and prior brake usage history.

In order to stop a vehicle safely, the brake system should provide repeatable, uniform deceleration for the same brake pedal input and provide an incremental deceleration rate that is essentially proportional to incremental pedal input. Further, the vehicle trajectory (direction and orientation) should be readily controlled by the driver during braking.

The limitation to decelerate a vehicle by conventional brakes depends ultimately on road/tire traction. This varies with tire design/condition, inflation pressure, tire loading, and wheel slip. Maximum braking requires the brake torque to be just enough so that the resulting wheel slip generates the peak traction force available at the tire-road interface. Excessive brake torque causes a progressive increase in wheel slip and decreases adhesion, and often results in wheel lock-up and skidding. Skidding may produce an unsafe condition, because directional control of the vehicle is reduced substantially and stopping distances may be increased. To achieve the maximum vehicle deceleration with a given road, weather conditions, and vehicle, not only the driver's skill is involved, but also the driver's knowledge of the brake system response. Thus the predictability of brake performance is important during critical brake usage.

The brake must have a sufficiently high torque capacity to decelerate the vehicle effectively and must have frictional characteristics which permit safe braking over a broad range of temperature, load, and wear conditions. Further, the brake actuating system must be able to transform the driver's pedal effort into frictional torque in a manner that minimizes the tendency for wheel lock-up and skidding, while at the same time providing sufficient brake torque to stop the vehicule quickly.

The brake system engineer is often confronted with conflicting requirements, resulting in the need for compromise and change. Interactions among the brake system components can be strong. Consequently, a change made to one of the system components may require the re-evaluation and possible major redesign of the brake system. This can result in time-consuming and costly development programs to insure safe and dependable brake performance.

VEHICLE BRAKE SYSTEM DESIGN CHARACTERISTICS

An overview of typical braking system configurations for conventional automobiles and trucks is presented in this section. The intent is to address those aspects of the braking system design which may be impacted significantly by changes of friction materials, and not to provide a tutorial on brake system design.

GENERALIZED BRAKE SYSTEMS

An automotive braking system is a complex closed loop system. The driver is a critical controlling element, generating the initial estimate of brake pedal input force and subsequently modulating this force to achieve the desired vehicle control. The driver must process information about the operating environment and prior brake usage experience to provide a brake pedal input that should decelerate the vehicle effectively. The actual braking performance of the vehicle depends upon several factors, the more important of which are:

- Accuracy of the driver's operating environment perception
- Dynamic response characteristics of the driver
- Predictability/reliability of the total brake system
- Vehicle/road characteristics
- Response characteristics of the braking system

Primary control of braking performance is provided by the driver. In some vehicles control is enhanced by an anti-lock brake system (ABS) which prevents wheel lock-up, thus improving vehicle control and generally stopping distance.

The response characteristics of the vehicle braking system are influenced by the friction material and the mechanical properties of the braking elements. Changes in these properties, either due to replacing the brake shoes with different friction materials, or due to wear, or prior usage history, or temperature, or loading effects, will change the response characteristics of the brake system. It is therefore critical that a brake system be designed and verified for effective performance over the full range of expected brake usage and operating environment that could exist in service. Such a verification effort should include the performance of the friction material over its expected lifespan.

HYDRAULIC BRAKE SYSTEMS

Hydraulic braking systems are commonly used on automobiles and light trucks. In these systems the driver's pedal effort is transmitted through mechanical linkages to a master cylinder, which pressurizes hydraulic fluid. This, in turn, is transmitted through tubing and hose to apply pressure to the wheel cylinders and/or calipers at each wheel location. The wheel cylinders then force the brake shoes against drums or rotors. The frictional force generated between these surfaces provides a torque to resist wheel rotation. For heavier vehicles, which require high braking forces, power brake booster systems are used to reduce the driver's pedal effort requirement. Power brakes are a popular comfort/ convenience option, providing a reduction of brake pedal force and often also the required brake pedal travel. Depending upon the type of brake booster, the response rate of this brake hydraulic system to brake pedal input force changes probably will differ.

AIR BRAKE SYSTEMS

Air brake systems are used commonly in large trucks, trailers, and transit buses to reduce the driver's brake pedal force and stroke requirements. These systems characteristically provide larger braking forces and somewhat slower response times than the more conventional hydraulic systems. Compressed air is provided by an engine-driven compressor, stored in a reservoir and transmitted to the brake chambers by valving that is actuated by the foot pedal action. The pressurized brake chambers at each brake actuate mechanical linkages to push the brake shoes against the drums or discs. To provide an added measure of safety, multiple pneumatic circuits sometimes are used to ensure adequate braking if one of the circuits fails, with a backup spring application of the brake, should there be an air supply pressure loss.

INFLUENCE OF BRAKE FRICTION MATERIAL CHARACTERISTICS ON BRAKE SYSTEM DESIGN

There are several situations where an existing hydraulic or pneumatic system might need to be modified or redesigned to accommodate changes in the properties of the brake friction materials. These are summarized in Table 1. As indicated in the table, the substitution of friction materials with different properties (e.g. non-asbestos or semimet for asbestos-based) requires a detailed characterization of the substitute material properties, followed by a careful evaluation and verification of the performance of the brake system.

Due to brake system design differences and system complexities, this generally must be done on a vehicle by vehicle basis.

The extent of engineering development time and effort needed to meet these requirements depends both upon the extent of differences in the friction materials and the extent of the available data base, including field experience, with the specific brake lining formulations. For example, the transition from an asbestos-based disc brake lining to a semimet lining should include system considerations, such as:

Thermal Fade — Semimet linings tend to be fade-free, so the front-to-rear brake balance under hard vehicle usage would probably be altered. More fade resistant rear linings (if available) may be used or the rear brakes could be increased in size (and weight) to compensate.

Environmental Sensitivity — Semimet linings are prone to "morning sickness" after exposure to moist air for an hour or more. This upsets the front-to-rear brake balance and, in addition, often provides the lowest brake effectiveness for all the operating conditions. Thus this condition determines the amount of power brake boost required. Since the engine may be cold at this time, the available engine vacuum for the power brake booster could be lower than normally found at the minimum brake effectiveness condition. The bottom line is that a larger brake booster, or a tandem booster may be required, even though the semimet brake linings have less thermal fade.

Brake Sizing — Semimet linings operate best with brakes that operate in the 200 to 300 degrees Celcius temperature range (about 400 to 550°F). A vehicle with large, well cooled front disc brakes may provide susbtantially poorer lining life and even high rotor wear, if usage involves infrequent or mostly low speed stops.

High Speed Braking — Semimet linings maintain effectiveness very well over a wide speed range, but the lining wear increases dramatically at high vehicle speeds (above 150 kilometers per hour, or 90 mph). Vehicles for race car usage, or those to operate on high speed highways (such as the German Autobahns), may not have acceptable lining life.

The above was not intended to take issue with the use of semimet linings. They have performed very well in a number of automotive applications. But they do have performance shortcomings, as all friction materials do, and thus can not be blindly substituted for other types of brake linings without possible serious performance shortcomings. The essence of good brake engineering is to minimize the shortcomings for a given vehicle brake system by a judicious selection of friction materials and balancing of system parameters.

For new vehicles, non-asbestos friction materials, such as the semimet linings, may be incorporated either into a new or an existing brake system. Depending on the characteristics of the non-asbestos friction materials, compared with prior materials, a brake system for a new vehicle could require minor modifications to the existing brake system or a major redesign of the entire brake system.

In order to achieve adequate braking performance, brakes are designed primarily on the basis of wear, stability, pedal travel, and brake effectiveness. Brake effectiveness is defined as the ratio of the brake friction torque to the applied force and is used commonly to describe the performance of drum brakes. Many brake design parameters are interrelated. For example, a large lining thermal expansion may require added running clearances, to avoid parasitic drag. This then results in need for greater brake pedal travel, which may lead to a master cylinder resizing. If pedal forces then become too great, power brakes may be needed, or (if already present) the booster may have to be upsized or a tandem booster installed. A complete introduction to brake design interrelations is beyond the scope of this document.

Thermal Distortion — After brake shoes or pads wear in, the lining pressure distribution and braking torque for a given pedal effort and travel should be fairly repeatable. However, the brake lining pressure distribution is also affected by lining thermal distortion. Thermal expansion through the friction material thickness is often much greater with non-asbestos brake linings. These new friction materials also tend to be much stiffer in compression. Therefore, the contact geometry and pressure distributions will be different, which can affect the level of friction forces generated at the contact area, especially on the larger drum brake assemblies that use thick linings. For this reason, friction materials with higher thermal expansion rates may cause inconsistent braking performance, especially with varying brake temperatures.

Wear — Wear also influence stability. As discussed in the next section, the tendency for drum brake lock-up depends upon the location of the center of pressure along the friction surfaces. Wear tends to shift the center of pressure location. Thus, substitute friction materials with different wear rates may also influence stability by changing the center of pressure location. Unfortunately, friction materials with low wear rates are the least stable. With high wear rates, the lining pressure distribution tends to be more uniform since locally high pressure regions quickly get worn away. In addition, high wear rates also tend to yield a more uniform friction behavior. This results both from less influence of external contaminants and from less effect of prior usage history on the lining surface chemistry.

Hot Spotting — An added complication may result from the greater thermal expansion rate compression stiffness of non-asbestos friction materials. This is called hot-spotting, a thermoelastic instability that causes the lining pressure distributions to become quite localized, with the resultant high thermal stresses and frequently erratic friction values. The basic principles are simple, but the total system effects can be extremely complex. For example, one particular site on brake lining may have a greater contact load than average, thus providing greater friction and heat generation. This then causes that site to expand, further increasing its excess load. If the lining wear rate is low, this cycle can continue for some time, leading to the formation of a hot spot. Hot spotting tends to occur during low temperature brake usage, with light brake applications, from highway speeds. Since this brake usage is not severe, it can easily be overlooked in the early stages of the brake development process, causing significant expense and time to correct.

Stability and Brake Factor — As described previously, it is important that a vehicle can decelerate rapidly, and in a controlled manner, during emergency braking. Thus the response of the vehicle to the driver's brake "commands" must be predictable, repeatable, and fast enough to stop the vehicle quickly, but not so fast that the driver cannot respond effectively with subsequent corrective braking "commands" (e.g., to avoid skidding or "fishtailing"). The relationships between braking (frictional) torque, applied force, and the coefficients of friction are important performance characteristics of brake systems and have a strong influence on vehicle stability. Two parameters which affect the stability of brakes are the brake effectiveness factor and the friction sensitivity index.

Figure 1 shows the forces acting on the shoes of a simple drum brake. As shown, the friction force on the "leading" shoe causes it to be further loaded against the drum, increasing its effectiveness, while the friction force on the "trailing" shoe causes it to oppose the application force, decreasing its effectiveness. The increase in brake shoe loading, due to friction and geometry effects, is referred to as self-actuation.

Although the phenomenon of self-actuation can increase brake effectiveness, brake effectiveness is also influenced by the frictional properties of the friction material. **Figure 2** shows brake effectiveness versus lining friction coefficient for several different brake types. Assuming a nominal friction coefficient of 0.4, a 12 percent change in friction coefficient can alter the brake effectiveness by approximately 44 percent for a duo-servo drum brake, 33 percent for the leading-trailing drum brake, but just 12 percent for the disc brake. In addition, the design of the brakes can affect the degree to which friction material wear and mechanical properties influence brake effectiveness. **Figure 3** shows the variation in brake effectiveness for different brake lining pressure distributions. Note the large change of brake effectiveness that is possible, for the same value of friction coefficient due to the effect of lining pressure distribution. On a drum brake the lining pressure distribution is affected by the stiffness of the drum, the shoes, and the linings, in addition to thermal distortions, wear properties, and prior usage history effects.

The brake designer can achieve the same brake effectiveness by several combinations of lining geometry, brake shoe geometry, and lining coefficient of friction. Thus changing friction material classes (as from asbestos-based to one of the several non-asbestos types) may provide significant effects on the brake system stability, due to different coefficients of friction, different thermal expansion coefficients, and different compression stiffnesses.

The "friction sensitivity index" is a brake design aid that helps determine the best possible combination of dimensions for leading shoe and duo-servo drum brakes, with a given design value of brake effectiveness. This index involves detailed geometric analyses of the drum brake to help determine dimensions for minimizing brake effectiveness variability. Present drum brakes have been optimized over the years for traditional asbestos-based brake linings. It appears they are not optimal for presently available non-asbestos friction materials.

Structural Integrity Issues

Vehicle braking systems generally include several structural components (e.g., calipers, pedal linkages, etc.). Forces generated during braking can cause high stresses in these brake components and in other vehicle-associated components (e.g., axles and suspension elements). These stresses result from the nominal braking torque as well as from thermal and other dynamic loads. Sufficiently large dynamic and thermal stresses superimposed on the nominal braking stresses might promote fractures or fatigue failures in some element, which then could result in an unsafe operating condition (e.g., inability to control or stop the vehicle). The brake friction material properties influence the dynamic behavior of some vehicle components during braking, since they affect the brake torque magnitude and its rise rate. One structural consideration results from the requirement of attaching the friction material to the brake shoe. This can be done by riveting, bonding, or "integral molding" the lining to the brake shoe. Non-asbestos linings generally are stiffer, more brittle, and more highly orthotropic (i.e., their physical properties vary greatly among length, width, and thickness directions). All of these adversely affect the fabrication breakage and attachment capabilities, such as rivetability, of the friction material.

TABLE 1

INFLUENCE OF SOME BRAKE LINING PROPERTY CHANGES ON THE POTENTIAL BRAKE SYSTEM RESPONSE, WITH POSSIBLE COMPENSATING DESIGN MODIFICATIONS

CHANGE OF BRAKE LINING PROPERTIES	POTENTIAL RESPONSE OF BRAKE SYSTEM	POTENTIAL BRAKE COMPENSATION
LOWER FRICTION COEFFICIENTS ° Front Brakes ° Rear Brakes ° Both Front/Rear	GREATER PEDAL FORCE REQUIRED, LEADING TO: ° Early Skid ° Early Front Skid ° Low Brake Capacity	LARGE BOOSTER OR SMALL MASTER CYL. ° Big Front W.C. ° Big Rear W.C. ° System Redesign
HIGHER FRICTION COEFFICIENTS ° Front Brakes ° Rear Brakes ° Both Front/Rear	LOWER BRAKE PEDAL FORCE REQUIRED, LEADING TO: ° Early Front Skid ° Early Rear Skid ° "Touchy" Brake Pedal	SMALLER BOOSTER/ BIG MASTER CYL. ° Small Front W.C. ° Small Rear W.C. ° System Redesign
POOR FADE CHARACTERISTICS ° Green Fade ° Thermal Fade ° Water Fade ° Flash Fade	HIGH BRAKE PEDAL FORCE REQUIRED FOR: ° Initial Hot Brake ° Any Hot Brake ° Wet Brakes ° High Speed Stops	RECALIBRATE/ADD BOOSTER POWER ° Scorch Linings ° Modify Linings ° Shield Brakes ° Modify Linings
INCONSTITENT FRICTION LEVEL ° Green Linings ° Usage History ° Wear Depth ° Within Batch ° Batch-to-Batch	VARIED BRAKE PEDAL FORCE NEEDED WITH: ° New Brake Linings ° Temperature Change ° Mileage Driven ° Brake Imbalance ° Car-to-Car Variations	CHANGE LININGS/ REDESIGN BRAKE ° Modify Linings ° Modify Linings ° Modify Linings ° Improve Process ° QC Improvement
ENVIRONMENTAL SENSITIVITY ° Water/Water Vapor ° Road Dust ° Oily Contaminants ° Oxide/Rust Effects	BRAKE PEDAL FORCE SENSITIVE TO: ° Humidity ° Dust Pickup ° Road/Rain Splash ° Moist Storage	CHANGE LININGS REDESIGN BRAKES ° Modify Linings ° Shield Brakes ° Shield Brakes ° Materials Change
LOWER LINING COMPRESSION MODULUS	HIGHER BRAKE PEDAL TRAVEL	REDESIGN/STIFFEN ACTUATION SYSTEM
HIGHER LINING COMPRESSION MODULUS	NOISE/ UNEVEN BRAKE EFFECTIVENESS	REDUCE SHOE/ DRUM STIFFNESS
HIGHER THERMAL EXPANSION/GROWTH	BRAKE DRAGGING/ HOT SPOTTING/ERRATIC EFF.	ADD CLEARANCE, THIN LININGS, NEW LININGS
LOWER TENSILE STRENGTH OF BRAKE LININGS	LINING FRACTURE/ RIVET FRACTURE/ DRUM SCORING	USE MORE RIVETS, BOND/MOLD LININGS
LOWER TOUGHNESS OF BRAKE LININGS	HANDLING BREAKAGE/ LINING USE FRACTURE	ALTER PROCESSING/ NEW LINING FORMULATION

FIGURE 1. FORCES ACTING ON DRUM BRAKE SHOES

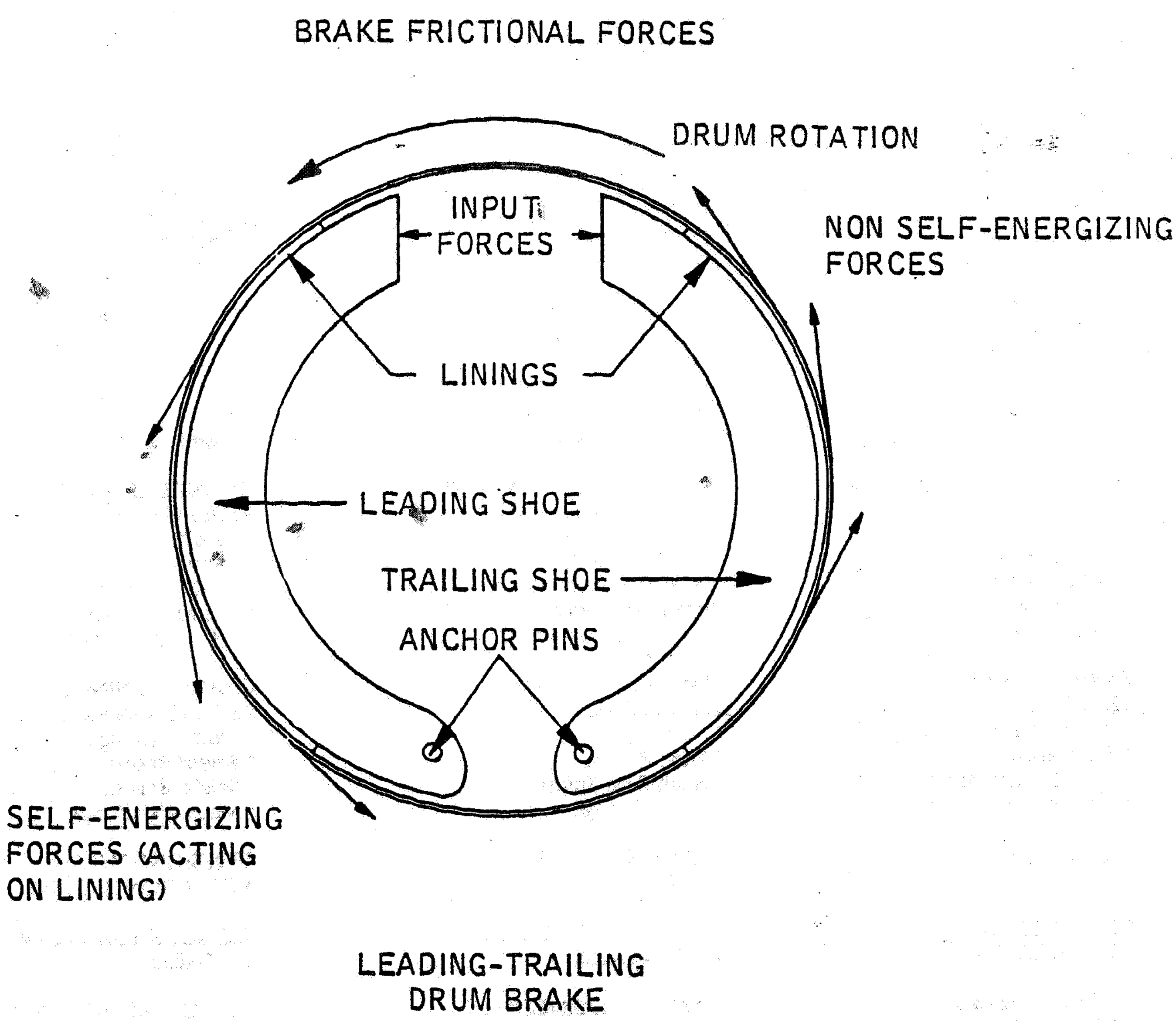


FIGURE 2. BRAKE EFFECTIVENESS-FRICTION CURVES FOR SEVERAL BRAKE DESIGNS

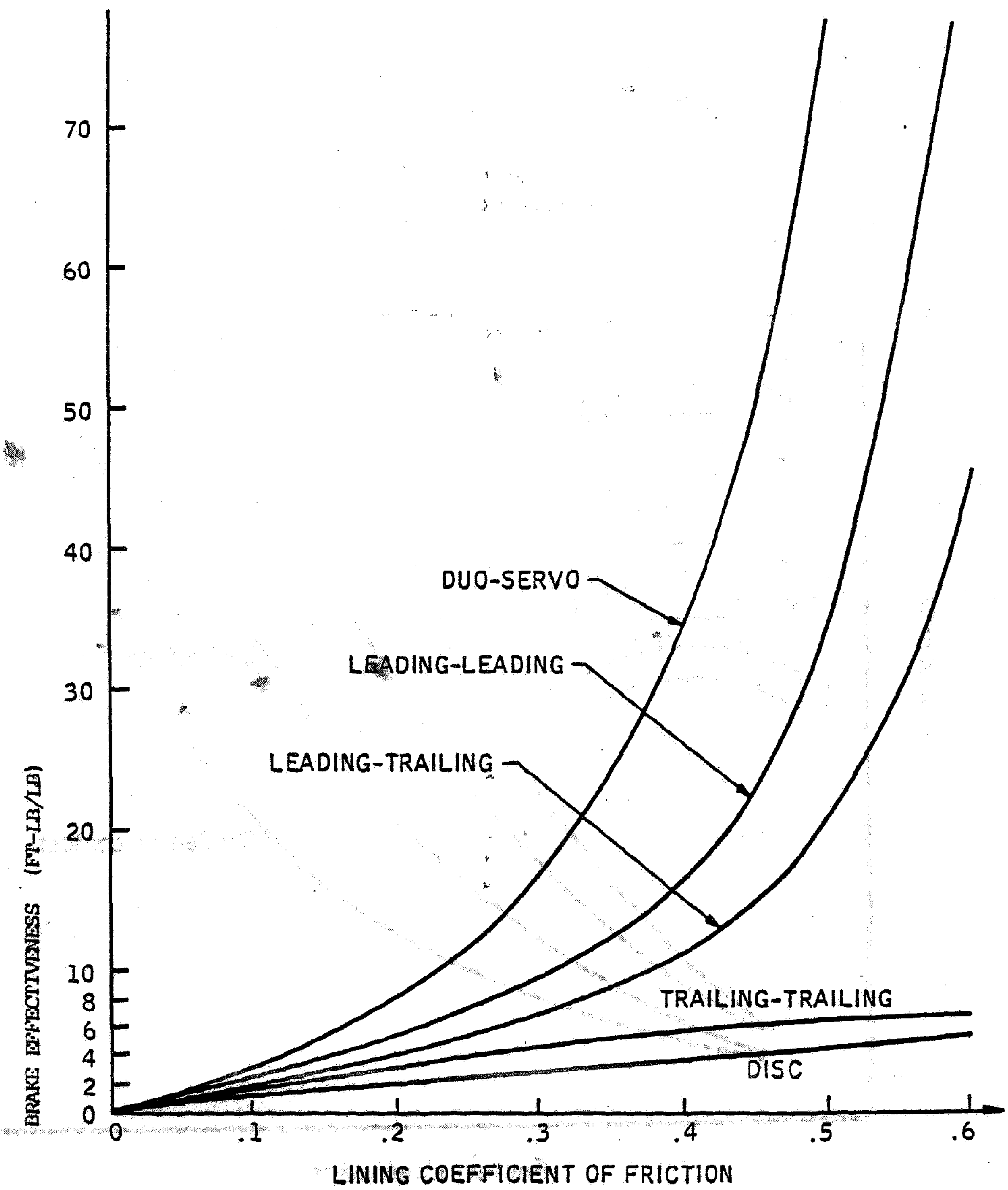
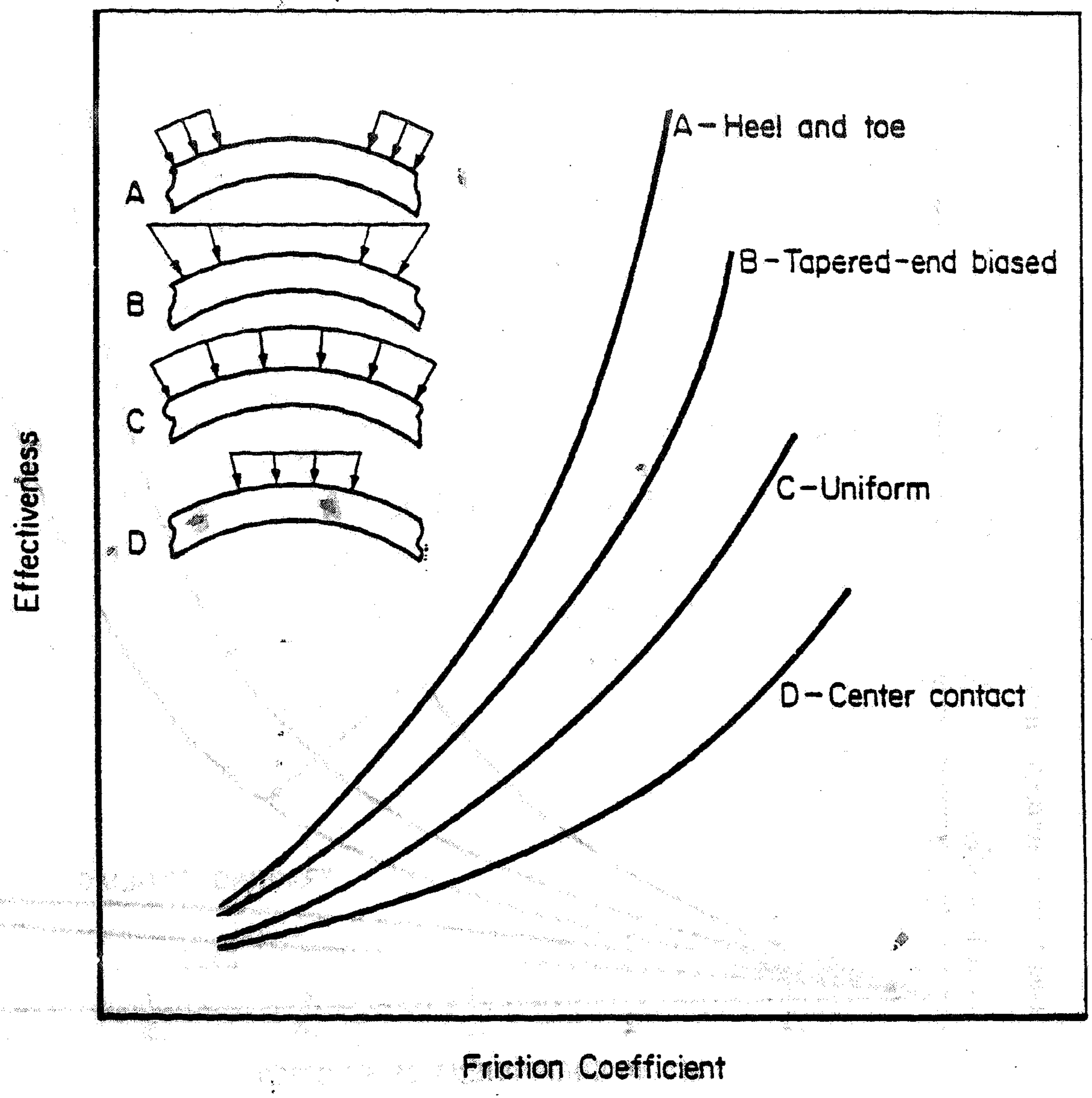


FIGURE 3. BRAKE EFFECTIVENESS-FRICTION CURVES FOR SEVERAL DIFFERENT BRAKE LINING PRESSURE DISTRIBUTION ON A LEADING SHOE



APPENDIX 2

EVALUATION OF FRICTION MATERIAL PERFORMANCE

FRICTIONAL MATERIAL PERFORMANCE CRITERIA

Friction material performance in vehicle brake systems may be qualified by meeting the requirements of the Federal Standards and evaluated by Society of Automotive Engineers (SAE) Recommended Practices, along with brake component and vehicle manufacturers' standards. These experiments are directed to maximizing safety, dependability, and customer satisfaction over a variety of brake operating conditions. For new vehicles, compliance with Federal and State motor vehicle safety standards is only the starting point for acceptance of a brake system. No Federal standards need be met by aftermarket linings.

The various evaluation criteria and techniques used to determine friction material suitability and performance are considered next. Friction materials inherently have some performance attributes, but full evaluation of a friction material requires installation into some brake system. It is only in the full brake system that many brake lining attributes properly may be determined, such as fade and fade recovery. A friction material may have inherent weaknesses and faults, but full characterization of a friction material requires complete evaluation in some specific brake system. Only then can it be fully rated.

Vehicle brakes are required to operate under a wide range of conditions, from hard braking with a heavily loaded vehicle on a steep downhill slope to minimal brake usage on interstate highways. Vehicle brakes must be completely reliable and must be minimally affected by temperature, water, or other contaminants. Brake actuation forces should be properly distributed, and brake friction must be consistent throughout the life of the friction material. Pedal actuation forces for non-power-assisted brakes should be within a band established by operator pedal force capability and vehicle brake pedal modulation sensitivity.

Vehicle braking performance can be closely related to loss of directional control in vehicles. Under skidding conditions, the tendency for wheel lock-up in some brake systems can accentuate loss of control. Commercial vehicles with lower effectiveness brakes have been shown to be less likely to encounter loss of control in accidents, presumably due to lower usage speeds and reduced tendency for wheel lock-up. Variation in the front-to-rear brake balance, due to changes in frictional performance, may adversely affect safety through reduced directional control and stopping efficiency.

Some friction material performance characteristics that are evaluated during new vehicle brake system qualification experiments include: fade resistance; fade recovery; delayed fade; effectiveness versus speed; friction stability; wet friction; moisture sensitivity; and wear rate. Each of these important performance characteristics will be highlighted under their respective headings. However, these are but the more important of a much larger set of brake performance attributes that are evaluated during brake system development.

Fade Resistance — Brake fade refers to a loss of brake effectiveness, generally as the result of excessive brake temperatures. Such excessive temperatures may occur under hard brake usage conditions, or less stringent conditions, should component cooling be restricted. Brake fade may occur under particularly hazardous driving conditions, such as descending steep and winding mountain roads. Five types of brake fade have been described:

Thermal	:	due to high system bulk temperatures
Delayed	:	due to resin migration during brake cooling
Blister	:	due to effects of near-surface lining blisters
Flash	:	due to high speed, high torque demand braking
Water	:	due to partial lubrication from water contamination

Figure 4 shows a thermal fade performance comparison between a good quality friction material and a poor one. The poorer quality friction material exhibits a more rapid drop-off of brake effectiveness, compared with the higher quality material, and a lower temperature for this effectiveness loss. Poor brake fade behavior could also be exhibited by high quality materials, if used in inappropriate brake applications, so brake lining fade behavior is meaningful primarily in the context of a particualr brake lining, brake, and vehicle usage situation. It is important to note that the driver does not perceive the fade response as a curve, only as discrete points involved during specific brake applications. Thus the steepness of the slope can relate to the abruptness of fade that the driver experiences. Depending of the usage sequence and lining response curve, a driver may sense an impending fade as a gradual increase of pedal force requirement, or have essentially no warning whatsoever.

Fade Recovery — Fade recovery refers to the ability of the friction material to quickly regain normal effectiveness after fade. This recovery is depicted in **Figure 5.** As the brake disc or drum cools with time after experiencing fade, the friction level should return rapidly to approximately the pre-fade level. Poor friction materials may exhibit slow recovery, compared with good friction materials, and may produce either a decrease or increase of brake effectiveness as a lasting consequence of the fade. Again it is the slope of the response curve that is indicative of the brake performance change from one brake application to the next.

Delayed Fade — Delayed fade is a phenomenon which may occur with some friction materials. This phenomenon is illustrated in **Figure 6.** During the fade recovery, brake effectiveness may drop unexpectedly, causing a temporary but potentially hazardous increase of brake pedal force requirement. This "delayed fade" is insidious in that it is often totally unexpected. It occurs well after a period of hard brake usage and usually with no warning signs. Since brake effectiveness takes a sudden drop when delayed fade occurs, that portion of the curve is dashed. Another graphical presentation of delayed fade behavior is to plot the effectiveness points only during the brake applications and leave the remaining time periods blank. Delayed fade then presents itself as a sudden drop in brake effectiveness value that occurs during the brake cooling period, and after a period of high brake temperature.

Brake Effectiveness versus Speed Characteristics — To ensure proper brake balance over a wide range of stopping speeds, the brakes on each axle should exhibit similar effectiveness characteristics with vehicle speed. In general, brake effectiveness decreases with increasing speed. Consequently, a brake application from 100 km/h usually requires greater brake pedal effort than from 30 km/h. Good brakes provide less "speed spread", or difference in brake effectiveness at different braking speeds, and good brake systems employ friction materials that provide proper front-to-rear brake effectiveness at any expected vehicle usage speed. **Figure 7** shows the general relationship between brake effectiveness and deceleration for brakes with poor and good "speed spread" performance. As illustrated, the effectiveness above 150 km/h is markedly different from that below 100 km/h for the drum brake, using a relatively poor friction material. Disc brakes are inherently less speed sensitive than high servo factor drum brakes, so they typically show less speed spread.

Friction Stability — To ensure consistent vehicle braking performance, the brake effectiveness characteristics should be stable throughout the life of the brake linings. **Figure 8** illustrates the difference between friction materials with good and poor friction stability with wear. The brake effectiveness of some friction materials can deteriorate with accumulated usage history and wear, as indicated. The formation of a surface glaze on some brake linings, during prolonged light duty usage, has been associated with a loss of effectiveness. Linings with low wear rates tend to glaze more readily than those with poor wear life, since this characteristic results from a gradual chemical composition change at the rubbing interface. Linings with poor wear life continually present a "fresh" surface, reducing the tendency to glaze by a sacrificial wear process.

On vehicles equipped with a balanced set of friction materials on all four brakes, a gradual reduction in brake effectiveness will provide a gradual increase in pedal pressure to decelerate the vehicle, and brake stability will be essentially unaffected. However, on vehicles employing two different and unmatched friction materials on the front and rear axles, a shift in effectiveness of one braking axle, relative to the other, will alter braking balance and could adversely affect controllability of the vehicle during hard braking. For this reason, many brake experts recommend changing the brake linings for all wheels at the same time. To be conservative, the original equipment brake linings are recommended.

Wet Friction — The performance of vehicle brakes when wet can provide a significant safety concern. Disc brakes usually are less affected by water than are drum brakes, largely because of their lower inherent servo factor. However, both disc and drum brakes can show large effectiveness losses when wet. Tires also change frictional behavior when wet.

As expected, some friction materials can provide a greater loss of brake effectiveness than others, when wetted, and take a considerably longer time to recover friction capability, in the time period after wetting. This is illustrated in **Figure 9**. Permeability, heterogeneity, and compression stiffness are some of the brake lining properties which determine wet friction response. A complete understanding of this behavior is not known, so full brake dynamometer and vehicle tests are used to establish the wet friction behavior of brake systems.

Moisture Sensitivity — Friction materials are typically somewhat porous, fibre-reinforced composites that are capable of absorbing atmospheric moisture when a vehicle is parked, such as overnight. For some friction materials, this moisture has been shown to lower brake effectiveness temporarily, leading to a phenomenon called "morning sickness". Other "morning sickness" effects result from rusting of the cast iron disc/drum surface when a vehicle is parked for some time, causing abnormally high initial brake effectiveness. Under some environmental conditions, it is possible for the friction material to rust-bond to the cast iron. A substantial torque may be required to break this bond, and the rusted surface of the brake drum or disc may generate a temporarily uneven brake torque with brake angular location. Some of these characteristics can be investigated in the laboratory, but full vehicle environmental testing is required to establish acceptability of new friction material formulations.

Figure 10 depicts the effect of moisture sensitivity on brake effectiveness. The ideal brake assembly exhibits little or no moisture sensitivity. When present, it usually persists for a few brake applications, then disappears when brake heat drives the moisture from the brake lining or wear removes the surface rust.

Lining Wear Rate — Friction materials exhibit wear rates that are temperature, prior usage history, and load dependent. In general, wear is directly proportional to applied normal load and speed. At moderate brake drum and disc temperatures, friction material wear rates are not affected greatly by temperature. However, at high brake temperatures, wear of the friction material may increase exponentially due to thermally-induced degradation of the organic resin binder material.

Figure 11 shows representative wear performance curves for three different types of friction materials. Low quality materials may utilize cheaper, less heat resistant binder resins, providing a wear curve like that labelled "A". This may give acceptable wear rates at low brake temperatures, but rapid wear rates at higher brake temperatures. OEM type materials behave like curve "B" and heavy brake linings wear like curve "C". As is often the case, the heavy duty lining does not offer wear life improvement, except at the higher brake temperatures.

Since the full brake assembly represents a tribological system, surface conditions at each contacting interface, both the brake lining and the brake drum (or disc) will influence brake lining wear behavior. For example, the use of abrasives in the friction material may promote brake drum and/or brake disc wear, but the use of such materials may be required to achieve a needed brake effectiveness, or to remove lining transfer layers or rust from the cast iron surface.

LABORATORY AND VEHICLE FRICTION MATERIAL EVALUATION

Laboratory specimen testing machines are commonly used to characterize and audit the quality, or "sameness", of friction materials, using specimens from full brake linings. The advantages of using laboratory systems for evaluation include: automated testing, careful control of operating conditions, and more rapid measurement of brake lining characteristics. In addition, laboratory evaluations utilizing a specimen test are less costly than full-scale brake dynamometer or vehicle experiments.

Several different laboratory machines are used to determine brake lining properties. Four commonly used laboratory test machines are described briefly.

Friction Assessment Screening Test (FAST) — The Friction Assessment Screening Test (FAST) Machine was developed at the Ford Motor Company specifically for rapid "fingerprinting" of friction material specimens. It is used for in-plant quality control (QC) testing of brake linings and clutch facings, along with some specialized friction material screening and diagnostic tests. A 12.5 millimeter square specimen generally is used, but lining samples up to 25 millimeter squares can be tested. The small, flat sample assures rapid specimen seating to the flat cast iron test disc (38 mm thick, 180 mm diameter). QC tests run for 90 minutes, with the friction drag held to a constant value. With a constant rubbing speed (7m/s) and constant friction drag, the horsepower dissipated is also constant, providing repeatable temperature-time histories (20-290°C for QC). QC tests are often run on every "batch" of friction material at their manufacturing sites.

However, the small absolute size of the FAST specimen precludes confidently making correlations of laboratory performance with full brake behavior. This machine is used primarily for routine brake lining quality control testing. Specialized characterization test procedures for this machine are mostly proprietary, and require expertise for proper evaluation. These are used to reduce the amount of full brake tests, not to obviate their usage. Thus, while this machine reportedly has been used to perform friction material screening tests, it never has been recommended as a substitute for full scale brake evaluations.

Friction Materials Test Machine (FMTM) — This apparatus, developed by T.P. Chase of General Motors, uses an arced 1-in. (25mm) square specimen of brake lining material which is forced against the internal surface of a rotating 11 inch (280mm) diameter cast iron brake drum. Auxiliary heaters and air blowers are used to provide controlled brake drum heating and cooling rates. The FMTM Machine, is also used for quality control testing. SAE has designated a Recommended Practice (SAE J661a), used in conjunction with the FMTM, that is classified as a quality control test procedure. This test requires more test time and expense than the FAST QC procedures since it includes simulated burnish, wear, effectiveness, fade and recovery procedures. It is used more for periodic QC surveillance testing, as opposed to routine production batch testing. General Motors and others also have developed specialized testing procedures for evaluating brake lining materials on the FMTM.

Based on test data from the SAE J661a procedure, a brake lining friction rating specification (SAE J866a) has been used by some states for many years to classify and regulate friction materials. However, this brake lining rating system has been shown to be clearly inadequate for meaningful comparative testing with different types or classes of friction materials. The SAE Recommended Practice J866a (revised in 1984), includes this caution against such uses:

> *"Note: It is emphasized that this Recommended Practice does not establish friction requirements for brake linings, nor does it designate significant characteristics of brake linings which must be considered in overall brake performance. Due to other factors, that include brake system design and operating environment, the friction coefficients obtained from this Recommended Practice can not be reliably used to predict brake system performance."*

Technical papers have pointed out that laboratory specimen tests, such as those which use the FMTM, do not provide acceptable correlation with actual vehicle service, both with asbestos-based and non-asbestos linings. Different classes of non-asbestos brake linings, such as non-asbestos organic (NAO) and semimetallic (semimet), provide conflicting trends as well as different absolute values of friction on the FMTM (Chase) Machine.

Girling Scale Dynamometer — The Girling Scale Dynamometer is an apparatus which employs scaled-down brake components. A small brake disc is mounted on the end of a rotating shaft which carries inertia discs sized to ensure that the scaled disc pad will absorb the same amount of energy per unit area as a full size brake disc pad. The friction sample is pneumatically loaded against the rotating disc, and a torque control system is used to produce a repetitive, constant deceleration stop or drag.

Some brake characteristics scale by geometry and others are governed by absolute physical size. Consequently, great care and expertise is required when using a scale device, to be assured that the scaling process itself has not altered performance characteristics of the brake assembly. Thus this device, as the other specimen test devices, can produce good test results only when utilized by a person with expertise in such specialized tests.

Full Brake Inertia Dynamometer — A full brake dynamometer simulates vehicle braking by mounting a complete brake assembly to a large rotating, inertially-loaded shaft. The shaft inertial loading is usually adjusted to simulate the actual road inertia. Brake inertia dynamometers are designated by the number of ends, stations, or brake assemblies that can be tested at one time. Most are single ended, testing a single brake assembly at a time.

Double-ended dynamometers, while capable of simultaneous testing of two brakes, generally are used as single-ended brake dynamometers, so one test assembly can be installed as the other is being tested. Only a few four-ended brake dynamometers have been built. The difficulty of multiple station dynamometers is in controlling the air flow to provide balanced brake cooling. Most brake dynamometers place the brake assemblies in closed ducts, both to expedite cooling and to control smoke and smell. Faster cooling rates hasten testing, so most dynamometer tests have much greater air flow, and resultant cooling rates, than is found in on-road testing. Consequently, brake dynamometers are used mostly for controlled wear tests, basic effectiveness tests, initial fade/recovery tests, and parking brake tests.

Full brake dynamometers are available in a range of sizes, with inertial equivalents for motorcycle to railroad locomotive testing. There are no brake dynamometer standards, so almost every unit is unique. However, compact dynamometers now have been designed that are becoming popular, both because of reduced cost and because of essentially *de facto* standards. Dynamometer-to-dynamometer differences in test results can be significant, even for carefully matched linings and brakes, tested to the same inertia loading. As a result, most brake test engineers prefer comparative brake lining test data, obtained from a single brake dynamometer to data from different brake dynamometers.

A large source of data difference between different dynamometers has resulted from the use of brake lining thermocouples to control the brake test, as required in the FMVSS 121 Dynamometer procedure and as specified in most other procedures. Significant brake drum temperature variations occur with semimet and metallic linings, compared with conventional asbestos-based materials, when the test is controlled by lining temperature. Even different formulations of the same general type can provide test drum temperature differences, especially if they vary in metallic content or material density. Current brake testing practice now favors measurement of the cast iron temperature, at least for test control. In this way, differences of lining thermal conductivity do not significantly alter the temperature of the major heat sink (drum or disc mass). Also, the meaningful brake temperature, from a frictional work basis, is the brake drum temperature. Drum temperature measurement requires infrared pyrometry or thermocouple slip ring assemblies. Most good brake dynamometers now permit one or both of these instrument refinements.

Burnishing conditions also affect the test results, with most drum brake linings and blocks being sensitive to their initial usage history. When drum temperature control of the burnishing operation is performed, the test results are clearly better. It is possible, with proper instrumentation and good control of the burnishing procedure, to perform meaningful friction material screening tests on full brake dynamometers.

Except for replicating airflow over the brake and environmental conditions, such as water and dust contamination, full brake dynamometers now can closely replicate most vehicle in-service braking conditions and are invaluable for brake diagnostic testing. They can be excellent for initial brake lining screening tests. However, they are not sufficient to fully evaluate the acceptability of substitute brake linings.

Correlation of Laboratory and Vehicle Test Results — Numerous studies have been done to determine the degree of correlation between laboratory friction material test results and actual vehicle test results. In general, the only good analog of a vehicle brake is the brake itself. Consequently, there are no specimen or scale test devices that can consistently yield test data that correlates with full vehicle data. This does not mean that such laboratory tests are useless —just that they should not be used to "predict" field performance behavior. They can, and have, been used to screen friction materials with performance flaws, but require expertise in data analysis.

Even full brake dynamometers are difficult to correlate with on-road vehicle brake performance, unless careful instrumentation and test controls are used. It should be possible to correlate full brake dynamometer test results with on-road data, without need for questionable correction factors. This has been tried by many, published by few, but has not yet been verified by anyone.

FRICTIONAL MATERIAL QUALIFICATION

Qualification of friction materials for a vehicle service usually involves both dynamometer and vehicle testing. Dynamometer experiments permit controlled, fully instrumented brake lining testing in a safe and cost-effective manner. Vehicle tests are conducted to substantiate the results obtained through full brake dynamometer experiments and to include the many usage and other environmental conditions that are not readily performed on a brake dynamometer. The test procedures to qualify friction materials and brakes are, of necessity, quite involved and lengthy. What follows is an introduction to the process.

BRAKE DEVELOPMENT TEST METHODOLOGY

Good brakes are essentially "transparent". That is, drivers don't generally notice good characteristics. Inconsistent brake effectiveness, poor fade behavior, abnormal noise or vibrations, and other brake performance shortcomings, ad infinitum, are often noticeable and can be used to describe fundamentally poor characteristics of brakes. Good brakes simply perform repeatedly and consistently over a broad range of usage and environmental conditions, with minimal shortcomings. There is no ideal friction material. Brake development attempts to combine brake linings, brakes, and controls to provide the best compromise, that is, minimal shortcomings for the intended usage.

Testing brakes then involves evaluations under the widest possible sets of conditions to look for flaws or inconsistencies of behavior. Friction material formulation and testing both are more of an art than a science. If accurate models of brake performance were available, the testing would be much simpler. However, each friction material formulation is proprietary, and can be unique in many respects to other materials. Consequently brake test engineers use a combination of standard performance test procedures, to assure adequate capacity, and many customer service trials over the entire United States, to determine usage and environmental stability.

Prudent brake development engineers start with friction materials that have been fully screened with laboratory tests, then run full brake dynamometer tests to further screen the candidate brake linings and to initiate brake hardware adjustments. Only then are vehicle performance tests justified. When these are acceptable, the more difficult, costly, and time-consuming fleet and traffic tests are initiated.

FEDERAL BRAKING REQUIREMENTS AND OTHER BRAKE TESTS

As indicated, the qualification of vehicle brake systems and friction materials can involve numerous experiments to determine fade resistance, moisture sensitivity, wet friction, and other performance parameters. Some of the brake performance criteria are determined by Federal Motor Vehicle Standards

(105-75 for hydraulic brakes, 121 for air brakes), while other performance standards are determined principally by the standards of the vehicle and friction product manufacturers.

The following briefly introduces the Federal Motor Vehicle Safety Standards now in effect for hydraulic and air brakes. In addition, some of the numerous SAE brake test procedures used to evaluate brake system and friction product performance will be discussed.

FEDERAL MOTOR VEHICLE SAFETY STANDARD 105

This Federal Standard mandates hydraulic and parking brake performance under specific vehicle operating conditions. Under the provisions of this requirement, vehicles under 10,000 lbs gross vehicle weight are required to meet one set of braking requirements, while vehicles over 10,000 lbs gross vehicle weight have another set of braking requirements. General specifications are designed around stopping distances for braking with minimal tire skidding. Brake usage history is known to modify subsequent friction material performance. For this reason, specifications are listed both for new (pre-burnished) and used (burnished) friction materials.

FMVSS 105 outlines braking requirements for vehicles braking under flat straight dry clean pavement conditions, not representative of emergency stopping conditions, as well as for vehicles braking under conditions of brake fade and "spike stop". Requirements for vehicle wet braking as well as parking brake performance are also outlined. Specific braking requirements are outlined in the following section.

STOPPING DISTANCE AND FADE REQUIREMENTS

The Federal Code outlines a series of tests for brake effectiveness and dictates required stopping distances for passenger cars, vehicles (non-passenger car) with GVWR or less than 8,000 lbs, vehicles weighing between 8,000 and 10,000 lbs, and vehicles with a GVWR of greater than 10,000 lbs. The procedures describe required performance for new brake linings and for burnished linings that have accumulated a specified history of brake performance.

The procedures also specify vehicle braking system stopping distances, or limit brake pedal application forces, under "normal" braking duty, potential fade conditions, and under wet braking conditions. The performance under brake fade conditions limits the brake pedal force required to stop the vehicle under a prescribed set of repeated hard brake stops from 60 mph.

PARKING BRAKE REQUIREMENTS

The vehicle parking brake must be capable of holding the vehicle stationary for 5 minutes when parked on a 20 percent grade. This can be accomplished in part by using the transmission to brake the vehicle, provided the parking mechanism in the transmission is engaged before the ignition key can be removed. (With respect to replacement friction materials, the ability of replacement friction materials to satisfy these criteria can only be assessed by actual vehicle tests.)

FEDERAL MOTOR VEHICLE SAFETY STANDARD 121

Federal Motor Safety Standard 121 lists the performance requirements of air braking systems. These systems are commonly used in heavy trucks, tractor-trailer combinations, off-road vehicles, and transit buses. Specific examples include agricultural trailers, automobile transporters, pulpwood trailers, and heavy hauler trailers. This Federal Standard specifies requirements of stopping distance, brake activation time, brake release time, and parking brake operation. For these vehicles, brake loading can vary considerably, depending upon the service condition and cargo load carried by the truck or trailer. This standard is concerned with stopping distance requirements and both vehicle and full brake dynamometer experiments.

VEHICLE BRAKING EXPERIMENTS

Vehicule braking experiments under FMVSS 121 are different from those under FMVSS 105 in that stopping distance alone is used to evaluate performance, rather than stopping distance and brake pedal force. In addition, trailer brakes may not "lock-up" during braking.

Vehicule braking experiments are conducted on flat surfaces exhibiting different friction properties (as indicated by pavement skid numbers). Vehicle loads are adjusted to replicate heavy (loaded) or light (unloaded) conditions.

FMVSS 121 outlines test procedures and stopping distances for two general categories of vehicles using brakes: 1) trucks and buses, and 2) trailers. Test procedures used for both vehicle classes are essentially the same, except that trailer brakes must function with a specified control line pressure (90 psi) and be able to stop the trailer with no assistance from the towing tractor. Brakes are evaluated by braking the vehicle from 60 mph and 20 mph on a dry road surface with a skid number of 81 and by braking the vehicle on a wet road surface with a skid number of 30. Both dry and wet pavement braking are conducted under empty and fully-loaded conditions.

The braking test procedure for FMVSS 121, in contrast with FMVSS 105, has no decelerations designated. As expected, stopping distances are longer for trucks and trailers than for passenger vehicles (due both to the lower friction available from truck tires and the difficulties of brake balancing on multi axle vehicles). Road tests with new brakes are preceded by a brake burnishing procedure consisting of 500 brake applications. During burnishing, brake application frequency is used to control brake lining temperatures between

450°F and 500°F (Note that brake drum temperature is not controlled, a recognized shortcoming of this procedure.)

In addition to the regular brakes, the vehicles must have emergency braking systems capable of stopping the vehicle in the event of partial brake system failure. This requirement is similar to the FMVSS 105 requirements describing brake operation in the event of partial loss of hydraulic fluid.

PARKING BRAKE TEST

The parking brakes for trucks, buses and tractor-trailer combinations must be capable of holding the vehicle on a 20 percent grade, on a cement concrete roadway, under both empty or fully-loaded conditions. Initial brake applications can be achieved using air or hydraulic activators,although once actuated, the clamping application must be maintained solely by mechanical means.

DYNAMOMETER TESTING FOR FMVSS 121

FMVSS 121 describes procedures for inertia dynamometer evaluation of friction materials. These procedures require the installation of a complete air brake assembly on a inertia dynamometer. Stopping distance requirements cannot be met using an inertia dynamometer, since there is no tire-road friction limitation, so performance is determined by measuring brake torques and deceleration rates. Dynamometer inertia is determined by using the inertial equivalent to the load on each wheel.

SAE-RECOMMENDED PRACTICES FOR EVALUATING BRAKE SYSTEMS AND FRICTION MATERIALS

The Society of Automotive Engineers (SAE) has developed about 20 Recommended Practices for checking the performance of brake linings systems. These standards cover automobile, truck, and trailer brake system tests using both vehicles and dynamometers.

Prior to the adoption of FMVSS 105 and 121, the SAE procedures were intended to give some suggested standard guidelines to brake system evaluations. The passage of FMVSS 105 as a requirement for brake system certification shifted the emphasis of these SAE procedures to the role of supplementary tests that could be used to further qualify vehicle brakes and braking systems. The majority of the SAE brake codes have been directed toward qualifying materials for automobiles and light trucks, although some (SAE J880 and SAE J9781) have been developed for heavy commercial vehicles.

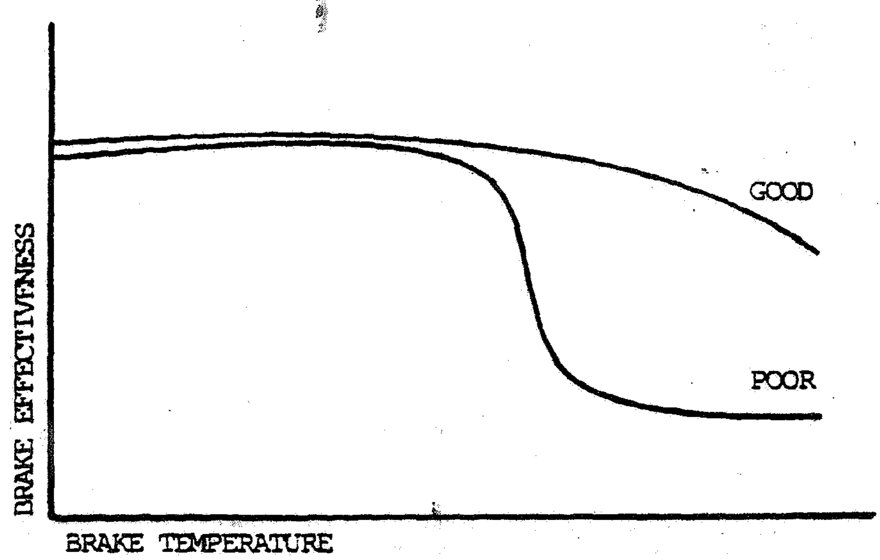


FIGURE 4 EXAMPLE OF GOOD AND POOR BRAKE FADE CHARACTERISTICS

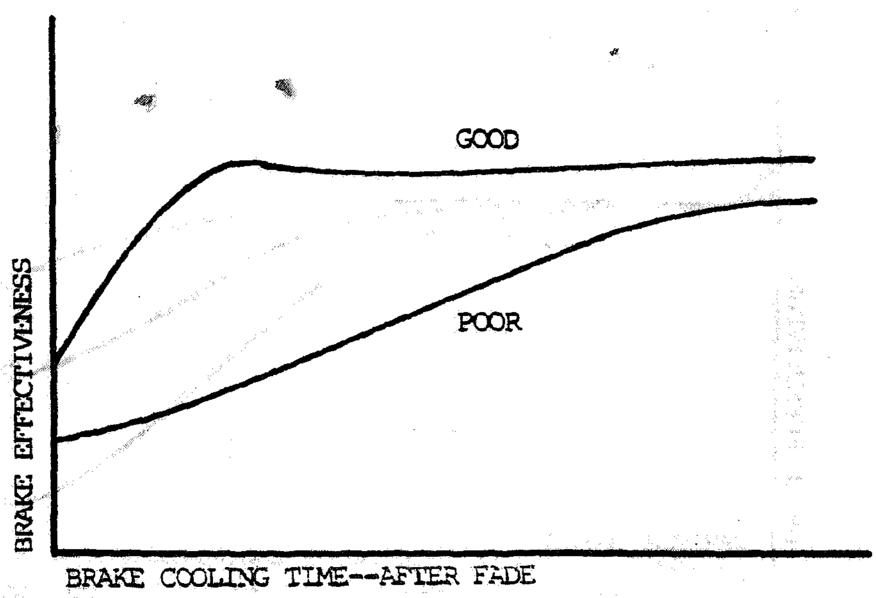


FIGURE 5 EXAMPLE OF GOOD AND POOR FADE RECOVERY CHARACTERISTICS

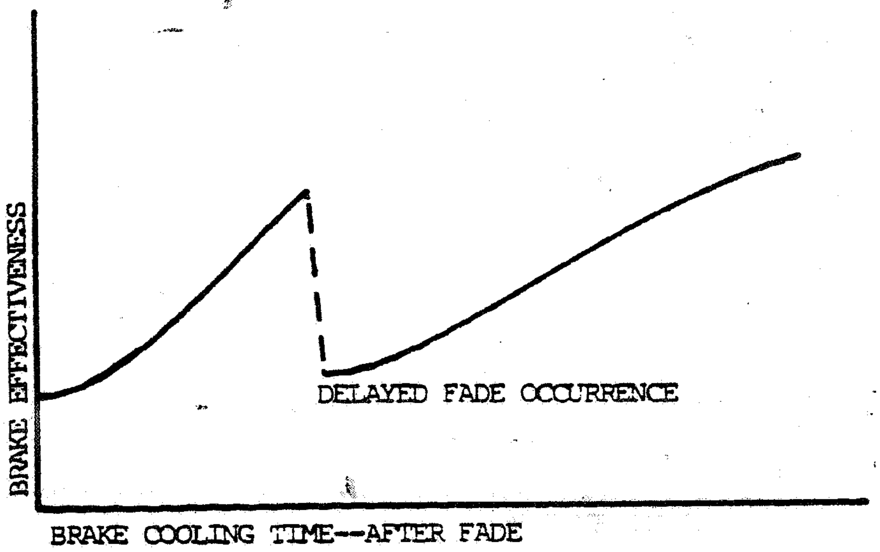


FIGURE 6 **EXAMPLE OF DELAYED FADE CHARACTERISTIC**

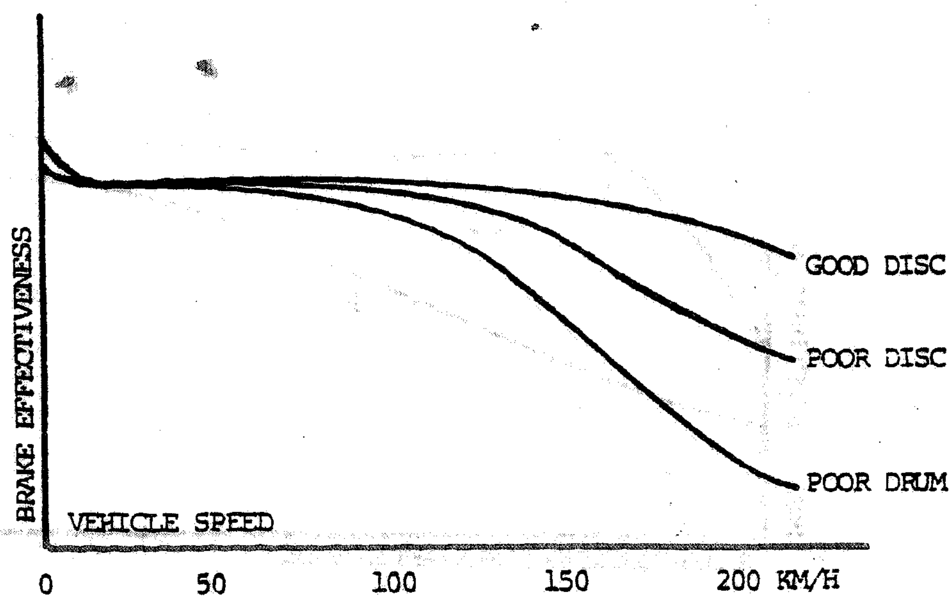


FIGURE 7 **VEHICLE SPEED EFFECT ON BRAKE EFFECTIVENESS**

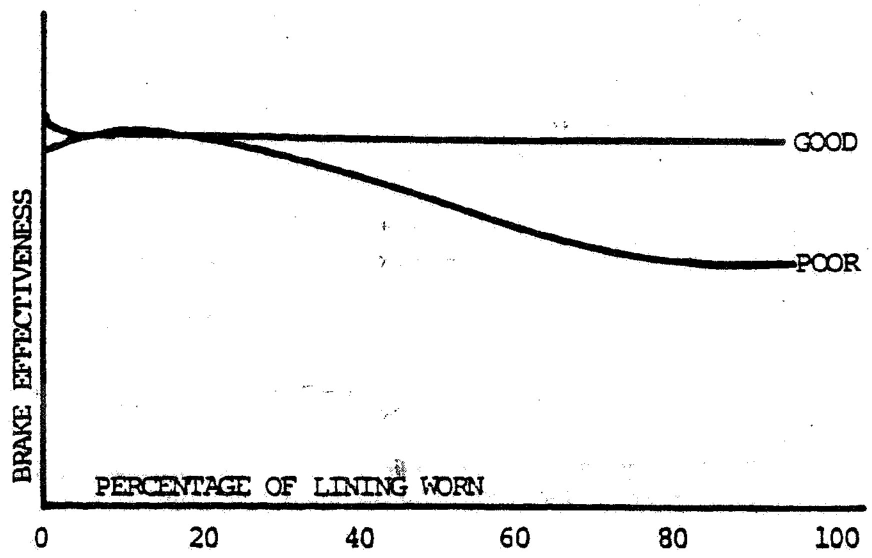


FIGURE 8 EFFECTIVENESS STABILITY WITH USAGE CHARACTERISTIC

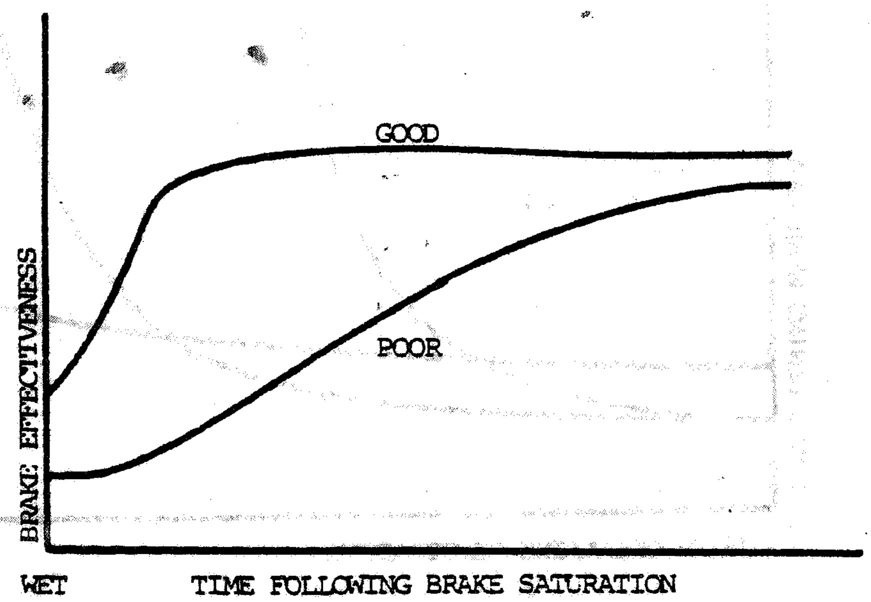


FIGURE 9 EXAMPLE OF GOOD AND POOR WET EFFECTIVENESS RECOVERY

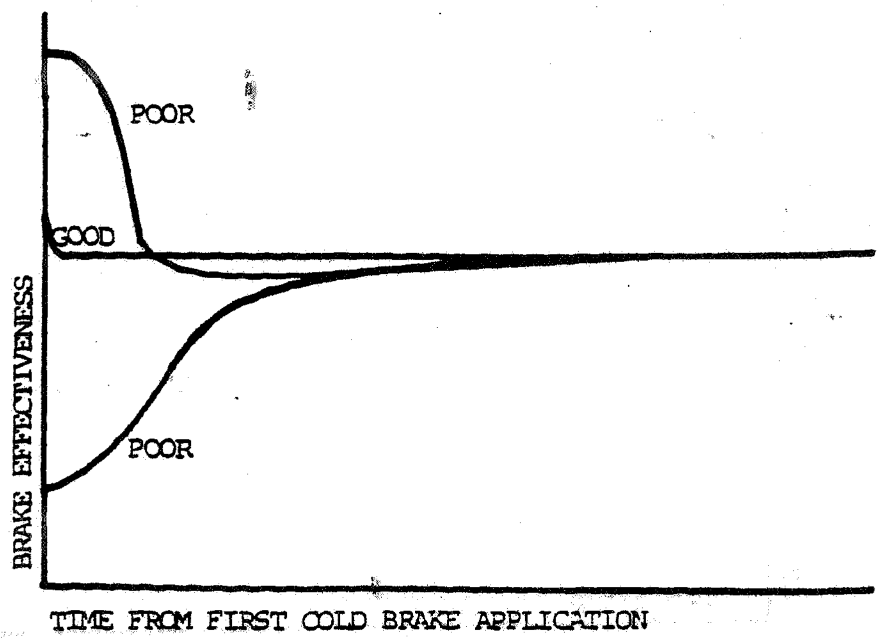


FIGURE 10 MOISTURE SENSITIVITY EFFECT ON COLD BRAKING PERFORMANCE

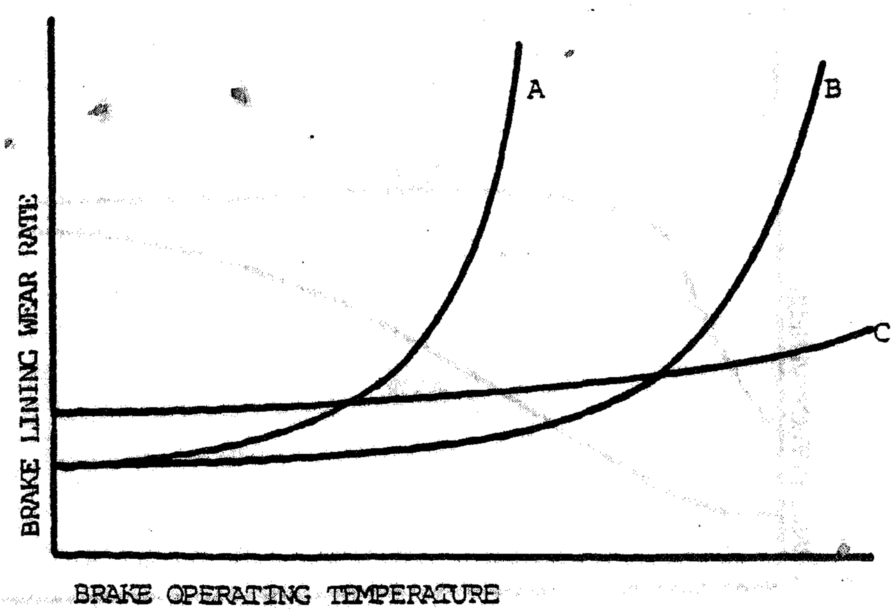


FIGURE 11 BRAKE LINING WEAR RATE CHARACTERISTICS

APPENDIX 3

Performance Attributes of Friction Materials Now in Use

Non-asbestos friction materials technology is advancing rapidly, with many new car, light truck, heavy truck, and off-road brake systems being released for new vehicle production. Materials are under development from all four general classes.

Semimetallic Friction Materials — Semimetallic, semimet, and resin bonded metallic (RBM) are all names for this popular class of friction material. Semimets utilize steel wool, some form of iron powder, graphite, binder resin, and various other constituents in their formulations.

Semimets have been used as disc brake linings on passenger cars and light trucks for about a decade. Presently they are the most common friction material used with US original equipment manufacturer (OEM) disc brakes. Although originally produced with a resin-asbestos backing layer, most semimet linings now use no backing layer, or a non-asbestos organic (NAO) backing layer. Semimet linings also have had limited usage in heavy truck drum and disc brakes.

These friction materials are usually hot-pressed to finished dimensions. Consequently, they are not readily made into drum brake segments, which require long, thin arced lining segments. Semimets also tend to be somewhat low in strength and stiffness, so they are better suited to the thicker disc brake lining and heavy truck block configurations.

Semimet linings have several unique performance characteristics. For one, they have a high initial wear rate, at least until a ferrous transfer layer is built up onto the drum or disc cast iron surface. This formation is rapid at high usage temperature, but can be quite slow for brakes that operate at low temperature, low speed, and light pressures. Lining wear life is greatest for moderate temperature service. Poor lining life can result from very low usage temperatures, so brakes are often designed to run hotter with semimet linings. Most friction materials have a lower friction level at higher rubbing speeds, but not semimets. These materials have nearly constant friction levels from about 50 km/h to beyond 150 km/h, providing potential front-to-rear brake balancing difficulties for some systems. While the friction is nearly constant at high speeds, the lining wear rate is not. Semimet linings have high wear rates, per unit work done, at the higher rubbing speeds. Thus they seldom are used for car racing applications or for cars designed for high speed road driving.

Water affects many friction materials greatly, but very little for semimets -- unless accompanied by a little oil. Then the frictional effect is roughly similar to most others. Since road splashing generally contain some oil, this can cause a loss of friction. Disc brakes are less water sensitive than most drum brakes and often run warm enough to dry quickly, so water effects usually are not critical or long lasting. Cool and humid ambient air conditions affect the semimet linings significantly, causing a temporarily low brake effectiveness called "morning sickness". Most semimet linings provide only about half the normal brake effectiveness for the first few brake applications after cooling to ambient temperature in a moderate to high humidity environment.

Non-Asbestos Organic Friction Materials — Non-asbestos organic (NAO) materials utilize a combination of fibres and other ingredients to fulfill the functions that chrysotile fibres had performed in resin-asbestos linings. Aramid (DuPont's Kevlar), fibreglass, mineral wool, wollastonite, steel wool, and processed mineral fibre are some of the common reinforcement fibres to be used along with the binder resin and various fillers and friction modifiers in NAO brake linings.

NAO brake lining formulations presently are used in some OEM drum brake applications for passenger cars and light trucks, and increasingly are used in brake blocks on heavy truck drum brakes. NAO disc brake linings reportedly have been released for some OEM disc brake applications. Development of NAO drum brake segments for the remaining OEM applications remains active.

NAO friction materials may look much like asbestos-based brake linings. Because friction material vendors have had to use a blend of fibres and other reinforcing agents to make useful NAO linings, they can and do come in a wide range of physical appearances and performance characteristics.

This class of friction materials offers the greatest hope as an effective asbestos replacement, but also provides the greatest problems to develop. There are over a thousand fibres and reinforcing agents that have been tried, generally in combination with several others. Finding the best combination for lining processability, friction level, friction stability, wear life, fade, recovery, contamination sensitivity, and mechanical properties is a formidable task.

Since there is essentially no technical communication and/or cooperation among the lining suppliers, each is working virtually independently at this task. In time, it appears likely that new NAO materials will be developed that are superior to the best of the existing asbestos-based linings. However, presently they tend to be hard, brittle, low in permeability, highly orthotropic, and prone to hot spot, blister, and crack in service.

Sintered Metallic Friction Materials — Usually solid state sintered, these heavy duty materials typically are of iron or copper base, but may generally contain inorganic filler and friction modifiers as minor constituents. Sintered ferrous drum brake linings were released for a few OEM passenger car applications two decades ago. They tend to be environmentally sensitive, both to temperature and moisture, which limits commercial applications. However, they are used for special service aftermarket automobile, some severe service commercial vehicle, and aircraft disc brake applications.

Sintered copper-based friction materials have been used in heavy duty brakes and clutches for around three decades. Often with another metal, forming a bronze, and a refractory, such as mullite, these materials can perform well in hard service usage. However they too are environmentally sensitive, and can cause severe galvanic corrosion in wet environments, when used against the typical grey cast iron countersurface materials. Aircraft disc brakes and heavy duty truck/tractor clutches are present uses for the sintered bronze friction materials. No known new application of these relatively old and well-developed friction materials has resulted from the search for asbestos substitutes, largely due to their cost and sensitivity to light duty environmental conditions.

Carbon-Carbon Friction Materials — These are space-age composites of carbon (graphite) fibre, held in a matrix of amorphous carbon using a costly and time-consuming manufacturing process. Military aircraft, race cars, and some commercial airliners now sometimes use the carbon-carbon friction materials for both the stationary and rotating elements of disc brakes. Carbon-carbon friction materials operate best when rubbed against themselves. Extremely high cost and environmental sensitivity limit additional applications.

BRAKE LINING PERFORMANCE COMPARISONS

FULL BRAKE DYNAMOMETER TESTS

One example set of data that follows supports the claim that no acceptable asbestos-free friction materials have yet been developed for certain drum brakes. In this case a full brake dynamometer was used to test four different sets of drum brake linings on a 12 inch duo-servo drum brake with a 3 inch lining width. Identical procedures and matching test components were used, so the brake linings were the only known variables.

The linings have been coded and, for simplicity of presentation, only the initial lining burnish test data is shown. **Figure 12a** shows this data for lining A, a NAO drum brake lining set. The test data is presented as brake line pressure versus equivalent vehicle speed. The brake line pressure relates to the amount of brake pedal effort exerted. All brake stops, after stop 3, were performed from the same initial speed (40 mph) and controlled to provide an equivalent of a quarter "g" deceleration, a normal braking application. Note the wide range of pressures required to make the same stop. Even after 100 burnish applications, the required hydraulic pressures varied by a factor of two adjacent stops. Also, the required brake pressures for this normal type of brake stop were almost to the limit for the power brake booster.

Brake lining A would be unacceptable for any OEM brake usage in this brake assembly. However, this lining formulation was released for production application on a different, smaller-sized drum brake. With a smaller brake and attendant thinner linings. Lining A met all of the service requirements for an OEM brake lining. This demonstrates how the acceptability of a friction material is not just dependant upon the properties of the brake lining, but also on the specific choice of brake, vehicles, and use conditions.

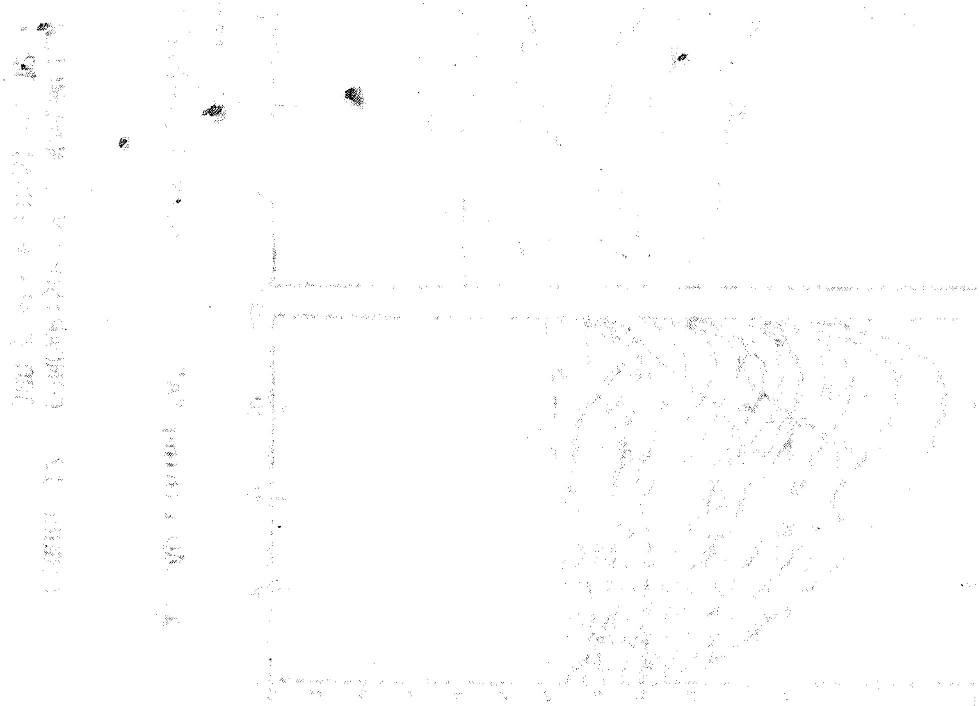
Figure 12b shows performance curves for a NAO material B. Lining B was a candidate NAO material, but was not released for production. It used a different non-asbestos fibre system from that used in A. This lining provided, on average, higher brake effectiveness, but with a greater range of brake application pressures for the same test. Although not illustrated here, other test data for this lining show it to have an undesirable 'morning sickness'— a very high initial effectiveness for the first few cold stops. A lining like this on the rear drum brakes, used with a semimetallic front disc brake lining, would provide a vehicle brake system with a very strong tendency for rear wheel lock-up (skidding) when cold and moist.

Figure 12c shows the performance curves for a material C. Lining C, a 'premium quality' aftermarket asbestos-based lining set, has been used for many years. Note the narrow band of brake line pressures for this burnish sequence. In particular, the stops from 40 through 100 were virtually identical. This consistency of brake effectiveness, although not guaranteed by the use of asbestos-based friction materials, is not yet available from any known NAO drum brake lining on this size of drum brake. Lining C had slightly higher, about 25 percent, lining wear rates than the two non-asbestos materials shown.

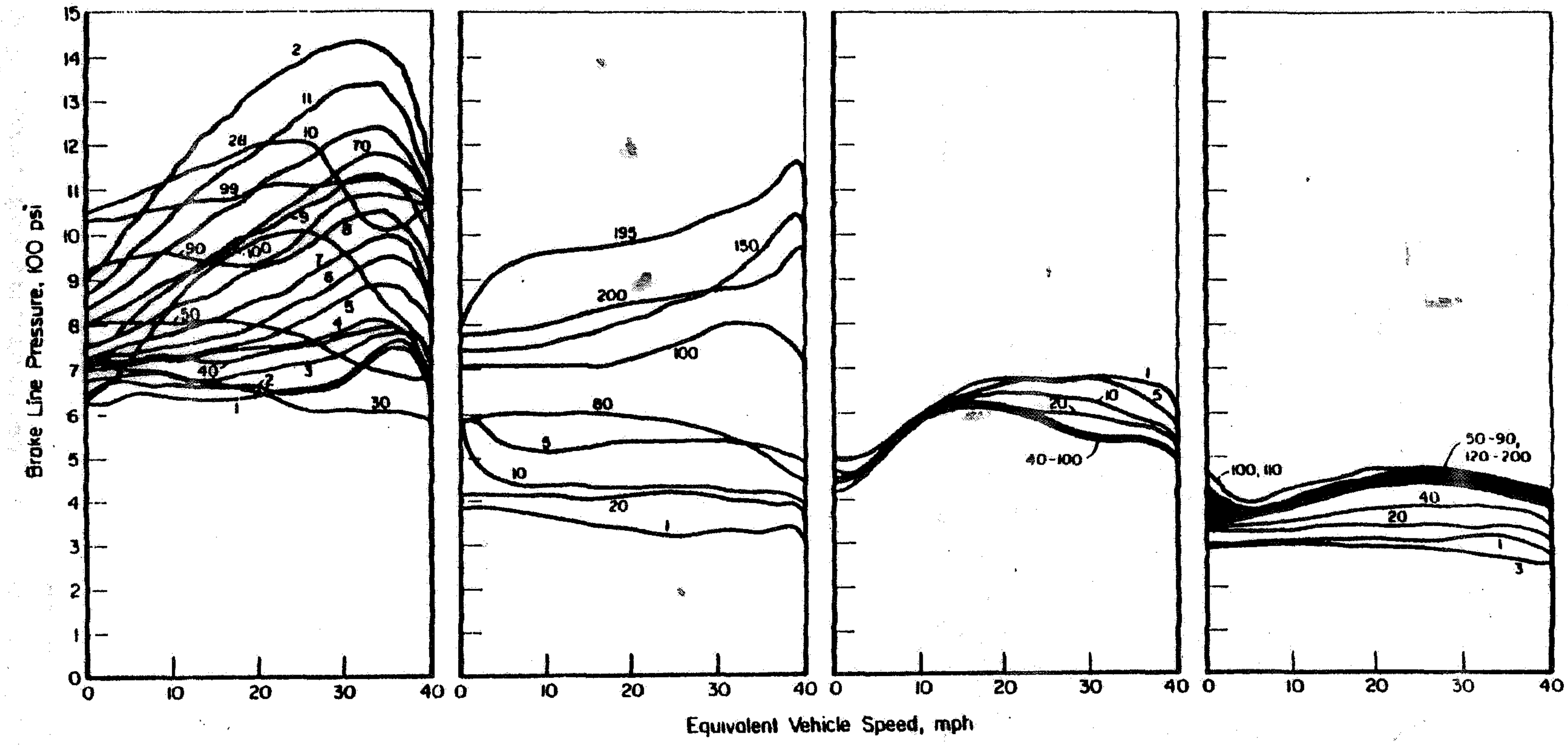
Figure 12d shows performance curves for asbestos material D. Lining D was the OEM released material for this brake system. It had the highest average effectiveness of the four linings and also the narrowest band of brake line pressures. In this case, the second 100 burnish stop data was included to illustrate the consistency of performance that can be obtained from this brake. About 45 brake applications were required to obtain steady-state frictional behavior. After these, the test data were very repeatable, and the variation of effectiveness with speed was quite acceptable for a duo-servo drum brake.

NHTSA VEHICLE TEST DATA — The performance of aftermarket brake linings was compared to the performance of OEM linings in a vehicle study conducted by the National Highway Traffic Safety Administration (NHTSA). These experiments were conducted using a compact size passenger car equipped with front disc brakes with semimetallic pads and duo-servo drum brakes on the rear. Twenty-three different aftermarket rear drum linings were obtained by purchasing them from automotive service centers and automobile parts outlet stores. These materials were identified with a letter code of A through W.

Experiments were conducted under conditions similar to those specified in FMVSS 105. To generate data representative of OEM lining performance, 10 sets of OEM qualified linings were also obtained and tested to generate a comparison baseline. **Figure 13** shows the measured brake effectiveness for the various aftermarket linings under two different test conditions [(1)] At least two separate sets and as many as four separate sets of the same linings were tested; variations in performance are illustrated by the range in brake effectiveness exhibited among different sets of identical materials. Note the wide range of effectiveness variability among the aftermarket materials. Lining material 'R' exhibited the highest variability in effectiveness. This material was the only non-asbestos lining of the 23 aftermarket materials tested. The remaining 22 test results also illustrate how wide variations in effectiveness can exist, even for asbestos-based materials.



(1) Test data obtained from "The Effect of Aftermarket Linings on Braking Efficiency." by Mark A. Flick, Richard W. Radlinski, and Russell L. Kirkbride, NHTSA Vehicle Research and Test Center, East Liberty, Ohio.



a. NAO Lining "A"   b. NAO Lining "B"   c. Asbestos Production Lining "C"   d. Asbestos OEM Lining "D"

FIGURE 12 COMPARISON OF DYNAMOMETER TEST RESULTS FOR FOUR DIFFERENT FRICTION MATERIALS, 300 F AFTER BURNISH, 12 x 3 DUO SERVO DRUM BRAKE

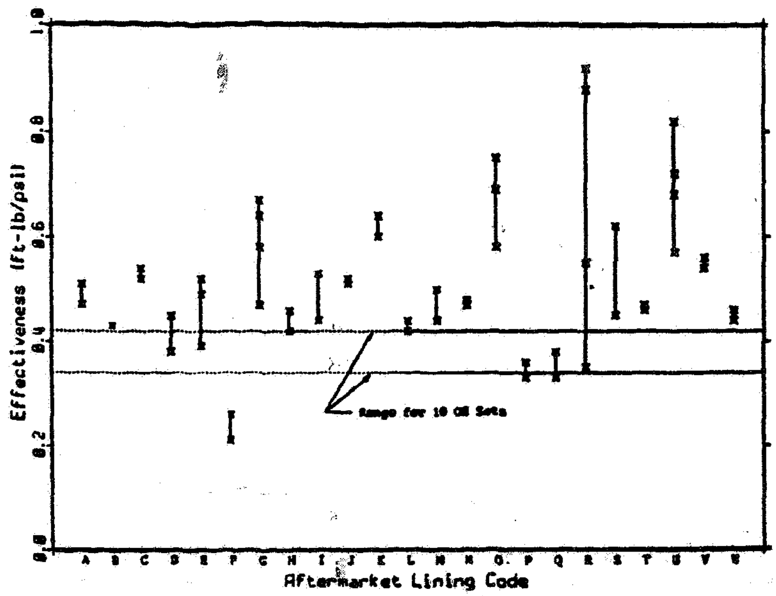


Fig 13a- 30 mph post burnish rear brake effectiveness results

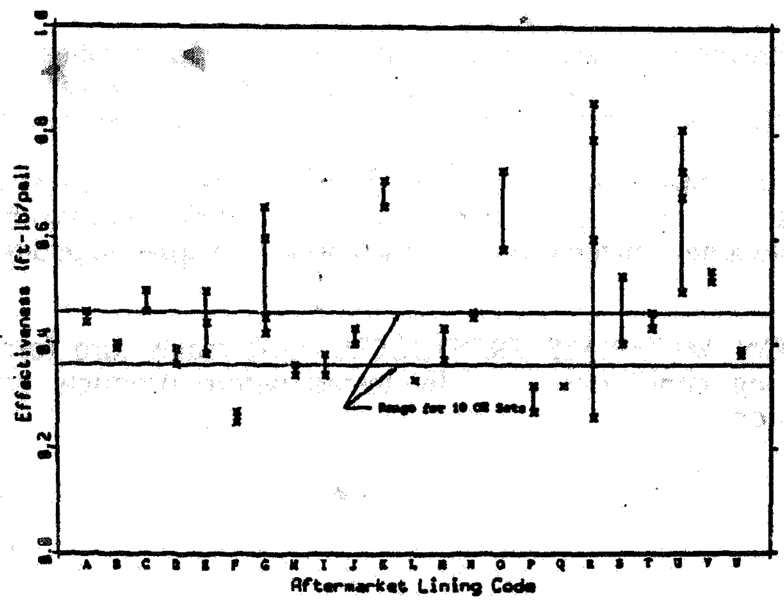


Fig 13b- 60 mph post burnish rear brake effectiveness results

SESSION I

FRICTION MATERIALS PERFORMANCE ISSUES

PANELISTS ABSTRACTS

James Trainor
Brake Systems Inc.
Stratford, CT

The friction material industry has made major progress in the development and commercialization of asbestos-free products. In certain areas, this has resulted in durability and performance that is superior to that attained with asbestos-based materials.

The technology is by no means complete, but as with asbestos and semi-met products, performance improvement will be an ongoing process. The recent ASME report to EPA summarizes the status and outlook for non-asbestos technology, and emphasizes the need for careful attention to friction stability over a wide range of conditions.

Non-asbestos materials appear to offer exciting opportunities for breakthrough to new levels of performance and durability. However, to achieve the potential, all segments of the industry will have to address the challenges.

FRICTION MATERIAL ENGINEERS must break away from traditional formulations, challenge the "rules" for compounding asbestos-based products, and build a new material on sound scientific principles, supported by definitive testing.

FRICTION MATERIALS PRODUCERS must make sure formulations and processing conditions are fully tested before products are released to production.

C. Dale Christie
Griffin Wheel Co.
West Chicago, IL

Railroad friction materials are similar to most automotive brake linings in many respects, yet have some fundamental differences. Tread brakes rub directly against a wrought steel or cast railroad wheel tread and are large in size, 12 to 18 inches long, 3 to 4 inches wide, and one-and-a-half to two inches thick. During the steam engine period, railroad brake linings were cast iron. Along with the advent of the diesel locomotive, asbestos composition brake linings were introduced in the late 1950's. These required greater resilience, toughness, and abrasion resistance than automotive brake linings, so used only 9 percent of chrysotile asbestos fibre. Abrasion resistance is important, since the wheel picks up particulates from the track surface that can be hostile to both the brake lining and to the wheel tread. The fricional performance properties of thread brakes are specified by the Amercian Association of Railroads, to minimize braking imbalance over the many individual brake assemblies.

The rapid development of non-asbestos friction products was simplified, with only a few different brake designs and with accepted industry standards for performance. After 1980, a non-asbestos composition shoe was introduced in response to customer demand. Currently, all railroad tread brake linings are asbestos free. The tread brake linings were relatively easy to convert to non-asbestos, with aramid and aramid/fibreglass formulations in use. However, railroad disc brakes, used on some transit systems, still may have asbestos-based linings. Development of non-asbestos friction materials for these applications is continuing.

John C. Hoffman
Ford Motor Company
Dearborn, MI

Asbstos-containing disc brake pads and drum brake linings have different performance characteristics from those that don't use asbestos. Thus one can not simply use a non-asbestos brake lining as a substitute and be assured that the brake system balance has not been altered.

Original equipement manufacture (OEM) friction material suppliers are painfully aware of the extensive work required to qualify a new lining for production. Ford Motor Company does not manufacture brakes — we purchase all of our brake systems and parts from outside manufacturers and suppliers. This includes all of the disc brake pads and drum brake linings.

An internal initiative has been undertaken, the goal of which is to eliminate asbestos-containing materials from all systems in all products by the early 1990's. Since 1979, significant reductions in asbestos-based brake linings have been achieved. Of two million passenger cars built in 1986, 46% of the front disc brakes and 18% of the rear brakes were asbestos-free. For the 1.5 million light trucks produced in this same year, 100% of the front disc brakes and 72% of the rear brakes were asbestos-free. This accomplishment results from team commitment of the lining supplier, the brake manufacturer, and the auto/truck manufacturer.

How much effort and time is required to verify a new lining prior to customer usage? Typically, to properly qualify a single new production lining for safety, noise, and durability on a single vehicle line requires:

- Starting vehicle testing at least two years before first production
- Running at least 45 seperate tests on the brake system
- Accumulating a million non-customer test miles at a cost of approximately a dollar per test mile

During this qualification process, about three months of brake noise screening can occur concurrently. The above does not account for the engineering time involved and is in addition to the extensive brake and lining testing that is performed by the lining and brake manufacturers.

At present, the asbestos removal program is on schedule. This has been accomplished by extensive behind-the-scenes effort and cooperation. Only through such team commitment programs can new friction products, and attendant new brake systems, be properly introduced to a new vehicle line.

Victor Suski
American Trucking Associations
Alexandria, VA

The American Trucking Associations is a federation with affiliated associations in every state and the District of Colombia. In the aggregate, ATA represents every type and class of motor carrier in the country.

ATA's principle concern regarding a ban on asbestos in brakes is the effect that this could have on vehicle braking and highway safety. Past and present experience with non-asbestos brake materials has in many cases shown unacceptable performance.

It seems that non-asbestos linings, for class 6, 7 and 8 trucks may suffer from less dimensional stability then asbestos, and cracking of the linings edges. In addition cold, wet conditions can cause some non-asbestos linings to pick up metal particles, causing 20% greater wear on drums. Industry doesn't really know the service failure modes nor how toxic these materials may be. It has been suggested that the same caution be exercised with non-asbestos linings as with asbestos until these aspects can be pinned down. Limited testing indicates that in some applications non-asbestos materials offer little or no improvement in lining life.

Fleet experience has been mixed. One fleet found the following during tests of a non-asbestos lining compared to the asbestos counterparts:

- Wheels lined with burnished absestos material always produced more deceleration than when lined with burnished or unburnished non-asbestos material.
- Wheels lined with non-asbestos linings produced similiar decelerations whether burnished or not, sometimes higher and sometimes lower.
- Wheels lined with unburnished asbestos material always produced less deceleration than when burnished or lined with burnished or unburnished non-asbestos material.

But other large, knowledgeable fleets have had a smooth transition to non-asbestos and have completely eliminated asbestos.

We do not believe that the relatively small contribution to ambient air concentrations of asbestos fibres that may occur from motor vehicle braking presents an unreasonable risk to the general public. Also, when used properly, asbestos in truck brakes does not present an unreasonable risk either to persons conducting brake service and repair, or the public in general from these activities.

Needlessly or prematurely banning asbestos from brakes could create a risk greater than that posed by asbestos released by vehicle braking being emitted into the air, i.e. unreliable motor vehicle braking.

This belief is reinforced by the American Society of Mechanical Engineers *"Analysis of the Feasibility of Replacing Asbestos in Automobile and Truck Brakes"* prepared for the Environmental Protection Agency in April 1987. This report further suggests that the substitution of unqualified non-asbestos friction materials in the aftermarket poses the largest potential safety issue. From the truckers perspective the aftermarket lining situation has contributed strongly to incompatibility in braking between tractors and trailers - i.e. one or the other vehicle of the combination does more than its share of the total braking effort. This has been with us for a long time and just when we think we are getting a handle on it the linings are supposed to change. We can't achieve compatibility with asbestos linings now. The situation will be much worse as non-asbestos linings mix with asbestos linings on the various brakes of a combination vehicle.

ATA suggest that, while it is certainly desirable and feasible to further reduce any additional risks that may be associated with the use of asbestos in brakes, and ended some fleets have converted to non-asbestos linings, it is not desirable, feasible, or neccessary to ban asbestos to achieve additional reductions in the small percentage contributed by the use of asbestos in brakes to overall ambient asbestos levels.

A substantial hazard to public safety may be created by banning the use of asbestos in brakes. For this reason, at this time, and for some time to come, asbestos-containing brakes for on-highway vehicles will be an essential use of asbestos.

*

Raymond Andrews
Trenton Brake
Trenton, NJ

Trenton Brake specialized in the resurfacing of truck, auto, and industrial drums and rotors. Riveting and bonding of automobive and industrial brake linings to their shoes is also done, as is final radius grinding of shoes. For the past 35 years, Trenton Brake has used vacuum cleaning, rather than air blowing to clean the brake assemblies.

This service has included heavy, medium and light trucks, passenger cars and industrial vehicles. I have been exclusively involved in brake service for over 35 years. My brake work has also extended to non-automotive brakes. As a consequence, I am versed in air, vacuum and hydraulic brake systems past and present. Consequently, I do a substantial amount of troubleshooting and other brake diagnostic work in the New Jersey area.

The point that I wish to make at this meeting is to consider the needs of the customer and of the brake mechanic in changing to non-asbestos linings. It has been my experience that there are many more problems of noise, high wear, lining breakage, and inconstistent braking on vehicles which use the new non-asbestos brake linings.

Sid Williams
National Highway Traffic
Safety Administration
Washington, DC

The National Highway Traffic Safety Administration, commonly referred to as the NHTSA, has the responsability for writing Federal Motor Vehicle Safety Standards for the safety performance of motor vehicles and motor vehicle equipment. The most well known standards which the NHTSA has issued specifying requirements for brake systems are Federal Motor Vehicle Safety Standards (FMVSSs) 105 and 121. FMVSS 105 specifies requirements for powered motor vehicles equipped with hydraulic brake systems while FMVSS 121 specifies requirements for motor vehicles equipped with air brake systems. The requirements of these standards are essentially summarized in Arnie Anderson's paper. The stopping distance performances specified in these standards, for heavy vehicles, which are dependent on brake lining performance, are not presently in effect, except for those which apply to hydraulically braked school buses and the emergency braking capability of other hydraulically braked vehicles. The agency's only other braking system standard is FMVSS 122 which specifies requirements for the braking systems used on motorcycles.

The only two standards which the NHTSA has issued for braking system components are FMVSS's 106 and 116. FMVSS 106 specifies requirements for brake hoses and FMVSS 116 specifies requirements for hydraulic brake fluids. The NHTSA has not promulgated any standards for brake linings. The most likely reason why the agency did not initially issue such a standard along with the brake hose and fluids standards is that the initial standards were to be based on existing industry standards. Then, as now, there were no published industry standards for brake linings appropriate for a Federal standard. The NHTSA did, however, issue an Advance Notice of Proposed Rulemaking (ANPRM) about the time the initial brake component standards were issued announcing its intention to write a standard for brake linings. This brake lining docket is still open.

After the brake lining ANPRM was issued the agency initiated research directed toward the development of a brake lining standard. This research ended in the mid-seventies when the NHTSA's Safety Research Laboratory, which was conducting the research, moved from Maryland to Ohio. The principal findings of this research was that requirements should be based on the performance of a complete set of brake linings either on vehicle or a dynamometer rather than on the performance of a small piece of brake lining on a laboratory test machine.

Brake lining research was begun again about three years ago but this time the research was directed at studying the performance of brake linings on brake inertia dynamometers rather than developing a test procedure for a brake lining standard. The initial work was on passenger car brake linings; it was summarized at last year's conference by Mr. Dick Radlinski of the NHTSA*. Presently the research is concentrated on heavy truck brake blocks. Two popular asbestos and non-asbestos brake blocks are being tested on an inertia dynamometer to determine how their performance varies:

(1) within a given batch
(2) within their formulation but from different batches
(3) in simulated use on the dynamometer, and
(4) after about 75,000 miles of actual service on line-haul truck-tractors

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* Also summarized in SAE technical paper #870267, *"The Effect of Aftermarket Linings on Braking Efficiency"*, by Flick, Radlinski and Kirkbride.

SESSION II

DUST CONTROL IN THE WORK PLACE

DUST CONTROL METHODS AND FIBRE EXPOSURE IN PRIMARY MANUFACTURING — YESTERDAY AND TODAY *

Rita Grisham
Nuturn Corporation
Nashville, TN

I have been asked to participate in the part of the program dealing with dust control in the work place, specifically, a review of dust exposure and control methods used in automotive-manufacturing facilities. My company, Nuturn Corporation, a member of the T and N Group in the United Kingdom, is a basic manufacturer of friction products to the automotive and heavy-duty markets, both for original equipment and after-market, replacement uses. I am in my fourteenth year with these businesses and it is really exciting when I come to something like this and see old friends. It is almost like old-home week to realize that, over the years, I have grown to know a lot of you and it is exciting to see many of you again.

No doubt this group has a diverse background. I would assume that we have scientists, we have operations people, we probably have engineers, both in research and development as well as process engineering marketing and safety professionals. So to set the stage for you, let me say that mine is not a technical presentation; that is not my background. It is very practical rather than theoretical. It is not an industrial-ventilation exercice, but some real-world, actual-work place discussions on the control of dust.

Of course, there is no way to cover in 15 minutes the entire subject line. What I would like to accomplish, for the next few minutes, is to look at the reasons for dust control, the impact of regulations, the necessity for a proper, hazard assessment and then I will end with an action list for each of us in playing our part in controlling dust in the future.

My purpose in all of this is to help us all continue to work toward providing a safe and healthy place to work. We might equate our situation and today's topic to a pendulum. Yesterday, the pendulum was on the side of apathy, carelessness, unawarness. Controls were not as good as they are today. Hopefully, they will be even better tomorrow.

* Transcript of oral presentation.

Today, in some respects, however, we have gone to just the opposite extreme on the side of runaway costs, confusion about what steps are going to be taken, turmoil as to the status of various regulations, especially, as they deal with asbestos. These regulations are threatening. They threaten our international competitiveness, they threaten our productivity. We then have to charge ourselves with balancing the pendulum so that our actions are not dictated by the goverment. We must fully understand the importance of clean uncontaminated air in an industrial work environment.

The friction industry is complex, both in operations and processes. We use an increasing number of chemical compounds and substances and educating ourselves and our public is critical. Our recognition of responsability and then acting responsibly on that recognition can prevent another of our substances from going the way that it would appear asbestos is going. To ban or not to ban, that is the question. I hesitate to even use the word "ban" because I have been accused of making two syllables out of it.

Before I leave asbestos, I too would like to mention briefly one of the major studies of mortality of friction workers in manufacturing. This is the Berry and Newhouse study that Terry alluded to. It was published in the British Journal of Industrial Medecine, as he said, in 1983. It covered a period of 1942 to 1980. It covered over 13,000 workers and 99% of that population was traced. Chrysotile was the fibre used except for a brief period prior to 1945, some crocidolite was used and they were able to isolate those people that had been exposed to that.

"The experience of this factory, over a 40-year period, showed that chrysotile asbestos was processed with no detectable excess mortality."

I would chalenge us to use our dusts in such a way as to experience no excess mortality. Dust then, as I am defining it today, does not equal asbestos. It means "any fine, dry, pulverized particle of matter; particles into which something disintegrates; something worthless..." that we find can be very costly. And then, as defined by Webster, "a fibre is a slender and greatly elongated natural or synthetic filament", and he said, "as of wool, cotton, asbestos, gold, glass or rayon; an element that gives texture or substance".

Much of the improvement in dust control in the friction industry is attributable to our efforts over the past 15 years, with which I am most familiar, to lowering our asbestos counts.

As we look at yesterday and think of today, let us very briefly look at the history of the regulations that deal with asbestos. The U.S. has been at two fibres per cubic centimeter from July 1976 through June 1986. So, for a ten-year period, we were dealing with a two-fibre standard here, but, in the middle of that time, back in Janurary 1983, when the United Kingdom moved to one fibre, my company adopted that as an international standard. And those of you who did not really adopt it perhaps also began to look at it and realize that we needed to start lowering our counts.

Late that year, in November-December 1983, an emergency, temporary standard was issued, as you will remember, that would have lowerd the count to 0.5 fibre per cc. Now that was overturned in the spring of following year. However, we, again, adopted that 0.5 standard in the fall of 1983 and we have never moved from that. So we have to credit asbestos, really, with having helped us to move into a lower exposure for all of our dust.

I thought I would share with you some actual Nuturn experience over the past 4 to 5 years frrom 1983 to 1986. There are three primary facilities from which these numbers were taken. You will see that in 1983 very few of our counts were below 0.2. By 1984, that had already improved to 40% under and then 46% in 1986, and then 50% in 1987. What I noticed when I really began to look at this, 1985 and 1986 are so flat, it would appear that we did nothing and, in fact, we spent millions. During this same time, we were moving away from asbestos and into some of the substitute fibres. We found - and like I said this is not a technical presentation so I cannot tell you why - but we found dust harder to control in those areas where we did not use asbestos. So all the work we were doing to move ahead and be up with the asbestos-lower count seemed not to be accomplishing any change in the non-asbestos areas. So we had to work doubly hard to get those counts down.

All of our facilities are mixed, some asbestos and some non-asbestos, in the same building and, of course, you know what that means. You have to live with the asbestos standard even if you are in a department that is completely non-asbestos.

For the first nine months of 1987, we do now stand at 82% below 0.2 fibres. We still have 18% that are between 0.2 and 0.5. We have not had any reading this year that have exceeded 0.5 fibres. It was interesting also, as I looked at that, to realize that the entire 18% that is between 0.2 and 0.5 is in non-asbestos areas. But, again, our people have to wear respirators, face masks because we have asbestos in the plant.

All of us, essentially, control dust in three ways: Engineering controls, work practices, and then personal, protective equipment. Of course, personal, protective equipment is not really a dust-control measure but rather a dust-exposure control measure. Our workers can have a significant impact on the level of dust and fibre to which they are exposed.

> *On a sample test, one person doing one job for 10 consecutive workdays, had a variation of count, ranging from a high of 0.49 to a low of 0.13, an average of 0.28. At the time we were running*

this test, we did a personal as well as an area sample. The area sample is much flatter, remaining below 0.10 throughout the ten day period.

So the key to the quality of our dust-control effort is largely dependent on how adequate and accurate our hazard assessment is. Work place studies are an essential part of such an assessment. We believe that we will not really attempt to control dust or any other hazard if we have not properly assessed the risks.

What are the worker exposures? What kinds of dusts and other toxins are they exposed to? We must then reduce our own worker exposures, keep our workers trained and informed through classroom and other on-the-job training - and I think that meeting the requirements of the hazard-communication standard helped us all a lot in this regard - as well as making our Material Safety Data Sheets available to our own employees and those of our customers.

Material Safety Data Sheets, as supplied by Nuturn for any fibre that I have listed here, include a reference to the Nuturn international standard of 0.5. You will notice that some of the fibres have different standards. Aramid, as I understand it, does not have an OSHA standard, but the major supplier here recommends a standard of 0.5 fibres per cubic centimeter.

As for ceramic, the two major suppliers with which I am familiar recommend a 0.2 fibre standard. Some of the others were simply classified as nuisance dust. But our Material Safety Data Sheets will give the information from the supplier, but also indicate that our internal work practice is 0.5 and that we recommend our customers use that same standard.

To understand why we treat all fibres the same, we must look at the fibres through a microscope. Magnified a thousand times, when the readers look through the microscope and see this fibre, of course they can count. For a combination of aramid and asbestos fibres, our readers cannot tell the difference, so they are going to count that too. Sometimes the readers can tell the difference in ceramic fibres, and under the new OSHA standard, they are allowed to eliminate that if they are totally sure it is not asbestos.

Mineral wool also appears very much the same. So all four fibres are more than likely to pick up under phase contrast microscopy as a fibre. We may very well then ask what the future holds and what we can do to have a positive impact.

One of my technical managers one time explained to me the problems he had when he began to substitute asbestos and, if I remember right, he used a glass of water as his example and said:"this glass of water was completely full. Now, half of it has been poured out and I have been told to fill it up again with something that looks like water, tastes like water, performs like water, makes the flowers grow but cannot be water". Well, I was really impressed as the job he was faced with was dealing with asbestos. When you take 50%, approximately of the product out of the material and then say, "replace it with something that will do just as good a job", then that is quite difficult. I am sure that many of our formulators feel that after they have removed all the fats and carcinogens, there is just not anything left!

I would challenge then that we have no need to overreact or panic or become irrational regarding asbestos or its substitutes. We must, however, take positive actions, change our material-handling practices and worker attitudes and have a true management commitment that permeates our decisions. That commitment then can be shown through some specific actions.

We can all play a part in more efficient, dust control. Someone here is responsible for equipment maintenance, no doubt. Do you check the pipes, the bag houses or other removal equipment for leaks or cogs? Do you inspect periodically for tears, especially if there is a loss of efficiency? Is make-up air efficient? Look at inlet air from make-up air units and supply fans. Look at outlet air from stacks, boilers, wheel abrators, bag houses, exhaust fans. Balance is critical and may be somewhat challenging because of varying system demands.

Consider a slight negative pressure in manufacturing environs. Is dust allowed to accumulate on plant interiors? Consider sufficient full-time people to keep the common areas, the walls, the pipes, the walkways spotless. It is absolutely amazing what a good job a worker will do with his own work area when, all around him, it is totally clean. Do you have poor, bag handling techniques? Mixing techniques? Bag disposal techniques? Perhaps you could formulate to use full bags of raw material so that a half empty bag is not left sitting around. Perhaps you could get your vendor to supply to you in the quantity that you need for your particular mix. Are spills cleaned up immediately? No sweeping, remember, and use only vacuums that have high efficiency particulate air filters.

Our health and safety personnel, when they make their inspections, carry tape with them so that, if they see a bag that is torn on the dock or in the warehouse or on the floor, they can immediately tape that bag so that no dust can fall into the work area. Are dry mix bins left uncovered? Do you leave the bin just sitting out open, or could you put poly or cardboard or metal over those bins?

Are personal fans used and where do they direct the air? Do they direct the dust into the worker's face or do they direct the dust into the extraction system? Even gas-powered fork-trucks can unsettle dust. There is nothing new and different or fancy about these items. Often, however, we are so close to a situation that we do not see the pitfalls.

Consider an outside auditor who simply comes into your facility to look at nothing except the way you handle dust... no other health and safety concerns, simply how you deal with dust. We did that two years ago and, in fact, have it scheduled again this month. I was just absolutely amazed at the things that I had overlooked and this outsider immediately solved and was able to help us correct some problems.

Formulators and R and D people, can you think less dusty? Can you try some less dusty components? If you are involved in production, you certainly can encourage and enforce careful material handling. Process engineers then, of course, are called on to compensate when the other two people do not quite get the job done. Industrial hygienists and health and safey and employee representatives need to liaise and bring all forces to bear. Be objective in dealing with all health and safety and dust-control issues and keep everyone on their toes.

Without a doubt, we are still doing something wrong and I wonder what criticisms the next generation will level against us. But, hopefully, this brief look will help us realize we need to maintain balance in our operations, taking the necessary precautions to protect ourselves, our workers, our customers, and continue our efforts to stay well informed. We must have a healthy respect— and that is no freudian slip— for all the fibres and dust we use, managing what we call substitutes in the most rational way possible and continuing to use dust control equipment as we minimize the potential for fibre release.

WET AND DRY METHODS FOR DUST CONTROL IN BRAKE REPAIR SHOPS

Jim Clayton
Clayton Environmental
Farmingdale, NJ

I was asked to speak about the cost of performing brake servicing with and without the use of engineering controls. Engineering controls add to the cost of performing a brake job without increasing revenues for the shop owner. These costs are often perceived to represent a barrier to the introduction of engineering controls to the private sector vehicle maintenance facilities.

As an entrepreneur and small-business man myself, I can fully empathize with businessmen and women who strive to control and reduce costs. It's very difficult to create hard numbers to represent the cost of using various engineering controls. While these costs are indeed significant, I believe that they are not so high as to preclude widespread acceptance of engineering controls.

I'd like to take a moment and acquaint you with my background and experience. I am the president and founder of a small business which designs, manufactures and markets engineering controls to vehicle maintenance facilities. For the past four years, I have travelled the U.S. and visited hundreds of such facilities and have had the opportunity to speak at length with thousands of professional mechanics who service and repair vehicle brakes and clutches. As a result of this experience, I have gained valuable knowledge on the subject of engineering controls and the acceptance of these devices by mechanics.

What types of engineering controls exist and how are they used to protect mechanics?

Engineering controls are products and/or devices which achieve some measure of control over occupational hazards thereby eliminating or minimizing worker exposure. These devices are designed to protect workers by controlling the potential for exposure by focusing on the source of that hazard and controlling emissions from the source.

By contrast, personal protective equipment, for example respirators, gloves, impermeable coveralls, etc., all provide a protective barrier on or about the worker, thereby isolating him or her from the hazards which continue to exist in the work place.

Engineering controls are the preferred means to protect workers. Personal protective equipment is used as a default option when engineering controls are unavailable or they may be used as an additional means to achieve greater safety when engineering controls are in use.

Engineering controls designed to protect mechanics and other workers from exposure to hazardous dust encountered during brake and clutch servicing can be categorized as either wet-type or dry-type. Wet methods may be as simple as a rag, sponge or brush used to apply soapy water from a basin. Other wet cleaners may be dispensed from aerosol cans or through the use of numerous wet cleaning systems which employ a spray or brush application of the cleaner. These methods generally contain a drip-pan or basin which is used to collect the solution which washes over the brake assemblies.

Dry methods commonly employ a HEPA (High-Efficiency Particulate Air) Filter Vacuum which is used alone or in conjunction with an enclosure device. A HEPA Filter is a generic description for high-efficiency filters which capture microscopic particles and must have a minimum collection efficiency of 99.97% on particles which are 0.3 microns or greater in size. An enclosure device is generally a bubble or cylinder which is placed around the brake assembly to achieve greater containment and collection of dust from the brake assembly. (Mechanics often relate these enclosure systems to sand or bead blasters which are commonly used to clean parts.)

Comparing the cost of using engineering controls to using no controls at all is moot. Today, we recognize the hazard of human exposure to dust containing asbestos fibres. Additionally, we have a justifiable concern for the health hazard potential resulting from exposure to dust of non-asbestos friction products as well. In the presence of these real and potential hazards to occupational health, how could one put forth an argument for continuing the practice of doing nothing to protect mechanics?

The use of any personal protective equipment or engineering control results in a non-revenue producing expenditure which will add to the cost of operations. Payback on these expenditures will be intangible in form and difficult to measure at best.

Initial purchase prices for engineering controls range from several hundred to several thousand dollars. In addition to the initial outlay, there is also the cost of consummable materials and supplies plus the cost of any additional labor resulting from their use.

Added labor cost is frequently estimated or imagined to be greater than it really is. Even the old technique of using compressed air to blow off the brake assembly adds to shop costs. Typically a mechanic will blow dust off of the brake and be forced to leave the area until the resulting cloud of dust dissipates. A conservative estimate would be that the use of an engineering control, in any form, will probably add three to five minutes to the service work for each brake assembly which is inspected and cleaned.

Important, yet hard to measure benefits of using engineering controls are:

(1) improved morale in workers who recognize and appreciate management's efforts to improve their work environment;
(2) a cleaner work environment for mechanics, management and anyone else visiting the service area;
(3) reduced absenteeism because workers will be healthier, and
(4) in the event of litigation for work related disease and disability, management will have demonstrated its commitment to maintaining a safe and healthy work place.

Mechanics acceptance of these engineering controls is great and continuing to increase. Mechanics today are more safety conscious and more concerned about occupational health than ever before. While asbestos has given impetus to the development and use of engineering controls most health professionals and mechanics recognize that the need for this equipment extends to non-asbestos products, also, at least until such time as these new materials are demonstrated to be free of any adverse health consequences.

SESSION III

FIBRES AND HEALTH ISSUES

SUMMARY REMARKS

Arthur M. Langer
The Mount Sinai School
of Medicine, New York, NY

It is the perceived risk to health from asbestos which has driven the field of research on fibrous substitutes for use in friction formulations. Although chrysotile asbestos performs admirably in these composites, concern has been voiced about the effects on the health of workers who fabricate, install, and repair brakes. The possible risk to health among people in the general population, who experience low-level exposure to fibre which may under some circumstances be emitted from brakewear debris, is an issue as well. These concerns have been outlined in the United States Environmental Protection Agency's (EPA) proposed ban on asbestos importation and manufacturing in the United States. The ban, which includes asbestos-containing friction products, is in part based on the notion that substitute fibres are available which are inexpensive, biologically "safe" through their entire cycle of use, and are capable of equivalent performance standards. Are these assertions true?

Dr. Nolan informed us about the complex properties of inorganic fibres and how these properties control their toxicity. Asbestos is a commercial descriptive term for different fibrous minerals with peculiar and unique properties. The mineral fibres marketed in the United States today as asbestos are chrysotile, amosite, and crocidolite. They are different on a mineralogical and physicochemical basis, and these differences carry over into the area of biological potential. Although each of these fibres may be associated with the asbestos diseases, they show attack rates which range considerably. As an example, crocidolite produces many mesotheliomas, whereas chrysotile produces very few. His supporting evidence included data which show some 2,000 mesotheliomas among workers from the crocidolite fields of the northwestern Cape Province of South Africa as compared to some 20 mesotheliomas among workers from the chrysotile mines and mills of the eastern townships of Quebec. These data show the following:

The varietal types of asbestos fibres display different properties. As a result of these differences, they possess different toxicities and produce human disease to greater or lesser degrees.

In addition to the profound differences in properties and activities exhibited by the different asbestos fibre types, single mineral varieties may exhibit a range of properties, properties which are both natural and superimposed, that effect biological potential. For example, chrysotile which has been acid-reacted produces fewer mesotheliomas in laboratory animals as compared to the unreacted fibre; chrysotile which has been ground in a ball mill for size reduction shows a marked decrease in crystallinity, and a concomitant reduction in cytotoxicity and carcinogenicity. Also, amosite in the Transvaal of South Africa has produced only some 10 mesotheliomas among the thousands of workers in the mines and mills of the area whereas the same amosite, used for making ship insulation and lagging for the United States Navy in Paterson, New Jersey and Tyler, Texas, has produced a 5% mortality due to mesothelioma among the plant workers. Dr. Nolan suggested that re-fibreization in the United States altered fibre diameter, fibre length, dust surface area, absolute fibre number per unit mass of dust, and that these alterations concomitantly produced a change in biological potential of the fibre.

It was also important for Dr. Nolan to mention lung cancer mortality in chrysotile-exposed workers. Among the industries cited, i.e., textile, cement, friction product manufacturing, and mining and milling, the standardized mortality ratios for lung cancer range over an order of magnitude at the same "dose" (exposure) value. He explained this range on the basis of dust character. What he did not include was an unpublished prevalence study of about 1200 brake repair workers which showed comparatively little pleural or parenchymal diseases among present employees with more than 20 years of work history. The superimposed properties, imparted from product use, further diminished chrysotile's activity. What are the important conclusions?

Single fibre types can possess a great range in biological potential as a function of both natural and superimposed properties. If health risk for chrysotile asbestos is to be compared with substitute or other fibres, then it should be industry — or application-specific. Friction product manufacture with chrysotile carries very low risk of mesothelioma and lung cancer. Dust from worn friction pads may carry an even lower risk.

Dr. Nolan described the Stanton hypothesis to you and its application to the prediction of the probability that a fibre may or may not induce mesothelioma. Although limited in applicability, the assertion is clear that **all** fibrous substitutes for chrysotile, by virtue of shape, are **by definition** biologically suspect. Therefore:

> *All inorganic, durable fibres which are respirable must be tested for their biological activity before widespread introduction into products.*

In further support of this, he showed data which indicated that there are other fibrous minerals, currently unregulated by the Federal government, which produce human mesotheliomas. He mentioned the fibrous zeolite mineral, erionite, and its association with endemic pleural mesotheliomas in Karain, Turkey. The important conclusion to be drawn from these data is:

> *Asbestos fibres are not the only mineral fibres which produce mesothelioma in humans. This crucial variance may carry over to other durable fibres.*

Janet Hughes spoke about human epidemiological studies, focusing on lung cancer, mesothelioma, and dose-response relationships. The slopes of the dose-response curves are presented as linear; a form accepted by virtually everyone. Of course, when investigators generate the mathematical formulations for these curves, **they use data from the linear portions of these curves only**. However, the dose-response curves for asbestos and lung cancer show a very flat response per incremental dose increase in both the low-exposure and high-exposure regions. The "sigmoid portions" of the curves are always dropped from the dose-response calculation for simplification of the mathematical model. It is important to recognize that:

> *Dose-response effects which are extrapolated to low doses from the **linear** portion of the curve may not be correct; they are mathematically unsupportable. Some effects will never be statistically discernible in human populations due to low-level exposures. To paraphrase Galen,* "The poison is in the dose".

Exposure to chrysotile in textile plants has produced high lung cancer mortality and few mesotheliomas among the workers. In comparison, mining and milling, and friction manufacturing has produced small excesses of lung cancer and these excesses only among the most heavily exposed workers. The Berry and Newhouse study from Great Britain of more than 13,000 production workers showed little excess lung cancer (SMR ~1.03) even in those workers with the longest latencies and highest exposure categories. Ten mesotheliomas were found, but these may have been related to the limited crocidolite usage in the plant. Eight of ten mesotheliomas had exposure to crocidolite, this documented through tissue burden study. The study by McDonald and colleages in the friction product manufacturing plants in Connecticut, with some 3,600 odd workers, showed very similar low lung cancer risk. These data support the general impression that:

Friction product manufacturing, with state-of-the-art dust control technology and banned cigarette smoking (Great Britain), carries very low risk to lung cancer. This risk is more than an order of magnitude less than for the same dose chrysotile exposure experienced among workers in the textile industry. The risk for mesothelioma is also very low.

The risk model for mesothelioma, used by the EPA in their asbestos ban proposal, includes the data set of the insulation workers of the United States, basically amosite-exposed, with chrysotile and some crocidolite (if they ever worked in shipyards), and the data set of those involved with insulation manufacturing, e.g., the Paterson workers, an amosite exposure. Dr. Hughes showed that mortality due to mesothelioma is very much greater where exposure to amphibole asbestos has occured. She mentioned important caveats in conducting cross-study comparisons. However, review of cohort data obtained on workers around the industrialized world shows greater excesses of malignant disease, especially mesothelioma, after amphibole exposure, as compared to chrysotile exposure only.

Dr. Hughes mentioned Andrew Chrug's Thetford Mines (Québec) study which shows that in addition to chrysotile present in the pulmonary tissues of workers dying with mesothelioma, there is tremolite present as well. This is another amphibole fibre. Incidently, the work of Patrick Sebastien, on mineral assay of the pulmonary tissues obtained from workers in the Charleston, South Carolina, textile plant who died with lung cancer, also shows the presence of tremolite fibre in high concentrations. Again, the implication is that amphibole fibre may be more important than chrysotile as an agent in the etiology of malignant asbestos diseases:

Tissue burden studies are supporting the epidemiological data which associate greater malignant disease mortality after amphibole asbestos exposure. Chrysotile fibre, which is not measurably contaminated with tremolite, may be associated with markedly less cancer risk in controlled environments.

Dr. Enterline commented on carcinogenicity of man-made vitreous fibres (MMVF) and their toxicity relative to asbestos. He stressed dimensionality and its importance for respirability. He showed data on experimental studies, those involving inhalation, interpleural inoculation, and intratracheal installation of glasses into rats. Small numbers of tumors were produced in the laboratory animals. Dr. Pott's studies from Düsseldorf showed that using rat and hamster models and various routes of administration, MMVF were capable of inducing malignant tumours. Even with small numbers of tumors produced, there are questions concerning the properties of MMVF, e.g., particle number, surface area, chemistry, etc. How do these properties compare with those obtained from study of the asbestos minerals?

Man-made vitreous fibres, of many varieties, in a number of experimental models, have produced malignant tumors in laboratory animals. Although the routes of administration may have been artificial, the doses high, and the animals sensitive to the dust, the end-point of malignancy appears to be biologically plausible. Multiple species of animals and routes of administration lend credence to concern. Caution is advised before widespread use of any MMVF as an asbestos substitute, especially in the absence of controls and control guidelines.

And what about human studies? The cohorts studied in the United States and in Europe show that continuous filament fibre and glass fibres have shown no excess lung cancer, but rock and slag wools have. These excesses are small but statistically significant.

Using lung cancer SMR's, Dr. Enterline compared MMVF with data from the Charleston, South Carolina textile plant. The Charleston plant has the highest standardized mortality ratio for lung cancer among all asbestos cohorts. The reason for its use, I assume, is that the best dust-level information comes from this plant. Unhappily, it compares the greatest lung cancer risk for asbestos (~1100%) with that of mineral wool, with an excess of about 48% of lung cancer. This comparison may have been more meaningful if he had chosen data from, e.g. friction product manufacturing in Great Britain (~3%):

Comparisons of toxicity of MMVF should be made with the material it is being considered as a substitute for. If MMVF is substituted for asbestos textile manufacturing, then the SMR's from Charleston would be appropriate. However, if MMVF is substituted for asbestos in friction formulations, then data from other cohorts would be more appropriate.

In terms of small-diameter glass fibres, we need more data. The problem of excess lung cancer in MMVF-exposed workers could be one of dose. Dr. Enterline ended his talk with the request for continuing these studies to piece these data together.

Experimental studies were presented by **Dr. Donaldson** of the Institute of Occupational Medicine, Edinburgh, on aramid and ceramic fibres. His laboratory used a number of testing models, both *in vivo* and *in vitro* in design. The kevlar material could not be aerosolized for inhalation study so that a different route of administration was required for animal exposure. The results were mixed. The ceramic fibre, Kaowool, an aluminum-silicate, is biologically active. It appears to be a material which warrants concern. Reports of inflammation (these materials induce inflammation in intact animals) could be important in terms of tumor promotion. For example, the bulk of lung cancers among the asbestos-exposed workers is associated with cigarette smoking. Many experimental studies indicate asbestos fibre acts as a co-carcinogen or promoter insofar as lung cancer is concerned. Therefore, data produced on substitutes should also focus on their promotion potential for lung cancer. In this regard:

> *Although the biological end-points considered important are frank malignant tumours, scarring and inflammation may be of great consequence for cigarette-smoking workers.*

Experimental models cannot be easily compared. Although a single experimental model may suggest a material lacks activity, a full data set, obtained on as many systems and models, should be sought.

Bob Glenn, the Director of the Pneumoconiosis Unit of NIOSH (Appalachian Laboratories), focused on wollastonite. In the data he reviewed, we saw that the number of individuals studied is small, their corresponding exposure latencies short. Chronic bronchitis among American workers studied in 1976 did not reappear in the 1982 follow-up study. There were small numbers of "simple pneumoconiosis" observed in only 3 of 108 individuals. There were no pleural changes nor was there any progression of scarring. The data from Finland cannot really be compared with those of the United States because of these, as well as other, fundamental differences. One such factor may be the mineral deposits themselves, in which mineral contaminants and dose are controlled by local geological features. The important lesson learned from these data is:

> *Although mineral substitutes may be proposed for asbestos, both biological and human data from many sources are needed for evaluation of toxicity. Mineral deposits range considerably in quality of ore and associated contaminant minerals. Therefore, data from one source should not be considered a universal experience. Wollastonite has limited practical appeal as an asbestos substitute in that only several hundred thousand tons of high quality ore is available for exploitation. Its harshness also limits its suitability in a number of applications.*

Ernest Rosenberg of the Alternate Materials Institute (AMI) stated, among his many comments, that the EPA is interested in asbestos in the ambient environment, and that the EPA perceives asbestos in friction products as a major source of this air pollution. The EPA experts consider chrysotile in ambient air to constitute an unreasonable health risk to the general population. Therefore, asbestos and its products should be banned. So says the EPA.

> *However, the assessment of risk of asbestos disease among people in the general population by the EPA is based in large part on data obtained on amphibole-exposed workers in the*

occupational setting. The risk attributable to chrysotile should be based on chrysotile data.

Dr. Nair, from the Monsanto Company, produced data obtained from a number of elegant animal studies. Unfortunately, Dr. Nair used the Stanton model for exposure, a pledget vehicle surgically implanted in the thoracic cavity of animals. The outcome was production of fibrous sarcomas consistent with mesothelioma. She commented that perhaps the numbers of particles "overwhelmed" the biological system. This conclusion was also reached by Dr. Wagner, of Cardiff, when he tried to reconcile mesothelioma data for chrysotile in animals with humans. "Why is it that chrysotile asbestos produces mesotheliomas in laboratory animals to a high degree, and why is it we see so few in humans?" he said. Chris Wagner maintained, as does Dr.Nair, that the chrysotile itself was administered in such great concentrations that the dose delivered to the "target" tissue overwhelmed the biological system. What is it we may conclude from the observations?

Fibre exposure and route of administration into an intact animal has always required the most careful attention so that the model is biologically relevant. Multiple animal species and routes of administration buttress biological data sets obtained on animals.

Dr. Wheeler presented her data on the metallic and semi-metallic brake residues and again showed us that results may be related more to the nature of the assay used rather than the materials themselves. Cytotoxicity measurement is a more defined and limited end-point. The cytotoxicity of crocidolite or amosite has never been very great, much less than that assayed for chrysotile. Yet, in terms of disease production, the amphibole fibres are more active. Obviously, cytotoxicitiy data must be used with a different biological outcome in mind other than carcinogenic potential.

Lack of cytotoxicity of substitutes is just a single data-point. Based on data obtained for amphibole asbestos minerals, additional data sets are required in the assessment of biological potential.

In summary, this session has attempted to convey to the audience an overview comparison of the biological properties of chrysotile and many proposed asbestos substitutes: **chrysotile in friction formulations may not be as hazardous nor substitutes as safe, as we previously thought.** Data from a number of sources, both human and experimental, suggest that chrysotile used in controlled work place environments for friction formulations may carry little risk of disease. Data also suggest that most of fibrous substitutes studied must be controlled in the work sites where exposure to workers may occur. Additionally, fibrous substitutes need to be tested *after use* in that alteration may introduce unwanted properties.

A dust exposure standard should be considered for each new inorganic material introduced into the work place. Asbestos minerals, non-asbestiform silicate minerals, man-made vitreous fibres, organic fibres, and all other proposed friction substitutes require some form of dust control. As data are gathered and standards evolve, some permissible exposure levels may increase and some may decrease. Prensently, all materials are subject to scrutiny.

QUANTITATIVE ASPECTS OF FIBRE MORPHOLOGY

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Abstract — *Both man-made and naturally occurring mineral fibres have been shown to be biologically active. These fibres are solids which can be amorphous or crystalline. The fibres display two common features: morphological appearance (form) and surface structure (which imparts surface chemistry). The fibre length and diameters can display significant variation over a range of sizes, which have profound effect on biological activity. This extent of variability has been shown for single fibre types and appears to hold true among the different types of fibres.*

The fibre dimensions are important for both in vitro *and* in vivo *experiments. Aerosol stability is important for inhalation potential and site of deposition, while length and diameter (which control surface area), and surface chemistry are important once the fibre is at the target tissue. The term diameter is misleading by implying that all fibres are cylinders and therefore have circular cross-sectional configurations. This need not be the case.*

The surface structures of the different fibre types can impart large differences in their physico-chemical properties. Within a single fibre type the surface structure can vary depending on mechanical manipulation, conditions of fibre growth, chemical modification, and thermal history.

The diseases which the inhalation of fibrous minerals are most strongly associated with are fibrosis of the lung, lung cancer (greatly enhanced by cigarette smoking) and mesothelioma. Depending on the physico-chemical properties of the fibres, the stability to induce each of these diseases can vary over orders of magnitude.

INTRODUCTION

Health hazard evaluation of fibres involves the integration of information obtained in a variety of ways.

- Epidemiology studies to determine if a population of people exposed to a fibre (or fibres) have a higher mortality from a particular disease(s) than would be expected for the general population (Wagner et al., 1971; Wagner et al., 1980; Doll and Peto, 1985).
- Animals exposed to fibres using various routes of administration (Wagner, 1962; Wagner and Berry, 1969; Berry and Wagner, 1969; Pott et al., 1974; Wagner et al., 1974; Pott, 1978; Wagner and Pooley, 1986).
- Effect of fibres on single cell types and organs in culture to evaluate cytotoxicity, genotoxicity, activation of particular enzymes and metabolic pathways, characterization of the physico-chemical properties of fibres by which cells recognize them, etc. (Beck and Bignon, 1985).

The aspect most common to the above research areas are the fibres. In environmental exposure and experimental studies physico-chemical characterization is important to associate the characteristics of a fibre dose with a particular biological outcome. Fibre and chemical carcinogenesis differ in that fibres exert their biological effect not as individual molecules but as macroscopic objects. Therefore morphology has been considered a determinant of a fibre's potential to produce adverse health effects. (For review see Harington, 1981).

A single mineral most commonly exists with a distribution of fibre diameters and lengths (National Research Council, 1984). A single fibre type, depending on physical manipulation or origin, can display a range of size distributions. It follows that different populations of the same fibre, of identical mass will most commonly show different surface areas, particle numbers, and size distributions. A quantitative description of fibre morphology, the origins of the fibre morphology hypothesis, and the limitations of this hypothesis, is the subject of this paper.

QUANTITATIVE DESCRIPTION OF THE MORPHOLOGICAL CHARACTERISTICS OF PERFECT FIBRES

A population of fibres can be described on the basis of morphology. The regulatory criterion for an object to be referred to as a fibre is that its length be 5µm or greater and that its long axis exceeds its width by a ratio equal to or greater than 3:1. The ratio of length to width is referred to as the aspect ratio. A fibre population will contain a distribution of fibres of various lengths and diameters. Often only these two dimensions are used to describe three dimensional fibres due to the assumption that fibres are cylinders. The cross-sectional configuration of the fibres are not often described. The extent of variation in surface area and particle number per unit mass of dust will be determined by the size distribution, density and cross-sectional configurations of the component-fibres.

For the purpose of analysis an idealized fibre population which has a uniform length of 9μm is considered. The cross-sectional configuration is assumed to be square and the size of the square will be varied across a range of sizes similar to those which are respirable (**Table 1**). Both the surface area and the mass of the individual fibre increase as the square becomes larger and the aspect ratio decreases. The surface area of the the idealized fibre is completely defined by the sum of all its dimensions. The mass of the fibre is dependent on the density (mass per unit volume). Populations of different fibres, of identical number and dimensions, will have *different masses* which can be rationalized and calculated using density data.

A fibre has at least two distinctly different surface areas. One is the sum of all surface areas expressed by planes along the length of the fibre axis, and the other is the sum of both cross-sectional areas on the fibre ends. The percentage of the total surface area of the fibre which is cross-sectional varies as a function of the end-square size. For small diameter fibres (small end areas) with high aspect ratios the surface area at the ends contributes very little to the total fibre area. Conversely, as the diameter increases, this contribution becomes more significant (**Table 2**). Therefore the surface area of long, narrow diameter, fibre is very dependent on planes defining the fibre sides (length) and not the planes defining fibre ends.

It is useful to understand surface area and fibre number in terms of populations of fibres. A convenient method for selecting a population of fibres is by mass. When comparing two populations of fibres of identical dimensions both the fibre number per unit mass and the surface area per unit mass will vary with the *density* of the fibre. Fibres of high density require fewer particles to constitute the same mass value as compared to fibres of low density. Therefore it is useful to calculate these values for a range of densities as well as end-square sizes. The smallest end-square size, coupled with the lowest density, will yield a dust with the greatest surface area and the largest number of fibres per unit mass. These values will decrease by almost 43% for a 9μm fibre of any given square-end size as the density increases from 2.00 to 3.50 g/cm^3 (see **Tables 3** and **4**). As the density increases, each individual fibre increases in mass and the absolute number of particles required to constitute a gram quantity of dust decreases.

First, consider the number of fibres/g, again assuming the fibres are 9μm in length with various end size squares for cross-sectional configuration. The number of particles, per gram, is reduced by 99.97% (which is over a 3500-fold reduction) as the diameter of these fibres increases from 0.05 to 3.0μm (**Table 3**). The number of fibres, within each square population, changes with density, although the percentage change in the number of fibres as a function of square size is the *same* for each density. Secondly, the surface area (m^2/g) is reduced by a factor of 50-fold as the square size increases from 0.05 to 3µm for each given density (**Table 4**).

The assumption that the fibres have square cross-sectional configurations is useful to simplify the problem for a calculational analysis. For a 9µm long fibre with a cross-sectional configuration of a circle (diameter = 0.05µm), square (0.05µm by 0.05µm) and rectangle (0.05µm by 0.0025µm) the total surface area is 0.00086µm^2, 1.81µm^2 and 0.945µm^2. The error in the surface area calculation may be large if an incorrect cross-sectional configuration is assumed.

Real fibres differ from ideal fibres in many ways. Asbestos occurs with many individual fibrils closely packed to form fibre bundles. The splayed ends, and the contoured surfaces, are commonly referred to as polyfilamentous (**Figure 1**). Manipulation to disaggregate these fibre bundles will significantly alter the size distribution, making the description of the distribution of diameter sizes difficult. Therefore the distribution of diameters is strongly dependent on manipulation of the fibre. Even among the non-asbestiform amphiboles (shown in **Figure 2**) the large distribution of length and diameters is significant. To assume these fibres are cylinders would require justification. Impurities within the fibre specimen such as magnetite or nemalite (Liebling and Langer, 1972) can significantly alter its density. Among the synthetic fibres the process of fiberization may not be complete and therefore non-fibrous particles will be present.

STANTON HYPOTHESIS

The hypothesis that morphology is the single most important determinant of the carcinogenic activity of fibres is often referred to as the Stanton Hypothesis. Stanton and his co-workers concluded that the probability of pleural sarcoma induction was highest in specimens containing the greatest numbers of fibres 0.25µm or less in diameter and more than 8µm in length. (Stanton et al., 1981). These narrow fibres of course have the greatest surface area and particle number per unit mass of dust. This hypothesis was based on an experimental model which involved the surgical implantation of a thin pledget of a coarse fibrous glass 30 x 30 x 2mm, weighing about 45mg, into the pleura of the animal. Generally a forty milligram dose of fibre was allowed to harden, from a gelatin suspension, onto the pledget surface before being placed directly against the visceral pleura of the left lung. (Stanton et al., 1969; Stanton and Wrench, 1972; Stanton et al., 1977; Stanton et al., 1981). Recently mesotheliomas have been induced in rats by intraperitoneal inoculation using 50µg, 800x less than the dose used by Stanton, of fine asbestiform actinolite (Pott et al., 1988, **Figure 3**). The model generated a significant number of tumors with a large variety of fibres.

The fibres were sized by determining the log of the number of fibres in a standardized mass of dust (in thirty-two different indexed size ranges). Statistically the probability of tumor induction was correlated with the number of fibres in the challenge dust having dimensions of less than 0.25µm and greater than 8µm. These experiments raised the possibility that not only asbestos but all fibres of a certain dimension, if durable, might be carcinogenic (Stanton, 1974).

Fibres of the Stanton dimensions are optimum but are not the only fibres possessing carcinogenic activity. Fibres 1.5µm by 4µm also correlate but to a lesser extent (Stanton and Layard, 1987). These "fibres" lack a three to one aspect ratio, are shorter than 5µm (see Dunnigan, 1984, for discussion). Fibres less than 5µm are generally considered inactive. Recently a re-examination of the size distribution of seven crocidolite samples used by Stanton concluded that the optimum size distribution is weak enough that "factors other than size and shape may play a role" (Wiley et al, 1987). Crocidolite was the first fibre associated with human mesothelioma (Wagner et al., 1960; Harington, 1981).

The control experiment involving the implantation of the pledget alone showed no carcinogenic activity. A large literature exists on foreign body carcinogenesis. (Oppenheimer et al., 1958). Implantation of film and coverslips subcutaneously in animals have induced tumors (Brand et al., 1967). The induction of tumor has been shown to be sensitive to subtle surface characteristics of the implanted objects (Bates and Klein, 1966 and Karp et al., 1973). The pledget may sensitize the tissue to transformation by the fibres.

EPIDEMIOLOGY

Adverse health effects, such as increased incidence of cancer and lung fibrosis, among people exposed to a particular fibre is useful information for health hazard evaluation. Unfortunately, these studies require that a population of people be exposed to a fibre, therefore placing them at risk. Additionally, the population may be exposed to a number of other agents also present in the work place which renders interpretation of the results ambiguous. It is also possible for the exposure to occur in a different environment prior to their current employment. For example, the development of mesothelioma among foreign guest workers in Sweden is attributed to exposure to a mineral fibre earlier in their lives, before their immigration from Turkey (Boman et al, 1982). The latency period required for disease to be seen can be many decades from onset of first exposure.

The most important problem in evaluating epidemiology studies is that even among populations exposed to the same fibre type the patterns of disease can be very different. The asbestos textile workers from Charleston, South Carolina have very high excess lung cancer rates (Dement et al., 1982; McDonald et al., 1983). These workers were exposed to chrysotile asbestos. The Charleston mortality experience represents the highest excess lung cancer among chrysotile exposed workers anywhere in the world. Contrasted to this, the workers involved in the manufacture of friction products using chrysotile have little, if any, excess lung cancer deaths (Berry and Newhouse, 1983; McDonald et al., 1984). These differences may be due to exposure levels and the characteristics of the dust and fibre used. Also, smoking in the plant studied by Berry and Newhouse was discouraged (Skidmore and Dufficy, 1983).

Berry and Newhouse reported 11 mesotheliomas among the friction product manufacturing workers they studied. Eight of the 11 had worked with crocidolite on a special project. Additionally, one worker, with mesothelioma, not assigned to the project, may have been exposed to the crocidolite as well. Of the remaining two mesothelioma cases, one was only employed for two weeks and the other had worked for 10 years in an asbestos cement factory before working in friction products. Very few mesotheliomas have been reported among brake repair workers (Langer and McCaughey, 1982). Chrysotile exposure and mesothelioma has recently been reviewed by Churg, 1988.

This pattern of variable attack rate is also true for human mesothelioma. In South Africa, where mesothelioma was first associated with asbestos exposure (Wagner et al., 1960), it had been reported that in mining areas which were geographically separated, although the mining activity of both were very similar, very different mesothelioma attack rates occurred. Crocidolite from Cape Province was responsible for most of mesotheliomas in South Africa (some 1,800) while crocidolite and amosite from the Transvaal area had produced as few as five mesotheliomas, up to 1979 (Harington, 1981). Other factors such as medical services and extent of mining have been discounted and the most likely explanation seems to be differences in fibre dimension, i.e., diameter. (Timbrell, et al., 1971). In the northwest Cape Province the average crocidolite diameter is 0.073µm while in the Transvaal, crocidolite and amosite show average diameter of 0.212µm and 0.243µm respectively. Fibres from both the Cape Province and the Transvaal have induced mesotheliomas in rats by intra-pleural inoculation. The Cape fibre was more effective than the Transvaal in producing mesotheliomas (59% compared to 40%) in one experiment and 68% compared to 31% in another experiment (Wagner and Berry, 1969; Berry and Wagner, 1969). Using the intra-pleural model, the crocidolite/amosite from Transvaal was less active.

A similar argument can be made concerning the lack of reports of mesothelioma among the Finnish anthophyllite workers. The Paakila anthophyllite, mined in Finland, has only about 1%of the fibre with diameter of less than 0.1µm (Harington, 1981).

The zeolite mineral erionite, has been associated with pleural and peritoneal mesothelioma among inhabitants of three villages in central Turkey (Baris et al., 1987). The mortality from mesothelioma among these villages was higher than among heavily exposed asbestos workers. Inhalation experiments with erionite have induced mesothelioma in 27 of 28 rats. The 28 animals exposed to crocidolite failed to develop a single mesothelioma (Wagner et al 1985). In previous inhalation studies using all the commercial asbestos types 11 mesotheliomas were induced in 648 animals. (Wagner et al., 1974). Not only did virtually every animal exposed to erionite develop mesothelioma, but the latency period for the tumors to appear was significantly shorter. The size distribution of the crocidolite and erionite fibres were very similar. The erionite studies strongly indicate additional properties to morphology are important in fibre carcinogenesis.

*

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TABLE 1. For a 9um fiber with a square cross-sectional configuration, the surface area/fiber, mass/fiber, and aspect ratio as a function of square size is calculated.

Square size (um)	0.05	0.10	0.20	0.40	0.60	0.80	1.00	2.0	3.00
Surface area/fiber (um^2)	2.50	4.02	8.08	16.32	24.72	33.28	42.00	88.0	138.00
Mass/fiber (pg^*)									
Density (2.00 g/cm^3)	0.045	0.180	0.720	2.80	6.40	11.50	18.00	72.00	162
(2.53 g/cm^3)	0.057	0.228	0.911	3.64	8.20	14.60	22.80	91.10	205
(3.40 g/cm^3)	0.077	0.306	1.22	4.90	11.00	19.60	30.60	122	275
Aspect ratio	180.00	90.00	90.00	45.00	22.50	15.00	11.25	9.00	4.5 3.00

* Mass given in picogram (10^{-12}) assuming 2.00, 2.53 and 3.40 g/cm^3 the approximative density of erionite, chrysotile and crocidolite respectively.

TABLE 2. The percent of the total surface area which is on the ends of the fiber for a 9um fiber with a square cross-sectional configuration varying square size.

Length of Square (um)	% of Surface Area Which is End
0.05	0.28
0.10	0.55
0.20	1.10
0.40	2.17
0.60	3.23
0.80	4.26
1.00	5.46
2.00	10.00
3.00	14.29

TABLE 3. Number of particle/g of fibers which are a constant 9um in length with a square cross-sectional configuration of various sizes.

Square Size	0.05um	0.1um	0.2um	0.4um	0.8um	1.0um	2.0um	3.0um
Density g/cm^3				Number of Particles/gram				
2.00	$2.17x10^{13}$	$5.56x10^{12}$	$1.39x10^{12}$	$3.47x10^{11}$	$8.68x10^{10}$	$5.56x10^{10}$	$1.39x10^{10}$	$6.17x10^{9}$
2.25	$1.93x10^{13}$	$4.94x10^{12}$	$1.23x10^{12}$	$3.09x10^{11}$	$7.72x10^{10}$	$4.94x10^{10}$	$1.23x10^{10}$	$5.49x10^{9}$
2.50	$1.74x10^{13}$	$4.44x10^{12}$	$1.11x10^{12}$	$2.78x10^{11}$	$6.94x10^{10}$	$4.44x10^{10}$	$1.11x10^{10}$	$4.94x10^{9}$
2.75	$1.58x10^{13}$	$4.04x10^{12}$	$1.01x10^{12}$	$2.53x10^{11}$	$6.31x10^{10}$	$4.04x10^{10}$	$1.01x10^{10}$	$4.49x10^{9}$
3.00	$1.45x10^{13}$	$3.70x10^{12}$	$9.26x10^{11}$	$2.31x10^{11}$	$5.79x10^{10}$	$3.70x10^{10}$	$9.26x10^{9}$	$4.12x10^{9}$
3.25	$1.34x10^{13}$	$3.42x10^{12}$	$8.55x10^{11}$	$2.14x10^{11}$	$5.34x10^{10}$	$3.42x10^{10}$	$8.55x10^{9}$	$3.80x10^{9}$
3.50	$1.24x10^{13}$	$3.17x10^{12}$	$7.94x10^{11}$	$1.98x10^{11}$	$4.96x10^{10}$	$3.17x10^{10}$	$7.94x10^{9}$	$3.53x10^{9}$

TABLE 4. Surface area per gram of fibers which are a constant 9um in length with a square cross-sectional configuration of various sizes.

Square Size	0.05um	0.1um	0.2um	0.4um	0.8um	1.0um	2.0um	3.0um
Density g/cm^3	Surface Area (m^2/gram)							
2.00	39.24	20.11	10.11	5.111	2.611	1.111	1.111	0.778
2.25	34.88	17.88	8.99	6.542	2.321	1.877	0.988	0.691
2.50	31.39	16.09	8.09	5.888	2.089	1.689	0.889	0.622
2.75	28.54	14.63	7.35	3.717	1.899	1.535	0.808	0.566
3.00	26.16	13.41	6.74	3.407	1.741	1.407	0.741	0.519
3.25	24.15	12.38	6.22	3.145	1.607	1.299	0.684	0.479
3.50	22.42	11.49	5.78	2.921	1.492	1.206	0.635	0.444

TABLE 5. Densities of commonly used mineral fibers, synthetic organic fibers and man-made mineral fibers. Densities given in g/cm^3.

Naturally occurring mineral fibers

	g/cm^3 (a)	g/cm^3 (b)
Chrysotile	2.53	2.55
Crocidolite	3.396	3.37
Amosite	3.54	3.43
Anthophyllite	3.09	2.85 - 3.1
Actinolite	2.9-3.2	2.9 - 3.2
Erionite	2.02	
Wollastonite	2.80 - 3.10	
Palygorskite	2.4	
Halloysite	2.114	

Synthetic organic fiber

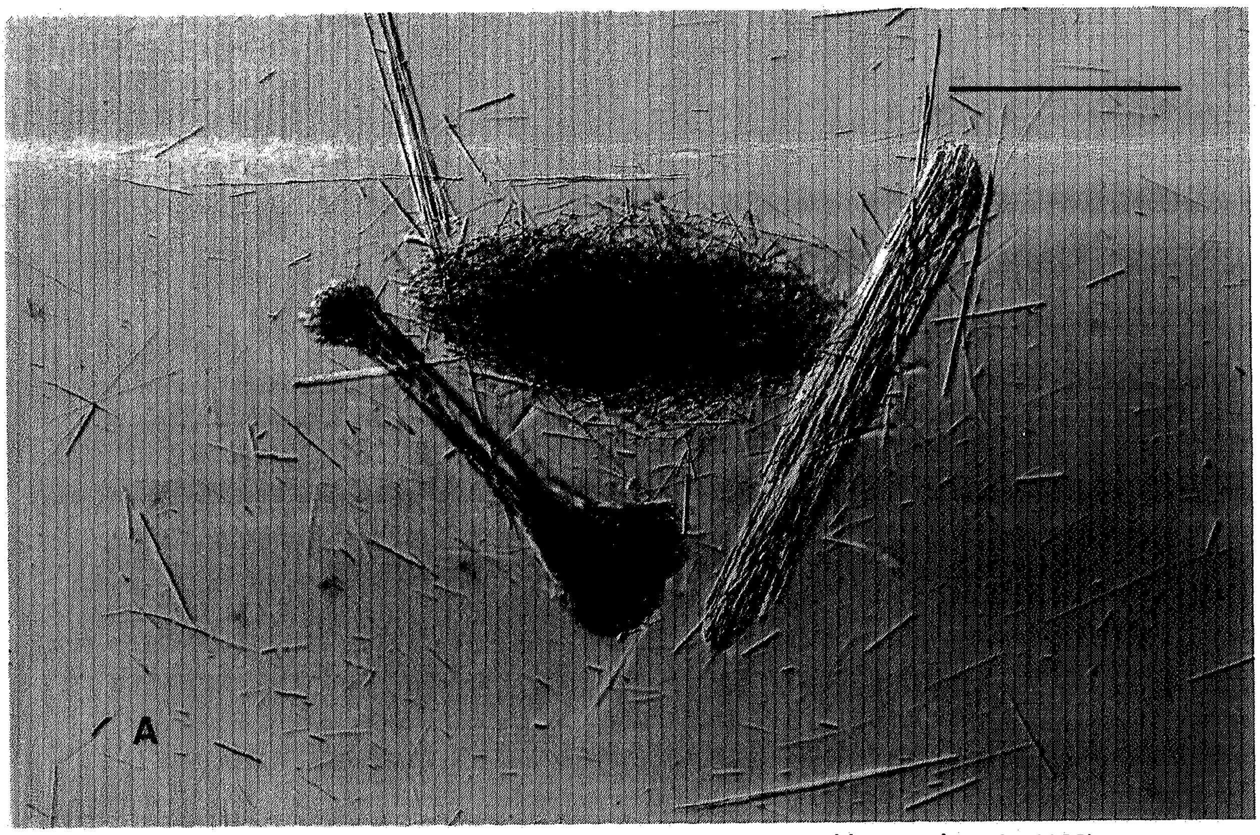
	g/cm^3 (b)
Polyacylonitrile	1.7
Polyvinylalcohol	1.3
Polypropylene	0.9
Kevlar 49	1.45
Kevlar 29	1.44
Aramid (Nomex)	1.38
Dolan 10	1.16
Teflon	2.1

Man-made mineral fibers

	g/cm^3 (b)
Glass	2.5
Mineral wool	2.5
Silica	2.19
Alumina-silicate-zirconia	2.63
Alumina	3.15
Zirconia	4.84
Silicon carbide	3.21
Boron nitride	1.90
Silicon nitride	3.18
Xonotlite	2.7

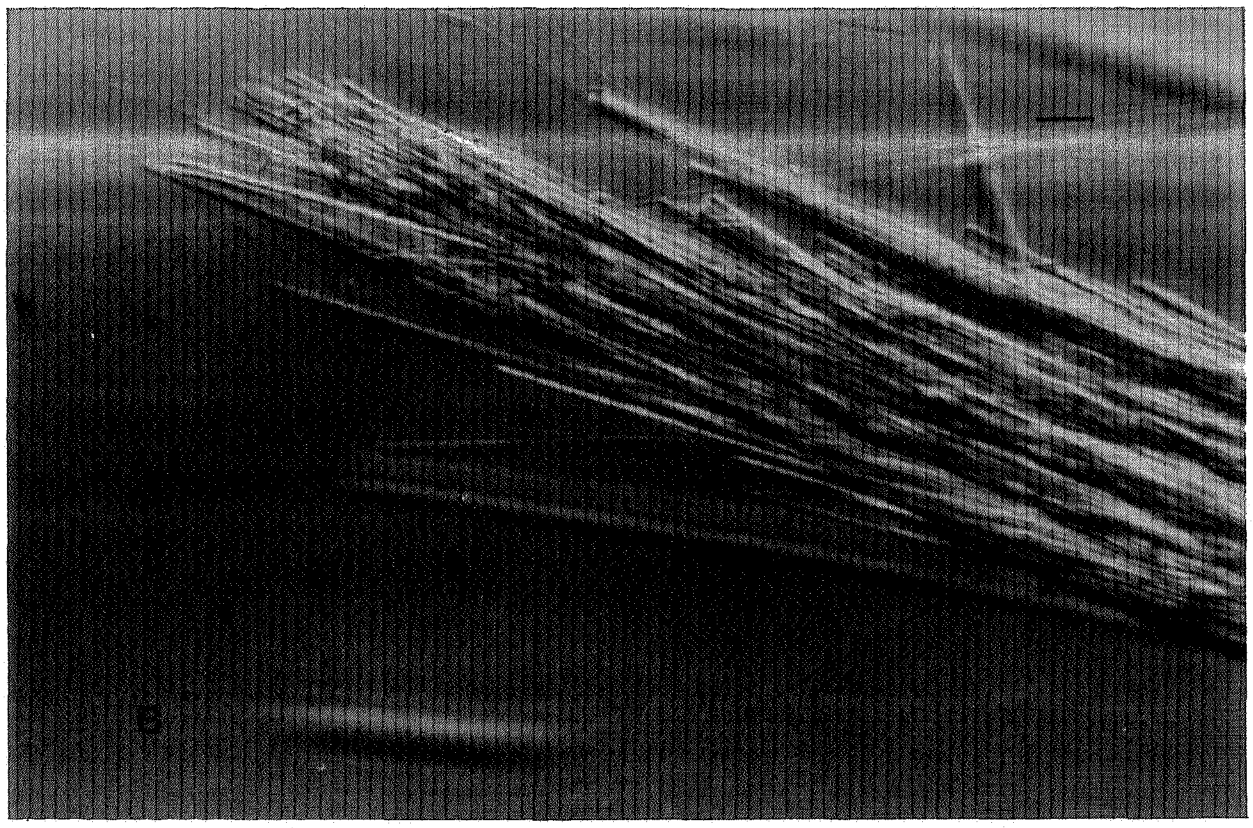
(a) Joint Committee on Powder Diffraction.
(b) Hodgson, 1985 and references within.

FIGURE 1A



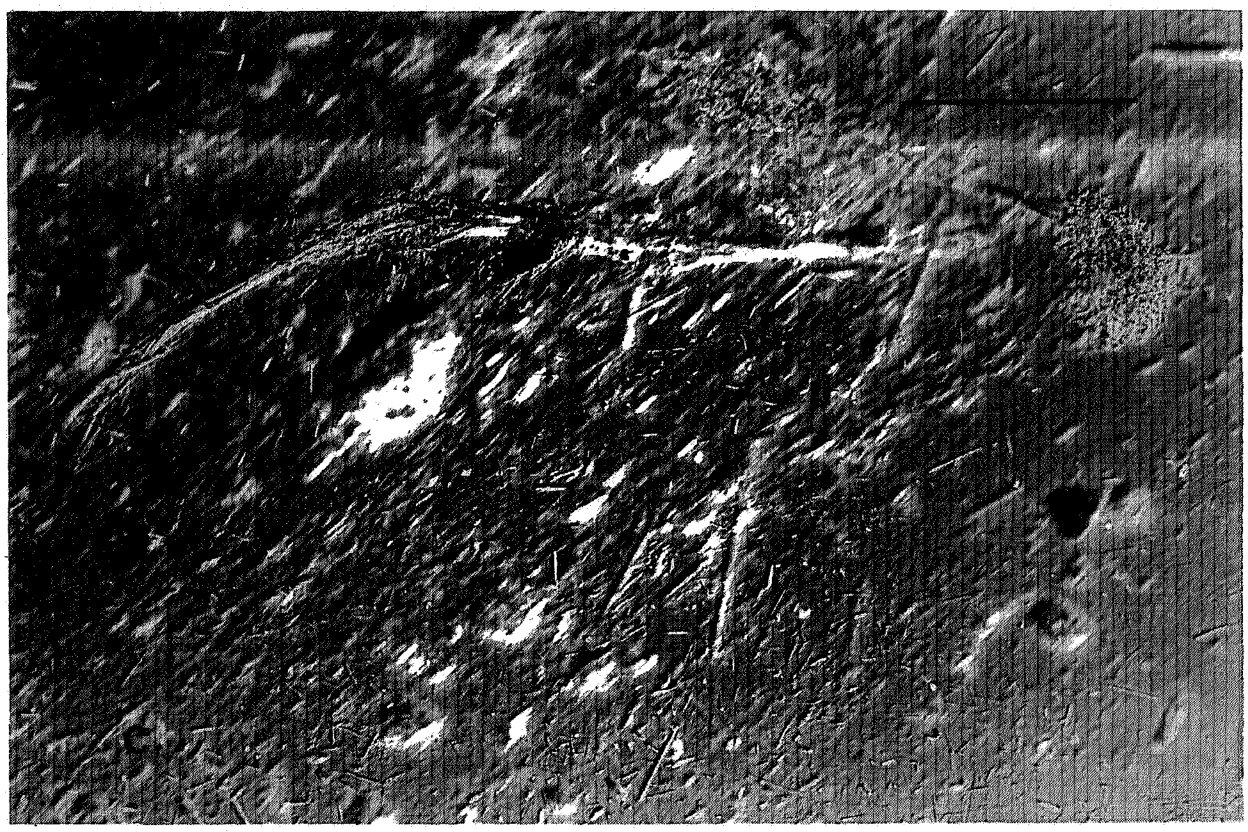
Light photomicrographs of amphiboles Tremolite, Jamestown, California (Addison and Davis, 1988).

FIGURE 1B



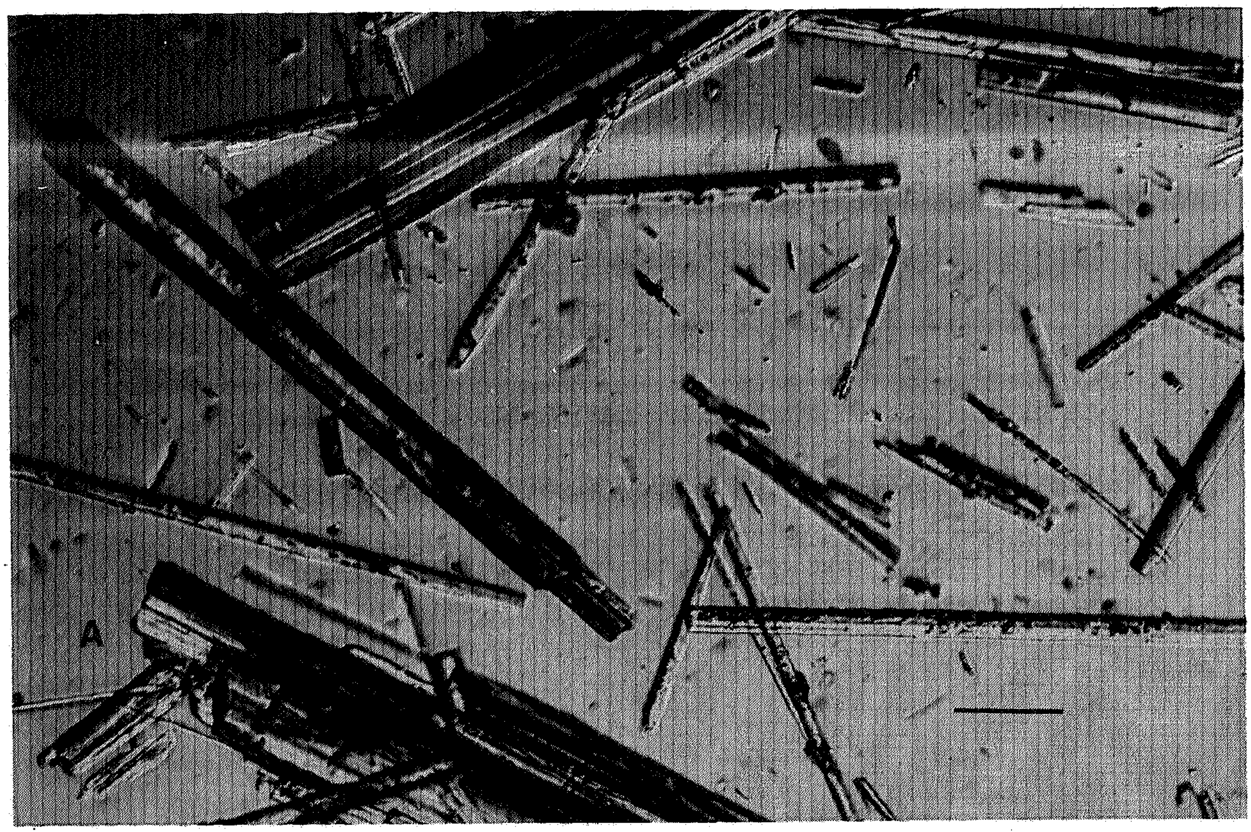
Light photomicrographs of amphiboles Tremolite, Jamestown, California (Addison and Davis, 1988).

FIGURE 1C



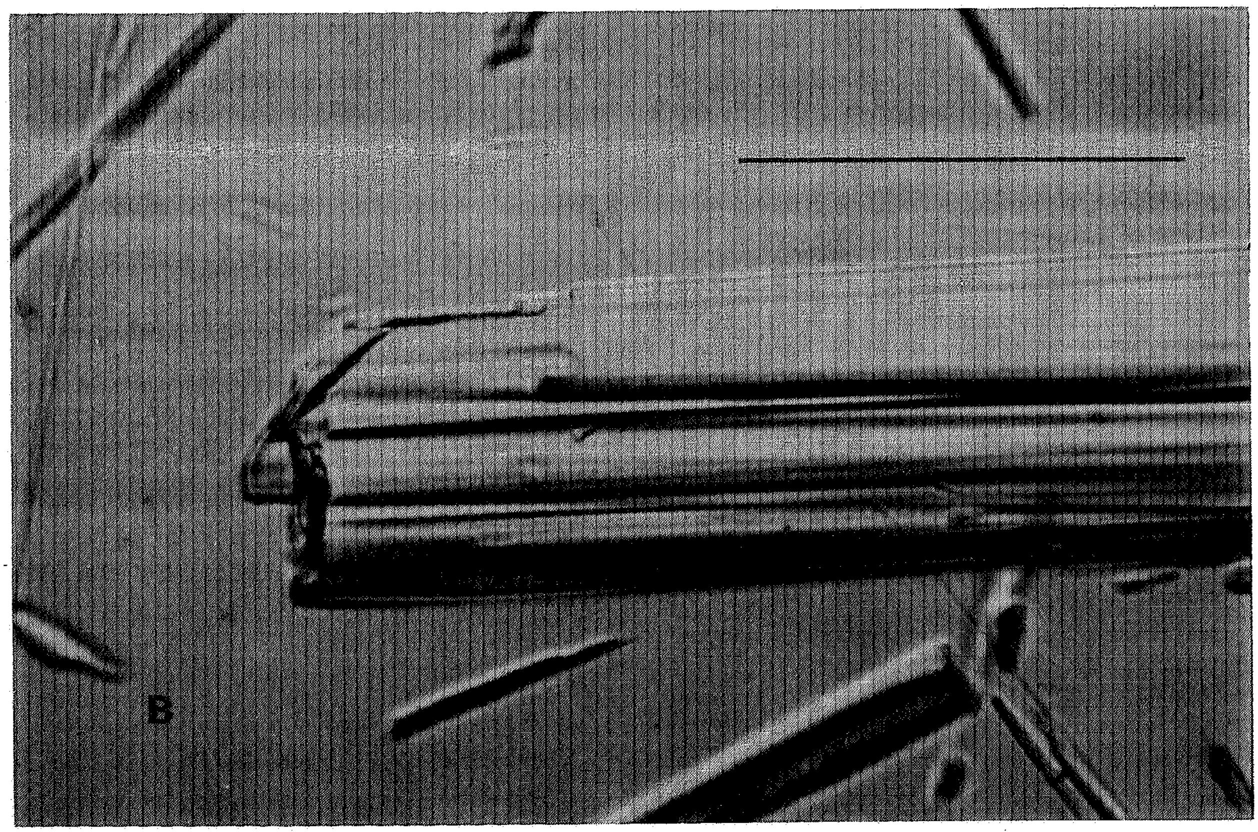
Light photomicrographs of amphiboles Tremolite, Metsovo, Greece (Langer et al., 1987). The polyfilamentous bundles and curvilinear morphology are apparent. Bars represents 200 μm.

FIGURE 2A



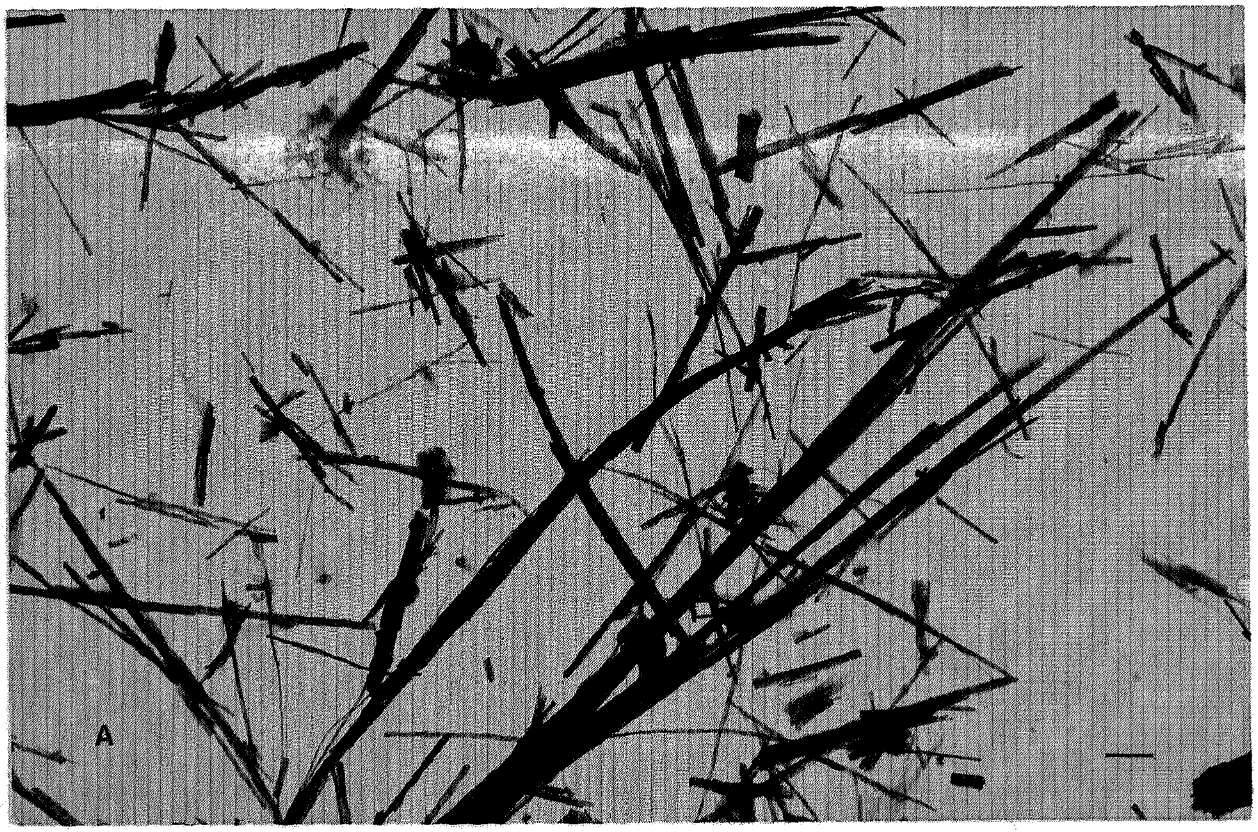
Light photomicrographs of non-asbestiform amphiboles Actinolite, Hamilton, Montana.

FIGURE 2B



Light photomicrographs of non-asbestiform amphiboles Tremolite, Italy (Addison and Davis, 1988). Bars represent 100 µm.

FIGURE 3A



Electron photomicrographs of asbestiform actinolite from Germany (Pott et al., 1988). **Figure 3A** represents the actinolite after sonication with a cell disrupter fo 30 seconds. The fibres are shown to be polyfilamentous, consisting of fibrils significantly less than 1 micron in diameter. (Bar in lower left represents 1.0 micron).

FIGURE 3B

Electron photomicrographs of asbestiform actinolite from Germany (Pott et al., 1988). **Figure 3B** represents a portion of the field in (A) as viewed at higher magnification. Note that many fibrils are narrow in width and curvilinear, rather than "straight sticks". (Bar in lower left represents 1.0 micron).

FIGURE 3C

Figure 3C represents a portion of the field in (A) at very high magnification. Unit fibres, even at high magnification, are shown to possess defect structures, both twinning and Wadsley in nature. Splitting of fibrils occurs along these defect surfaces (see upper left). Fibril marked *"f"* is 400Å (0.04 µm) in diameter, the average dimension of *chrysotile fibrils*. (Bar upper portion of micrograph represents 1.0 micron).

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TOXICITY OF ASBESTOS FIBRE TYPES, AND THE HEALTH EXPERIENCE IN BRAKE MANUFACTURING AND REPAIR *

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We want to consider today what the epidemiologic data are telling us about risks of lung cancer and mesothelioma from asbestos with particular emphasis on fibre-type differences. Speaking first of lung cancer, there have been many studies from numerous countries which have demonstrated a relationship between asbestos exposure and lung-cancer risk.

However, only relatively a few studies have been able to estimate the amount of asbestos exposure of the individual workers and then to relate the observed lung cancer risk to the level of asbestos exposure. When this has been done, we get a fairly reasonable fit to the data using a linear relationship; for instance, doubling of the cumulative asbestos exposure generally results in about a doubling of the excess lung cancer risk.

However, as already indicated, we get quite a difference in the slope of the dose-respose relationships. What we want to point out is that the textile manufacturing seems to have the highest lung cancer risk. If you consider a particular cumulative exposure, for instance, maybe 40 fibre per ml, fibre per cc/years, the SMR for textile exposure is approximately 200, which means the observed number of deaths is about twice the number expected. The lowest slopes have been observed in mining and two friction product manufacturing, workers' studies; for cumulative exposure of, again, 40 f/ml, there is not nearly as much excess risk as in textiles.

There is a lot of speculation why that might be the case. Nobody really knows the answer. Some believe it has to do with the length and diameter of the fibres. In the mining and in the friction product manufacturing, because of the processing of the fibres, perhaps they are much shorter in those industries and, therefore, perhaps less carcinogenic.

For our purposes here in estimating how much the risk might be from friction product manufacturing, we will assume we have a relatively shallow slope.

We now consider briefly the two friction product studies that were represented. It was primarily chrysotile asbestos that was being used; however, for very well defined, short periods of time, crocidolite was used because of

* Transcript of oral presentation.

long term workers; however, there were ten mesotheliomas in this population.

In this study, the authors took these ten people who had mesothelioma and, for each case, found four workers who were comparable as far as being born about the same time and started in the plant about the same time. So the authors had ten people who got mesothelioma and 40 who did not and then they looked at their work histories and determined how much exposure they had and to what fibres. They found that, of the ten mesothelioma cases, eight had definitely worked with crocidolite and another one probably had. So 90% of the cases had worked with the crocidolite, whereas, among the controls, only 30%. So they found a definite relationship between the mesothelioma occurring and the type of fibre the workers were exposed to in the same plant.

The other study of friction product manufacturing workers was done in a plant in Connecticut; there were approximately 3600 workers studied. Here, again, it was primarily chrysotile asbestos, and the amount of crocidolite was very minimal: only about 400 pounds used on an experimental basis.

Among the short term workers and the lowest, cumulative exposure workers, there was some excess lung cancer risk, but not among longer term workers. This has been observed in other working populations. It has been speculated that maybe the short term workers are the people who get assigned to the dirtiest jobs. However, we would still expect to observe excess risk in the long term workers. Another explanation is that the short term workers are different from the general population in other ways, i.e. in their health care, personal habits (smoking), and so on. So if we ignore that group, then, in the longer term workers and people in the higher exposure categories, again, it was similar to the British study, i.e. very little or no excess lung cancer risk in those groups.

However, in this study, there were no mesotheliomas. This is possibly indicative of the differences in fibre type used in the two plants.

Now, speaking of mesothelioma, it is a relatively rare cancer compared to lung cancer. Asbestos is the only commercially used substance which has been demonstrated to result in mesothelioma. As indicated, naturally occurring erionite is generally believed to be causing the epidemic of mesotheliomas in Turkey. Now, because there are many fewer cases, we have even more limited quantitative information from our epidemiological studies for establishing a dose-response relationship between the amount of asbestos exposure and mesothelioma risk.

However, what is known is that the incidence goes up steeply with time; it looks like it rises as approximately a power of three with time from initial exposure. Here, we have three studies which observed a good fit between the number of years since the workers started the exposure and the incidence of number of years since the workers started the exposure and the incidence of mesothelioma. So, in estimating how much mesothelioma risk there might be in a population, incidence is usually expressed as a power of three since starting the exposure.

Now, these studies of mesothelioma incidence were of populations exposed to mixed fibres, chrysotile, crocidolite and amosite. However, there is very good evidence that the mesothelioma risk varies considerably with the type of asbestos fibres. There have been three case-control studies. One of them was the British, friction product manufacturing plant that I already mentioned. All three studies did essentially the same thing, i.e. compare the cases and the matched controls by examining their work histories. And what distinguishes them is that the cases have more crocidolite exposure than the controls, but very similar chrysotile exposures.

Then there have been two case control studies which did a similar thing except, instead of looking at work histories or environmental histories in trying to estimate the amount of exposure the workers had, they got lung tissue samples and counted the number of asbestos fibres in their lungs. What they found was similar in that they found comparable levels of chrysotile but higher levels of crocidolite in the cases.

These studies are very convincing in establishing that crocidolite is more hazardous in mesothelioma risk than chrysotile, but they do not give us quantitative estimates of risk. [In trying to estimate just how much greater risk might arise from mixed fibres than from chrysotile only, we can make a cross study comparisons.]

Now, the mortality experience in various studies, of course, can vary because of the size of the population, the age distribution and the amount of asbestos exposure. But, in order to adjust for that, let us just look at the excess number of lung cancer. So, in the chrysotile only populations combined, we have seen 99 excess lung cancers and 12 mesotheliomas. So, expressed as a percent of excess lung cancers, that is about 12%.

If we go on and look at the crocidolite studies, we are only seeing about 32 excess lung cancers but 52 mesotheliomas. So, as a percent of the excess lung cancers, mesotheliomas are 165%. And the mixed fibre studies are intermediate; the mesotheliomas are about 66% of the excess lung cancers.

These ratios suggest that the amount of mesothelioma risk in a mixed fibre exposure might be approximately five times the risk in a chrysotile exposed population (66% versus 12%). So, a factor of five will be used in our risk estimates in adjusting for chrysotile-only exposure.

Now, I should point out that, although most people agree that chrysotile probably is capable of causing mesothelioma, Dr. Andy Churg has recently presented some interesting data. He looked at mesothelioma cases and controls in chrysotile exposed workers and found that, indeed, the mesothelioma cases did have greater chrysotile exposure than the controls, which would be expected, since there is likely a dose-response relationship. More interesting, the bigger difference between cases and controls was in the tremolite, which can contaminate the chrysotile deposits. This evidence is suggestive in that perhaps what is really important in the chrysotile is whether or not it is contaminated with tremolite.

To get some idea of how much risk we are talking about, I used these models assuming we are looking at 100,000 men who are working in friction product manufacturing; that means I am going to use a relatively low slope for lung cancer. Let us assume they are exposed to an average of about 0.2 fibres per ml.

Now, according to U.S. 1982 lung cancer data, the background number of lung cancers you would expect is 7,860. Now, how many excess cases are we going to see as a result of the asbestos exposure? Assuming they worked for ten years, which means they have a cumulative asbestos exposure of 2 fibres per ml./years, the lung cancer dose-response relationship estimates around nine excess lung cancers.

Now, for mesothelioma, of course, we have to ask if exposure is to mixed fibres or chrysotile only. If it is mixed, we would estimate from those curves about 100 mesotheliomas; if it is chrysotile, using this factor of five, it is about 20. And so we have our totals here.

What is important in mesothelioma is that, because the incidence goes up with time since initial exposure, it is important when you start the exposure. So, if you do not start the exposure until you are age 40 or 50, you are probably not around 40 or 50 years later to experience the very high incidence. But, if you started at a very young age, you probably are around that long to experience the high incidence. So, I have taken age 20 here as the age at hire; if it were later, the mesothelioma risk would be less. And if they worked their whole career of 45 years, we get these estimates.

Now, a word of caution: I do not think that anybody, who does this sort of modeling, thinks these numbers are etched in stone. I certainly do not think so but I think they give us some idea of what level of risk we are talking about and they certainly point up, based on the data, what the difference is if the exposures are to chrysotile only or to mixed fibres.

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ESTIMATED LIFETIME RISK OF CANCER [LUNG CANCER AND MESOTHELIOMA] AMONG 100,000 MEN EXPOSED TO ASBESTOS IN FRICTION PRODUCT MANUFACTURING AT A CONCENTRATION OF 0.2 F/ML, ASSUMING A HIRE AGE OF 20 YEARS, BY FIBRE TYPE AND DURATION

[BACKGROUND LUNG CANCERS 7,860]

DURATION [YRS]	LUNG CANCER	MESOTHELIOMA		TOTAL	
		MIXED	CHRYSOTILE	MIXED	CHRYSOTILE
10	9.4	101.9	20.4	111.3	29.8
20	18.9	153.0	30.6	171.9	49.5
45	42.4	182.4	36.5	224.8	78.9

TOXICITY OF MAN-MADE MINERAL FIBRES
[Glass and Rockwools]

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Micrographs showing man-made mineral fibres and asbestos fibres were presented and differences discussed. It was noted that the diameters of made mineral fibres can vary and that some are in the respirable range. While these fibres resemble asbestos there is one important difference, and that is that whereas asbestos fibres break longitudinally, man-made fibres tend to break laterally and with abrasion may become very short or cease to be fibres. This difference is important in the light of our understanding what it is about fibres that makes them dangerous for man. Fibres that are shorter than the diameter of a macrophage - the scavenger cells that digest foreign material in the lung can be completely digested by these cells. A micrograph was presented that showed how, when fibres are longer than a diameter of a macrophage, this digestion process is interrupted and a process is initiated which is believed to result in carcinogenesis. Long thin fibres are potentially the most dangerous whereas very short fibres may be fairly innocuous.

The results of a number of animal studies were presented. These studies were carried out to find out if, in fact, man-made fibres such as glass fibres have the same kinds of effect as asbestos fibres. Three kinds of studies were presented. These where inhalation studies, intertracheal administration studies, and studies where fibres are implanted in the pleura or peritoneum of animals. For inhalation studies, the route by which man would receive fibres, none of six studies presented had produced positive results. For intertracheal administration studies, where fibres were artificially introduced into the lung, two of four studies were positive. Of 13 implantations studies ten were positive.

Details on the two positive intertracheal administration studies were presented. In these studies glass fibres were compared with chrysotile asbestos fibres. For glass fibres, out of 34 rats in one experiment there were five that developed tumors while for asbestos fibres out of 34, 14 developed tumors. This study suggests that if the glass fibres are carcinogenic for humans they are somewhat less so than chrysotile asbestos fibres. In another study which involved hamsters the results were similar. Animals studies support the notion that short fibres are less carcinogenic than long fibres and demonstrate the existence of a dose-response relationship, with more carcinogenic than glass fibres for a given amount of fibre.

There have been two large studies of humans exposed to man-made mineral fibres-one involving 17,000 workers in the United States and one involving

23,000 workers in Europe. These workers could be divided into those exposed to glass filament, those exposed to glass wool and those to mineral wool. There was no excess in death rates for lung cancer among filament workers, a small excess in glass wool workers, and a larger excess in mineral wool workers. For the latter the European studies showed a 24% excess while the US study showed a 33% excess.

Comparing the studies of mineral wool workers with a study of workers from a chrysotile asbestos textile plant showed some similarities in results 20 years or more after first exposure. Both groups of workers exhibited an excess for all causes of death, with largest excesses in both studies for respiratiory cancer and nonmaligant respiratory disease. The magnitude of the excess however was smaller for mineral wool workers and only the pattern of excesses was similar in these two groups of workers.

Three aspects of man-made mineral fibres are important in evaluating their possible health effects. These are the dimensions of the fibres, the durability of the fibres and the dose received. Fibres must be fairly tiny to be respirable, probably less than three microns in diameter, and if they are to produce any tissue response should be fairly long, certainly longer than the diameter of a macrophage. Durability is important since it is generally believed that when fibres disappear quickly from the lung, they probably have no lasting effect. While man-made mineral fibres vary greatly in their durability, with some fibres being more durable than asbestos, asbestos fibres are more durable than man-made mineral fibres taken as a group. Finally, it has been well demonstrated in the case of asbestos that the concentration of fibres in the air is extremely important in determining the amount of disease that is produced. Generally exposure to man-made mineral fibres is much smaller than to asbestos in most environments in which they are encountered by man so that if they have an effect it is likely to be small.

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TOXICITY OF CERAMIC AND ARAMID FIBRES IN ANIMAL AND *IN VITRO* STUDIES

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Abstract — *We have examined the toxicity of ceramic aluminium silicate glass fibre (ceramic fibre) and an aramid fibre for short and long-term toxicity in animal models. Comparisons were made with the non-toxic dust titanium dioxide and the pathogenic fibrous dust chrysotile asbestos. In a short-term assay of ability to cause inflammation in the mouse peritoneal cavity, both ceramic and aramid showed marked activity. On long-term exposure to airborne, respirable ceramic fibre, a substantial number of rats developed lung tumours and fibrosis. Intra-peritoneal injection studies with both aramid and ceramic fibre produced small numbers of mesotheliomas. Three different* in vitro *assays were also utilised and these produced conflicting data as to the toxicity of the two test dusts with the only unequivocal evidence of toxicity being shown by the aramid sample in the macrophage cytotoxicity assay. These studies have therefore revealed that (i) both ceramic and aramid fibre may have the potential to cause lung disease in humans (ii) the toxicity of ceramic and aramid fibre, evident in the* in vivo *assays, was not reliably detected in the 3* in vivo *assay systems used.*

INTRODUCTION

Evidence that asbestos fibres cause disease in humans and in experimental animals has stimulated a search for other fibrous materials with the advantages of asbestos but which are less hazardous. Reason dictates that these substances should themselves be comprehensively tested for their ability to cause disease. Amongst the man-made fibrous materials which have some of the useful properties of asbestos are ceramic aluminium silicate glass fibres (ceramic fibres) and aramid fibres. Both of these materials are made by industrial processes whose details are given elsewere(1)(2). At the Institute of Occupational Medecine we have tested these materials in short and long-

(1) Preston J., 1978. Aramid Fibres. In: Encyclopaedia of Chemical Technology, Vol. 3. John Wiley & Sons Inc. New York, 213-242.
(2) Miller W.C., 1982. Refractory Fibres. *In* Encyclopaedia of Chemical Technology, Vol. 20. John Wiley & Sons Inc. New York, 65-77.

Materials and Methods

Preparation of Minerals

Ceramic aluminium silicate glass fibrous insulation material (Triton, Kaowool, Morganite) was received as a bulk sample and passed through steel rollers to disaggregate it. This material was then dispersed as an airborne cloud, using a Timbrell dust generator, passed through a cyclone system to obtain respirable fibres and then into an inhalation exposure chamber at 10 mg/m^3 (for full details see Davis et al 1984)(3). For injection and *in vitro* studies airborne dust from the chamber was collected on the filters of NCB, MRE dust sample.

Aramid fibre (Kevlar, DuPont) was received as a bulk sample of the pulp. Due to difficulties encountered in generating a respirable cloud from the bulk sample, no inhalation studies were undertaken with the Kevlar aramid. Instead, a portion of the bulk pulp was suspended in sterile saline and disaggregated by utilising the cavitational forces generated by a tissue homogeniser (for details see Davis et al 1987)(4); the aramid sample used was not representative of that which individuals might be exposed to by inhalation. In long-term *in vitro* assays (V79/4 and A549 assays) the aramid fibre was found to be microbially contaminated; aramid samples were therefore autoclaved (130°C, 10 mins) or irradiated (150K RAD) prior to use in these assays.

Characterisation of the Minerals

The size distribution of the ceramic dust, as collected from the chamber air, is given in **Figures 1 & 2.** These reveal that whilst there were few long, thin fibres there were large numbers of short, thin fibres (90% fibres <3µm long and <0.3 µm diameter).

In the case of the aramid sample it was not possible to carry out a length distribution since the disaggregation process was complete and many fibres were incompletely separated from tangles of fibre. Diameter estimates were however possible (**Figure 3**) and these showned that 50-60% of fibres had diameter of <0.25 µm.

For comparision with the ceramic and aramid fibres we used UICC 'A' standard chrysotile asbestos as a positive control and titanium dioxide (Rutile;

(3) Davis J.M.G., Addison J., Bolton R.E., Donaldson K., Jones A.D., Wright A., The Pathogenic Effects of Fibrous Ceramic Aluminium Silicate Glass Administered to Rats by Inhalation or Peritoneal Injection. *In* Biological Effects of Man-Made Mineral Fibres - Proceedings of a WHO/IARC Conference, Copenhagen, April 1982.

(4) Davis J.M.G., 1987. Carcinogenicity of Kevlar Aramid Pulp Following Intraperitoneal Injection into Rats. Institute of Occupational Medicine, Report No. TM/87/12.

For comparision with the ceramic and aramid fibres we used UICC 'A' standard chrysotile asbestos as a positive control and titanium dioxide (Rutile; Tioxide Limited) as a negative, non-toxic control dust; the toxic, non-fibrous dust, quarts (DQ12) was also included as a control in some experiments.

ASSAYS OF BIOLOGICAL RESPONSE

1. Inflammation in the mouse peritoneal cavity — For studies on the inflammatory potential of the dusts in the mouse peritoneal cavity, the particulates were administered by injection of 0.5ml of dust containing 50μg dust. This was injected into groups of three mice and the effects assessed 2, 4 and 8 days after injection. Mice were killed by ether overdose and the peritoneal cavity lavaged, to obtain the leukocyte population, with 3 x 2 ml washes of saline containing 10U/ml of Heparin. The cells were washed, counted and differential counts obtained from cytocentrifuge preparations stained with Giemsa stain.

2. Inflammation in the rat lung — Groups of three rats anaesthetised with ether and their tracheas exposed by dissection. The dusts were prepared at 5mg/ml in sterile saline and 0.5 ml deposited in the lung through a blunt needle introduced into the trachea down to the level of the bifurcation. The skin was closed with metal clips and rats were conscious within 2 minutes and fully recovered by 24 hours. Three days later rats were killed by overdose with Nembutal, the lungs removed and the bronchoalveolar space lavaged with 4 x 8 ml volumes of saline at 37°C. The leukocytes of the bronchoalveolar space were washed and differentially counted as given above for peritoneal leukocytes.

3. Pathology — In the experiments aimed at assessing the ability of the dusts to cause long-term pathology, two different approaches were taken. In the case of ceramic fibre, both inhalation and injection studies were carried out. Rats were placed in the chamber and exposed to the dust cloud generated as described above for 7 hours/day, 5 days/week for a total of 244 days (one calendar year). Most animals were allowed to survive for their full life-span when the number of tumours and the extent of lung fibrosis were assessed both macroscopically and microscopically from stained sections. In injection studies 25mg were injected into the peritoneal cavity of a group of rats. In the case of aramid, where a dust cloud could not be generated, 25 mg of the disaggregated fibre was injected into the peritoneal cavity of rats and the development of mesotheliomas assessed[5]; the fibrogenic potential of the dust in the peritoneal cavity was also assessed qualitatively in stained sections.

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(5) Bolton R.E., Davis J.M.G., Donaldson K., Wright A., 1987. Variations in the Carcinogenicity of Mineral Fibres. Ann. Occup. Hyg. 26: 569-582.

4. *In Vitro* assays —

(i) *Cytotoxicity to rat alveolar macrophages*

The ability of ceramic and aramid fibres to damage rat alveolar macrophages was assessed using a ^{51}Cr release assay[(6)]. In this assay freshly harvested rat alveolar macrophages are pre-labelled with ^{51}Cr and the ability of test dusts to cause injury is assessed by release of ^{51}Cr following incubation with the cells for 24 hours.

(ii) *V79/4 assay*

Details of this and the A549 cell assay are given in Brown et al 1986[(7)]. Briefly, dusts at various doses are cultured with a lung fibroblast cell line - V79/4, for 6 days and the number of colonies present at the end of this time is assessed by staining and visual counting.

(iii) *A549 cell assay*

In this assay dusts are assessed for their ability to cause increases in the size of the cells of an alveolar epithelial cell line - A549. Different concentrations of dust are incubated with cells for 4 days, the cells detached and their diameter assessed. Previous studies have demonstrated the activity of fibrous, carcinogenic dusts in the V79/4 and A549 assay systems[(7)] while the toxic, non-carcinogenic dust quartz has low activity.

STATISTICAL ANALYSIS

Results were examined by analysis of variance and differences in treatment groups assessed using a 't' test.

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(6) Donaldson K., Brown G.M., 1987. Assessment of Mineral Dust Cytotoxicity towards Rat Alveolar Macrophages Using a ^{51}Cr Release Assay. Toxicol. Appl. Pharmacol. (in press).

(7) Brown G.M., Cowie H., Davis J.M.G., Donaldson K., 1986. In Vitro Assays for Detecting Carcinogenic Mineral Fibres: a Comparison of Two Assays and the Role of the Fibre Size. Carcinogenesis 1971-1974.

RESULTS

INFLAMMATION IN THE PERITONEAL CAVITY

These results, shown in **Figure 4** reveal that the titanium dioxide sample caused no substantial inflammation in the peritoneal cavity at the doses used. The UICC chrysotile sample produced a marked burst of inflammation which was sustained throughout the 8 days of the experiment. Ceramic and aramid fibre produced quite different responses, both substantially more than the titanium dioxide control. Compared to the UICC chrysotile the two test dusts produced inflammatory responses which were low in magnitude in the early stages but which progressed and were still present to a considerable degree by day 8.

INFLAMMATION IN THE RAT LUNG

We have observed that the number of cells recovered from the lungs following injection of fibrous dusts is low and this effect was evident with both the ceramic and aramid fibre samples. However, assuming that the cells which are obtained by bronchoalveolar lavage are representative of the cells within the lung the percentage of neutrophils gives an indication of the level of inflammation. In the alveolar spaces of normal rat lung there are 0% neutrophils and with titanium dioxide injection there is a slight neutrophil influx (**Table 1**). It is evident from **Table 1** however that UICC asbestos, ceramic and aramid fibres all produced more marked inflammatory responses as judged by the neutrophil levels.

PATHOLOGY

Table 2 shows the number of lung tumours produced by inhalation of airbrone ceramic fibre or chrysotile asbestos at 10 mg/m^3 airborne concentration. In addition both dusts cause marked parenchymal fibrosis.

Table 3 demonstrates the ability of the aramid, ceramic and chrysotile samples to produce mesotheliomas following intraperitoneal injection in the rat. Fibrosis was evident in the peritoneal cavity of rats injected with aramid fibre.

IN VITRO STUDIES

(a) Cytotoxicity to alveolar macrophages

Figure 5 shows that ceramic fibre is not substantially cytotoxic to rat alveolar macrophages compared to TiO_2 while aramid and autoclaved aramid both showed significant toxic effects as assessed by release of ^{51}Cr after 24 hours. The toxic effect was, however, less marked than that chrysotile or quartz.

(b) V79/4 cell assay

This assay, (results shown in **Figure 6**), as expected from previous studies, revealed quartz to be low in activity and chrysotile to be very active in inhibiting colony formation. Ceramic fibre and the two aramid samples were virtually inactive in this assay system.

(c) A549 cell assay

As shown in **Figure 7** mean size of A549 cells and percentage of cells greater than 36 μm diameter was low in control and with TiO_2 or quartz treatment and increased with chrysotile treatment. With ceramic, and both Kevlar samples, cell size was moderately but significantly increased, with the aramid sample appearing to be slightly more active.

DISCUSSION

This study has demonstrated that both ceramic fibre and aramid fibre have activity in both long and short-term assays of toxicity in animals. Both dusts caused significantly more inflammatory response following injection into mouse peritoneal cavity and the rat lung, than titanium dioxide which has low activity in causing lung damage except at a very high dose[8]. The pattern of the inflammatory response in the peritoneal cavity with ceramic and aramid was different to that produced by chrysotile asbestos and was still present 8 days post-injection. The significance of the difference in pattern of inflammatory response from that produced by UICC chrysotile is not clear.

In terms of long-term pathology following exposure, differences between dusts is complicated by the different exposure regimes used. Ceramic fibre could be prepared as an airborne cloud so rats were exposed by inhalation. Administered in this way ceramic fibre showed a marked ability to produce both tumours and fibrosis in the lung. With aramid, the failure to generate respirable clouds precluded its use in inhalation studies. Both aramid and ceramic were utilised in intraperitoneal injection studies where both were found to cause few tumours at the high dose used (25 mg), a dose at which chrysotile asbestos produced tumours in virtually all exposed animals. With aramid the low number of tumours obtained may be explained on the basis that there were not very many small fibres present due to the problems with the efficiency of the disaggregation process; thus the dose of fibres in the size range known to be optimal in causing mesotheliomas (see discussion in Brown et al.)[7] was likely to be quite small in terms of the total mass injected. The net

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(8) Lee K.P., Trochimowicz, Reinhardt C.F., 1985. Pulmonary Responses of Rats Exposed to Titanium Dioxide (TiO_2) by Inhalation for Two Years. Toxicol. Appl. Pharmacol. 79: 179-192.

result is, therefore, that activity of a truly respirable sample of aramid is likely to be greater than that indicated in these experiments.

The *in vitro* assay of alveolar macrophage cytotoxicity revealed ceramic fibre to be very low in toxicity; aramid fibre however was markedly cytotoxic as has been shown by Dunnigan et al.[9] using a similar assay system. In the V79/4 and A549 *in vitro* assay systems which are sensitive to fibrous dust and may reflect their carcinogenic potential[7] the results were inconsistent. The V79/4 assay showed no activity while the A549 assay was suggestive of mild toxic potential in both ceramic and aramid fibres. These findings are in agreement with the problem of occasional anomalous results in these assays which we have described previously[7] and confirms that, although *in vitro* assays may be useful indicators, they cannot at present replace *in vivo* testing of asbestos substitutes.

The relative activities of ceramic and aramid fibre compared to titanium dioxide and chrysotile in the assays used here are shown, in summary, in **Table 4.**

The findings presented here on the biological activity of aramid are in agreement with those of several previous studies which have demonstrated toxic effects. Pott et al.[10] reported a 12.9% incidence of tumours in the peritoneal cavity following injection of Kevlar aramid into 31 rats. Lee et al[11] exposed rats for only 2 weeks to airborne Kevlar aramid and found septal thickening and granuloma formation. Dunnigan[9] et al. using a small fibre size fraction found aramid to be highly cytotoxic to alveolar macrophages *in vitro* as assessed by release of enzymes. Clearly the present and previous studies, with the exception of Lee et al.[11], used non-inhalation exposures and samples of dust prepared in various ways which make them of questionable direct relevance to inhalation exposure in humans. However, previous work with asbestos and other toxic dusts have shown that injection and *in vitro* assays have given an indication of the ultimate toxicity of dusts and on the basis of this some caution on the use of aramid is warranted.

In the case of ceramic fibre, Pott et al.[10] once again found tumours following injection into the peritoneal cavity of rats with two different ceramic samples. We know of no published studies other than our own on the use of ceramic fibre in short-term animal assays or *in vitro* assays. The results so far, however, also suggest that ceramic fibre should be treated as a potential risk until shown otherwise.

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(9) Dunnigan J., Nadeau D., Paradis D., 1984. Cytotoxic Effects of Aramid Fibres in Rat Pulmonary Macrophages: Comparision with Chrysotile Asbestos. Toxicology Letters 20: 277-282.
(10) Pott F., Ziem V., Reiffer F.J., Huth F., Ernst H., Mohr V., 1987. Carcinogenicity Studies on Fibres, Metal Compounds and Some Other Dusts in Rats. Exp. Pathol. (in press).
(11) Lee K.P., Kelly D.P., Kennedy G.C., 1983. Pulmonary Response to Inhaled Kevlar Aramid Synthetic Fibres in Rats. Toxicol. Appl. Pharmacol. 71: 242-253.

ACKNOWLEDGEMENT

The authors acknowledge the financial assistance of the Brithish Asbestosis Research Council.

✱

TABLE 1

Proportions of leukocytes in the bronchoalveolar lavage 3 days after intratracheal injection of 2.5mg of the indicated dusts: x(SD) of 3 rats

DUST	MACROPHAGES	NEUTROPHILS	LYMPHOCYTES
TiO_2	86.3 (5.5)	6.7 (4.7)	7.0 (1.0)
UICC chrysotile	74.3 (11.9)	23.7 (12.7)+	1.7 (0.6)
Ceramic	76.3 (4.7)	21.0 (4.6)+	2.0 (1.0)
Aramid	75.7 (7.6)	21.3 (7.1)+	2.7 (3.0)

+ significant increase over TiO_2 $P<0.01$

TABLE 2

Numbers of tumours produced following inhalation exposure of rats to ceramic fibre or chrysotile asbestos at 10 mg/m^3 airborne dust concentration

NUMBER OF RATS	DUSTS	NUMBER OF LUNG TUMOURS
48	Ceramic	8
40	UICC Chrysotile	15*
40 + 20	Control	0

*Results from Davis J.M.G. et al., Br J. Cancer 37: 673, 1978.

TABLE 3

Development of tumours following intraperitoneal injection of aramid fibre or chrysotile asbestos into the peritoneal cavity of rats

DOSE(mg)	DUST	NUMBER OF RATS	NUMBER OF TUMOURS (MESOTHELIOMAS)
25.0	Aramid	32	2
25.0	Ceramic	32	3
25.0	UICC chrysotile'A'	31	30*

* Data from Bolton R.E. et al., Ann. Occup. Hyg. 26: 569, 1982.

TABLE 4

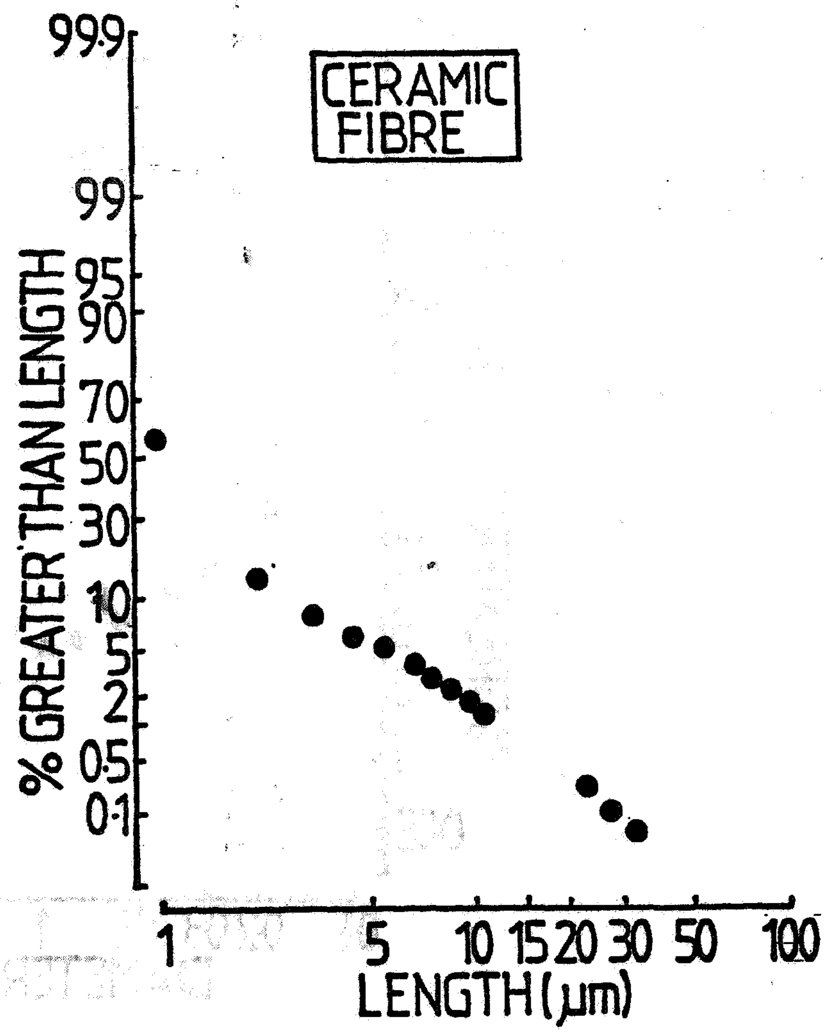
Summarised activity of different dust samples in assays of biological response carried out at the Institute of the Occupational Medicine

DUST	INFLAMMATION ASSAY PERITONEAL CAVITY	LUNG	IN VITRO ASSAYS	LUNG PATHOLOGY FIBROSIS	TUMOURS	PERITONEAL MESOTHELIOMA
TiO2	0	0/+	0	ND	ND	ND
UICC chrysotile	+++	++	+++	+++	+++	+++
Ceramic	++	++	0/+	++	++	+
Aramid	++	++	+	ND	ND	+

ND = not done

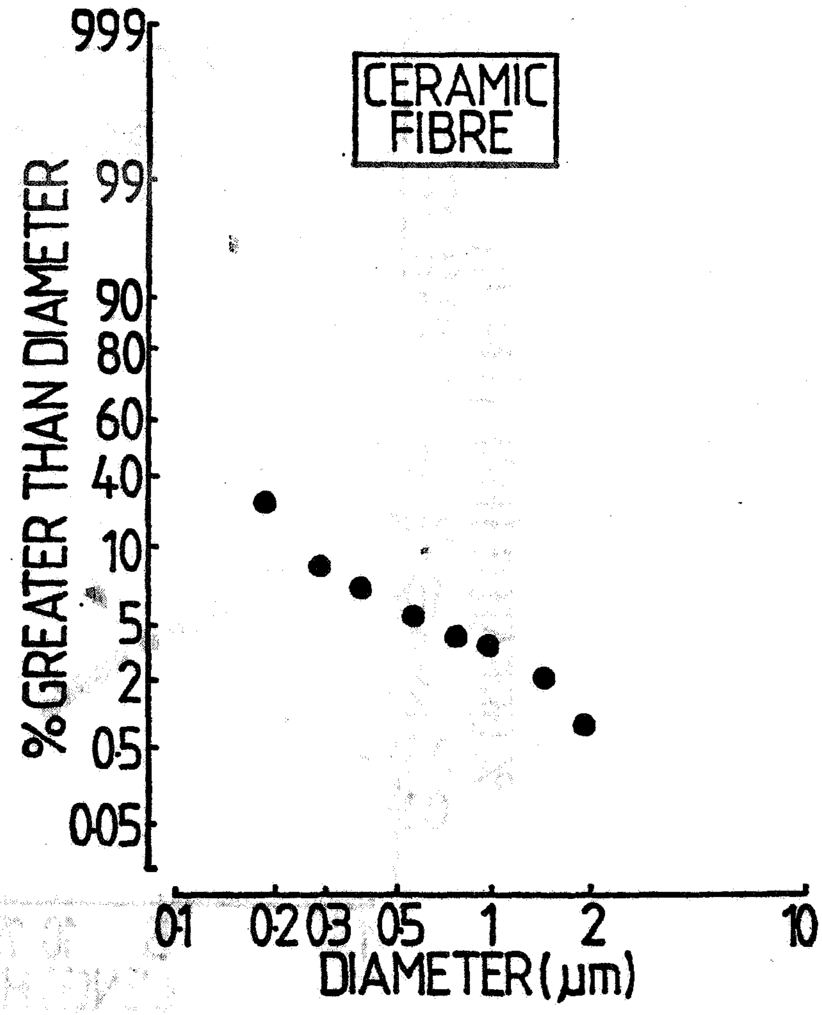
Scale of activity: +++ = marked —> 0 = minimal.

FIGURE 1



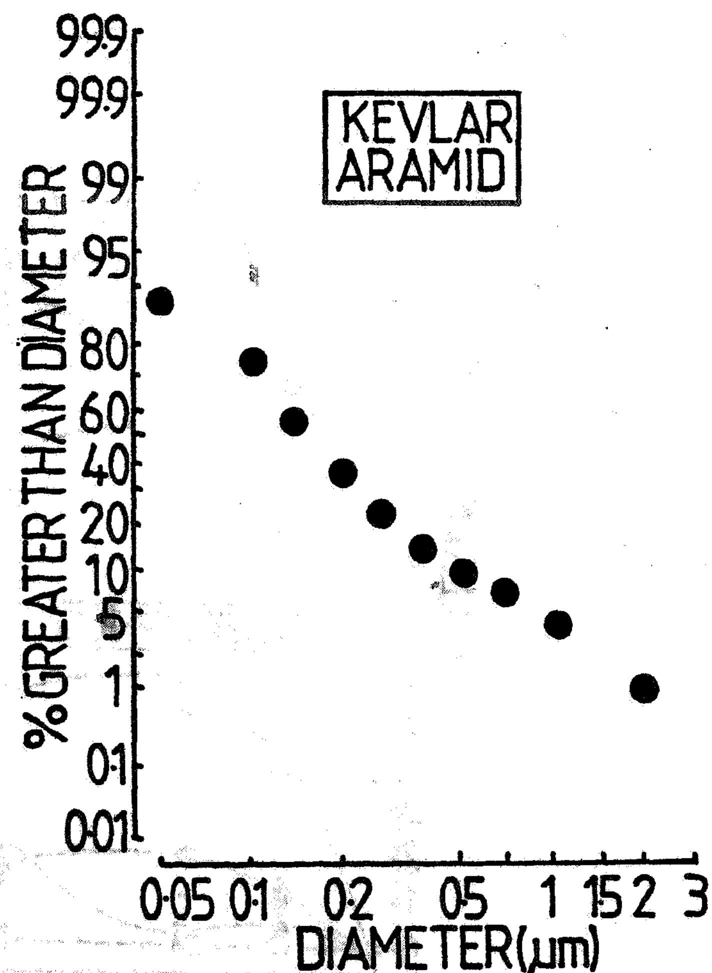
Fibre length distribution of ceramic fibre used the study; 900 fibres counted at a magnification of 10,000x by Scanning Electron Microscopy.

FIGURE 2



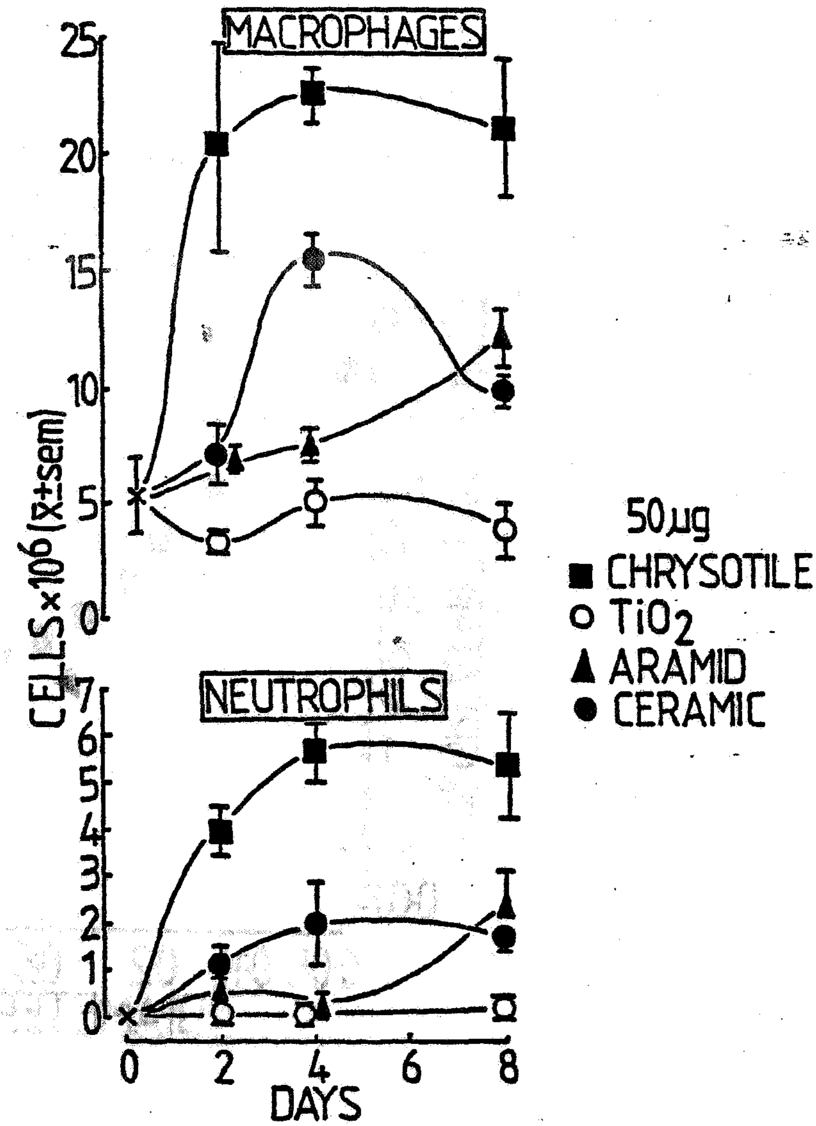
Fibre diameter distribution of ceramic fibre used in the study; 900 fibres counted at a magnification of 10,000x by Scanning Electron Mircroscopy.

FIGURE 3



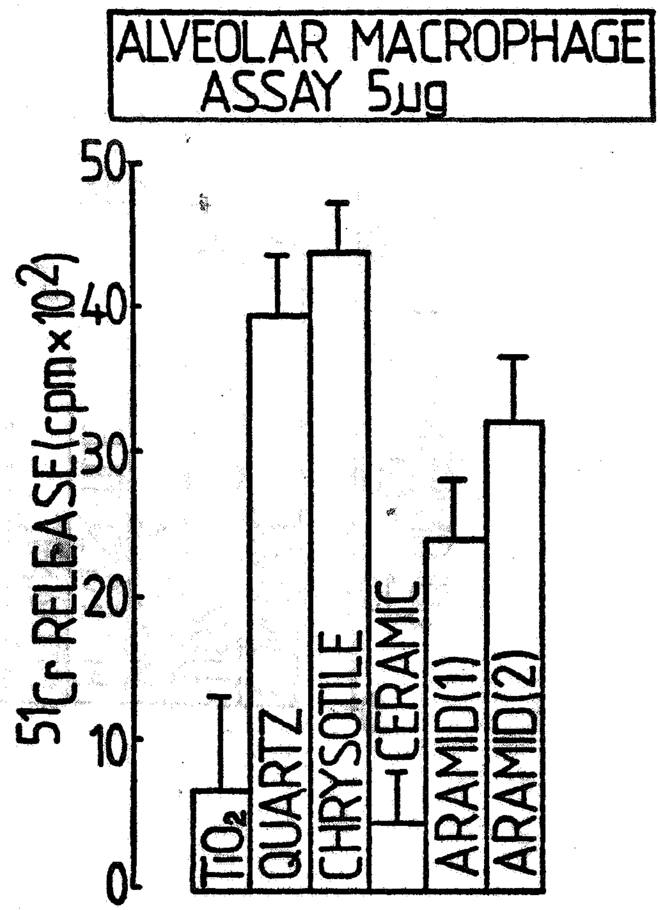
Fibre diameter of the aramid fibre sample used in the study; 900 fibres counted at a magnification of 10,000x by Scanning Electron Microscopy.

FIGURE 4



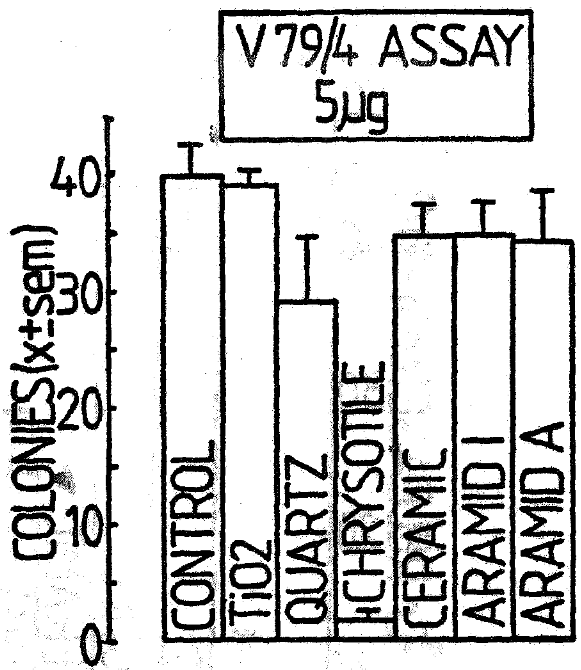
Recruitment of neutrophils and macrophages into the mouse peritoneal cavity following injection of 50 µg of the indicated dusts. Each point represents mean ± SEM of 3 mice. Significant ($P<0.05$ - $P<0.001$) increases with all dusts compared to TiO_2.

FIGURE 5



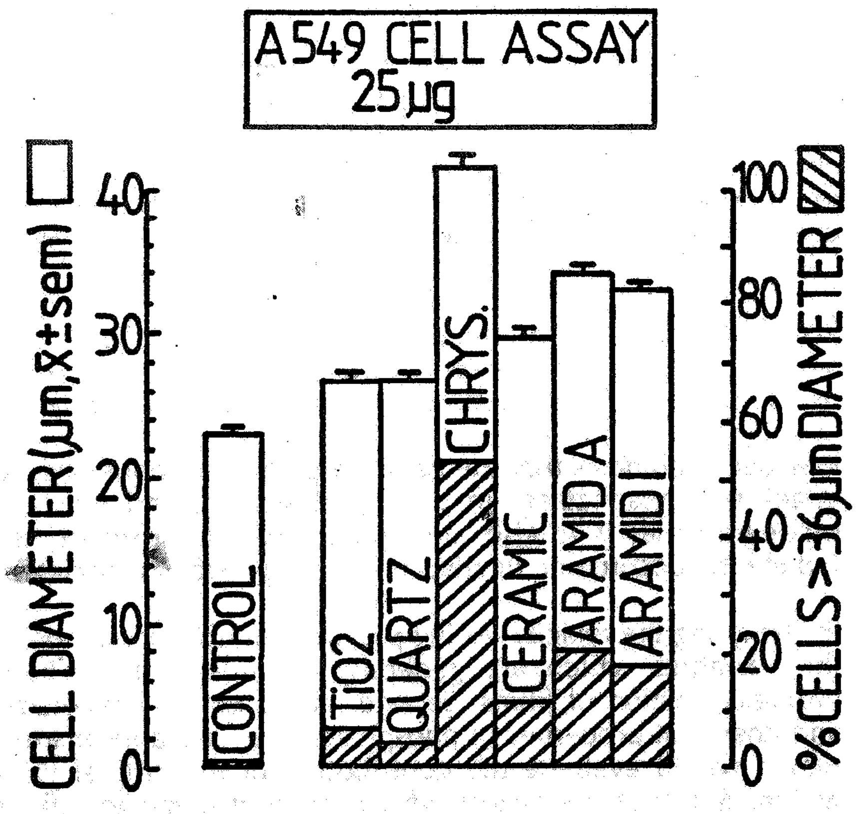
Cytotoxicity of the indicated dusts as assessed by release of ^{51}Cr from pre-labelled rat alveolar macrophages - dose 10µg. TiO_2 = Titanium dioxide; Aramid 1 = non-autoclaved; Aramid 2 = autoclaved Aramid. Mean ± SEM of 3 replicates. Significant ($P<0.01$-0.001) increases over TiO_2 with all dusts except ceramic.

FIGURE 6



Number of V79/4 cell colonies present after 6 days or culture with 5 µg of the indicated dusts. Aramid A = autoclaved; Aramid 1 = irradiated; mean ± SEM of 3 replicates. Significant difference for control with chrysotile, (P<0.001).

FIGURE 7



Diameter (open bars) and percentage of cells greater than 36 µm (hatched bars) of A549 cells treated with the indicated dusts. Aramid A = autoclaved; Aramid 1 = irradiated; mean ± SEM of 200 cells.

DESIGN AND EXECUTION OF A TOXICITY TESTING PROGRAM FOR A UNIQUE FIBRE: PHOSPHATE FIBRE

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Phosphate fibre is a novel inorganic polymer fibre material which is composed of condensed polyphosphate chains in a specific crystalline lattice. The unit cell of the crystal lattice is calcium sodium metaphosphate. Polyphosphate chains are linked by covalent bond and parallel chains are linked by weaker ionic bonds. Thus, the cristal blocks fibrillate parallel to the polyphosphate chains to yield small diameter fibres of high aspect ratio which as most of you know is defined as the ratio of length to diameter.

Phosphate fibre has a typical average diameter of 2-3 microns, an average length of 50-100 microns and an average aspect ratio of 20-30. Large standard deviations reflect that the fibre is quite heterogenous in terms of dimensions.

It is our hypothesis that the polyphosphate backbone should be amenable to attack by phosphatases in biological systems and thus the fibre would be biodegradable. It is also anticipated that this property should prevent or reduce the occurrence of adverse effects generally associated with fibres.

In designing the toxicity testing program for phosphate fibre we first examined the variables which are generally considered to influence the ultimate biological action of fibres. Second, based on our knowledge of the physical and chemical properties of phosphate fibre, we tailor-made a testing program which would evaluate the contribution of the critical variables in its toxic action. Some of the factors which are considered to influence fibre toxicity are: (i) *size of the fibre* (ii) *shape of the fibre* (iii) *physical and chemical properties* (iv) *durability of the fibre.* Now to examine phosphate fibre and try to predict the toxicity based on these critical factors.

(i) *Size of the fibre* influences both aerodynamic behavior as well as ultimate biological action. Fibres with diameters less than 3 microns are generally considered to be respirable. It is also believed that fibres less than 1.5 microns in diameter and greater than 8.0 microns in length are more likely to be active at the cellular level. Thus, we knew that a certain percentage of the fibres in a sample of standard phosphate fibre indeed fit the geometric characteristics of what could be considered to be a potentially toxic and respirable fibre. Thus, an inhalation study in animals would have to be an integral part of the testing program.

(ii) In terms of *shape*, we know that many of the phosphate fibres have split ends. This would make the fibre behave as though it had a larger diameter than the diameter of the narrowest point and thus be deposited more in the upper respiratory tract when compared to a fibre of equivalent diameter with a more perfect cylindrical shape.

(iii) *Physical property* of weaker ionic bonds connecting parallel polyphosphate chain suggests that there might be some longitudinal splitting of fibres resulting in generation of long thin fibres. However, the chemical structure of polyphosphate would render the fibre with a special property. Since biological systems can hydrolyse long-chain polyphosphates it is anticipated that phosphate fibre can be degraded in biological systems. The breakdown products are natural constituents of the body and thus would not be expected to produce any excessive toxicity.

(iv) Thus, in terms of *durability*, phosphate fibre would be considered biologically non-durable and this property would prevent or reduce occurrence of adverse effects generally associated with fibres. Our testing program was thus designed to consist of two phases. Phase I concentrating on evaluating degradability of phosphate fibre and clearance from lung and Phase II evaluating long-term toxicity of phosphate fibre because we knew that our fibre would have a certain fraction of respirable fibres.

We evaluated the degradability of phosphate fibre by incubating radiolabelled (P^{32}) phosphate fibre for 1 to 7 days in a culture medium with and without lung epithelial cells (LEC) or rat alveolar macrophages (RAM). The solutions were filtered, and the amounts of radioactivity were determined. It was noted that the filterable radioactivity was increased in the presence of LEC and RAM, demonstrating that the cells degraded phosphate fibre.

The clearance and toxicity of phosphate fibre was determined after both intratracheal instillation and inhalation in male Fischers 344 rats. During intratracheal instillation, 0.5 cc of a fibre suspension (0.35 mg fibres/cc) was instilled into the trachea of a rat three times in one day for a total dose of 0.5 mg/rat. This procedure was carried out on six groups of eight rats each. Six separate groups of eight rats each were exposed to the highest attainable concentration of phosphate fibre for three hours by intratracheal inhalation. At days 1, 7, 21, 57 and 176 after exposure, eight rats from each of the intratracheal instillation and inhalation groups and four control male rats were sacrificed. Their left lungs were taken to evaluate the fibre burden and their right lungs were processed for histological evaluation of fibrosis. Left lungs of separate group of rats on day 176 were utilized to assay for elastin and hydroxyproline. The latter two biochemical parameters are considered markers for development of fibrosis.

We now look at the clearance after intratracheal instillation and inhalation. Approximately 84% of the initial fibre load after instillation was cleared in six months while after inhalation approximately 93% of the initial fibre load was cleared by six months. The clearance curves can be broken down to the two phases, the Phase 1 representing the quick clearance from the lung which is probably primarily carried out by mechanical means, i.e., the mucociliary transport system. The second slower phase, was considered primarily due to degradation of fibre by alveolar macrophages. Biochemical and histological evaluation of lungs of animals exposed to phosphate fibre showed no fibrogenic response.

The fate of radiolabelled phosphate fibre was also studied in the rat using a technique referred to as whole body autoradiography. Radiolabelled fibres were administered either by the intratracheal instillation or by the intraperitoneal route. A section of rat taken the day the phosphate fibre was first administered by intratracheal instillation showed that radiolabel was confined to the lung. The fate of the radiolabel 14 days after administration by intratracheal instillation demonstrated clearly that a part of the breakdown products from the phosphate fibre migrated to bone which is a natural storage area for calcium and phosphate ions. Thus, this work provides us with qualitative evidence that some phosphate fibre does break down to its backbone chemicals, calcium and orthophosphate ions.

We will now discuss the two chronic studies that have been undertaken. The first study, the chronic pleural implant study, was started when only limited quantities of the product were available. This study was considered to provide us early answers to tissue reaction to phosphate fibre, fibre degradability and carcinogenic potential if the fibres did not biodegrade. The experiment was performed by the standard Stanton protocol which has been used extensively to evaluate many mineral fibres. In our study 40 milligrams of phosphate fibre or chrysotile asbestos were embedded in gelatin and the gelatin pledgets containing the fibres were implanted in the pleura of 75 Osborne Mendel rats. The sample of chrysotile asbestos that we used was a commercial sample of asbestos with a mean diameter of 0.19 μ while the sample of phosphate fibre used had a mean diameter of 1.6 μ and mean length of 30 μ. While most animals were sacrificed after two years, a small group of animals in each treatment group were sacrificed at 6, 12 and 18 months.

In general, the tissue response to phosphate fibre was markedly different than the response to chrysotile asbestos. With phosphate fibre a very cellular and acollageneous response was observed while with asbestos an acellular, collageneous response was observed. No lung tumors were observed up to the 18-month sacrifice. Among the animals sacrificed at 24 months, 3 fibrosarcomas were observed in the phosphate fibre group and 4 fibrosarcomas were observed in the chrysotile asbestos group. Based on the available data phosphate fibre as implanted did not appear to fully biodegrade in the pleura as had been hypothesized. Thus, the tumor data support the Stanton hypothesis that tumors will occur if fibres of the right geometry remain in the pleura. Evaluation of the pleural implant study in light of the other biodegradation data, suggests that at least 2 factors may have hindered biodegradation. These are:

(1) Gelatin matrix — phosphate fibre interaction— In retrospect, we have found references which show that gelatin chemically reacts with long chain polyphosphate. It is possible that this chemical interaction may have hindered biodegradation.

(2) The dose administered (40 mg) may have overwhelmed the biological capacity available in that localized area which could normally attack and degrade smaller amounts of the fibre. Thus, for those of you who might be considering evaluating a new fibre, a new design of the Stanton protocol of a pleural injection of 20 mg of a fibre suspension is recommended.

The last toxicity study that we have undergoing with phosphate fibre is the chronic inhalation study in rats. In this study, groups of 80 male and 80 female rats are being exposed to 0, 1, 5 or 25 mg/m^3 of phosphate fibre. Interim sacrifices have been conducted at 3, 12, 18 and 24 months. In addition, a group of 5 animals/sex/group were part of a recovery experiment which was initiated at the 18-month interval of the study. Up to the 18-month sacrifice, an increase in lung weights has been observed in the high level. Histologically, we have observed epithelial hypertrophy and/or hyperplasia, in other words slight thickening, at the terminal bronchiole alveolar duct junction in the 5 and 25 mg/m^3 concentration groups. The lung slides have been examined by two independent pathologists, one has concluded minimal fibrosis at the 5 and 25 mg/m^3 group and the other pathologist failed to confirm significant fibrosis in any group. Both pathologists consider these changes to be a non-specific response to low grade irritation.

The chronic study was originally designed to end at 2 years. However, following an extensive review of published literature and discussion with numerous experts in the field of fibre toxicity we were able to establish two facts: (i) Most lung tumors following asbestos exposure are observed at 26-28 months post exposure. (ii) Also, exposure beyond 12-24 months is not necessary to observe these tumors. Thus, we decided to extend our study beyond two years and exposure was terminated at 24 months. The current plan is to observe the animals until survival in any group approaches 20 percent, at which point all animals will be sacrificed. It is our prediction, this will result in an extension of the study by more than six months.

Thus in summary, data on phosphate fibre indicate that this substance is degradable in biological system and has low potential for fibrogenic response. Under the conditions of our study, it did produce a low incidence of pleural fibrosarcoma in the pleural implant however because of the unique way in which the fibre was presented to the animals, the results should not be directly extrapolated to risk in the work place. We feel the results of the chronic inhalation study will be more useful in assessing potential risks in the work place. To date, the changes in the lungs of rats in the chronic inhalation study show minimal pathologic changes and these changes are considered to be a non-specific response to low grade irritation.

This concludes the toxicology presentation, but my comments would be incomplete without a business postscript.

As favorable as the safety data were, we were gaining equal encouragement from customer applications and from our manufacturing facility on costs and the process. However, earlier this quarter, Monsanto announced that it would be terminating the program because of a general concern over the product liability climate in the United States. Specific concerns are the costs of defending lawsuits even without merit, and the potential, in our opinion, for more misapplication or expansion of product liability laws. We are pursuing potential sale of the technology with specific worldwide companies, and certainly, should any agreement be reached, this will be widely communicated to groups such as this.

THE CYTOTOXICITY OF SEMI-METALLIC BRAKE RESIDUES IN CULTURED CELLS: A COMPARISON WITH ASBESTOS AND NON-ASBESTOS FIBRES

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Abstract — Substitute materials have been developed as replacements for asbestos in automotive friction materials but the potential health impact of these asbestos substitutes and the residue generated through the use of these materials is largely unknown. The purpose of this study was to compare the toxicity of semi-metallic disk and drum brake lining residue with various asbestos and non-asbestos fibres in vitro. *A viability index was calculated to reflect changes in both cell number and viability. At equivalent concentrations (μg/mL), the relative cytotoxicity was amosite, crocidolite, chrysotile > calcium sodium metaphosphate fibres > semi-metallic drum residue > semi-metallic disk residue, Fiberfrax > semi-metallic disk and drum filings. These results suggest that the semi-metallic disk and drum brake residues were generally less toxic than the fibrous materials studied.*

INTRODUCTION

Asbestos, because of its unique physical properties has been the material of choice in numerous automotive applications including that of a brake lining friction material. However, because of the potential adverse health effects associated with asbestos exposure and changes in engineering requirements, a number of non-asbestos materials are now under consideration as potential replacements for asbestos. While substitute materials have been developed, the potential health impact of these asbestos substitutes and the residue generated through the use of these materials is largely unknown. The impact of these materials on human health will depend on the amount of material deposited in the lung, the ability of the lung to clear the material, and the physical properties (size, shape, and durability) of the fibres themselves.

The respiratory system is the initial contact between inhaled materials and the rest of the body. The lung has two major systems to deal with inhaled foreign matter. The first of these, the mucociliary escalator, protects the conducting airways by trapping and sweeping inhaled material up and out of the lung. The second clearance mechanism is located primarily in the gas exchange regions of the lung and involves the alveolar macrophage. Alveolar macrophages are phagocytic cells whose primary function is to engulf and retain inhaled matter, thereby serving to keep the surface of the lung sterile and free of debris. These cells also serve an important function in the immune response of the lung through the production and release of various chemical mediators or chemotactic factors. Chemotaxis may be defined as the directed movement of cells by substances in their environment. A number of studies have shown that the interaction of inhaled materials with alveolar macrophages stimulates these cells to produce and release factors which in turn recruit additional macrophages and polymorphonuclear leukocytes, another phagocytic cell type, into the lung amplifying the response and thereby, helping to clear the lung[(1)(2)]. Therefore, because of the importance of these cells, adverse effects on the activity of the alveolar macrophage can lead to increased retention of inhaled materials and an increased susceptibility to disease. This study was designed to evaluate and compare the toxicity of semi-metallic disk and drum brake lining residue with crocidolite, amosite, and chrysotile asbestos and two asbestos substitute fibres, calcium sodium metaphosphate™ (manufactured by Monsanto) and Fiberfrax (a ceramic fibre, manufactured by Sohio) in an *in vitro* macrophage-like cell system.

EXPERIMENTAL

Cultivation of Continuous Cell Lines — A mouse macrophage-like cell line, J774A.1, was obtained from the American Type Culture Collection (Rockville, MD) and grown in an atmosphere of 5% CO_2 at 37°C in Dulbecco's MEM medium supplemented with 10% fetal bovine serum, 2 mM L-glutamine, 0.1 mM MEM non-essential amino acids, 100 units/mL penicillin, and 100 µg/mL streptomycin.

Fibre Exposure — Cells were exposed to fibres *in vitro* by cultivating 1.0×10^5 adherent J774A.1 cells with no fibres (control, 0) or with 0.25, 2.5, 25, or 250 µg fibre/mL in one mL of Dulbecco's MEM supplemented with 10% fetal bovine serum, 2 mM L-gultamine, 0.1 mM MEM non-essential amino acids, 100 units/mL penicillin, and 100 µg/mL streptomycin for 24 hours at 37°C in an atmosphere of 5% CO_2. Exposures were all performed on a weight per volume basis and did not take into consideration differences in the size of the materials or their relative densities.

Test Materials — The residues and fibrous materials used in this study differed significantly in size and shape. Semi-metallic disk and drum brake residue **(Figures 1a, 1b)** was generated using a dynamometer to simulate driving conditions. Analysis showed this material was of respirable size having an aerodynamic diameter of approximately 6 µm and 3 µm respectively[(3)]. Both

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(1) Wheeler, Candace S. and Garner, Charles D., 1986. The Effect of Diesel Particulate on Alveolar Macrophage and Polymorphonuclear Leukocyte. Chemotaxis. GMR-5325.

(2) Idem, 1986. The Role of Phagocytosis in Alveolar Macrophage Chemotaxis. GMR-5311.

(3) D'Arcy, J.B., Schreck, R.M., and Siak, J-S., 1986. Health Effects Analysis of Wear-Generated Particles from Semi-Metallic Brake Materials. GMR-5611.

the semi-metallic disk and drum brake lining residue dispersed freely forming homogeneous suspensions and were composed mainly of iron and iron oxide although barium, magnesium, and sulfur were also detected. Virgin semi-metallic disk and drum brake lining samples (**Figures 2a, 2b**) were generated artificially by filing the brake linings themselves. These samples contained slightly larger particles composed mainly of iron, carbon, and a phenoxy resin binder and did not disperse as readily with some of the material remaining in small clumps.

Chrysotile, crocidolite, and amosite asbestos (UICC) were used as positive controls. Both crocidolite (**Figure 3a**), and amosite (**Figure 3b**) have straight needle-like fibres, while chrysotile (**Figure 4**) has curled fibres. All three dispersed with sonication into the incubation medium with the exception of the highest concentration (250 µg/mL) of chrysotile which could not be dispersed. The calcium sodium metaphosphate (fine, lot no. 3075084N) and Fiberfrax (milled fibre) fibres were obtained from Monsanto (St. Louis, MO) and Sohio (Niagara Falls, NY) respectively. The calcium sodium metaphosphate fibres ($[CaNa(PO_3)_3]_n$, **Figure 5a**) differed greatly in length and diameter while Fiberfrax (**Figure 5b**), composed mainly of Al_2O_3 (49.2%) and SiO_2 (50.5%), had uniform, straight blunt-ended fibres approximately 14 µm long and 2-3 µm in diameter. Both dispersed easily forming homogeneous suspensions.

Analysis — Following exposure, changes in cell morphology were assessed using phase contrast photomicroscopy. Cell counts were made and viability measured using trypan blue exclusion. A viability index was calculated by multiplying the number of cells in the treated samples as a percent of control by the percent viable cells (as a percent of control) to reflect changes in both of these parameters.

$$\text{Viability index} = \%\ \text{viable cells} \times \frac{\text{total cells in test sample}}{\text{total cells in control sample}}$$

RESULTS

Cell morphology was not significantly altered after a 24 hour incubation with any of the materials studied. In all cases, the cells appeared to be an intact adherent monolayer engaged in active phagocytosis. **Figures 6** and **7** show control J774A.1 cells (**6a**) and those exposed to 2.5 (**6b**), 24 (**&a**), and 250 (**7b**) µg calcium sodium metaphosphate fibres/mL medium for 24 hours using phase contrast microscopy (200x) The cells appear to have clearly defined nuclei, distinct cellular organelles, and intact plasma membranes. A number of cells contain engulfed fibres (arrows in **Figures 6b, 7a,** and **7b**) and in some cases large fibres are surrounded by more than one cell.

Cell number and viability were assessed using trypan blue exclusion. No significant effect on J774A.1 cell number was observed following 24 hour incubations with any of the fibres or particles studied (CR, crocidolite; AMO, amosite; CHR, chrysotile; MP, calcium sodium metaphosphate; FF, Fiberfrax; DKR, disk lining residue; DRR drum lining residue; DK, disk lining filings; DR, drum lining filings) at the two lowest concentrations of 0.25 and 2.5 µg/mL incubation medium (**Figures 8-9**). At a fibre concentration of 25 µg/mL, cell suspensions treated with all three of the asbestos fibres and both of the asbestos substitute fibres (calcium sodium metaphosphate and Fiberfrax) showed significant reductions in cell number (**Figure 10**). Neither the disk or drum residue or disk and drum samples showed any significant reduction in cell number at this concentration. At the highest concentration of 250 µg/mL, all of the samples studied (including the semi-metallic brake lining materials) showed significant reductions in the number of J774A.1 cells remaining following a 24 hour incubation with the test fibres or particles (**Figure 11**).

None of the materials produced any change in cell viability when incubated with J774A.1 cells for 24 hours at the lowest concentration of 0.25 µg/mL (**Figure 12**) and only chrysotile asbestos produced a significant reduction in viability at 2.5 µg/mL (**Figure 13**). The J774A.1 cells showed a greater response to the fibres at 25 µg/mL with significant decreases in cell viability being observed for all three of the asbestos-treated samples and both the disk and drum residue samples (**Figure 14**). At the highest concentration of 250 µg/mL, significant reductions in viability were again seen in the asbestos-treated samples (chrysotile data not available) as well as for the calcium sodium metaphosphate fibres (**Figure 15**).

A viability index was calculated by multiplying the number of cells as a percent of control by the percent viable cells (as a percent of control) to reflect changes in both cell number and cell viability. All of the fibres studied produced a concentration-dependent decrease in viability index when incubated with J774A.1 cells (**Figures 16-19**) for 24 hours. This decrease was significant at the two highest concentrations for chrysotile, crocidolite, and amosite asbestos, the two asbestos substitute fibres (calcium sodium metaphosphate fibres and Fiberfrax) and the semi-metallic drum and disk brake residues. The effect of the semi-metallic disk and drum filings, however, was significant only at the highest concentration of 250 µg/mL.

DISCUSSION

The actual amount of material deposited in the lung is dependent on the concentration of the material in the environment as well as the size, shape, and other physical properties of the fibres. In general, for fibres to be respirable, they must be less than 3.5 µm in diameter and less than 200 µm in length. In addition, straight rod shaped fibres have been shown to deposit at a rate more than 5x greater than curled fibres and curled fibres have been shown to deposit more easily at bifurcations in the airways than in the peripheral alveoli. Therefore, for example, the amount of chrysotile asbestos which actually deposits in the lungs would be expected to be lower and to accumulate mainly in the bifurcations of the alveolar ducts when compared with the fine, straight fibres of crocidolite asbestos, since chrysotile fibres are more curled and interwoven[4]. Furthermore, the ability of the lungs to clear these fibres depends on the site of deposition as well as the amount of material deposited, integrity of the alveolar macrophages and again the size, shape, and biodegradability of the fibrous particles. Calcium sodium metaphosphate fibres[5] have been cited as being biodegradable and would, therefore, be expected to be less toxic to the lung than a durable fibre such as asbestos.

A number of parameters have been used to evaluate the cytotoxic effect of environmental pollutants *in vitro*. Two of the most commonly used criteria in the assessment of cellular integrity are the enumeration of cells as a measure of cell replication[6] and the exclusion of trypan blue for the assessment of cellular viability[7][8][9] Waters *et al.*[10] have combined both parameters into a viability index and have found it to be particularly useful in cases of cytotoxicity testing where cell death occurs by mechanism which result in differing degrees of cell lysis.

Determination of the sequence and mode of cell death may be of importance in the case of alveolar macrophages since nonviable macrophages, containing phagocytized materials, which do not lyse may still be transported up the mucociliary escalator and out of the lung fulfilling the protective purpose of these cells. On the other hand, death and immediate lysis of these cells would result in the release of the inhaled materials which would then be in direct contact with the epithelium and available for reengulfment or interstitial absorption. This would prolong the residence time of the material and could contribute to the development of lung disease.

The magnitude of the cytotoxic response (reduction in cell number) was greatest for the asbestos samples. The calcium sodium metaphosphate fibres

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(4) Lee, K.P., Kelly, D.P., and Kennedy Jr., G.L., 1983. Pulmonary Response to Inhaled Kevlar Aramid Synthetic Fibres in Rats. Toxicology and Applied Pharmacology 71: 242-253

(5) Li, A.P., Myers, C.A., Flowers, L.J., Short, R.D. Jr., Hines, D., 1986. *In Vitro* Evaluation of the Biodegradability and Cytotoxicity of Calcium Sodium Metaphosphate Fibre: A Novel Manmade Fibre. The Toxicologist 6(1): 136.

(6) Streissle, G., Schwobel, W., and Hewlett, G., 1981. Evaluation of Antiviral Compounds in Cell Cultures with Acute or Persistent Virus Infections. In Advances in Cell Culture, ed. K. Maramoroch, Vol. 1, pp. 67-90, New York: Academic Press.

(7) Seglen, P.O., 1976. Preparation of Isolated Rat Liver Cells. Methods in Cell Biology 13: 29-83.

(8) Paul, J., 1975. General Quantitative Techniques. In Cell and Tissue Culture, 5th ed., pp. 354-384, New York: Churchill Livingstone.

(9) Muller, L., 1984. Differential Sensitivity of Integrity Criteria as Indicators of Cadmium-induced Cell Damage. Toxicology Letters 21: 21-27.

(10) Waters, M.D., Gardner, D.E., Aranyi, C., and Coffin, D.L., 1975. Metal Toxicity for Rabbit Alveolar Macrophages *in vitro*. Environmental Research 9: 32-47.

also produced a significant cytotoxic response when compared to the other fibre or particulate samples and were more cytotoxic than Fiberfrax, the other asbestos substitute fibre studied. The disk and drum filings and disk residue, like Fiberfrax, were less toxic than the asbestos or the calcium sodium metaphosphate fibres. The drum residue, on the other hand, while not as cytotoxic as the asbestos or the calcium sodium metaphosphate fibres, was more toxic than its matched control (drum filings).

While significant reductions in viability were observed, the magnitude of the responses were more variable and were not as dramatic for any of the fibres studied as were the reductions in cell number (cytotoxicity). The greatest decrease in cell viability, 32%, was observed in the J774A.1 cells after 24 hours of incubation with amosite asbestos at the highest concentration of 250 μg/mL medium in comparison to the 79% reduction in cell number observed for this same fibre.

The asbestos fibres, therefore, produced a consistent concentration-dependent reduction in both cell number and cell viability. The asbestos substitute fibres, on the other hand, had a greater effect on cell number than on cell viability. These results suggest that these fibrous materials produced immediate cell lysis which was reflected in the decrease in cell number observed in these experiments and that cell damage in the absence of immediate lysis of the cells (decrease in cell viability) was observed only at higher concentrations. The effect of the semi-metallic brake lining material appeared to be greater on cell viability than on cell number. In this case, the cells, while damaged, remained intact (did not immediately lyse) increasing the probability that the fibre or particle engulfed would be removed from the lung, thereby decreasing the exposure of the more sensitive cells of the respiratory tract.

Using the viability index as a method to compare the cytotoxicity of the various fibres and particulates studied, it may be concluded that the asbestos fibres were significantly more toxic than the other fibres studied with the calcium sodium metaphosphate fibres almost as toxic as these positive controls. The semi-metallic brake drum residue was somewhat more toxic than the remainder of the materials studied although it was significantly less toxic than the asbestos or the calcium sodium metaphosphate fibres. The Fiberfrax and semi-metallic disk brake residue appeared to be slightly more toxic than the disk and drum brake filings although this difference was not statistically significant.

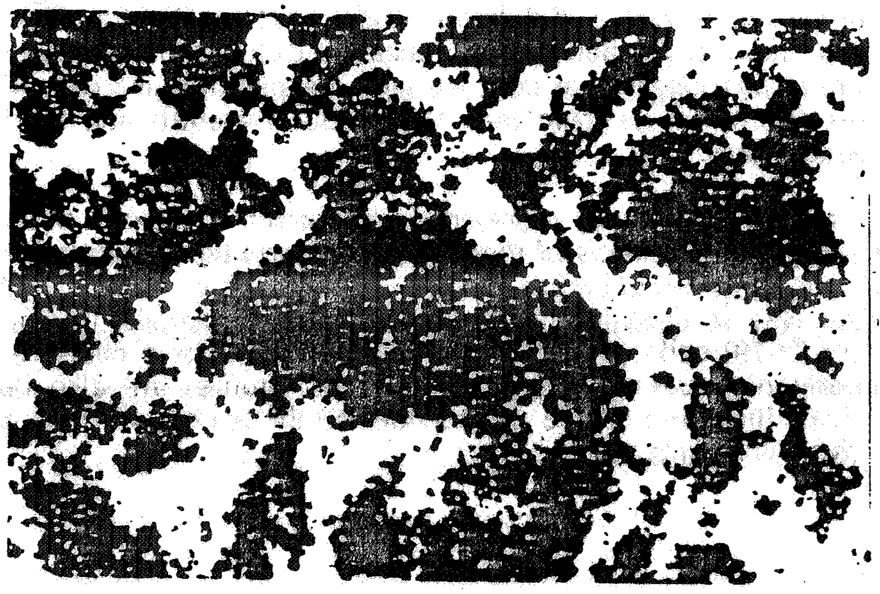
In conclusion, measurements of cell number, cell viability, and cell morphology provided a fast and inexpensive method for comparing and evaluating the relative cytotoxic effects of a broad spectrum of fibrous and particulate materials in a mammalian cell system. Through the use of simple but quantitative markers of cellular integrity, the present study has established the relative cytoxicity of the various fibres and particles under study. At equivalent concentrations (µg/mL), the three asbestos fibres, amosite, crocidolite, and chrysotile, were found to be slightly more toxic than the calcium sodium metaphosphate fibres which were significantly more toxic than semi-metallic brake drum residue. These in turn were slightly more toxic than the semi-metallic disk brake residue and the Fiberfrax fibres which were slightly more toxic than the semi-metallic disk and drum brake lining filings. These results suggest that both the semi-metallic disk and drum brake residues were generally less toxic than the fibrous materials and in particular, the asbestos fibres.

The results of this study represent an important first step in the analysis of the potential health effects of these materials, additional data must be obtained and should be extended to include *in vivo* systems. Subsequent studies are under way to determine the effects of these materials, in Chinese hamster ovary (V-79) cells on chromosomal aberrations as a measure of the direct tumorigenic potential of these materials. Studies are also being done to evaluate the effect of size and number on the toxicity of these materials both *in vivo* and *in vitro*.

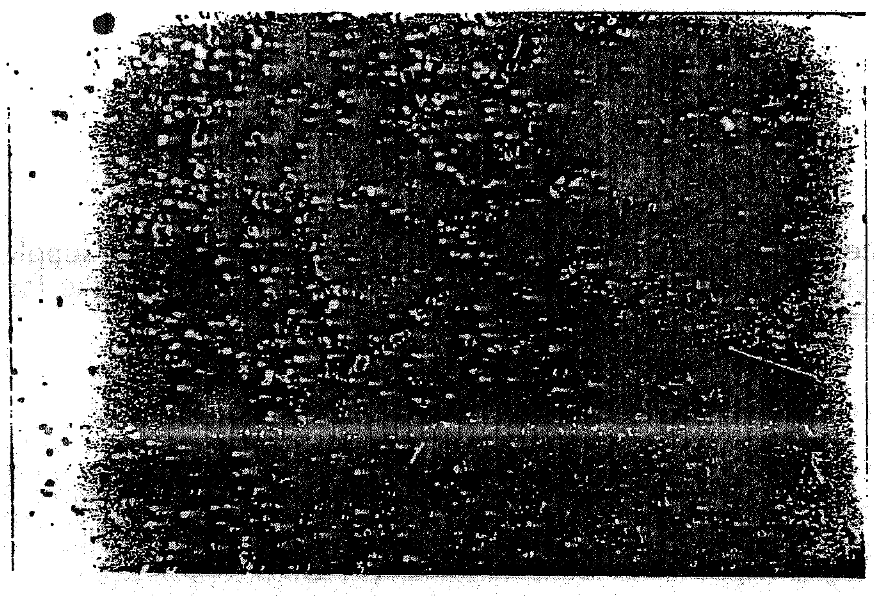
Acknowledgement

The authors would like to thank Mr. James B. d'Arcy for supplying the semi-metallic brake lining materials and Mrs. Marlaine Scheske for the asbestos samples used in this study.

FIGURE 1

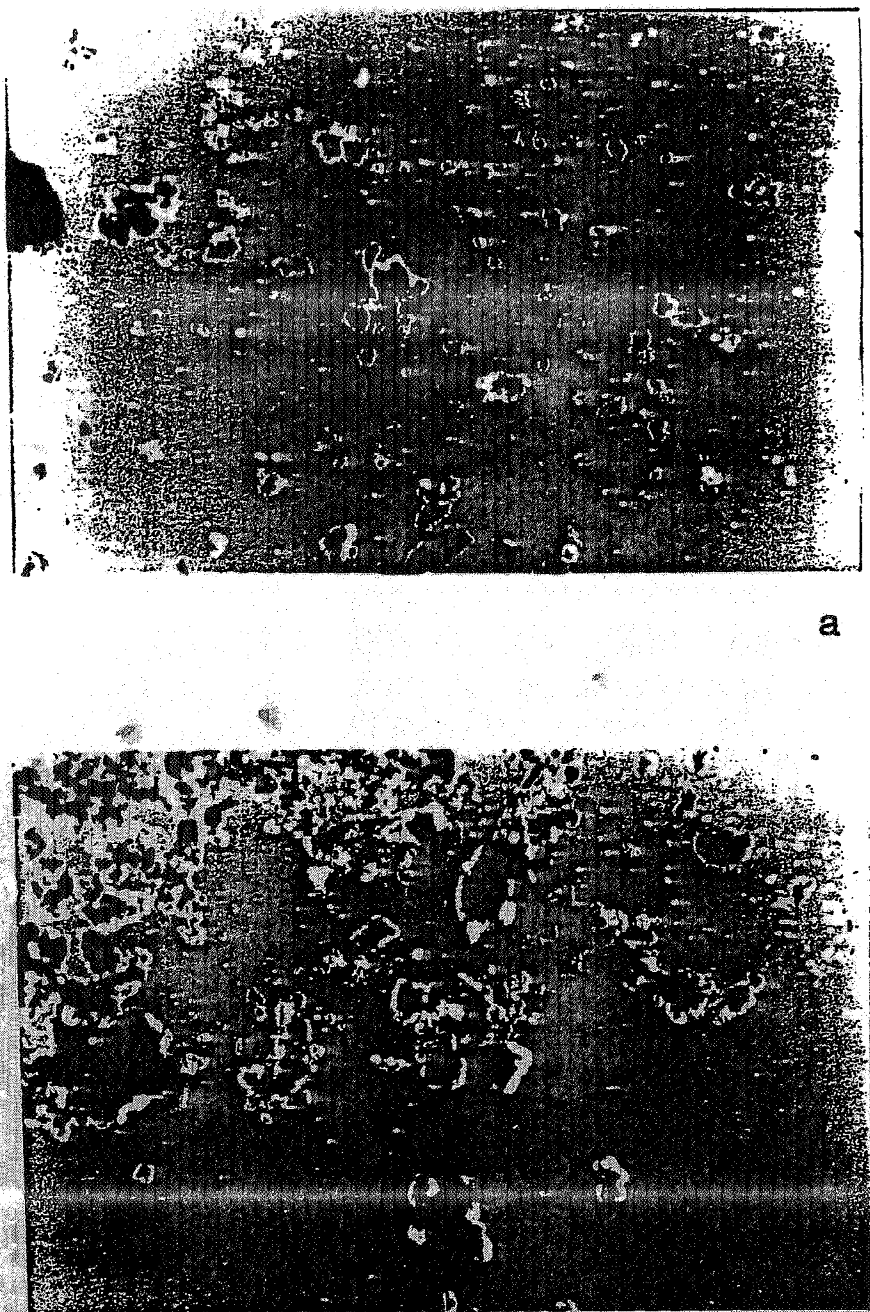


a



b

FIGURE 2

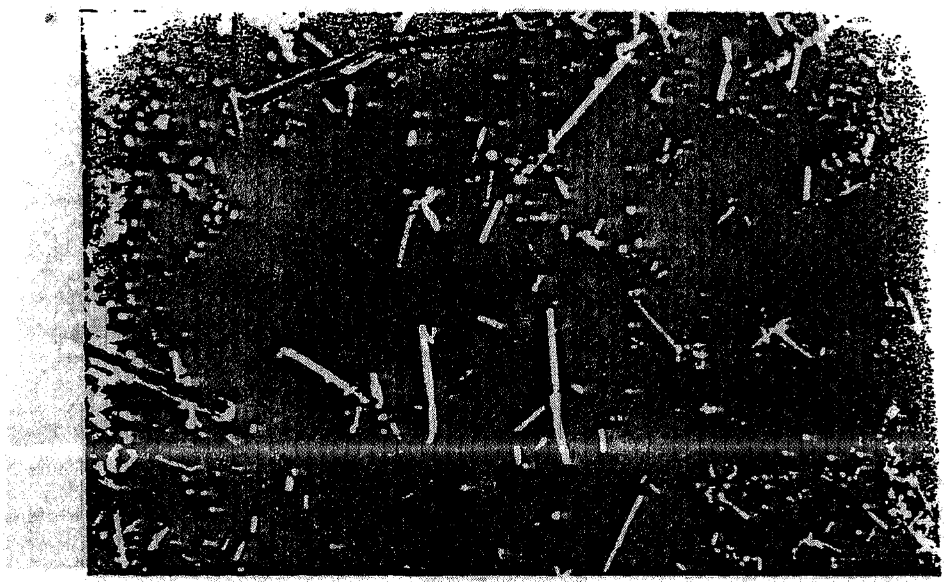


a

b

FIGURE 3

a



b

FIGURE 4

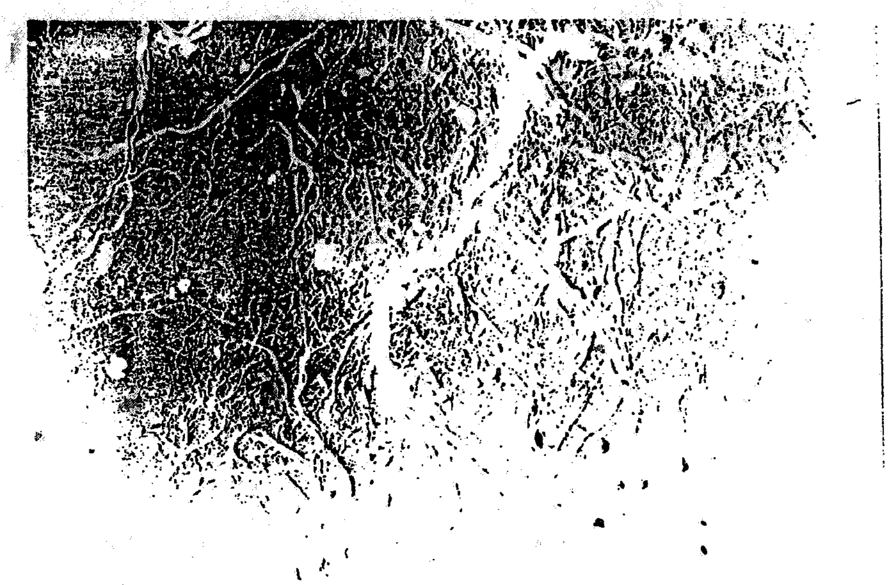
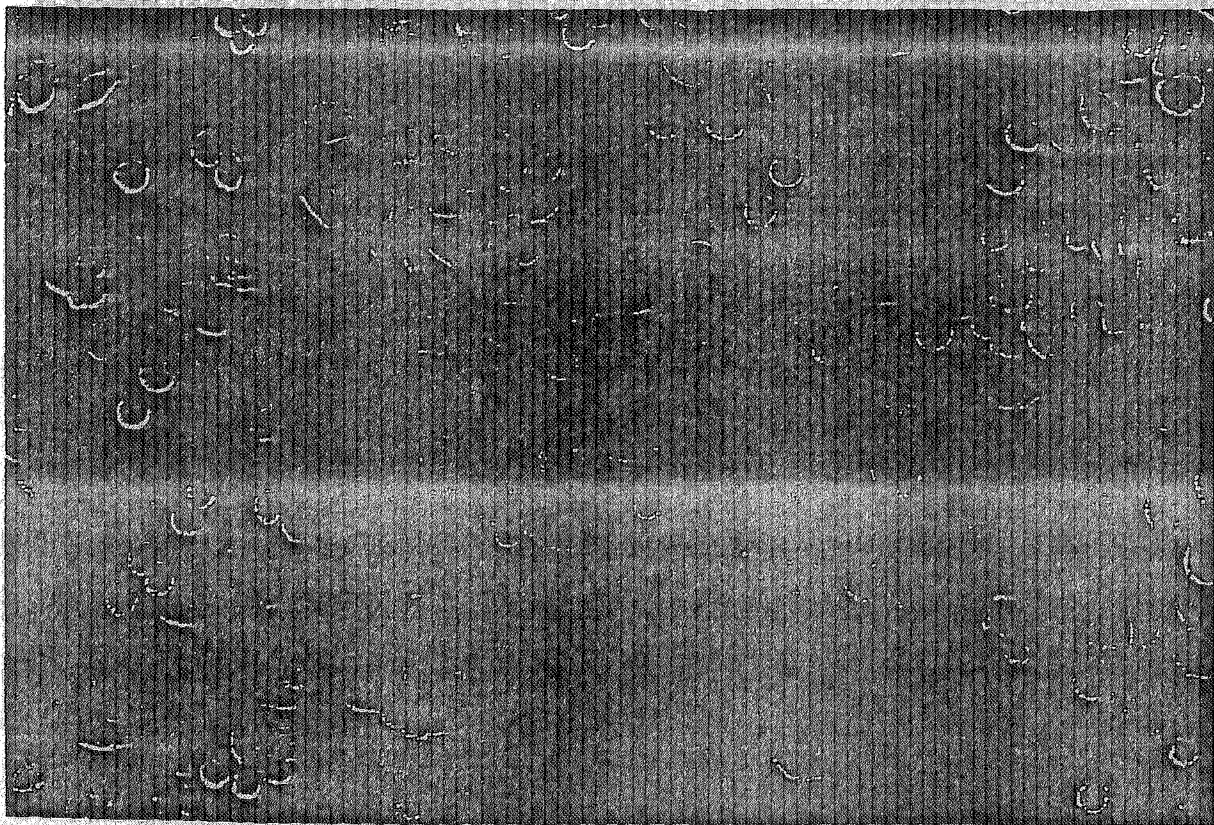


FIGURE 5

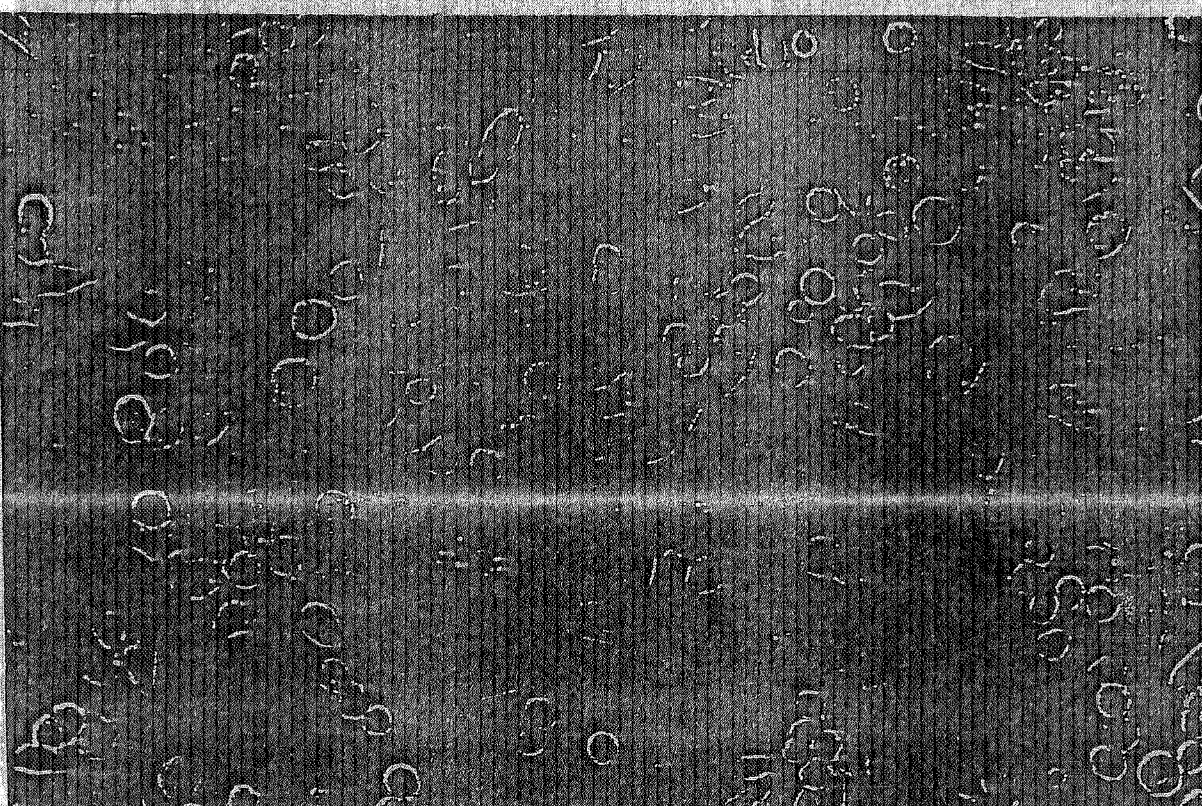
a

b

FIGURE 6

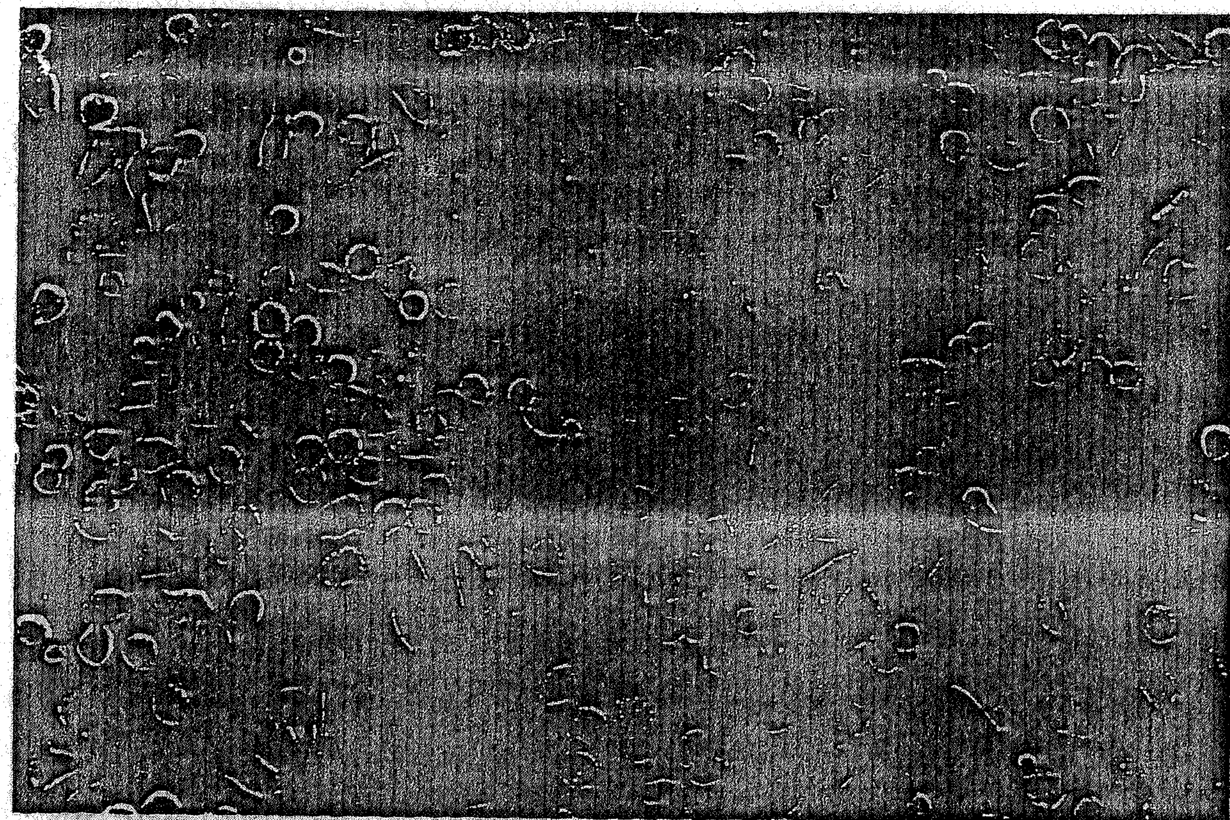


a

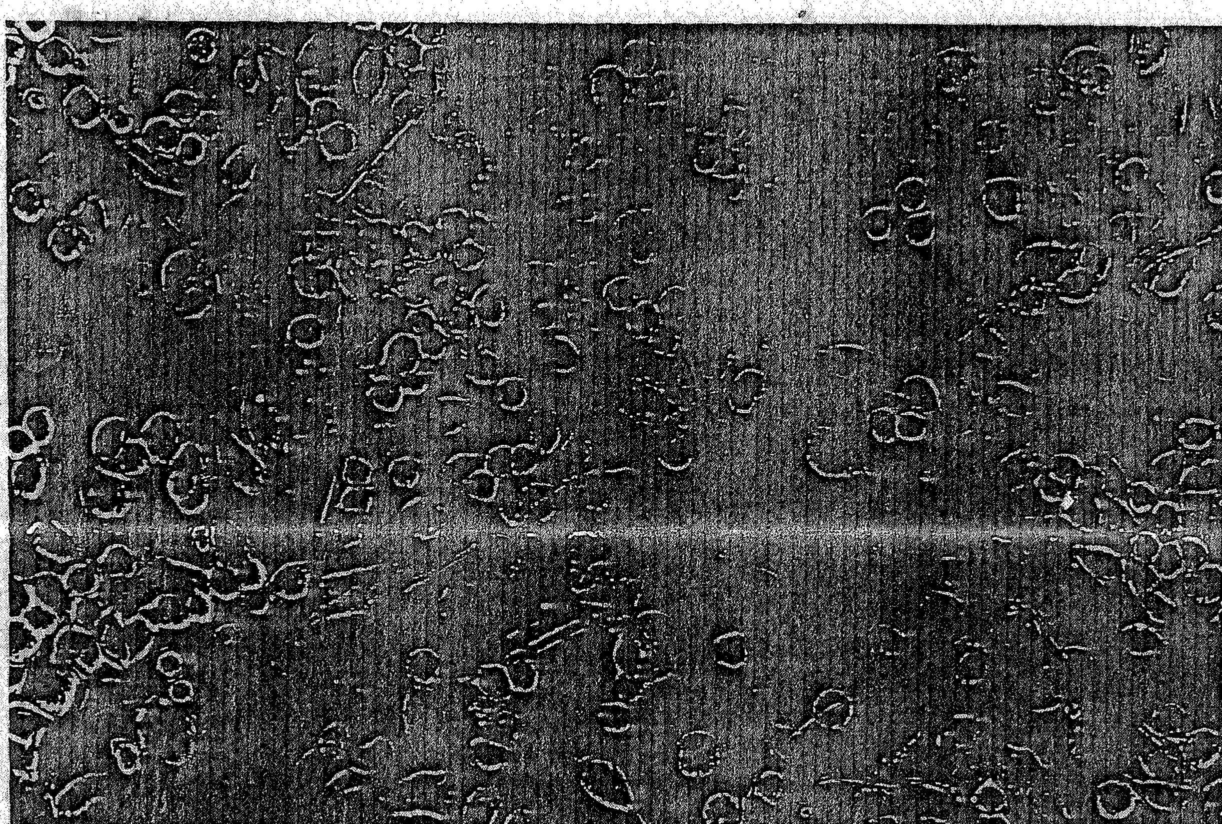


b

FIGURE 7



a



b

FIGURE 8

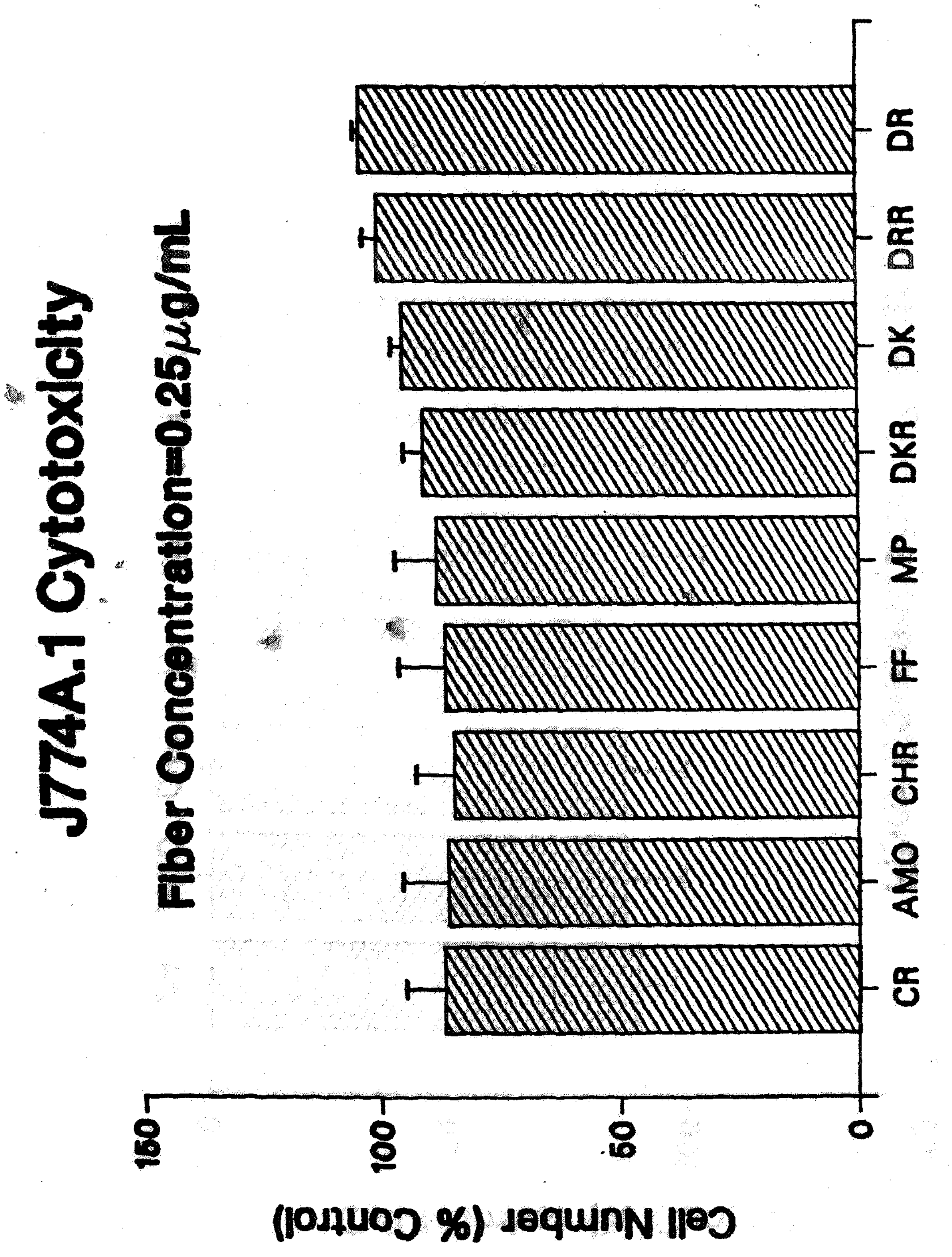


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FIGURE 9

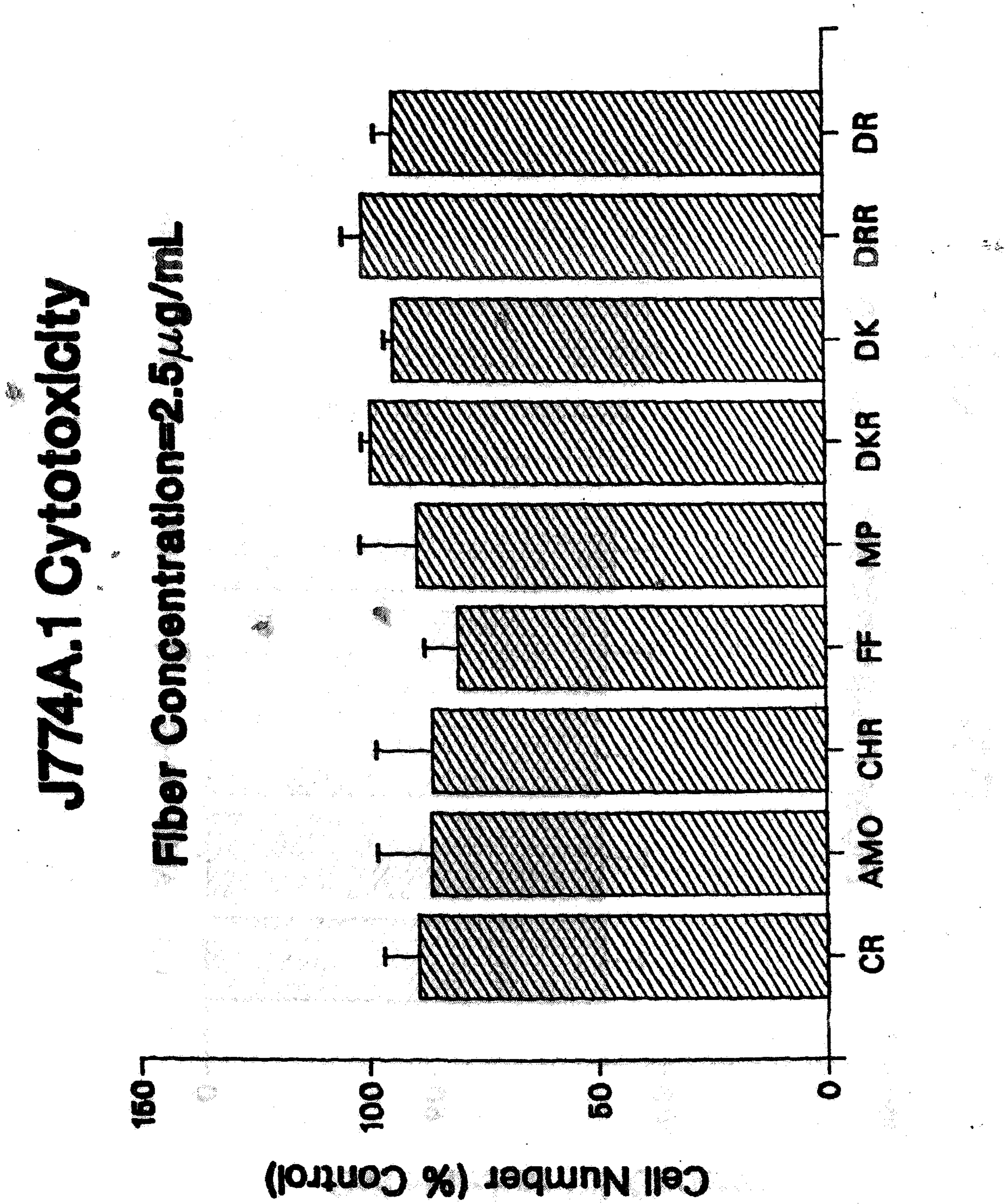

J774A.1 Cytotoxicity
Fiber Concentration=2.5μg/mL
Cell Number (% Control)
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR

FIGURE 10

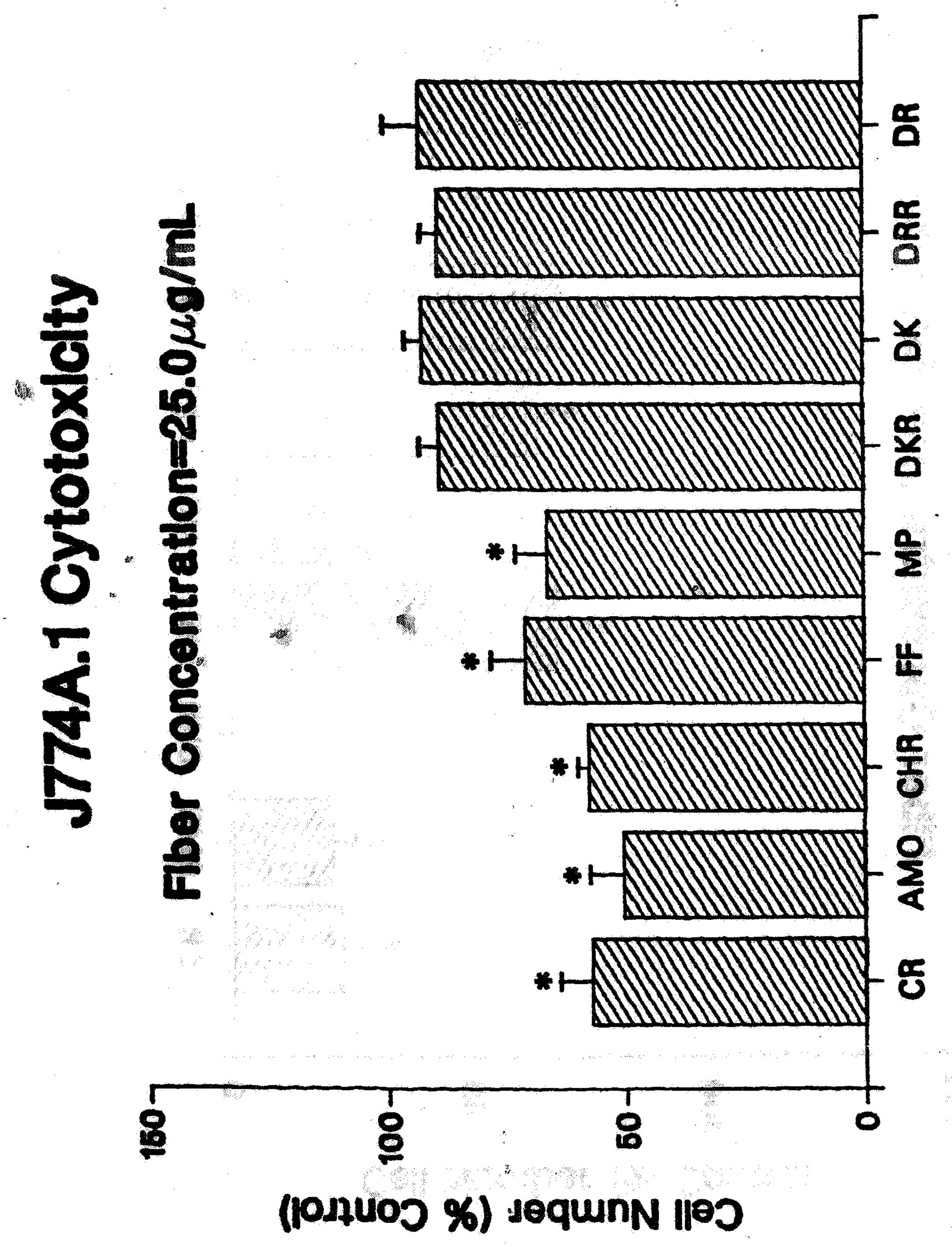
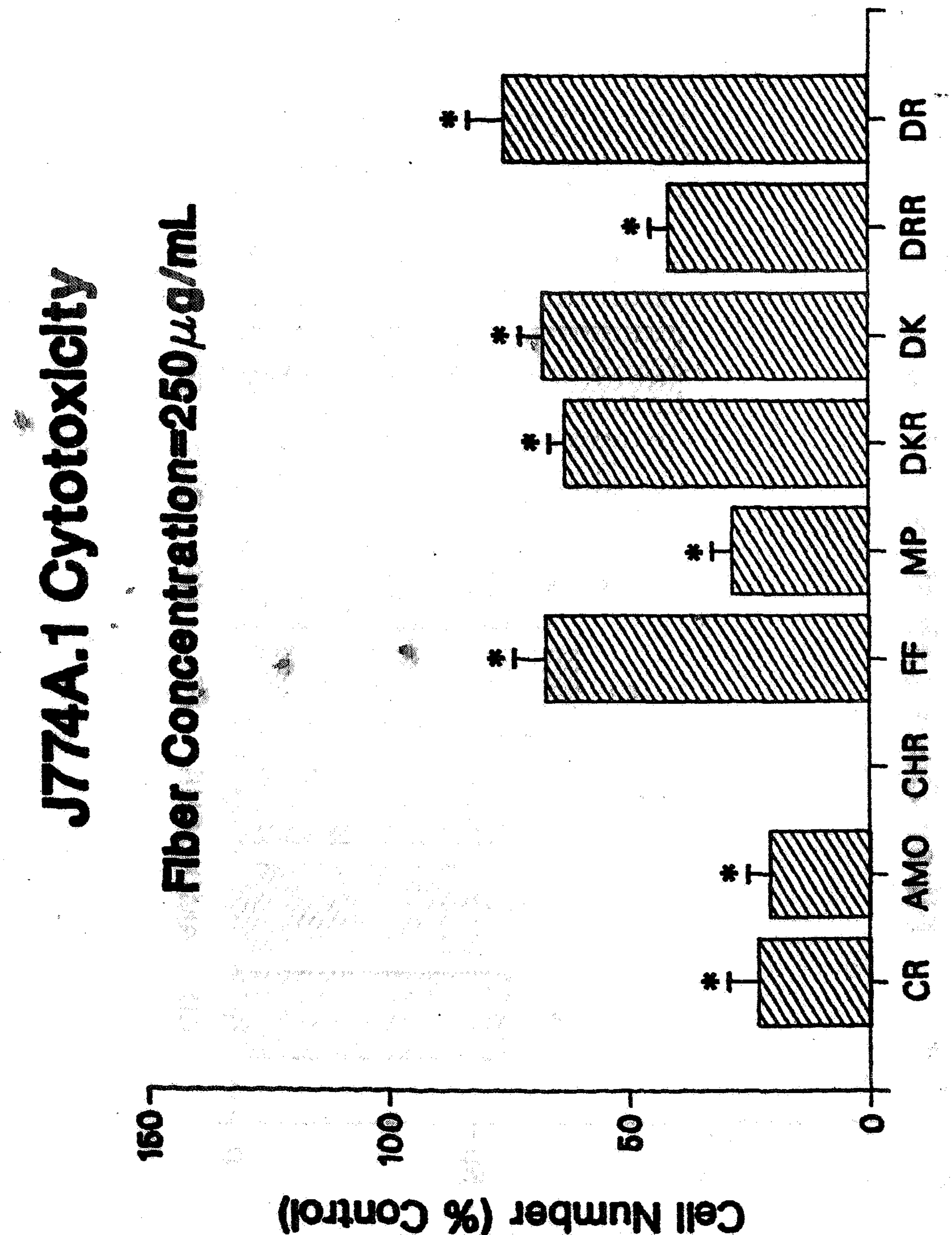
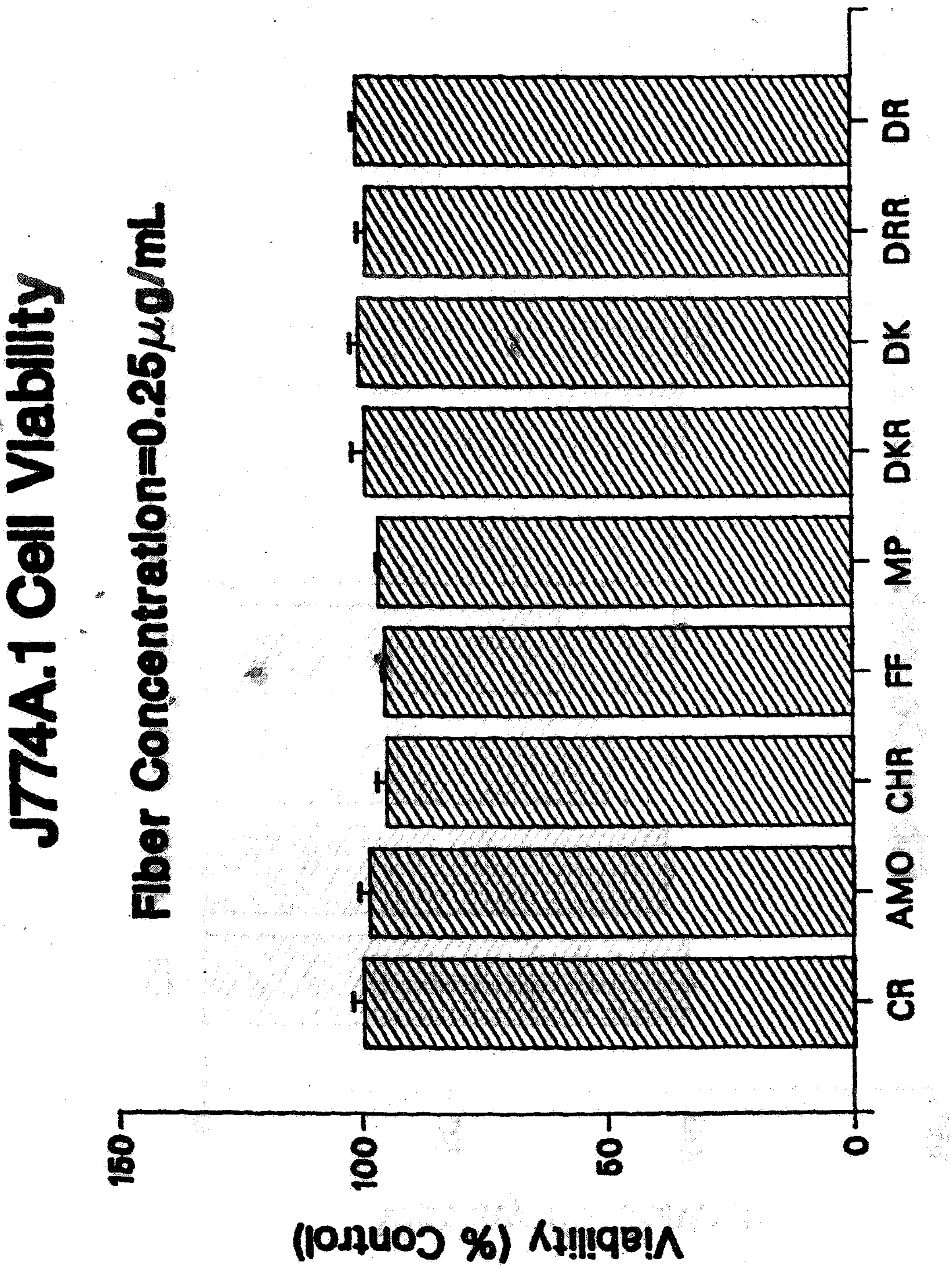

J774A.1 Cytotoxicity
Fiber Concentration=25.0μg/mL
Cell Number (% Control)
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR
*
*
*
*
*

FIGURE 11



J774A.1 Cytotoxicity
Fiber Concentration=250μg/mL
Cell Number (% Control)
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR

FIGURE 12


J774A.1 Cell Viability
Fiber Concentration=0.25μg/mL
Viability (% Control)
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR

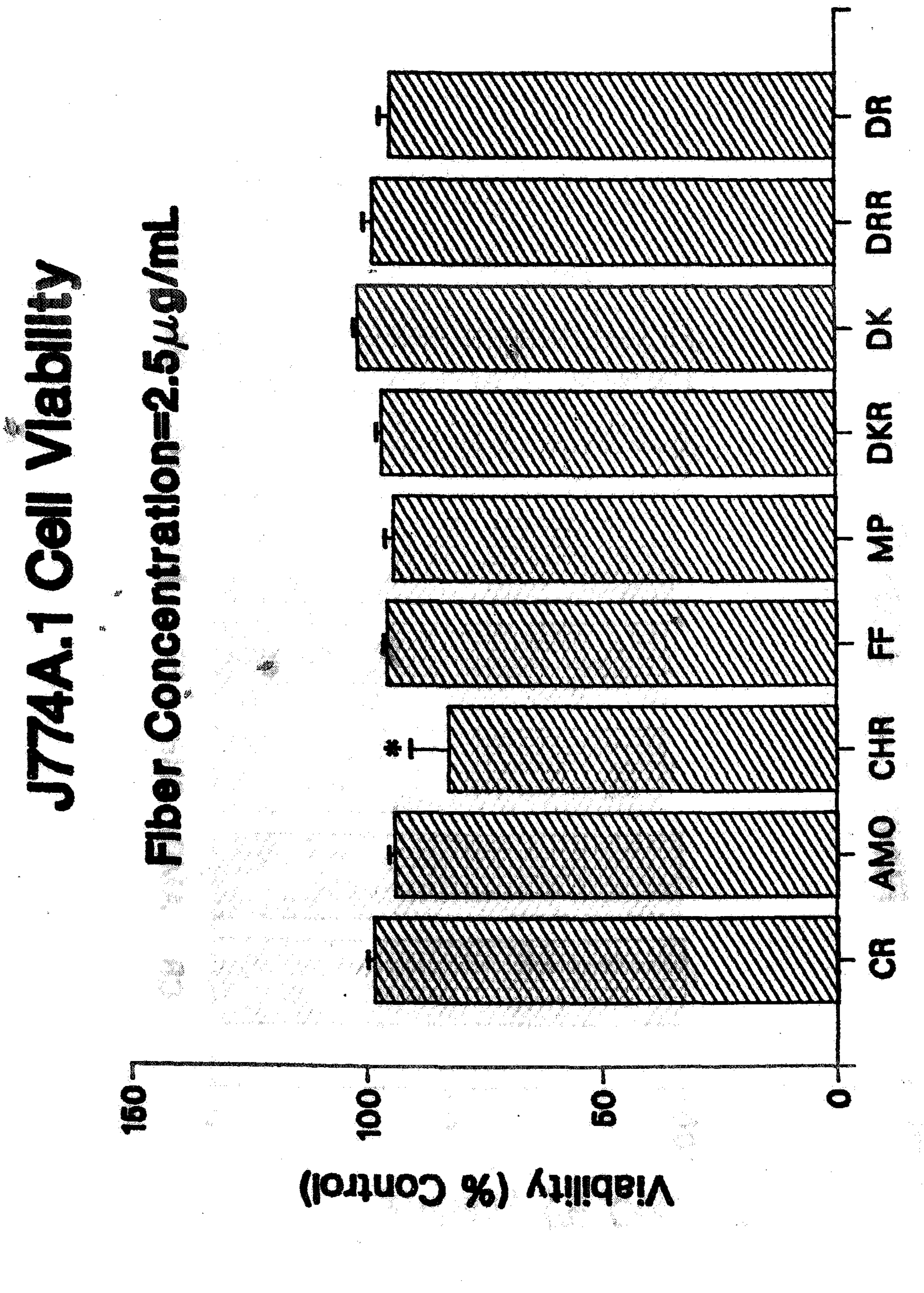
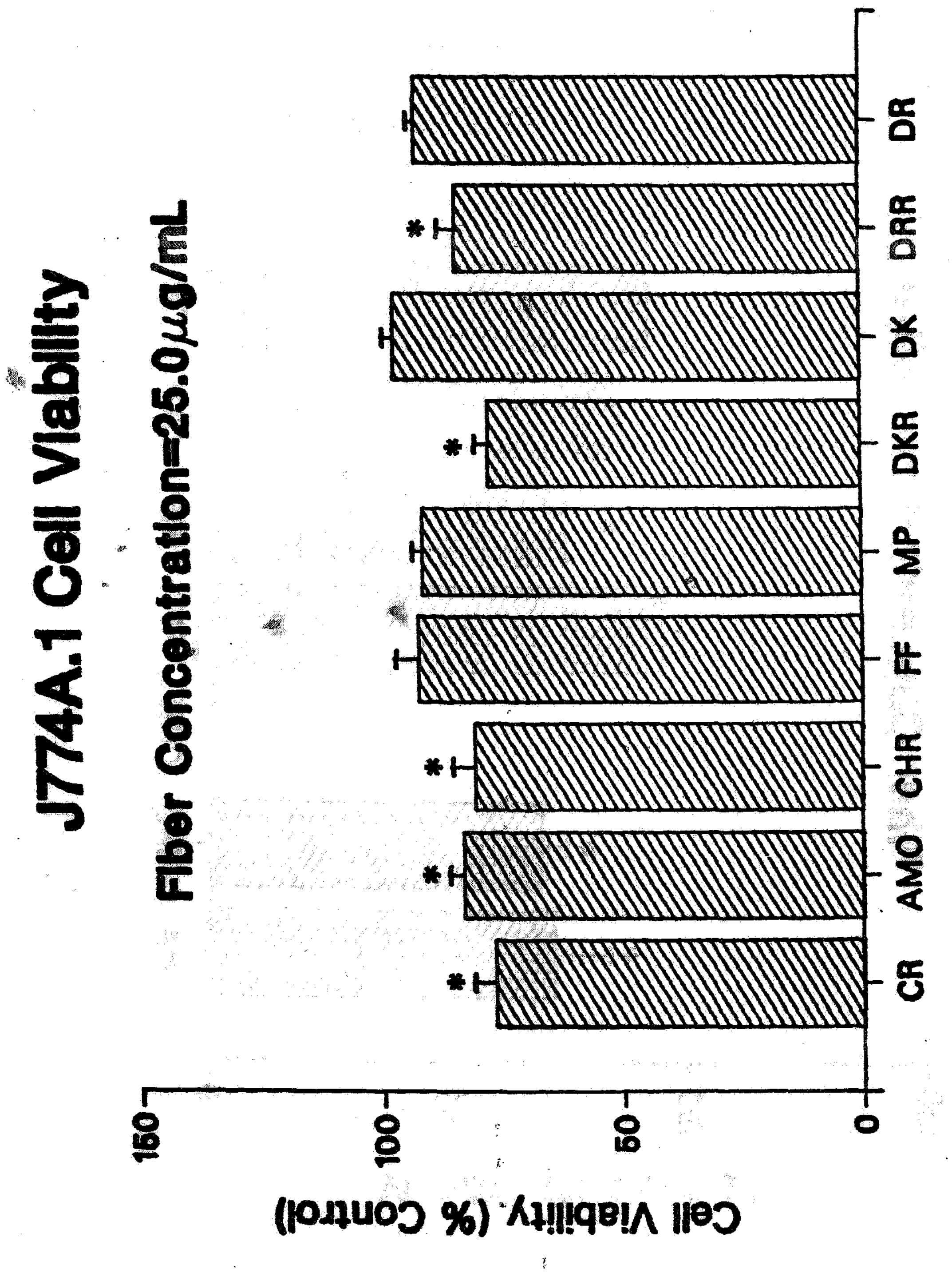

J774A.1 Cell Viability
Fiber Concentration=2.5μg/mL
Viability (% Control)
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR
*

FIGURE 14



J774A.1 Cell Viability
Fiber Concentration=25.0μg/mL
Cell Viability (% Control)
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR

FIGURE 15

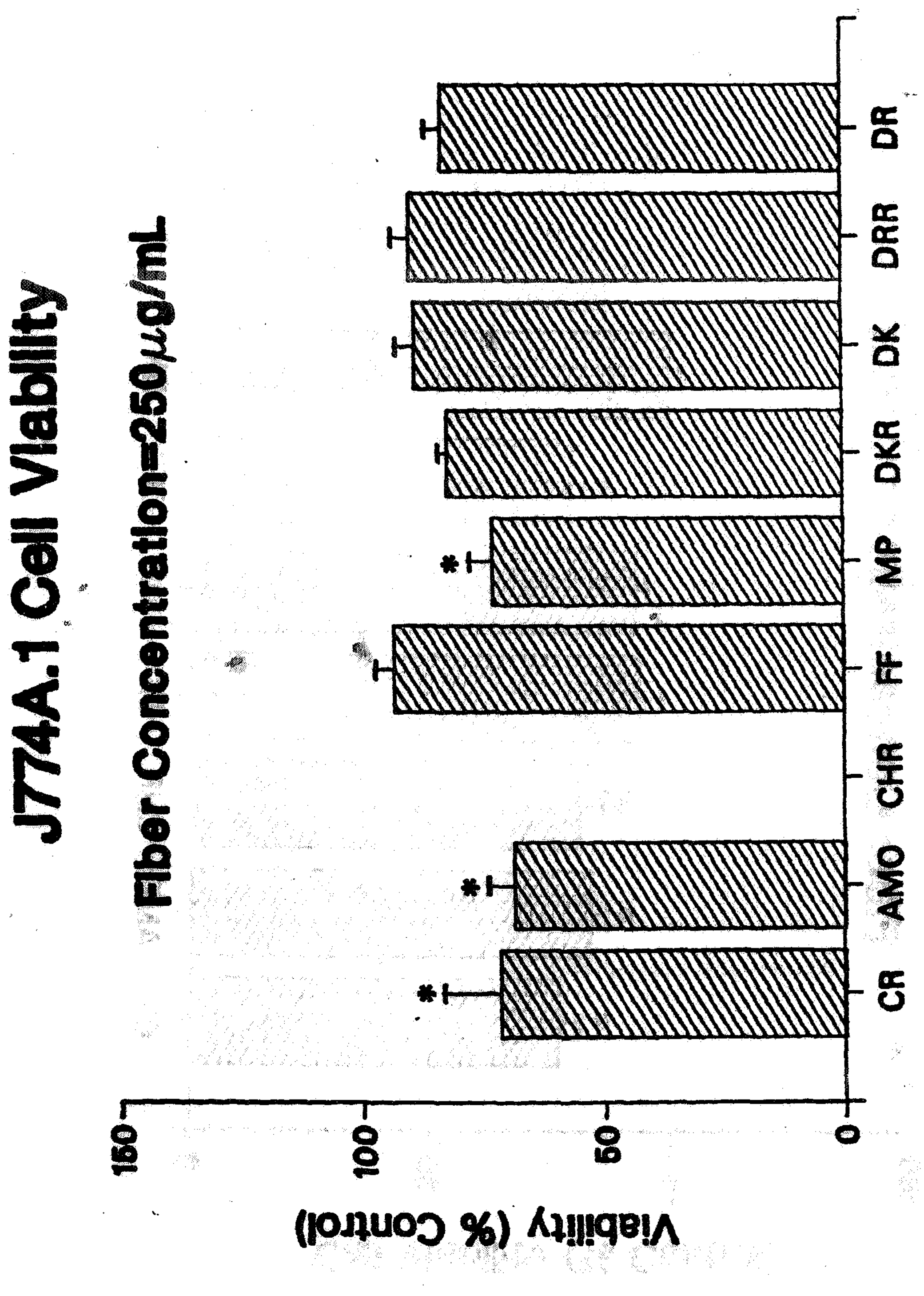

J774A.1 Cell Viability
Fiber Concentration=250μg/mL
Viability (% Control)
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR
*
*
*

FIGURE 16

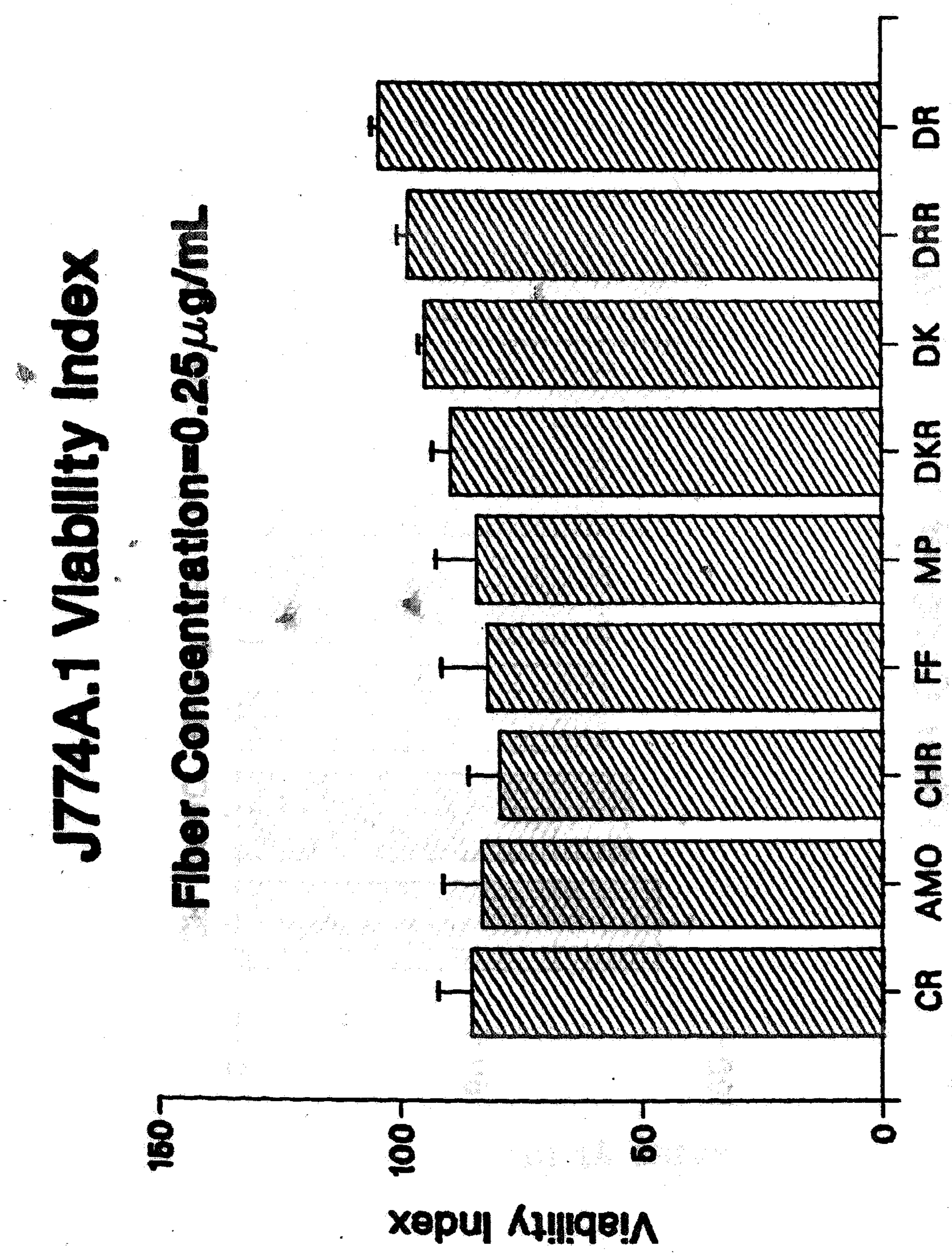
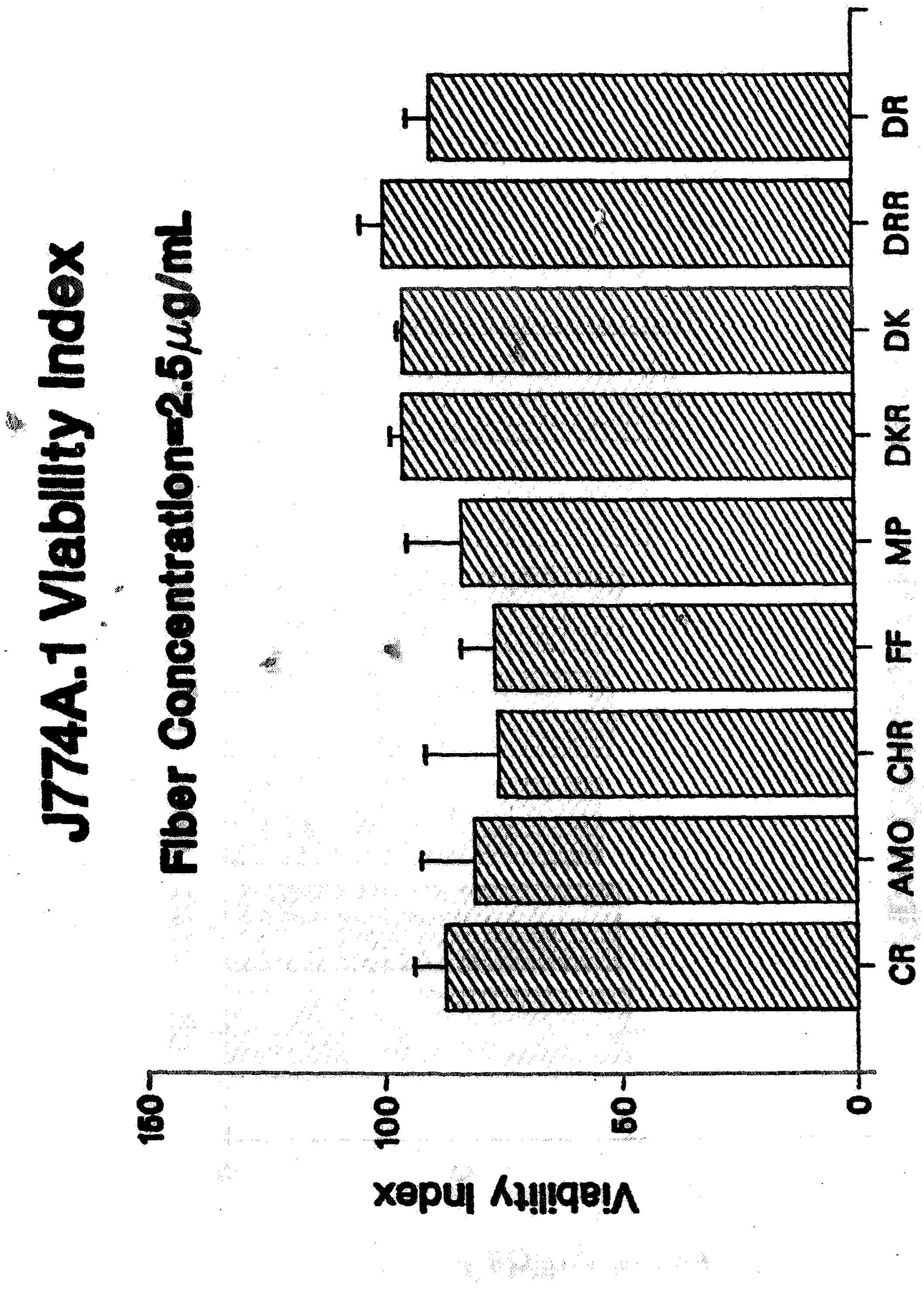

J774A.1 Viability Index
Fiber Concentration=0.25μg/mL
Viability Index
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR

FIGURE 17



J774A.1 Viability Index
Fiber Concentration=2.5μg/mL
Viability Index
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR

FIGURE 18

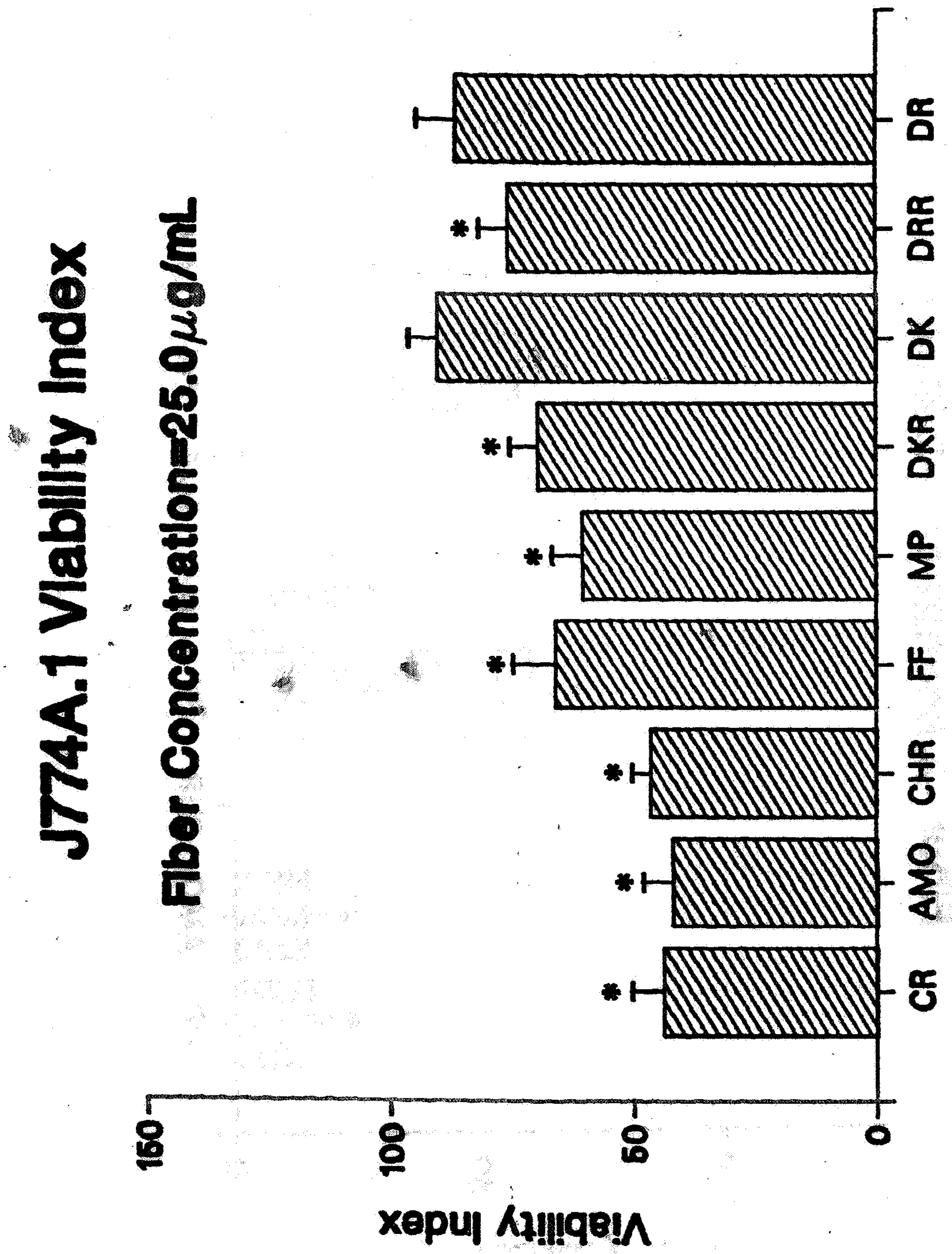
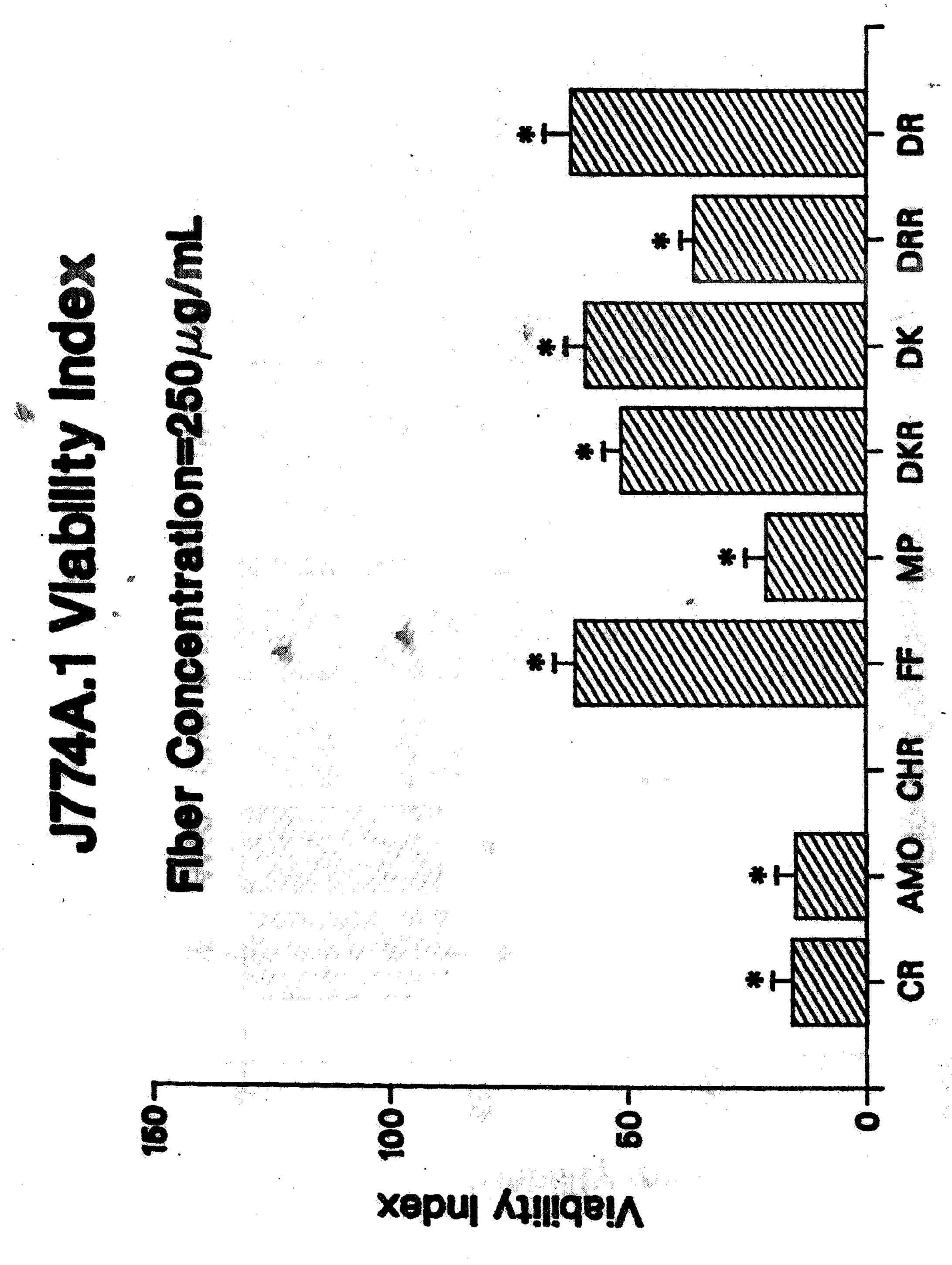

J774A.1 Viability Index
Fiber Concentration=25.0μg/mL
Viability Index
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR
*

FIGURE 19


J774A.1 Viability Index
Fiber Concentration=250μg/mL
Viability Index
150
100
50
0
CR
AMO
CHR
FF
MP
DKR
DK
DRR
DR

SESSION III

QUESTION AND ANSWER PERIOD

Part I

Unidentified voice: I have two questions, one for Dr. Donaldson and one for Dr. Enterline.

Dr. Donaldson, in this last presentation, you compared the activity of ceramic fibres 90 percent shorter than 2 or 3 microns to much longer fibres of chrysotile (UICC preparations A).

My question is: What would be the results if you had compared the ceramic fibres, whose rate of tumor production was 8 out of 48 animals with similar, shorter lengths of chrysotile?

KENNETH DONALDSON: Our experience with long and short asbestos fibre samples at the Institute of Occupational Medecine would suggest that using short fibre chrysotile reduced the number of tumors.

Unidentified voice: What do you mean by substantially? What would be the tumor yield caused by injecting chrysotile fibres wich are 100 percent or 90 percent below 2 microns?

KENNETH DONALDSON: We have never done that. I don't like making predictions, but I think it would be very low.

Unidentified voice: Possibly even lower than the yield with ceramic fibres?

KENNETH DONALDSON: Possibly, yes.

Unidentified voice: Thank you. My second question is to Dr. Enterline. You have compared the excess and deficit cancer risk of mineral wool workers with asbestos textile workers, and the latter is possibly the worst-case scenario. If you compare mineral workers with asbestos brake-lining workers, would you have the same results?

PHILIP ENTERLINE: It would be an interesting comparison. I think one of the problems is that few studies deal in pure chrysotile, crocidolite, or amosite fibres. But I would agree that the brake-lining worker studies do not seem to show very large excesses in respiratory cancer.

Unidentified voice: Yes, I agree with you because, at least in North America, brake-lining worker are exposed to pure chrysotile asbestos not mixed fibres.

PHILIP ENTERLINE: I think you have to think about the dose too. Obviously, it is important somehow to standardize these studies for the extent of exposure.

D. WARHIDE: These are very fine presentations, but many people in the audience who are unfamiliar with toxicological or epidemiological data must be very confused about all the different numbers. Initially, Dr. Nolan told us about the Stanton hypothesis being greater than 8 microns in length and less than 0.25 microns in diameter. But I do not think you mentioned that this was probably an interpleural or interperitoneal injection. Then we had the data from the erionite fibres, which were 2 microns in length and 0.1 to 0.2 microns in diameter. It is very short fibre; however, it produced tumors in all inhalation models.

Then Dr. Enterline presented data showing that, with fibreglass and man-made mineral fibres, there were essentially no tumors through inhalation. There were, I believe, two tumors through in intertracheal injection and several tumors in interperitoneal or interpleural injections.

And then, with Dr. Donaldson's slides, we saw some tumors caused by inhalation, but tumors were primarily caused by interperitoneal injection.

The first question that I have is: How relevant are intertracheal and interperitoneal models? I believe that inhalation is really the only true way to test these things. Interperitoneal injection does not simulate exposure at all. The lung does not see the amount of dust injected in interperitoneal models.

The second question is addressed to Dr. Hughes. You presented some very interesting data on asbestos-related tumors. In 1984, we demonstrated that chrysotile asbestos is a very fibrogenic dust. The fibrogenic process begins within 48 hours, even after a mere one-hour exposure, and so it is truly a progressive lesion. I would like to ask Dr. Hughes whether those individuals who developed asbestos-related tumors also had asbestosis. What is the correlation between the development of fibrosis and tumors? I think they may very well be related.

BETTE MEEK: With respect to your first question, I think that the method of administering fibre samples must be taken into account when assessing health effects associated with fibrous materials. I would like to have the various aspects of this question addressed in some detail. May I suggest that we defer the question until after every one has made a presentation?

With respect to your second question, Dr. Hughes, would you reply to the question of the correlation of fibrosis and tumors?

JANET HUGHES: I think the question you raise about relationship between lung cancer and asbestos is very important. Unfortunately, it is very difficult to answer, as I am sure you know. Asbestos-associated lung cancers are not identifiable in any way from those that are, say, smoking-related. Some people have tried to divide populations into those with and those without asbestosis, and then look at subsequent lung-cancer risk. People with asbestosis presumably have elevated asbestos exposure, and we know asbestos exposure is related to lung cancer, and so this approach in itself presents problems.

Certainly, there are people who believe that asbestos is a necessary first condition to lung cancer, and I think that the newest data supports this hypothesis. But, as I say, it is very hard to get really definitive data.

Unidentified voice: Dr. Enterline has highlighted what seems to be the key questions: Is the fibre durable and is the fibre respirable?

To the best of my knowledge, the friction-material industry is using only continuous filament glass fibre of a diameter greater than 6 microns. It is also essentially borasilicate glass, which, I think, is one of less durable glass fibres tested to date. Does Dr. Enterline therefore believe that the glass fibre used in the industry is "safe"?

PHILIP ENTERLINE: I do not really know enough about your industry to say that is safe. It is true, however, that any non-respirable fibre is unlikely to be a cause of lung carcinomas. To my knowledge, there is no evidence that filament has produced cancer in men or animals. I think the German scientist, Pott, has actually implanted filaments, but I do not know the result. Does anybody know what Pott's filament study has shown? No cancer.

So I think the answer to your question is that with large fibres, there is very little chance of producing any kind of pathological change in humans.

Unidentified voice: Dr. Hughes, how do the risks faced by brake manufacturing and repair workers at 0.2 fibres/cc exposure compare to risks faced by workers in other industries, such as general manufacturing or mining of other hazardous materials?

JANET HUGHES: I think the only way we can answer that is indirectly. We do not have sub-groups exposed, say, to 0.2 fibres in the various industries for whom we can look at their subsequent cancer risk. But we do have dose-response relationships for lung cancer. Friction product manufacturing has a much shallower slope than textiles. So we would say that the risk of lung cancer in friction products and mining is much less than in the parts of the industry which have been studied so far.

Unidentified voice: What is the risk for brake repair workers compared to workers in other industries? Let's say in comparison to the accident rate in mining or general manufacturing in the United States?

JANET HUGHES: I do not know the relationship to other causes of death. For lung cancer and mesothelioma, we would say there is some excess risk due to the asbestos exposure. Where there is no asbestos exposure, there would not be the contingent excess risk. I have not compared friction product manufacturing studies to other causes in other industries. I just do not know the answer to your question.

Unidentified voice: Using the figure 10^{-5} per year that Dr. Hughes gave, exposure 0.2 fibres per ml causes two to three deaths per year. That is substantially lower than construction work or coal mining. If you are comparing deaths from cancer it is in the low range for manufacturing industries. Deaths from occupational accidents are a very different thing.

Unidentified voice: Dr. Enterline, given the data that you have, how urgent is it to move torwards a new standard for mineral wools and glass wools from the nuissance-dust standard that OSHA now uses?

PHILIP ENTERLINE: It depends on what you believe. If you believe that the effect of fibres depends on their geometry, I think it would be very wise to treat man-made fibres in the same way we treat asbestos. But I must point out that the amount of normal exposure to the right-sized man-made fibres that is, ones that cause cancer is very, very tiny. In any event, I think that, given our experience with asbestos, we should seriously consider putting some kind of limit on exposure to man-made fibres.

Unidentified voice: Do you believe those limits would be the same as for asbestos, or less stringent?

PHILIP ENTERLINE: I do not think we know the answer to that. It depends on how safe you want to play it. I do not think I would make it more stringent than asbestos.

Unidentified voice: Dr. Donaldson, I was very interested in what you presented. I infer that if Kevlar fibres are inhalable, they will probably be as toxic as ceramic fibres to the human system. Is that correct?

KENNETH DONALDSON: It is possible to draw that conclusion. As it has been pointed out, however it is difficult to extrapolate between these assay systems. I belive that DuPont is carrying out an inhalation study. Perhaps someone from DuPont would comment on the long-term results of exposure to Aramid.

Unidentified voice: Dr. Enterline, how good is saline as a physiological medium for durability studies?

PHILIP ENTERLINE: I do not know. The literature is very confusing.

Bette Meek: I might add that we need a great deal more research on models for relative solvability of the fibres in different parts of the body.

Unidentified voice: With reference to Dr. Donaldson's remark on Kevlar, Dupont carried out a two-year inhalation study using four different dose levels. They had to use a specialized microjet just to get the fibrils up into the air. At 400 fibres/cc they did find a few of what were interpreted as keratinizing cysts, possibly tumors, in a small fraction of the female animals. There were none in the male animals and none in the other three dose levels.

Bette Meek: Thank you very much. We have to cut the questioning off at that.

SESSION III

QUESTION AND ANSWER PERIOD

Part II

Unidentified voice: Dr. Wheeler, I would like to know why you used a macrophage-cell line instead of primary cells from animals?

Secondly, I would like to know if you were able to generate the various dusts that you had into animals and then lavage them and take those macrophages, would you see the same sorts of data as on the parameters that you measured? Finally, perhaps you could start the discussion on the merits and disadvantages of *in vitro*, pseudo-toxicity studies, including inhalation studies.

CANDACE WHEELER: One of the reasons we chose the macrophage-cell line in the initial studies was because we had done a number of studies comparing the primary cells. We preferred to use these primary cells; but they are more difficult to obtain because they come from animals. So we began the study looking at "J" cells, or model-cell lines. We characterized them as to phagocytolysis and found that they were very similar. We characterized them for chemotaxis and various other parameters and found them also to be similar. Obviously, there are differences between the cell lines, and it is always better to use the primary cells that we have developed where possible.

I think that, if we used an inhalation model generating the material *in vivo*, we would see different effects. Generally speaking, there are differences between *in vitro* assays and *in vivo* results, and *in vivo* systems are obviously needed. In my paper, I conclude that when you get to the preceding stade (the first part), *in vitro* data are necessary. *In vitro* data have their place. They are very useful in screening materials, for looking at initial effects, and for studying mechanisms. They tell us a lot of about how these things act, how they are interacting with the membranes, how they activate macrophages, what the responses are, what materials are released, and the various enzymatic processes while these functions are going on. That is impossible in the *in vivo* situation. But, as far as deposition, clearance of the material, fibrosis, and things of that nature, then it is very important to look at inhalation in an actual *in vivo* system.

BETTE MEEK: I think that is a mistake to look at the results of any one type of study in isolation. However, for many of the fibrous materials being proposed as replacements for asbestos, we do not have a battery of tests run by standardized protocols. That is one of the problems in interpreting the data on the fibre substitutes.

Unidentified voice: Question to Mr. Rosenberg. Do any of the companies that you represent provide guidance to users of their asbestos substitutes regarding recommended or suggested exposure levels for workers? And, if they do, what are those levels and could you provide a brief rationale?

ERNEST ROSENBERG: I think that there are both quantitative and qualitative differences in the behaviour of a number of these materials and the risks they present. The short answer to your question is, yes, the manufacturers provide information recommending exposure limits in their material-safety sheets. I have not reviewed them in a while, but, as I recall, they did not recommend a specific ambient concentration. They simply recommended that, in processes that generate a significant amount of dust, masks be worn to reduce inhalation of the material. And that is based on the belief that it is better not to get something in the lung than to get something in the lung, even if it's the most benign of materials.

Unidentified voice: I just got a brochure from Johns Manville recommending that exposure levels to fibreglass be kept below 1 fibre/cc and that masks be worn if levels are greater. They did not say why.

To change the subject, in animal experiments, the inhalation studies in rats are fraught with many difficulties. Fibres greater than 1 micron in diameter are not readily inhaled and deposited in the alveoli of the lung. Consequently, those studies cannot be used to estimate risk for human beings. That is why injection studies are done to determine whether these fibres might be carcinogenic in humans.

The International Agency for Research on Cancer uses that injection data to determine whether these substances might be carcinogenic in humans. It does not have the responsability for determining relative risk. Considering the amount of money that has been spent since we discovered that exposure to asbestos is related to high incidence of disease, and, since most of the evidence indicates that risk is related to fibre dimensions, it is probably wise to take care both with the research and in making recommendations regarding man-made mineral fibres.

The general feeling is that these fibres are carcinogens, promoters, or co-carcinogens, and that their effet is based on their fibre dimensions. If research proves that fibres less than 1.5 microns in diameter and greater than 8 microns in length are not carinogenic in these test systems, then, perhaps, we can re-evaluate those particular fibres. Perhaps we can develop fibre preparations that are not carcinogenic. Until then, we should be very careful with these man-made mineral fibres.

BETTE MEEK: Just one comment, David. Would you agree that, given the limitations of the inhalation studies, a positive result, would be important for risk assessment?

Unidentified voice: Oh, yes.

J. RICHMAN: I am from Friction Division Products, and I have a general question for the panel. For the first time in my life, I saw a picture of a macrophage cell. Do you think it would be possible to biologically tamper with cells so that they could remove more contaminants from the lung and thus reduce the incidence of lung cancer?

CANDACE WHEELER: Macrophages themselves have a way of doing that; in fact, the lung has a way of "amplifying" their response. When exposed to various particulate materials, including fibres, marcophages interact with these fibres, releasing chemicals which actually recruit additional macrophages into the lung. There is some debate on whether or not these cells divide in the lung after exposure to a number of materials like this. Some macrophage division in the lung occurs to accommodate the increased amount of material in the lung. The cells actually divide and recruit additional cells into the lung,...not only macrophages, but also polymorphic, nuclear leucocytes which are nutrafils, and other phagocytic cells which are important in the inflammatory response. These cells then have an amplification effect, and clear the lung.

If you wanted to tamper, I suppose, you could try to give some of these cells chemotactic factors. A number have been isolated and are available, but I am not sure what effect this tampering have on other systems. If you get enough of these inflammatory cells in the lung, you generate an inflammation response. And, as we heard this morning, prolonged inflammation can lead to fibrosis. Right now, there is some sort of balance.

JACQUES DUNNIGAN: Ms. Wheeler, with reference to experiments on the toxicology of brake residues... with all due respect, I fail to understand the validity of comparing the toxic effects of residues of semi-metallic brake linings with those of pure fibres, Fiberfrax, crocidolite, amosite, chrysotile. Do you plan to compare the toxicity of residues from semi-metallic brake linings with those of brake linings made with chrysotile...a comparison which, in my mind, would be more relevant?

CANDACE WHEELER: I appreciate your question. We looked at the effects of semi-metallic residue with intact fibres as a positive control. We fully realized that, as wear products, free asbestos fibres are less than 1 percent of the wear material and that a small percentage of this is respirable. So one would anticipate that the toxicity of this material would be much less.

We do have *in vivo* studies planned right now to look at the toxicity of asbestos residue and other non-asbestos-containing residues as wear products. We shall compare them to asbestos as a positive control to the other residues.

Bette Meek: If there are no more questions, I would like to take this opportunity to thank the speakers very much for their presentations and also the audience for your attention.

SESSION IV

REGULATORY AND LEGAL ISSUES

NEW PERFORMANCE STANDARDS HARMONIZATION OF EUROPEAN AND AMERICAN STANDARDS (NHTSA 135) AND AFTER-MARKET STANDARDS

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***Abstract** — The properties of friction materials used in brake linings are to a large extent dependent upon the braking requirements contained in the Federal Motor Vehicle Safety Standards issued by the National Highway Traffic Safety Administration (NHTSA), NHTSA's current policies and activities regarding passenger car brake standards and aftermarket lining regulation are described.*

The purpose of this paper is to outline the activities of NHTSA which can affect the properties required of friction materials in brakes. The international harmonization policies of NHTSA, which led to its proposal to revamp the passenger car brake standard, are discussed, together with the most significant changes in braking requirements contained in the proposed FMVSS 135. Regulatory activities in the area of aftermarket brake linings – which currently are not subject to Federal regulation -- are also described.

NEED FOR INTERNATIONAL HARMONIZED OF SAFETY STANDARDS

The growing trend of worldwide competition in the automobile industry argues for changes in governmental practices which pose barriers for free trade or which inhibit efficient design and manufacturing practices. Government regulation of the automobile, particularly for safety purposes, is one such practice which can have the above mentioned undesirable effects.

The international reality of automobile manufacturing is that nearly a third of the more than 40 million vehicles produced each year find their way into international trade. Of even more importance is the fact that the manufacturers of these vehicles are becoming truly international in character.

The opening of manufacturing plants in the United States by Japanese companies and the joint ventures in design and/or production among Japanese/European/North American companies attest to the international character of automobile development. Honda's Ohio plant, General Motors' and Toyota's joint production of the Chevrolet Nova in California, Ford's North American and European production of vehicles and the collaboration on design of the Sterling by Austin Rover and Honda are but a few examples of the above trends.

What this connotes is that if manufacturers must design and/or manufacture vehicles differently for the varied markets in which they operate, then the costs of such production increase. These higher costs for manufacturers are passed on to consumers as higher vehicle purchase prices. While the regulation of vehicules for safety purposes is accepted as necessary, and while differences in national regulations are also to be expected, to the extent that similarities in regulations can be achieved without sacrificing safety, then both consumers and manufacturers come out ahead.

U.S. ACTIVITIES IN HARMONIZATION

Regulation of motor vehicle safety in the U.S. is, for the most part, under the aegis of the National Highway Traffic Safety Administration (NHTSA). NHTSA has, as one of its highest priorities, the international harmonization of its Federal Motor Vehicle Safety Standards (FMVSS's). To achieve this goal, agency technical staff attend the semi-annual meetings of the several Groups of Rapporteurs of the Groups of Experts on the Construction of Vehicles. (Working Party (WP) 29), which is under the Inland Transport Committee of the United Nation's Economic Commission for Europe (ECE). The agency has also demonstrated its commitment to international harmonization through the establishment of an Office of International Harmonization. This office, which reports directly to the Administrator of NHTSA, is responsible for formulating strategies for dealing with issues arising from the agency's harmonization program. Other harmonization activities include the close coordination of regulation development between NHTSA and Transport Canada (e.g., assuring consistency of regulatory requirements regarding daytime running lights) and bilateral discussions with Japan's Ministry of Transport.

While there are other standard setting bodies throughout the world (e.g., the International Standards Organization -- at whose meetings NHTSA also typically participates -- and the European Economic Community (EEC or Common Market), the ECE, with its 27 member countries (two of which, Japan and Australia, are observers only), is recognized as the premier such group in the world. For instance, the Japanese Government has recently established a policy of actively participating in all ECE-WP 29 meetings, is attempting to establish a permanent office in Geneva (where WP 29 meetings take place), and has agreed to "expeditiously introduce into the Japanese system" the regulations of the ECE.

International Harmonization of Braking Standards

Since the early 1980's, the Group of Rapporteurs on Brakes and Running Gear (GRRF) of WP 29 has been working toward developing an international harmonized brake standard for passenger cars. As voting member of the ECE, the U.S., represented by NHTSA, has actively participated in that work. The GRRF attempted to achieve a compromise between the then existing ECE directive, Regulation 13 (R.13) and the existing U.S. Standard FMVSS 105, Hydraulic Brake Systems. The culmination of this effort was the production of a draft harmonized proposal known as R.88. R.88 contained parts, but not all, of both FMVSS 105 and R.13.

The May 1985 NPRM

On May 10, 1985, NHTSA published in the *Federal Register* a Notice of Proposed Rulemaking (NPRM) which constituted its first formal notice proposing to harmonize brake standards for passenger cars. The agency believed that the NRPM, although it was not a verbatim adoption of R.88, represented a significant step by the U.S. toward international harmonization. The notice proposed a new set of requirements which, the agency believed, would ensure the same level of safety for the aspects of performance covered by FMVSS 105, while also improving safety by addressing some additional aspects of performance not included in Standard No. 105. Vehicles other than passenger cars would still be required to meet the FMVSS 105 requirements.

Like Standard No. 105, the proposed new standard number 135 included requirements for service brake effectiveness, fade and recovery, partial system failure, parking brake performance and equipment integrity. Also, the proposal included adhesion utilization requirements to ensure stability during braking under all conditions of traction. The agency also proposed to delete the water recovery requirements of FMVSS 105. These latter requirements existed to assure that brakes would have adequate braking capability after exposure to water, such as driving through a flooded area. However, the agency tentatively concluded that the requirements were no longer necessary, primarily due to the switch to front disc brakes on U.S. passenger cars.

It is not the purpose of this paper to discuss all the specific requirements proposed by the May 1985 notice. A detailed description of those requirements and the reasons for their proposal can be found in the Federal Register of Friday, May 10, 1985 (50 FR 19744-19760).

THE JANUARY 1987 SUPPLEMENTAL PROPOSAL

Comments were received on the NPRM from vehicle manufacturers and industry groups as well as the GRRF. The GRRF expressed disappointment that NHTSA did not simply adopt the requirements contained in R.88. They, as did other commenters, expressed their belief that the NPRM represented an increase in stringency of the safety requirements as compared to FMVSS 105 and did not contain sufficient harmonization proposals.

NHTSA carefully considered these comments and, on January 14, 1987, issued a supplemental NRPM (SNRPM) on the subject of the international harmonization of passenger car braking standards (See 52 FR 1474-1494). This SNPRM, for which comments are due from the public on October 13, 1987, represents NHTSA's current thinking on future passenger car braking requirements. Since these requirements could affect, and are affected by, the friction materials used in brake linings, a summary of those requirements is discussed below.

First, the SNPRM retained requirements for adhesion utilization, although modified from those proposed in the original NPRM. Basically, these requirements provide that a vehicle must meet the specified stopping distances in the proposal while limiting the deviation from theoretically ideal brake balance and, should wheel lockup occur, the front brakes must be the first to lock. While the basic adhesion utilization performance requirements proposed in the SNPRM are similar to those in R.88, the additional requirement for a practical method (test) to determine the adhesion utilization of actual vehicles represents a major departure from R.88. The current requirement being proposed, which is different from that in the first NPRM, would require that a vehicle, when tested in the lightly loaded and fully loaded conditions on surfaces with skid numbers of 20 and 50, must not have both its rear wheels lock prior to both front wheels locking. The two surfaces were chosen because a skid number (SN) of 20 represents a typical surface under snowy conditions and a SN of 50 is typical of a wet roadway in somewhat degraded condition. NHTSA believes that these simple tests encompass the conditions under which wheel lockup is most likely to occur, without imposing unduly burdensome testing requirements.

In addressing other comments on the NPRM, the agency recognized that there may be tradeoffs in brake design between pre-burnish and post-burnish stopping distances. Therefore, given the relatively short period that brakes are actually in the pre-burnish condition, NHTSA proposed deleting the pre-burnish stopping distance tests. The agency also proposed in the SNPRM a new burnish procedure, which include 200 stops from 80 km/h. For all stops, the pedal force would be limited to 500N (112.4 lbs.) and lockup of any wheel would be prohibited (except for adhesion utilization tests) at speeds greater than 15 km/h.

The post-burnish, or cold effectiveness stopping distance tests, were also revised in the SNPRM. The agency recognized that the changes being proposed in the test procedures (e.g., reduced level of burnish, higher test speed, and prohibition of wheel lockup) could have an effect on the capability of a vehicle to stop in a specified distance. Thus, the stopping distances in the SNPRM for the cold effectiveness tests have been lengthened from those in the NPRM to 70m (230 ft) from a speed of a 100 km/h (62.1 mph). The agency believes that vehicles which currently meet the shorter stopping distances in FMVSS 105 will meet the SNPRM stopping distances with approximately the same margin of passage. Conversely, were the SNPRM distances shortened, the agency believes that vehicles which pass FMVSS 105 would not be able to pass the stopping distance requirements of the proposed FMVSS 135. NHTSA believes that the apparent longer stopping distances are an artifact of the different test conditions and will not lead to vehicle redesigns which would actually degrade a given vehicle's stopping capability. To verify this belief, NHTSA has been conducting a series of tests on about 20 vehicles to determine the stopping distance capabilities of the same vehicles using both the FMVSS 105 and the proposed 135 test procedures.

Other changes from the NPRM to the SNPRM reflect different stopping requirements for the high speed effectiveness tests, a slightly lengthened (to 165m) stopping distance for the circuit and power assist failure tests, a slightly shorter stopping distance (70m versus the NPRM's 72m) for the engine failure test, a separation of the antilock and variable proportioning valve failure requirements, a lenghthening of the antilock failure stopping distance requirement from 80 to 86 meters, and a 112m (vs 80m in the NPRM) requirement for the variable proportioning valve functional failure.

NHTSA also included in the SNPRM a new test procedure for the fade and recovery tests along with a somewhat shorter stopping distance for the hot stop test of 86m. The agency also changed its parking brake requirements to include a hand control force limit of 400 N (90 lbs), and a changed stopping distance requirement of 74m. The agency included in its SNPRM a proposal to delete the spike stop test, as well as the final effectiveness test. Finally, several test conditions were changed, such as the burnish procedure, the order of the tests, and the number of runs per stopping distance test. The new standard would be optional 30 days after a final rule is published but would become mandatory on September 1 of the year, five years after publication.

FUTURE ACTION

While the provisions of the SNPRM relating to the establishment of FMVSS 135 reflect NHTSA's current thinking on future passenger car braking performance requirements, they do not represent a final decision. As was stated earlier, the agency is in the process of conducting tests, and analyzing the data therefrom, from 20 cars tested to both the FMVSS 105 and 135 test procedures. Results from this analysis may lead the agency to conclude that its most recent proposals are in need of further modification. Similarly, as occurs with all agency rulemakings, the agency will carefully consider all comments from the public. Until such comments are received and analyzed, a final decision will not be made.

After-Market Brakes

Currently braking standards in the U.S., be they for hydraulic braked vehicles (FMVSS 105) or for air braked vehicles (FMVSS 121), are vehicle, as compared to equipment, standards. That is, they apply to new vehicles only, and do not reflect regulation of after-market, or replacement, brake equipment, particularly brake linings.

During the calendar year 1987, NHTSA received two petitions related to after-market brake linings. The first, from a private citizen, requested that the agency issue a regulation which would require, for brake linings for all motor vehicles, standards for stability, friction, fade, and "proper identification with a consideration of wear requirements." The second petition, submitted on behalf of the American Trucking Association (ATA), urges NHTSA to set standards for procedures to measure brake lining effectiveness and to require the permanent markings of linings for heavy commercial motor vehicles. The ATA petition urges NHTSA to adopt a draft SAE recommended practice which modifies the FMVSS 121 dynamometer procedure in the areas of control of the initial lining fit to the drum, the control of thermocouple location, and the flow of dynamometer cooling air. ATA argues that these changes will improve the consistency and reproduceability of lining ratings.

The agency is in the process of carefully analyzing these petitions for rulemaking. While the disposition of these two petitions can not be discussed in this paper and will be decided by NHTSA based on statutory criteria, some observations can be made. First, current NHTSA regulations vary with respect to after-market regulation. In its crash avoidance standards (the "100" series of standards), NHTSA regulates both new vehicles and equipment as well as the after-market in such areas as brake fluids and hoses, tires, and lighting but regulates only new vehicles (i.e., *not* replacement equipment) in the areas of brake performance or windshield wipers/washers/defoggers/defrosters.

Second, the petitioners claim that the current brake lining rating procedures, SAE Recommended Practices J661, *"Brake Lining Quality Control Test Procedure"*, and J866, *"Friction Coefficient Identification System"*, were intended for quality control use, not for establishing actual performance in a vehicle. It is also contended that the accuracy and reproducibility of identification using the current SAE procedures has been called into question by the National Bureau of Standards and the Technical Advisory Group (TAG) of the ATA. For example, the TAG found that, using the J866 procedures, variations in friction coefficient of 6 percent can be found in the same lining block and variations of 12 percent can be found when measuring different linings from the same batch. Also, the friction coefficient groupings prescribed in J866, which result in a letter code have been criticized as being too broad. For example, the code D is to be given to linings with friction coefficients of 0.15- 0.25, a variation of 67 percent. Thus, it is claimed, a new process is required.

Third, the agency has a stated policy of regulating when a safety need exists and when voluntary standards or practices are not meeting that need. NHTSA generally sees no need to issue a regulation which simply codifies existing industry practices. Without passing judgment on any activities or specific standards, NHTSA is aware of recent SAE activity in the area of brake linings. We are also aware that responsibility for development of a proposed new brake lining rating and marketing procedure for heavy vehicles has recently been transferred from SAE's Motor Vehicle Council to is Truck and Bus Council. Whether these activities will affect agency decisions on granting or denying these petitions is yet to be determined.

Thus, the basic questions NHTSA has to address include whether a safety need would be met by issuing the requested regulations; whether the same goal is being achieved by voluntary means; and, if a regulation were to be issued, what would be its costs, benefits, and technical content. Decisions on whether to grant or deny these petitions for rulemaking are expected about the end of the year.

SUMMARY

The international harmonization policies of NHTSA have led it to propose a new hydraulic brake standard for passenger cars. The revised test procedures and performance requirements contained in this proposal, particularly those relating to stopping distances and wheel lockup, could affect the friction materials used in brake linings. In addition, NHTSA is carefully examining whether to require performance and/or marking standards for after-market brake linings.

DEVELOPMENTS IN INTERNATIONAL AND NATIONAL POLICIES ON ASBESTOS AND OTHER HAZARDOUS MATERIALS

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INTRODUCTION

Mr. Chairman, Ladies and Gentlemen,

To present a paper to this congress is regarded by me as a great honour. However, I must admit that I feel a bit out of place. I understood that the objective of this congress is to stimulate scientific and technical discussions. The development of national or international policies is a complex process, which in fact is only partly determined by technical or scientific issues. I would like to elaborate a little on this point at the end of my paper.
I have structured my presentation into four subjects:

1. The ILO Convention, Recommendation and Resolution from 1986 (Asbestos)
2. EEC developments on carcinogens and the EEC regulations on asbestos.
3. Some remarks on developments in a number of European states
4. Some remarks on factors which play a role in the determination of national and international policies.

THE ILO CONVENTION, RECOMMENDATION AND RESOLUTION FROM 1986

Before I deal with the content of these ILO instruments, I would like to say a few words about this International Labour Organisation, in order to provide the necessary background for those who may only have a very vague picture of the ILO.

The ILO is part of the United Nations. It is an organisation, which deals with all aspects of labour relations (for instance freedom of association, collective bargaining, vocational training, etc.) The organisation is controlled by a tripartite board. Each year there is a large conference of 3 to 4 weeks, which is held in Geneva.

The board decides, which subjects shall be placed on the agenda of that conference. Usually there will be, amongst other points, also a subject regarding the area of safety and health at work.

The office of the ILO then prepares a text, which is discussed at the conference. Discussions and decisions on the text take place in a tripartite setting. This means that the employer members, the worker members and the governmental representatives together decide on the text of the proposed instruments.

A convention is a kind of an international treaty. Member states of the ILO are requested to ratify such a convention. This means that they promise to keep the requirements formulated in that particular document.

A recommendation is less strong. It has no obligatory strength. A resolution is a statement issued by the assembly of the conference.

Now I would like to highlight the major points of the Asbestos Convention. The convention is a document with a legislative character. After an introductory chapter, which deals with scope and definitions, *general principles* are formulated. Then a large chapter deals with preventive and protective measures. This chapter in fact provides elements for the formulation of national policies. Other chapters contain articles on the surveillance of the working environment and workers health (so measures at the level of the undertaking) and on training and information.

GENERAL PRINCIPLES

The following are the main general principles:

- A national policy, resulting in rules and regulations, which shall be revised in the light of technical and scientific progress
- Effective enforcement of the regulations
- Involvement of the social partners at the national level
- The objective of national regulations shall be prevention or control of exposure to asbestos
- Cooperation of employers and workers at the level of the undertaking

CONTENT OF THE NATIONAL POLICY

In order to achieve that objective governments are requested to choose from the following measures:

- Regulations which prescribe engineering controls, work practices and work place hygiene;
- Prescription of special procedures (for instance authorisation or notification) for the use of asbestos, or particular types of asbestos, asbestos products or work processes.

In addition if the protection of the health of workers so requires and if it is technically practicable, the national regulations shall also require the substitution of asbestos (or specific types of asbestos/asbestos products) by less harmful substitution products; in that case the competent authority is requested to verify as far as possible the lower grade of hazard. If necessary for health reasons, and reasonably technically possible, a total or partial prohibition of the use of asbestos/certain types of asbestos, should be considered.

This last point has been made explicit in the convention by requiring the national governments to ban the use of crocidolite and also the spraying of all types of asbestos. On both prohibitions competent authorities may grant exemptions, but only after consultation with the social partners.

Other main points relating to the national policy are:

- A labelling requirement
- Prescription of limit values
- Reduction of exposure levels as far as reasonably practicable (below the limit values)
- Demolition of buildings/structures containing friable asbestos insulation only by specialised firms
- Waste removal in a suitable manner (no exposure to workers and no contamination of the environment)

MEASURES AT THE LEVEL OF THE UNDERTAKING

The convention further requires measures at the level of the undertaking:

- Adequate monitoring of the exposure of workers and adequate medical surveillance of the health of the workers; the workers have the right to request the monitoring of the working environment;
- Written policies by the employers on the information and training of the employees in relation to the health hazards.

SUMMARIZING

The convention states a number of general principles and requires national policies in order to prevent or control exposure. The measures required in the national policies are formulated in a general way, except for some specific points, which deal with some well known high hazards (crocidolite, spraying of asbestos and demolition of loose asbestos).

At the level of the undertaking, employers are required to monitor the workers exposure, the workers health and to provide information and training. Employer and workers are required to cooperate.

THE RECOMMENDATION

This instrument is a supplement to the convention. It therefore deals with the same areas of attention and it has the same structure:
again
- General principles
- Measures at national level
- Measures at the level of the undertaking
- Training and information

In the recommendation, speaking in a wide sense, one finds two kinds of subjects:

- Elements, which are in fact a further detailed formulation of requirements already existing in the Convention;
- Elements, which formulate furthergoing requirements and which by the majority of the ILO-conference are felt to be desirable but not suitable as a hard requirement.

Some examples of further detailed formulations:

- The listing of a number of activities, which involve risk of exposure
- The description of some means of worker participation
- Items to be supplied to the competent authority in case of a notification
- Specification of items to be mentioned in a work plan for demolition projects
- The specific measures at the level of the undertaking to prevent and control exposure
- Details of work place monitoring
- Details of medical surveillance

Also now some examples of furthergoing requirements:

- The requirement that competent authorities should encourage research into technical and health problems relating to exposure to asbestos, substitute materials and alternative technologies
- Wherever necessary for the protection of the workers, the competent authority should require the substitution of asbestos, wherever possible
- The evaluation of potential substitute materials on possible Harmful effects, before use in any process
- Standards to be set by the competent authority for respiratory protective equipment
- Requirements to be imposed on producers and suppliers of asbestos containing products

Reading the Recommendation carefully, it will be noted, that mainly general approaches of policy are formulated. Sometimes, however, items of particular detail are present. For instance the requirement for rest breaks in case respiratory equipment is being used.

The background for this mix of requirements is that the formulation of the Convention as well as the Recommendation is negociated in a tripartite discussion. Sometimes one of the parties attaches such a great importance to a particular detail, that the other parties will accept the inclusion of that particular item.

Finally one other remark on the Recommendation. It may seem that the content of some points is somewhat superfluous or unnecessarily detailed. Apart from the different weight of importance just mentioned, one has to realize that the content of the Recommendation also serves as an inventory list for the developing countries. From that content a choice can be made to use selected items as building blocks for a national policy.

Summarizing the Convention and Recommendation I conclude, that both instruments provide the headlines for national policies aimed at the prevention and control of exposition to asbestos fibres.

A small number of specific prohibitions are prescribed, that is to say, the use of crocidolite and the spraying of any asbestos. It is left to the individual member states to decide how far they wish to go, in matters such, as substitution, authorization, notification.

National policies should be developed in cooperation with the social partners.

THE ILO RESOLUTION

At the end of the 1986 conference a Resolution on the Health Risk of Fibres, whether natural or artificial, was accepted. This resolution in fact invited the Governing Body of the International Labour Office to use resources for examination and evaluation of health risks of any fibre other than asbestos. The background is clear. One of the measures which has to be considered in order to control the exposition to asbestos, is substitution. But the important question is: are the substitute materials less harmful?

The conference invited the ILO to strengthen the attention which was already given to the assessment of inorganic fibres and to extend this activity also to organic fibres.

Further, it was thought to be necessary to install a tripartite group of experts in order to study this subject. The necessity of cooperation with, in particular, the World Health Organization was stressed, bearing in mind the need for standard setting for fibres other than asbestos. The ILO was invited to consider the need for draft instruments.

I think that at the moment one can say that the ILO has honoured this resolution for an important part. As you probably all know, in October 1986, the WHO, in cooperation with some other organisations, convened a scientific symposium in Copenhagen on the toxicity of man-made mineral fibres. As I understood, a general conclusion of that symposium was, that rockwool and slagwool were to be considered with a suspicious eye and that for safety reasons it would be best to use similar limit-values as for asbestos.

I also understood from information regarding a recent symposium at Lyon, on all kinds of mineral fibres in non-occupational exposure, that this suspicion of rockwool and slagwool is maintained by the ILO and the WHO. The ILO and the WHO (as far as I know) are now in cooperation working at the development of health criteria for man-made mineral fibres.

THE ILO INSTRUMENTS

I now want to leave the global scene and I ask you to focus on a smaller area: Europe and in particular the European Community. It is my intention to provide an overview of the EEC approach to toxic materials, and in particular asbestos.

The EEC policy on the handling of dangerous (read toxic) materials at the work place received an important stimulus in 1980, when the Council of European ministers accepted a so-called framework directive. A directive is a piece of European legislation, which has to be implemented by the member states into their own legislation. So it has obligatory force. This framework directive specified several general measures which can be taken in order to control exposition to toxic materials.

Examples of these measures are:

- Limitation of use
- Limitation of number of workers involved
- Technical preventive measures
- Occupational hygiene measures
- Information and training of workers
- Medical surveillance
- Prescription of limit values
- Partial or total prohibition

So again: elements for national policy.

The idea was to issue individual directives for particular substances, which would contain, in addition to the general features, specific measures for those substances. So far two directives on individual substances have been issued in this manner, namely: the Lead Directive and the Asbestos Directive. These directives are now being implemented into the legislation of the EEC states.
On the same basis, two other directives are under discussion: a directive on benzene and a directive concerning the ban of four notorious carcinogenic substances.

As this policy would lead to an endless amount of legislative work and also because the Asbestos Directive to be an example for the regulation of other carcinogenic materials, the EEC is now shifting to the following general line of policy:

- A ban on a limited number of high potential carcinogenics (benzidine, B naphtylamine, 4-aminodiphenyl, 4-nitro-diphenyl)
- Controlled use of carcinogens (with lesser potential) under stringent conditions (for instance closed systems if reasonably practicable)
- General occupational hygiene measures, including in particular, the prescription of limit values for other less toxic substances

The measures which are being proposed for the controlled use of carcinogenic substances resemble very much the preventive measures of the ILO Convention on Asbestos.

This is not so surprising because the EEC Directive on Asbestos at the work place was more or less used as a model for the proposal regarding carcinogens in general. And this EEC directive on asbestos contained many items which were later also included into the ILO Convention.

The EEC approach towards asbestos is however more complex than you might expect. The point is that up till now I have informed you only on the aspects of health and safety legislation. However the EEC accepted also two other directives, which were developed from the viewpoints of environmental protection and from the angle of elimination of trade barriers within the EEC. The total picture is as follows:

Controlled use of asbestos has been accepted, though under rather stringent conditions:

- Low limit values for the working environment, effluents and emission concentrations
- Thorough monitoring of the work place and of worker's health
- Obligation to notify of certain activities
- Prohibition of the spraying of asbestos
- Prohibition of the use of crocidolite, except for a limited number of applications
- Labelling of asbestos containing products
- Prohibition of the use of asbestos for a number of products

The use of asbestos in brake and clutch linings is still accepted. The European Commission (the EEC administrative body) has announced that studies will be carried out in order to decide whether further substitutions will be desirable. It is clearly stated however, that not only the technical and economic aspects are to be evaluated but also the health and environmental consequences of substitute materials.

(This was the content of an answer very recently to a question in the European Parliament).

EEC Member States and Other European Countries

Some member states of the EEC pursue a policy which is more restrictive than the EEC approach. Therefore I shall now briefly touch on the situation in a number of EEC countries and one or two other European states.

Denmark

The headline of the policy is the approach towards a total ban. From the first of January next year, asbestos products will only be allowed for specific purposes:

- Metal asbestos gaskets for heavy duty (high temperature - high pressure) (There is no time limit foreseen).
- Asbestos Friction linings in cars no longer allowed in new cars as from 1-4-1988. Any car that use asbestos free linings should apply these linings. Exemption for heavy duty vehicles.
- Special linings for ships.
- Commutators in electrical motors accepted until 1990.

Asbestos containing products entering the country will be registered. Before any work on asbestos containing materials in building is started, that work has to be registered (requirement from unions).

SWEDEN

In Sweden there exists almost a total ban. The application of asbestos in gaskets is allowed, however only after permission from the authorities.
A prohibition on brake linings in cars from 1988 onwards has been notified to GATT.

Prohibition on the use in heavy duty vehicles is foreseen in 1989. A limit value for MMMF is introduced.

GERMANY

Employers are obliged to use substitute materials if less harmful alternatives are available.

The application of substitute materials should be reasonably practicable.
Prohibition of asbestos friction linings from 1988 onwards if alternatives are technically possible and available.

The German fibre cement industry is working at a voluntary program to reduce asbestos content in their products.

AUSTRIA

The government in Austria intends to ratify the ILO Convention. In that light, several legislative changes are prepared. In addition friction linings containing asbestos will be prohibited for cars from early 1988 onwards. For heavy vehicles, prohibition is planned at 1 January 1990.

The asbestos cement industry is still using crocidolite for the production of pipes with a large diameter. Research efforts are made to use substitutes.

UNITED KINGDOM

The U.K. is following the EEC regulations, but are keeping lower limit values at the work place.

There is no prohibition of asbestos friction linings foreseen. The application of man-made mineral fibres is followed by the Health and Safety Executive very cautiously. A guidance note on work with these materials was issued in order to draw attention to the importance of prudency towards these materials.

BELGIUM

The approach is that of controlled use. EEC regulations are followed. There seems to be a growing concern about substitute materials.

NETHERLANDS

Again a policy of controlled use. Prohibition of products with a higher risk of generating loose fibres. A test and standard was developed to determine the strength of the bond between asbestos fibres and other materials in final products. Below a certain level products are classified as loosely bound. These products are banned. On the toxicity of man-made mineral fibres, advice is sought from a Scientific Advisory Committee.

So far, Mr. Chairman, my remaks regarding the situation in a number of European countries.

With this information provided in my presentation, I tried to draw an outline of policy developments at supernational and national levels.

Before I close however, I would like to add some remarks concerning the policy making process. These remarks are of a more personal nature. I am adding this to my paper, which was intended to be descriptive, as I presume, that this symposium is intended to stimulate scientific and technical discussions.

I think Mr. Chairman, that it is rather important to realize that scientific and technical evidence are only partially contributing to the determination of policies.

The final decision by governments is at least as much, but probably even more influenced by the the viewpoints of interest groupings (employers organisations, unions, public, media).

In the ILO-discussions the formulation of the content of the instruments is determined by the balance of the three blocks. It is a tripartite discussion. In that discussion a large number of considerations other than scientific or technical nature play a role. For instance: at the ILO discussions, European states may want to reject the content of a particular article, not because they do not agree with the technical background, but because the content of that article is not compatible with the trend of deregulation, which is the leading thought in Western Europe at the moment.

Likewise authorities from developing countries sometimes want to include many and far going requirements, not because they are convinced about the necessity of all these requirements, but because the content of an ILO instrument is a strong help in the development of their policy at home.

At national level the viewpoints of employers and unions have a large influence. In particular, in the countries where a tripartite consultation or even administration exists. These viewpoints may change considerably under.the influence of economical or commercial considerations. All these influences and considerations are legitimate I think.

I close my presentation, Mr. Chairman, with these general remarks, as I wish to emphasize that the choice for a particular line of policy depends not only on the nature, properties and performance of the products but will finally be the result of an interaction of many factors originating from completely different backgrounds.

Thank you.

RISK ASSESSMENT AND THE DETERMINATION OF SIGNIFICANT RISK

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I. INTRODUCTION

A. A GENERAL FRAMEWORK FOR REGULATION OF CHEMICAL RISK

Risk, which may be defined as the probability of injury, disease, or death under specific circumstances, is an inherent feature of human life. All activities involve risk— eating, drinking, breathing, exercising, playing golf, traveling, working, or anything else one may do with one's time. Indeed, mere existence carries with it certain involuntary external risks from phenomena as accidents, suffocation and electrocution. **Table 1** depicts the risks attendant to a variety of everyday activities.

Society has limited resources to devote to risk reduction (as well as to every other endeavor). The public policy goal consistently embodied in most of the federal statutes for health, safety and environmental regulation is the reduction of chemical risk. Virtually all of these statutory schemes incorporate some test of significance of risk or hazard as a prerequisite for regulatory action.

Public health officials have long been confronted with the challenge of deciding how best to use their limited resources. The most commonly used approach in public health administration is a process of priority setting which usually rests on a more or less detailed characterization of the public health concerns facing the agency (a risk analysis) and a ranking of those concerns in some order related to their perceived importance (significance).

Accordingly, policy makers should limit their regulatory activities to reduction of the most significant risks. "Significant" risks may be defined, loosely, as those risks of sufficient magnitude to justify further inquiry -- i.e., into the costs and benefits of regulation -- and, where appropriate after also considering other issues such as feasibility and cost, regulation or other forms of risk reduction.

TABLE 1

Lifetime Risk of Death Per 10,000 Persons From Selected Common Activities[1]

Activity	Lifetime Death Rate Per 10,000
Motor-vehicle accident	1,372
Home accidents[3]	770
Fall[2]	343
Drowning[2]	168
Poisoning (accidental)[2]	161
Fires, burns[2]	140
Suffocation[2]	91
Firearms (accidents)[2]	56
Electrocution[3]	37
Air travel (radiation from one transcontinental trip/year)[4]	14
Tornado	4

(1) Lifetime figures have been calculated by multiplying yearly average death rates by 70, the approximate number of years in a lifetime.
(2) See National Safety Council, Accident Facts (1984) at 6-7.
(3) E.A.C. Crouch & R. Wilson, "Inter-Risk Comparisons,", in Asssessment and Management of Chemical Risks
(4) P. Hutt, "Unresolved Issues in the Conflict Between Individual Freedom and Government Control of Food Safety," 33 Food, Drug and Cosmetic L.J. 565-66, 1978.

In assessing significance of risk, policy makers often look at two distinct population segments or types of risk: occupational and non-occupational (or "general population"). This dichotomy recognizes that several factors distinguish risks encountered on the job from those resultant from everyday contact with the natural and man-made environment. Among these factors are the direct compensation received by workers; the voluntariness of employment; and the great multiplicity of environmental risks. While one may differ with any one or all of these factors, the fact of the matter is that, by and large, individual environmental risks are of lower orders of magnitude than occupational risks, and people in general find acceptable work-related risks greater than those they find acceptable as consequences of living in the environment.

While numerous possible "significant risk" cutoffs might be suggested, there are substantial precedents for adopting lifetime risks of 1 in 1,000 for occupational risks, and 1 in 100,000 for general population risks, as rough "rules of thumb" regarding significance of risk. These precedents can be found by examining the implicit and explicit bases for the regulatory actions of a number of federal agencies over the past decade.

B. Occupational Risks

In the occupational setting, the Occupational Safety and Health Administration (OSHA) is the primary agency charged with assuring worker health and safety. OSHA is required to find risks significant before it may address them. As the Supreme Court ruled in Industrial Union Department, AFL-CIO v. American Petroleum Institute (the Benzene Case), the Secretary of Labor, before promulgating any safety or health standard, must "make a finding that the workplace in question is not safe." However,

> *"Safe" is not the equivalent of "risk free." There are many activities that we engage in everyday—such as driving a car or even breathing city air—that entail some risk of accident or material health impairement; nevertheless, few people would consider these activities "unsafe." Similarly, a workplace can hardly be considered "unsafe" unless it threatens the workers with a significant risk of harm.*

As the Supreme Court noted, individuals face a multiplicity of risks in activities which they do not consider "unsafe." In determining the level of occupational risk that constitutes "significant" risk, an approach suggested by the Court — comparison of the risk in question to other common occupational risk levels — seems particularly fruitful.

Such a comparison suggests a lifetime occupational cancer risk of 1 in 1,000 as a good "rule of thumb" for identifying significant risk. This risk level is low compared to other fatality hazards in jobs commonly thought of as "safe". On the basis of data collected by the Bureau of Labor Statistics for 1983 and 1984, the lifetime risk of a work-related death in private sector establishments with 11 or more employees is 2.5 to 5.9 per 1,000 (assuming 45 years of employment). For persons working for 45 years in the mining, construction, and transportation and public utilities industries, the lifetime occupational fatality rates were 12.4 to 18.6, 10.3 to 11.8, and 6.0 to 7.6 per 1,000, respectively, while those employed in the wholesale and retail trades had a risk of 1.4 to 1.5 and those employed in finance, insurance and real estate had a lifetime risk of fatality of just under 1 in 1,000. **Table 2** on the next page presents lifetime risks of work-related fatalities per 1,000 workers for a number of industries.

Not surprisingly, OSHA and other federal regulatory agencies have used fatality rates such as those depicted in **Table 2** as "benchmarks" for evaluating the significance of worker health risks. Both EPA and NRC, for example, have proposed to set federal radiation standards using as a yardstick the fatality rates prevalent in industries commonly considered to be "safe". These decisions indicate that a risk of 1 in 1,000 is a reasonable "cutoff" point for significant occupational risk.

In its radiation protection proposal, EPA noted that "the risk of job-related accidental death in the safest of all major occupational categories, retail trades, [was] an annual death rate [of] 60 per million workers in 1975." This risk equates to a 45-year worklife risk of 2.7 in 1,000. The Agency based its proposed radiation protection guidelines on its finding that radiation risks of a magnitude similar to 3 in 1,000 "do not appear unreasonably high" because "they are comparable to risks of accidental death in the least hazardous occupation."

In a similar vein, NRC's recent radiation protection proposal follows the approach recommended by the International Commission on Radiological Protection (ICRP), which developed its guidelines by "comparing [radiation] risk with that of workers in industries...which are recognized as having high standards of safety." As NRC pointed out, in such "safe industries average annual mortality due to occupational hazards does not exceed 10^{-4} [i.e., 1 in 10,000]." This annual rate amounts to a 45-year lifetime risk in excess of 4 in 1,000. Like EPA, NRC proposed standards on the basis that occupational mortality risks due to radiation are "acceptable" if kept at or below this "safe industry" risk level.

Health standards promulgated by OSHA, generally have stopped short of regulating occupational cancer risks below 1 in 1,000. As **Table 3** shows, the residual risks (i.e., those remaining after implementation of the latest **P**ermissible **E**xposure **L**evel [**PEL**]) per 1,000 employees associated with the inorganic arsenic and ethylene oxide standard are in OSHA's estimation, 8 and 1 to 2, respectively. Further, the residual risks associated with the proposed benzene standard are 5 to 16 per 1,000.

TABLE 2

Lifetime Risk of Work-Related Death
Per 1000 Persons in Selected Industries, 1983 and 1984[5]

Industry	Lifetime Death Rate/1000
Mining	12.4 to 18.6
Construction	10.3 to 11.8
Transportation and Public Utilities	6.0 to 7.6
Agriculture	5.7 to 7.3
Manufacturing	1.9 to 2.0
Wholesale and Retail Trade	1.4 to 1.5
Services	1.0 to 1.8
Finance, Insurance, Real Estate	0.8 to 0.9
Total Private Sector	2.5 to 5.99

(5) See Cotter, Work-Related Deaths: BLS' 1984 Survey (Draft), Table 1. Each annual fatality range consists of the 1983 and 1984 figures from id., with the lower figure presented first. Lifetime rates assume 45 years of work exposure.

TABLE 3

Lifetime Risk of Death From Cancer per 1000 Persons Associated With Occupational Exposure at Previous and Recent OSHA Permissible Exposure Limits (PELs) for Selected Substances(6)

SUBSTANCE	RISK/1000 AT PREVIOUS PEL	RISK/1000 AT RECENT PEL
Inorganic arsenic	148 to 767	8
Ethylene oxide	63 to 109	1 to 2
Ethylene dibromide (proposal)	70 to 110	0.2 to 6
Benzene (proposal)	44 to 152	5 to 16
Vinyl chloride	500	4
Acrylonitrile	390	39
Dibromochloropropane (DBCP)	—	2
Asbestos	64	6.7

(6) See Arsenic Statement: 48 Fed. Reg. at 1897, 1902; ETO Standard, 49 Fed. Reg. at 25764; Occupational Exposure to Ethylene Dibromide; Notice of Proposed Rulemaking, 48 Fed. Reg. 45956, 45975 (Oct. 7, 1983); Benzene Proposal, 51 Fed. Reg. at 50538-39. Vinyl chloride risks calculated by ENVIRON using EPA model. Acrylonitrile risks at current PEL derived from Albert, "Discussion," 33 J. Am. Poll. Control Ass'n., 836, 837 (1983); risks at previous PEL derived by linear extrapolation from current-PEL risks. DBCP risks calculated by ENVIRON; asbestos risks as calculated by OSHA, Occupational Exposure to Asbestos; Final Rule, 50 Fed. Reg. 22612, 22647 (June 20, 1986).

Although these OSHA standards have also been based in part on considerations of feasibility, their associated risks are in the range of those that have been observed in private sector industries (**Table 2**) and have been regarded as insignificant by EPA and NRC. They thus also serve as a rationale basis for assessing the significance of risks attributed to various levels of asbestos exposure.

The above discussion suggests that a risk of one-in-1,000 presents a good "rule of thumb" for significant occupational risk. This conclusion follows not only from the risks in "safe" occupations, but also from the informed judgement of various regulatory agencies.

It should be remembered that the 1-in-1,000 mortality rate is based upon the *average* risk in "safe" industries. Employees in particularly high-risk subgroups with regard to particular occupational hazards ought not to be compared to their counterparts in industries or occuaptions generally regarded as safe. For example, the NRC has noted, "it would be desirable to compare the risks to the individual workers who might be exposed *at* the annual limit for a substantial fraction of their lifetime to the individuals in *higher* (rather than average) risk categories in 'safe' industries." Unfortunately, the data necessary to make such a comparison are not available. It may reasonably be speculated, however, that the higher risk individuals in "safe" industries probably incur risks at least three or more times that of the "average" employee. In any case, to the extent that an **OSHA PEL** represents an upper bound limit on exposure that few workers will experience for 45 years of employment, the use of 1 in 1,000 as a benchmark for significant risk adds yet another safety margin.

C. GENERAL POPULATION RISKS

As is true in the case of occupational risks, the significance of risks to the general population can be examined by reference to other commonly accepted risks. Analyses by a variety of regulatory agencies, advisory bodies, and experts, using comparisons with other risks, as well as other methods for defining significance, converge upon a lifetime risk of approximately 1 in 100,000 as an appropriate "significance" cutoff for non-occupational risks.

Of particular relevance in determining what constitutes "significant" public risk is the Environmental Protection Agency's (EPA's) treatment of non-occupational risks in its regulatory decisions under Section 112 of the Clean Air Act, which provides for promulgation of National Emissions Standards for Hazardous Air Pollutants (NESHAPs). EPA expressly agreed with the Supreme Court's view, expressed in the *Benzene* decision, that "safe" is not equivalent to "risk-free," and determined that "standards under Section 112 should protect against *significant* public health risks."

EPA's application of this prerequisite of "significant risk" illustrates, in quantitative terms, the sort of public risk that is *not* significant, as the Agency has declined to regulate those emissions sources that pose risks the Agency finds insignificant. EPA's standards for categorizing risks as "significant" or "insignificant" are quite instructive, for the Agency has focused upon *two* factors crucial to risk — giving weight to both.

As EPA explained in its notice withdrawing proposed regulations of radionuclides from elemental phosphorus plants and other sources, two summary measures of risk provide important information about significance. The first, "nearby individual risk," refers to the "estimated increased lifetime risk from a source that is faced by individuals who spend their entire life at the point where predicted concentrations of the pollutant are highest." The second, "total population impact" looks at the aggregate risk to *all* exposed persons in terms of total yearly fatalities.

These two estimates together provide a superior description of a risk than either alone, EPA has explained, because "nearby individual risk" tells us the highest risk to which anyone is subject, but not *how many* persons face this risk. (In fact, the number generally is small, for "generally few people reside at the points of maximum concentrations and spend their whole lives at such locations.") Conversely, "total population impact" "describes the overall health impact" of a substance, but says nothing about the most exposed individuals.

EPA has found the maximum individual risks and total population risks from a number of radionuclide and benzene sources too low to properly be deemed "significant." For instance, benzene emissions from maleic anhydride process vents created maximum individual risks of 7.6 in 100,000, and an aggregate yearly cancer incidence of twenty-nine *thousandths* of a case. Radionuclides from the Department of Energy (DOE) facilities would expose a person who accrued lifetime exposure to a plant's most concentrated emissions to risk of 1 to 8 in 10,000, while, in the aggregate, only eight-hundredths of a cancer would be predicted to occur yearly, or roughly once every thirteen years. A summary of the radionuclides and benzene risks found insignificant by EPA is provided in **Table 4.**

As **Table 4** reveals, EPA found risks to be insignificant when the most exposed individual faced as much as one chance in one thousand of death after 70 years of exposure to radionuclides or benzene. Of course, account must be taken of the fact that *average* personal risk would be well below maximum risk. In view of the maximum risks found insignificant by EPA, 1 in 100,000 seems to be a good rough indicator of what EPA has considered to be an insignificant average risk. This is true at least in cases where, as with the sources outlined in **Table 4**, aggregate population risk does not exceed a fraction of a cancer yearly.

TABLE 4

EPA-NESHAPs Insignificant Risks[7]

Substance and Source	Maximum Individual Risk	Aggregate Risk (cancers/year)
Radionuclides— Elemental Phosphorus Plants	1.0×10^{-3}	0.06
Radionuclides— DOE Facilities	1.0×10^{-4} to 8.0×10^{-4}	0.08
Radionuclides— NRC Licensed Facilities	2×10^{-4}	0.02
Benzene— Maleic Anhydride Process Vents	7.6×10^{-5}	0.029
Benzene— Ethyl/Benzene Styrene Plants	1.4×10^{-4}	0.0057
Benzene— Storage Vessels	3.6×10^{-5}	0.043

(7) Risk estimates from Radionuclides NESHAPs Withdrawal Notice, 49 Fed. Reg. at 43911-12; Benzene NESHAPs Withdrawal Notice, 49 Fed. Reg. at 8389-90.

A number of studies of risk reach conclusions consistent with the regulatory decisions that I have just discussed. The Ontario Royal Commission on Asbestos, for example, found a risk of 0.029 per 100,000 population per year [or a 70-year lifetime risk of just over 2 in 100,000] to be insignificant because it is "orders of magnitude below the other risks faced by the general population."

Professor Roy Albert, former head of EPA's Carcinogen Assessment group, arrived at a nearly identical cutoff for societal concern about non-occupational risk using a somewhat different method analysis. He noted that well-run, safe industries have a death rate of about 1 in 10,000 annually, or 3 in 1,000 for a working lifetime. Accordingly, occupational risks from chemical and radiation hazards, he argued, ought to be controlled to the level of about 1 in 1,000. Dr. Albert then derived a "target" environmental risk level. He recommended a factor of ten below the occupational risk level by reference to the significant occupational risk level to account for the likelihood of more susceptible individuals— such as children— in the general public, and an additional factor of ten "because of multiple carcinogen exposure in the general public." The result of this analysis is a "target level" for public risks of 10^{-5}, or 1 in 100,000.

The reasonableness of 1 in 100,000 as a "rule of thumb" for significance of non-occupational risks is reinforced by the recommendations of the International Council on Radiological Protection (ICRP). In formulating its recommendations on radiological protection, ICRP examined "acceptable" levels of risk. Because risks from radiation represent "a very minor fraction of the total number of environmental hazards to which members of the public are exposed, "ICRP judged it reasonable... to consider the magnitude of radiation risks to the general public in the light of the public acceptance of other risks of everyday life."

Having reviewed available information regarding regularly accepted risks, ICRP concluded that "the level of acceptability for fatal risks to the general public is an order of magnitude lower than for occupational risks." Accordingly, any individual member of the general public likely would find acceptable a risk in the range of 10^{-6} to 10^{-5} per year, or between 7 and 70 in 100,000 over a 70-year lifetime. In its recent proposed rule for radiation protection standards, the Nuclear Regulatory Commission adopted ICRP's "acceptable" risk range as a "subjective judgment of risk normally accepted in everyday life as producing no undue concern."

A British Royal Society Study Group followed essentially the same analytical path used by the ICRP, and reached a similar conclusion. The Group suggested that "an imposed risk [could] legitimately be treated as trivial by the decision-maker" at the "point at which individuals who are aware of the risks they run would not commit significant resources of their own to reduce them." The Group estimated this point, on an annual basis, to fall commonly around 10^{-6} [1 in 1,000,000], "Report at 17, with a range on either side of a factor of 10 (i.e., 10^{-5} to 10^{-7}), with the lower end of the range (10^{-7} or one in 10,000,000) appropriate perhaps only "if clear causal links are established in the risks from certain consumer products." This range of annual risks equates to a 70-year lifetime risk of 0.7 to 70 in 100,000.

Examination of the risks of common human activities demonstrates that the NRC, ICRP, Ontario Royal Commission and British Royal Society were quite correct in concluding that a lifetime risk of 1 in 100,000 or more is within the realm of, or orders of magnitude below, everyday risks that generally do not cause undue concern. These are risks that people, while they are aware of them and may have *some* concern or fear over them, do not in general alter their behavior to avoid. As Table 1 illustrated, the risks from many activities greatly exceed the level of one in 100,000.

In comparison to these background risks of "everyday activities," a lifetime risk of 1 in 100,000 is relatively small. Accordingly, regulatory action will not generally be justifiable unless risks are substantially higher than this 1 in 100,000 "benchmark".

II. Assessment of Asbestos Risks Against A General Framework for Regulation of Risk

Asbestos-related disease has been one of the most serious occupational health problems of the 20th century. This phenomenon is almost totally related to a specific set of employment circumstances that are no longer in existence in this country. Uncontrolled exposures of a very high magnitude associated with shipbuilding and ship repairing operations commencing around World War II and subsequent insulation manufacture and installation activities are largely to blame for the large number of asbestos disease cases which began to be recognized clearly by the mid-sixties.

Regulation of work place exposures by OSHA beginning in 1970 coupled with the effects of burgeoning personal injury and product liability claims have brought about substantial changes in the patterns of use of asbestos and dramatically reduced exposures. More important to this proceeding is the clear distinction between the historical conditions of asbestos use and the resulting potential for exposure and the nature of the products covered by the current EPA proposal. It is essential to understand the nature of these products and the potential exposures associated with their production and use in order to assess the potential risk of health effects in the future and the significance of those risks.

A. The Occupational Risks EPA Seeks to Regulate by Banning Asbestos

Occupational exposures in the work place present lifetime risks of much less than one-in-a-thousand to the great majority of asbestos-exposed workers. Furthermore, these risks accrue to a relatively small number of workers.

In the manufacturing sector, EPA estimates that employees will be exposed to 0.2 fibres per cubic centimeter (fibres/cc), the new OSHA Permissible Exposure Limit (PEL). Even assuming exposure beginning at age 20 and lasting for 45 years, at eight hours per day for 250 days per year, the total individual cancer risk for males is well within the realm of insignificance for friction products, vinyl-asbestos tile, adhesive, and coating manufacturing workers. Total cancer risk is only 0.88 in 1,000 for smokers, and half that (0.43 in 1,000) for nonsmokers. This represents a yearly individual risk of less than 2 in 100,000 for smokers.

Risks would be only one-fourth as high for exposures of 0.05 fibres/cc, a level that would be typical in many manufacturing operations under a PEL of 0.2 f/cc. They also would be substantially lower in the case of the exposure OSHA believes would prevail under the 0.2 fibres/cc standard. OSHA estimates that actual manufacturing exposures would range from 0.02 f/cc for asbestos cement pipe to 0.13 f/cc for A/C sheet, with exposures in most operations well below 0.1 f/cc.

For asbestos cement (A/C) pipe and A/C sheet manufacture using chrysotile only, risks for nonsmokers (using EPA's exposure assumptions) are estimated as 1.5 in 1,000 for 45 years exposure. For smokers, risks are somewhat higher, at 7.1 in 1,000. In examining these estimates, it should be noted that the 7.1 in 1,000 figure is unrealistically high as an average value, as it assumes exposures at the PEL and ignores the likelihood of improved work practices. Indeed, OSHA estimates that A/C pipe manufacturing exposure will be only 0.02 fibres/cc, suggesting that actual risk in that operation will be only 0.71 in 1,000 for smokers. In short, while the risks from A/C pipe and sheet manufacture cannot be dismissed out of hand, neither do they justify an extreme response.

In friction products repair, EPA estimates that employees will receive exposures of about 0.04 fibres per cubic centimeter. This level of exposure over 45 years poses an individual risk of only 0.18 per thousand male smokers. Moreover, OSHA estimates that actual exposure would be approximately 0.01 f/cc (one-fourth of EPA's estimate). All of these estimates lead to risks well below those that have generally been regarded as significant.

A/C product installers also face insignificant risks. Even without respirators, a male A/C pipe installer's lifetime risk — assuming exposure at 0.004 fibres/cc is 0.14 in 1,000 if he smokes, and 0.029 in 1,000 if he does not. In a population of only 164 such equivalent installers aggregate fatalities over 45 years, assuming 100% smokers, would total 0.022, the equivalent of one death every 2000 years. Very small risks such as this starkly illustrate the need, discussed above, to concentrate societal resources on truly significant risks, the reduction of which will be of benefit in a real sense in a realistic period of time.

A/C sheet installation presents individual risks which are somewhat higher. Among males who work 45 full years and wear respirators (or who work with A/C an average of 10% each year) — and hence have average exposures of 0.01 fibres/cc — lifetime risks are 0.35 per thousand for smokers, and 0.073 per thousand for nonsmokers.

Risks for A/C sheet installers also do not appear to be significant. For nonsmokers, the lifetime risk (using OSHA's 0.1 fibre/cc exposure estimate) is 0.73 in 1,000 while for smokers it is 3.5 in 1,000. Furthermore, the risks to installers likely are overstated, for these employees may spend only a small percentage of their time working with A/C sheet, and can employ respiratory protection. In any event, the equivalent population at risk is so small (390) that the overall risk is of limited concern.

As the above demonstrates, the occupational risks from asbestos are below or comparable to the risks associated with occupations generally regarded as safe, and consequently should not be considered significant.

B. THE GENERAL POPULATION RISKS EPA SEEKS TO REGULATE BY BANNING ASBESTOS

Although the thrust of EPA's case against new asbestos product use is on occupational risks, it also discusses general population risks: persons who will walk on newly installed vinyl asbestos floor tile and persons who live near asbestos cement manufacturing plants. If vinyl asbestos (V/A) floor tile production continues at current rates for the next 15 years, it is estimated that on average 3.0 million persons will walk on such tile. EPA believes they will thus incur exposures of 0.0005 fibres/cc. Even 8 hours daily and 250 days yearly at these levels, a male in a building with V/A tile would face a lifetime risk of 1.1 to 2.2 in 1,000,000, depending on whether or not he smoked.

For persons who live near asbestos cement plants, even accepting EPA's exposure assumption (which describe the "maximum risk individual"), the highest risk to which anyone is exposed (smoker exposed to mixed chrysotile and crocidolite) is 5.1 in 1,000,000. Using an estimated population-at-risk from EPA data of 325,000, this equates (even assuming that *all* are smokers exposed to mixed fibres) to 0.02 deaths per year, or one every 50 years. As **Table 4** above showed, this is a smaller risk, to the "maximum risk" individual and to the population, than almost all the risks EPA found to be insignificant in the context of NESHAPs for radionuclides and benzene.

C. DETERMINATION OF RISK SIGNIFICANCE AND REGULATION THROUGH BALANCING OF MULTIPLE FACTORS

Answering the questions of what constitutes significant risk, how much risk is necessary before regulation is warranted, and what type of regulation is appropriate, involves consideration of a number of factors in addition to the numerical estimation of risk alone. An evaluation of the benefits of the substance or activity associated with the risk in question is generally involved. In addition, regulators must consider the risks and benefits associated with substitutes for the substance or activity, as well as the availability of alternative approaches for achieving risk reduction. The statistical and biological uncertainties associated with the exposure and dose-response data underlying the numerical risk estimates should also be considered. Finally, one must assess the various control alternatives available to reduce risk.

In this case, EPA has proposed the most extreme option to reduce the risks associated with asbestos exposure. In proposing an across-the-board asbestos ban and phaseout, it has been inconsistent with its past regulatory practices and those of other regulatory agencies which, as I have described above, generally involve the acceptance of (finite) levels of risk greater than zero. It has also not considered the risks associated with asbestos substitutes, or the availability of control options other than elimination of the substance's use altogether to reduce the risks associated with exposure. In not considering these factors, EPA's proposal is inconsistent with the requirement of the Toxic Substances Control Act that there be "a reasonable basis to conclude that the manufacturing, processing, distribution in commerce, use, or disposal of a chemical substance or mixture, or that any combination of such activities, presents, or will present an unreasonable risk of injury to health or the environment." Consideration of all of the above factors should clearly lead to an alternative regulatory conclusion on the part of EPA in the case of asbestos.

CONCLUSION

Because risk is an inherent feature of virtually every human activity, regulators should forego the futile exercice of attempting to eradicate risk. Instead, in keeping with the Supreme Court's Benzene decision, decisions of EPA, NRC, and OSHA, and the informed judgments of advisory bodies and academic experts, EPA regulators interpreting TSCA should also address themselves only to significant risks — those of sufficient relative magnitude to warrant some expenditure of resources on further inquiry and/or regulation.

A sensible and widely-accepted basis for determination of what constitutes "significant" risks is the risk attendant to occupations generally considered "safe" or, in the non-occupational realm, activities and occurences, the risks of which are readily accepted in everyday life. These and other analytical approaches converge upon 1 in 1,000 and 1 in 100,000 as reasonable "rule of thumb" measures of significant risk in occupational and general population settings, respectively.

Measured against these "benchmarks," the occupational asbestos risks EPA proposes to regulate are, for the most part, clearly not significant, as are all the general population risks at issue. Those few occupational risks that might arguably be significant are, at worst, at the margins of significance, and accrue under circumstances that warrant use of a signficant risk "guideline" above 1 in 1,000. Moreover, sound policy should be based on the recognition that risks simply cannot be decreed out of existence. Economic dislocations and the risks of alternatives to asbestos, for example, must enter into any responsible analysis of the desirability of banning and phasing out asbestos. As a result, TSCA regulators should consider whether controls other than bans or phaseouts will be more effective and appropriate.

ASSESSMENT AND REGULATION OF RISKS

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Thank you, Barry, and thank you very much, ladies and gentlemen, for the invitation that I should join in this excellent symposium.

Yesterday, we had an extremely useful review of ways in which dust from friction materials could be controlled and, this morning, a wide ranging survey of health effects which showed the need for such control. So this is an important final section to review the standards for control of asbestos and of alternatives, which could be set, and set quantitatively, to ensure a proper degree of safety, at work particularly. And these words, I think, state the central problem, the "proper degree" of safety.

Firstly, how much risk to health is caused by any given fibre concentration of a range of different materials? And secondly, anyhow, how low a risk ought standards to ensure? Of course, the situation is not all that familiar. Industry, in general, has grown up with the obvious fact that some jobs are more hazardous than others and that there should be efforts, which are generally very successful efforts, to reduce those risks, but not with a specific, numerical limit; rather with some sort of break-even between the cost of further reduction and the fact that the money could be used better for other health effects, if one happened to live under a government which transferred funds from one health effect to another. These efforts are commonly taken without too much familiarity with the size of the risks involved.

There was not the need to square up to this difficult interface between scientific and technical and epidemiological evidence of the frequency of harmful effects, and the laws or codes of practice taking account of the size of particular kinds of risk. And this task is not easy. The public perception of the risks of harmful effects, in general, has often been influenced much less by the size of the risk than by other features: the type of conditions which caused the risk, whether it was imposed by industrial factors, by government or other human agencies or by the forces of nature, or by the choice of the individual. And, of course, the assessment of risk is influenced by the publicity and type of treatment that is currently being given to it by the media.

So, the size of a risk is only one of the factors affecting the importance that people attach to that risk, but it *is* an important one.

A conventional attitude to different occupational risks has often been the more or less unquantitative one, that some industries are risky and others are safe. Or where a more reasonably quantitative approach has been needed, this has been easily obtained from past records; for example, of the number of fatal accidents per year in each industry or, obviously much better, of the number per year, per one hundred thousand workers at risk in that industry. This often gives a useful criterion for comparing the safety of workers in different industries and also of the rate at which risks in these industries are being reduced.

Now, such data give clear-cut evidence of the range of risk in conventional industries and the recognition that no industry is entirely safe. Some are constantly many times as unsafe as the average and others are considerably safer than the average, and this difference in hierarchy of danger persists in spite of annual decreases in the risk of most industries.

In fact, the range of safety or risk is very large indeed, at least as indexed, for example, by the fatal accident rate at work per million or per hundred thousand per year. In the U.K., where detailed studies have been made on the risks of different subdivisions of total industry, the risks of fatal accidents per hundred thousand people per year ranged from about 0.3 in the manufacture of clothing and shoes, up to 300 in trawling and fishing at sea. That is a difference of three orders of magnitude in the risk, according to this criterion. The lower limit for the safest that I have mentioned, clothing and footwear, can be only determined with any precision if you have a large number of worker-years of experience to study. This estimate (1) depended on ten million worker-years to give 90% poison limits ranging from 0.22 to 0.42 with a central estimate of 0.31.

In the U.S., the industries are grouped in a rather simpler and more general grouping in your admirable publication of *Accident Facts* (2) and you will see that each of these categories remain roughly constant, although falling in all cases by a few percent per year (**Table 1**). The limit here in these rather coarse groupings of different types of trade, and different types of mining and quarrying ranges over more than one order of magnitude and the more you subdivide, of course, the greater difference you get between the lowest risks and the highest ones.

The same position is seen in Canada (**Table 2**). These values are from a Labour Canada publication(3) on a fatal accident rates with figures running from about 1.5 per hundred thousand per year in, essentially, I imagine, desk operations to rates of up to 200 where, again, we are two orders of magnitude in the range of the whole sequence. The rate of fall in the total of all of them, in this case, was about 5% per year, with a small standard error.

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(1) Quantitative bases for developing a unified index of harm. International Commission on Radiological Protection Publication 45. Annals of the ICRP 15 (3) 1-64, 1985.

(2) Accident Facts: Editions of 1957 to 1983. (US) National Safety Council, Chicago.

(3) Employment and occupational illnesses, 1972-1981. Labour Canada, Ottawa, 1984

This is a fairly general phenomenon in a number of different countries: for example in Belgium, France, the Federal Republic of Germany, Japan, Sweden and the United States (**Table 3**). Where the annual values, as a percentage of the mean rate, are falling progressively[1]. (I do not know if Rita is here, but she gave some figures yesterday for the rate of fall of fibre concentrations in air from 1983 to 1986. Rapidly putting down her figures and doing the calculation on them, the fibre content and, therefore approximately the risk, was falling at the rate of 6% per year over that time, a very creditable rate of fall, obviously, in this particular context.)

So here then we have a very wide range of safety in different industries. None are safe, but some are very safe, if you will accept that form of words. It is very easy to compare their safety in this way. And it is a help to define our perspective and our scale of ambition to review the range of industries seen in this sort of way. I will come back to this in connection with a point that was raised during this morning's session.

Such data give convincing evidence of the range of risk in conventional industries, but the position is entirely different when, as with exposure to ionizing radiation, risks are introduced which are unfamiliar ones, such as of causing fatal or curable cancers, genetic effects, or developmental defects, which are different in kind from the more familiar risks in other occupations, of fatal injuries, temporarily incapaciting injuries and some recognized occupational diseases.

The nature of the radiation risks have additional features which make it necessary that their size can, in most cases, only be assessed prospectively and not read off from past experience. I would like to outline these points, because I think there is a fair amount of common ground, in some respects, between the effects of radiation and those of asbestos, and partly perhaps of its alternatives.

For example, no induced cancers, induced by radiation, appear within the first few years of the radiation exposure which caused them, but such cancers may continue to appear for many years thereafter - perhaps during the rest of life. Obviously, that means that there should be prolonged studies after the initial or continuing exposure. The same may very well be true of asbestos. It certainly appears to be true of smoking if you accept this conclusion from the rise of cigarette consumption in England and Wales and the rise of deaths from smoking (**Figure 1**) suggesting an average lag of something between 20 and 25 years. There are ways in which this may not be a delay only in the cancer incidence, but it obviously shows a lag of some decades rather than of short periods of time.

So, knowledge of the frequency of occurrence of these effects per unit dose must depend on very long and full epidemiological follow-up of populations exposed considerably earlier and under the various different circumstances in which there has been a dose metrically known exposure of large populations, e.g. of radiologists, radium workers, the unfortunate populations of Hiroshima and Nagasaki, patients treated with radiotherapy or, in some cases, heavily exposed by many repeated, diagnostic procedures[4]

Another problem in radiation assessment is that the types of cancer caused are similar in all, or at least all presently recognizable, respects to similar types of cancer which occur naturally (whatever I mean by "naturally"). Assessment of the size of the excess per unit dose, therefore, depends on statistical comparisons with otherwise identical, or hopefully identical, but unequally-irradiated populations. So the risk in industries with a given annual dose-rate must, therefore, be based on prediction rather than on observation, except in just one or two occupations - e.g. hard-rock miners exposed at high-dose rates from high-ore bodies being one. The estimates are, therefore, less confidently accepted, despite radiation having an unusually strong basis of epidemiological and radiological evidence for the predictions.

For chrysotile asbestos, the problem seems to be similar in many respects. There appear to be adequate, although less copious and varied, sources of epidemiological evidence from human exposure; but a major difference in assessing the frequency of cancers caused is that, on the one hand, evaluating the excess of lung cancers is particularly difficult in view of the need for rather exact allowance for the substantially larger effects of smoking, while on the other hand, the natural occurrence of mesotheliomas is so low that the measurement of any excess of these tumors is less statistically exacting. In the latter case, the "signal to noise ratio" is so much greater that statistical detection and evaluation of the excess is easier. Asbestos may well, as we have been hearing, share with ionizing radiation a major, conceptual problem in regard to its regulatory control. If there is no fully safe threshold, below which no harmful effect will be caused, or if such a threshold cannot be assumed to exist for protection purposes, how low should occupational levels be set, i.e. what amount of risk of severe or fatal effect should be regarded as permissible?

The absence of a threshold can never be proved. There may be a threshold half as high as you investigated last week. For radiation, the absence of a threshold is presumed, at least as a prudent basis for protection, as a result of the decreasing dose in a number of studies of mutation frequency or carcinogenic effect and of cell transformation, with a liability for that cell to multiply and develop the carcinogenic potential.

Also, the absence of a threshold for cancer induction by radiation is suggested by the fact that such mutations and cell transformations are regarded, of course, as due to the passage of ionizing particles through the cells: of alpha

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(4) Pochin, E.E, Radiation Carcinogenesis, in "Epidemiology and quantification of environmental risk in humans from radiation and other sources; at pp. 1-16. (Ed. A Castellani). Plenum Press, New York, 1985.

particles, beta particles from radioactive material, on photons from x-rays or gamma radiation. The passage of such particles through cells causes energy to be released in cell nuclei traversed by the tracks of these particles, causing unrepaired damage to the DNA; although I must emphasize that DNA and its staff of resident enzymes that accompany it is a particularly forgiving system, and we would not all be here if it was not.

With decreasing dose, there is a decreasing frequency, both in time and in space, of such particle tracks, but the energy per track remains constant. If each track has a certain very low probability of causing unrepaired DNA damage, of a type leading to cell multiplication and ultimately to cancer, the cancer risk will remain proportional to the number of tracks at low dose and, hence, proportional to dose, even down to a single track. This will be true unless the repair of one cell in an organ in some way knows of the occurrence of similar damage to another cell at the other end of the organ, at a distance which, in terms of cell dimensions, is miles away. If the same applies to single fibres of asbestos or alternative fibres, with a low probability per fibre, the same suggestion of zero threshold would also apply.

So, how should or could regulations be developed, at least to set a maximum of risk to which people should be exposed, either in working conditions of different kinds or in the public, given the difficulty in doing so.

Firstly, there is the need to be predictive, at any rate, for alternative fibres where it is the exposure, 20 or 30 years ago, which is relevant to any subsequent cancer development.

Secondly, there is the need to be numerical in assessment of risk of alternative fibres, and numerical in terms of human effects. We have heard valuable data on the risks from fibres in different animals, but there are substantial species differences and, in fact, substantial strain differences in some forms of carcinogenesis in different animals.

And thirdly, in presentation of the risks, there is the need to compare unusual risks such as the induction of cancer with the familiar risks of fatal or other accidents at work. I think it is valuable to index the risks of occupations in terms of the number of deaths attributable to the occupation per year, whether those deaths are accidental deaths or deaths from exposure to fatal cancers. But there is a lot of difference between falling fatally off a ladder today and developing a cancer in 30 years time. (I know at my age which I would prefer , but that may be a special case.)

In the context of ionizing radiation, the International Commission on Radiological Protection has published two reports[1,5] on the frequency of fatal

(5) Problems involved in developing an index of harm. ICRP Publication 27. Annals of the ICRP 1(1) 1-24, 1977

and other occupational injuries in a range of manufacturing and other industries, and of fatal and other radiation effects that may result from current levels of occupational exposure. These reports suggest a possible basis for comparing the detriment that would be thought to result from each of these forms of harm, according to the lengths of time lost, either absolutely by the loss of life expectancy from fatal effects, or by periods of impaired health or capacity from non-fatal illnesses or injuries. According to the weight that was considered to attach to the loss of periods of healthy life in these ways, some form of Index of Harm might be developed, to make the necessary comparisons between different forms of industrial risk and their effects.

Some such criteria are essential in comparing the objective, and the perceived, harm in occupations which involve radiation exposure in addition to conventional risks of injuries and accidents at work, both in those occupations, such as some forms of uranium mining, in which both the exposure and the accident rate are relatively high, and in many other industries in which exposures and accident rates are lower.

The use of such criteria would allow the radiation risks to be seen, and estimated, in relation to other occupational risks. They suggest that, in most present occupations, with average exposure rates of only a few millisieverts per year[1], the risks would be equivalent to those in conventional manufacturing industries (**Table 4**) and probably within the lower quartile of such industries in different countries (**Table 5**).

It would be valuable for similar consideration to be given to comparing the risks of occupational exposures to asbestos or its alternatives, to those of accidents at work in different industries, even if this comparison was based only on the estimated frequencies of fatal effects in both cases. For example, epidemiological evidence quoted by Doll and Peto[6] indicate a variation of risk of fatal cancer in textile workers with duration of exposure and with age at first exposure, but imply an approximate risk, per year of exposure at 0.25 fibres per ml, in the order of 20 per 100,000 at risk (**Table 6**) - corresponding to the fatal accident rate at the upper quartile of manufacturing industries in different countries. Or, estimates quoted earlier in this symposium, of 2.5 per 100,000 worker-years of exposure at 0.25 fibres per ml, in conditions of exposure less hazardous than in the forms of textile, brake manufacturing production, would correspond in fatality rate with an occupation in the lower quartile of manufacturing processes, or in service industries in Canada.

These comparisons must be regarded as very tentative, but as indicating the need, and the possibility, of relating the detriment that is likely to be attributable to an unfamiliar form of occupational hazard, to those

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(6) Doll, R and Peto, J. Asbestos: effects on health of exposure to asbestos. (UK) Health and Safety Commission. HMSO, London, 1985.

occupational risks which are regularly experienced and assessed in other existing industries. Despite the difficulties and some uncertainties in doing so, it is surely necessary to establish a quantitative perspective on the total impact of different occupational risks, including those of possible cancer induction. In the attempt to do so, it is important to review the range of accidental risks in different industries, e.g. particularly of fatal accidents per 100,000 worker-years; to estimate similarly the number of fatal effects that may result per 100,000 worker-years of exposure to given fibre concentrations of forms of asbestos or alternatives - on the best available bases for quantification; and to study the extent to which fibre concentrations can be reduced in controlled working conditions.

If it cannot be assumed that there is any entirely safe fibre concentration, then the concern must be with limiting risk to as low a level as is reasonably achieved, rather than with hoping to eliminate all risk completely. And here, as in any occupational risk limitation, we are concerned with optimising total safety and health - not only in the production, development and use of equipment of different fibre compositions, but in the choice of asbestos or alternative fibres of appropriate efficiency and safe behaviour in their applications.

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6. Doll, R. and Peto, J., "Asbestos: Effects on Health of Exposure to Asbestos". (U.K.) Health and Safety Commission. HMSO, London, 1985.
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TABLE 1

ACCIDENTAL DEATH RATES
(USA, per year, per 100,000)

Occupational group	Year 1962	1972	1982	Mean 1957/82	Rate of change %/yr, 1957/82
Trade	9	7	5	7.3	-2.4 ± 0.1
Manufacturing	11	9	5	9.5	-2.0 ± 0.2
Service	13	10	6	11.0	-3.1 ± 0.2
Government	13	13	10	12.6	-1.3 ± 0.1
Transport & public utilities	43	36	26	35.7	-1.3 ± 0.3
Construction	74	70	40	65.5	-1.8 ± 0.2
Mining & quarrying	108	117	55	91.1	-2.6 ± 0.4
All groups	21	17	11	17.7	-2.6 ± 0.1

Source: "Accident Facts". Editions of years 1957 to 1983. US National Safety Council, Chicago.

TABLE 2

FATAL ACCIDENT RATES IN CANADIAN INDUSTRIES, 1975-1981
(10^{-5} y^{-1} rounded)

Finance	1.5
Services	2.5
Trade	4.5
Manufacture	7.5
Agriculture	9
Public administration	10
Transport	25
Construction	38
Mining	52
Forestry	116
Fishing	212

Rate of fall (total of all) by 4.9 ± 0.7 (SE) % y^{-1}

Source: Employment injuries and occupational Illnesses, 1972-1981 (Tables 1.32 — 1.34). Labour Canada, Ottawa, 1984.

Table 3

TRENDS WITH TIME IN FATAL ACCIDENT RATE

Country	Period	Annual change (% of mean rate)
Belgium	1964/74	-2.1
France	1954/79	-2.1
F.R. Germany	1949/77	-4.6
Japan	1968/76	-6.9
Sweden	1955/79	-4.4
USA	1957/80	-2.4

Source: International Commission on Radiological Protection, Publication 45, "Quantitative Bases for Developing a Unified Index of Harm", Annals of the ICRP, Vol. 15, No. 3, 1985 [in which primary references are quoted].

TABLE 4

FATAL ACCIDENT RATES IN ALL UK MANUFACTURING INDUSTRIES

[Standard Industrial Classification 3 to 18,1970-1980]
Deaths per year and per 100,000 at risk

	mean rate	±	SE
Clothing and footwear	0.3	±	0.1
Instrument engineering	0.9	±	0.2
Electrical engineering	0.9	±	0.2
Textiles	1.9	±	0.4
Vehicles	1.9	±	0.3
Paper, printing & publishing	2.4	±	0.2
Food, drink & tobacco	3.2	±	0.2
Metal goods (other)	2.9	±	0.2
Leather, leather goods & fur	2.9	±	1.0
Mechanical engineering	3.3	±	0.1
Timber, furniture, etc.	3.7	±	0.5
Chemicals & allied industries	6.7	±	1.1
Bricks, pottery, glass, cement, etc.	7.0	±	0.8
Shipbuilding and marine engineering	11.3	±	1.1
Metal manufacture	11.8	±	0.8
Coal & petroleum products	14.8	±	2.1

Sources: Annual Reports of UK Chief Inspector of Factories until 1974, the Health and Safety Executive "Health and Safety: Industry and Services" report in 1975, and its "Health and Safety: Manufacturing and Service Industries" reports subsequently.

TABLE 5

FATALITY RATES IN MANUFACTURING INDUSTRIES
Values at quartiles for all listed individual industries
[per 10^5 worker-years or per 2×10^8 working hours]

	No. of categories	Quartiles 25%ile	Median	75%ile
France, 1979	10	2.5	7.0	9.0
German Fed. Rep.,1978	14	4.0	7.0	9.0
Japan, 1979	18	2.0	5.0	8.0
South Africa, 1965/70	8	4.5	19.0	33.5
Sweden, 1979	8	3.0	4.5	6.0
Switzerland, 1968/72	22	4.5	11.0	27.5
United Kingdom, 1970/80	16	2.0	3.0	7.0
United States of America, 1982	25	0.7	4.3	11.2
Mean		3.0	7.5	14.0

The industries included are those corresponding to SIC orders 3 to 18 although ordinarily not so listed. All rates are rounded and approximate. Working populations in 11 manufacturing industries listed for the Phillipines are too small for reliable determination of individual rates, but they have a mean value of 300, from 10 deaths in 33,000 manufacturing workers. Differences in national rates may be partly due to differences in date of records.

Sources: as cited in ICRP Publication 45[1].

TABLE 6

PREDICTED ASBESTOS INDUCED DEATHS, PER 100,000 MALE TEXTILE WORKERS

(by age 80, from lung cancer and mesothelioma)
per year of exposure, at 0.25 chrysotile fibres per ml.

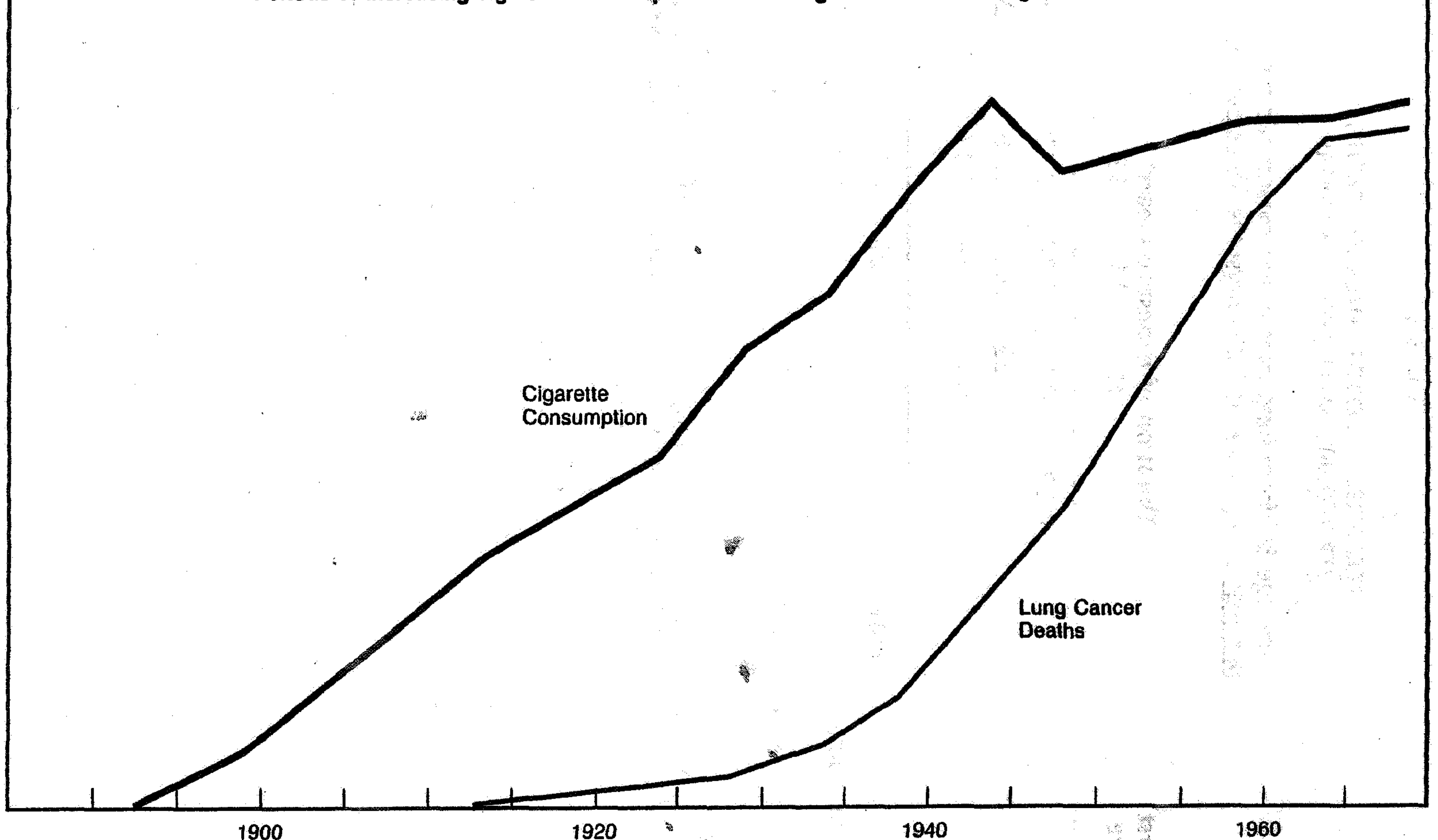
Age at first exposure	Duration of exposure (years) 5	15	25	35	
20	0.29	0.26	0.24	0.22	HSC Report
30	0.23	0.22	0.20	0.18	Doll & Peto, 1985
40	0.20	0.19	0.16	0.13	
Average	0.24	0.22	0.20	0.17	

or, from raw data, 0.21

Source: Doll, R. and Peto, J., "Asbestos: Effects on Health of Exposure to Asbestos". [UK] Health and Safety Executive. HMSO, London, 1985. (Table 6/1 & page 45)

Figure 1

Periods of increasing cigarette consumption and of lung cancer deaths: England and Wales



Source: World Health Organization data; reproduced, with permission, from Sentinel 1987 (7)

LEGAL AND REGULATORY IMPLICATIONS OF BRAKE LINING SUBSTITUTES *

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INTRODUCTION

The floodgate of litigation concering the dangers of exposure to asbestos has evoked world-wide concern regarding its myriad uses. Asbestos has been used extensively in the manufacture of brake linings. The public concern over exposure to asbestos-containing products has coerced many brake lining manufacturers into producing asbestos-free brake linings. This paper will address many of the issues presented be the current controversy over asbestos brake lining. Unfortunately, little is known about the asbestos substitutes currently being used in the manufacture of brake linings; therefore, no definitive answer can be reached until adequate research has been completed regarding these substitute products.

ASBESTOS GENERALLY

Asbestos is a generic term given to various groups of naturally occurring mineral silicate fibres. The names of these fibres are as follows : chrysotile, a fibrous serpentine, and actinolite, amosite, anthophyllite, crocidolite and tremolite, fibrous amphilboles(1)

Asbestos, the "magic mineral", has tremendous resiliency to heat and acid. Because of its resiliency, asbestos has over three thousand uses(2). Although asbestos has been used for thousands of years, the commercial use of asbestos dates only from the late 1800s to the present.

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* The speaker wishes to express appreciation to Roy J. Boyd, Jr., an associate lawyer at Freeman & Hawkins, for his assistance in the preparation of this paper.

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(2) Theodore and Selikoff, Asbestos fibres In Human Lung, Forensic Significance, The Amer. Jour. of Forensic Medecine and Pathology, Vol. 2, No.1 (March, 1981).

An important class of asbestos-containing products are the friction materials which are commonly used in brake linings. Friction material is composed of chrysotile asbestos fibre, by far most abundant form of asbestos[3] It is estimated that the level of chrysotile in friction material is approximately fifty percent[4].

CARCINOGENIC EFFECT

The commercial forms of asbestos, when tested in mice, hamsters, rats and rabbits, have all been found to be carcinogenic[5]. In humans, occupational exposure from chrysotile, amosite, anthophyllite, and mixed fibres containing crocidolite has been associated with an increased incidence of lung cancer[6]. Mesothelioma (a rare, malignant tumor of the mesothelial linings of the body, most commonly involving the peritoneal linings of the abdomen and pleural linings of the lung) has been observed in humans following occupational exposure to crocidolite, amosite and chrysotile[7].

Mesothelioma has also been diagnosed in people who did not work with asbestos but lived near factories, crocidolite mines or had daily household contact with an asbestos worker[8]. There is controversy over whether exposure to asbestos increases the incidence of gastrointestinal cancer[9]. An increase in cancer of larynx and esophagus has been associated with asbestos exposure[10]. Whether asbestos exposure is the sole cause or one of many contributing factors to the development of cancer is not known.

ASBESTOS AND THE BRAKE REPAIR WORKER

Until recently, the presence of asbestos-related illnesses in brake repair workers attracted little, if any attention. Asbestos-related illnesses have been reported in cases involving factory workers who manufactured asbestos brake linings and garage workers engaged in the repair, maintenance and

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(3) Castleman, Camarota, Fritsch, Mazzocchi and Crowley, The Hazards Of Asbestos For Brake Mechanics, Public Health Reports, Vol. 90, No.3 May-June 1975 (Ninety-five percent of world's asbestos production is chrysotile).
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(9) Id
(10) Id

installation of brake linings in automobiles and trucks[11]. In the U.S., a case of asbestosis in a brakeline worker was reported in 1940[12]. The British Industrial Injuries Act of 1948 recognized asbestosis as a disease common to brakeline workers[13]. Among brakeline workers, the asbestos-related illnesses initially recorded were generally confined to workers who manufactured and fabricated friction materials which contained asbestos. Subsequently, reports of lung cancer and mesothelioma were recorded for workers who simply installed or repaired friction materials[14]. There was little concern regarding exposure to brakeline workers since it was believed that the asbestos fibres remained locked in the brakelining matrix or were decomposed by the heat generated from the brakes[15]. Light microscopy initially indicated that dust remaining in brake drums was asbestos-free[16]. Subsequent tests revealed that sub-microscopic chrysotile fibres were present in the drum dust[17]. These later studies also showed that unaltered chrysotile fibres were released in the bevelling, refurbishing and refitting of brake pads; therefore, there was ample opportunity during brake maintenance and repair for brake workers to be exposed to chrysotile fibres in the drum debris[18]. Additionnal studies showed that brakeline workers were also exposed to unaltered chrysotile fibres when machining brake parts[19]

It is estimated that at least 900,000 United States citizens are currently employed as auto mechanics or garage workers and, therefore, exposed to asbestos brake linings[20]. It is also speculated that the asbestos released from brakes during normal automobile use may contribute to the presence of asbestos fibres in the air[21]. The amount of brake material worn away from brake linings each year is a staggering ninety million pounds[22]. Eighty to ninety

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(11) See, e.g., Mancuso, (1963) Methodology of Industrial Health Studies: The Cohort Approach With Special Reference To An Asbestos Compagny, Arch Environ Health 6, 210-226 (4 Peritoneal Mesotheliomas); Newhouse and Thomson, (1965): Mesothelioma of Pleura and Peritoneum Following Exposure To Asbestos In The London Area, B.R. J. Med. 22:261-269; Lorimer, Rohl, Miller, Nicholson and Selikoff, (1976): Asbestos Exposure Of Brake Repair Workers In The United States, Mt. Sinai Journal of Medicine (N.Y.) 43(3): 207-218 (twenty percent (18) of experienced vehicular maintenance workers studied showed x-ray findings consistent with asbestosis while six percent (5) had pleural thickening or calcification; Mancuso, Mesothelioma Among Machinists And Railroad And Other Industries, Amer. Jour. Of Ind. Med., 4:501-513 (1983)

(12) Mesothelioma In a Brake Repair Worker, The Lancet (Nov. 13, 1982).

(13) Id.

(14) Id.

(15) Id.

(16) Id.

(17) Id.

(18) Id.

(19) Id.

(20) Lorimer, Rohl, Miller, Nicholson and Selikoff, Asbestos-Exposure of Brake Repair Workers In The U.S., The Mt Sinai Journal of Medicine, Vol 43, No. 3 (May-June, (1976).

(21) Id.

(22) Id.

percent of this brake lining drops to the road or is emitted into the atmosphere[23].

If chrysotile has carcinogenic qualities, its use in the manufacture of brake linings presents three potentially dangerous situations: (1) Exposure to factory workers who manufacture friction materials; (2) Exposure to mechanics who repair or replace brake linings; and (3) Exposure to the general population when asbestos is released into the air.[24]

Notwithstanding the statistical data noted above, considerable controversy remains regarding the carcinogenic effects of the various forms of asbestos[25]. It is generally agreed that amphibole asbestos forms (predominantly amosite and crocidolite) play some unknown role in the development of mesothelioma[26]. From statistical data, it appears that crocidolite is the most dangerous of the amphiboles[27]. There is considerable thought among the medical community that exposure to chrysotile asbestos from brake linings has no harmful effect[28]. To date, there has been no recorded case of occupational mesothelioma where chrysotile ore components only were found in the lung tissue[29]. The cases implicating chrysotile also noted the presence of crocidolite and amosite components in the lung tissue[30]. There is evidence that certain amphiboles, more specifically, tremolite, actinolite, and anthophyllite, contaminants of chrysotile ore, may play some role in the development of mesothelioma; therefore, contaminants of chrysotile and not chrysotile itself may be the carcinogenic elements responsible for the development of cancer in humans[31].

The amount of chrysotile asbestos emitted from brake linings into the atmosphere is extremely small when compared to other asbestos sources[32]. Although brake linings are composed of at least fifty percent asbestos, the asbestos particles emitted during braking are only composed of .029 percent asbestos[33]. The remaining asbestos fibres are decomposed during the braking

(23) Id.

(24) Ehrenreich and Selikoff, Environmental-Occupational Diseases, The American Journal of Forensic Medicine and Pathology, Vol.2, No.1 (1981).

(25) Churg, Wiggs, Depaoli, Kampe and Stevens, Lung Asbestos Contact In Chrysotile Workers With Mesothelioma, Offic. Jour. of Amer. Thoracic Society, Vol.130, No.6 (Dec. 1984).

(26) Id.

(27) Id.

(28) Id.

(29) Id.

(30) Id

(31) Id.

(32) Muhlbaier and Williams, Characterization of Asbestos Emissions From Brakes, Environmental Science Department, General Motors Research Laboratories.

(33) Id.

process[34].Recent atmospheric samples taken downwind of freeways showed no significant increase in asbestos over upwind atmospheric samples[35]. Despite the low asbestos emissions from braking, some studies have shown that areas near the roadways and toll booths have higher levels of asbestos in the atmosphere; and the roadway debris near roadways and toll booths also exhibits a higher level of asbestos[36]. The statistics indicate that the excessive asbestos level near toll booths is probably the result of increased braking[37].

Alternatives to Asbestos Containing Friction Materials

Faced with the statistical data regarding potential hazards from the use of asbestos in brake linings, the feasibility of alternatives to the use of chrysotile asbestos in brake linings is being explored. The replacement of chrysotile asbestos with asbestos-free friction materials presents many complications. The replacement materials must be sufficient to withstand the wear and tear imposed upon brake lining. It is readily apparent that substitution of improper friction materials in new vehicles or in after-market vehicles poses a tremendous safety threat. Currently, no required performance test for after-market friction materials exists since most after-market non-asbestos material suppliers do not have facilities capable of properly evaluating their asbestos-free materials[38].

The essential requirement of any braking system is the ability to provide a controlled deceleration[39]. A vehicle must have the ability to be decelerated rapidly with control since most emergency situations do not allow much time for reaction[40]. The vehicle's response to the driver's braking must be predictable[41]. The effectiveness of a braking system is strongly influenced by the effectiveness of the frictional properties in the lining material[42]. Unfortunately, after-market friction materials from the various manufacturers exhibit much diversity in friction characteristics[43].

The most significant factors affecting proper braking are wear and thermal distortion[44]. Wear shifts the center of the pressure location; therefore,

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(34) Id.
(35) Id.
(36) Id.
(37) Id.
(38) Final Report On Analysis Of The Feasibility Of Replacing Asbestos In Automobile And Truck Brakes, The American Society of Mechanical Engineers, EPA (April 15, 1987).
(39) Id. at 13.
(40) Id. at 16.
(41) Id.
(42) Id. at 18.
(43) Id.
(44) Id. at 21.

asbestos-free friction materials with wear rates different from asbestos friction materials might decrease stability by changing the center of pressure[45]. This shift in the center of pressure might lead to a reduction in brake effectiveness or an increase in brake effectiveness which might lead to a wheel lock-up[46].

The various forces generated during braking cause stress to the brake components and also the vehicle-associated components such as axles and suspension elements[47]. These stresses can promote fractures or fatigue failures which might result in dangerous operating conditions[48]. Generally, friction materials are attached to the brake shoe by the use of riveting, bonding or integral molding[49]. Asbestos-free linings are generally stiffer than asbestos linings and are generally anistropic (sensitive to orientation)[50]. It is also believed that the asbestos-free fibres (fibreglass, aramid fibre (Kevlar), steel wool and wollastonite) create more noise than their asbestos-counterparts since they are single solid elements as opposed to the multi-strand make-up of asbestos friction materials[51]. It is believed that the strand like appearance of asbestos provides an inherent dampening of the vibration and noise[52].

(a) Asbestos Lining — For approximately the last eighty years, chrysotile asbestos has been a critical component in friction materials, and its characteristics are well known[53]. Chrysotile is the perfect element for friction materials since it offers a combination of physical, mechanical, thermal, tribological, processing and economic attributes[54]. Generally, two or more grades of chrysotile asbestos are blended together to produce the desired effects in the brake lining[55]. The vast majority of non-asbestos friction materials combine a blend from several hundred potential fibre and structural agents[56]. Basically, the non-asbestos friction materials represent a "fibre cocktail" that has been assembled to provide the necessary attributes for the brake lining while maintaining an acceptable cost level[57].

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(45) Id.
(46) Id.
(47) Id. at 23.
(48) Id.
(49) Id. at 24.
(50) Id.
(51) Id.
(52) Id.
(53) Id. at 53.
(54) Id. at 54.
(55) Id.
(56) Id.
(57) Id.

(b) Asbestos-Free Brake Lining _ Unlike the impressive history behind the use of chrysotile asbestos in friction materials, the use of non-asbestos friction materials has a scant twenty-year history; the vast majority of research conducted on these materials was done in the last ten years[58].

The asbestos-free friction materials have four developmental classes: Non-Asbestos Organic, Semi-Metallic, Sintered Metallic and Carbon-Carbon[59].

The **Semi-Metallic** and Resin Bonded Metallic friction materials utilize steel wool, iron powder, graphite, binder resin and other ingredients in their formulations[60]. The Semi-Metallics have been used for disc brake linings on passenger cars and light trucks for approximately ten years[61]. Semi-Metallics are the most common friction material used with disc brakes in the United States[62]. Unfortunately, at present, Semi-Metallic Linings have little usage in heavy truck drum and disc brakes[63]. Although water has little effect on Semi-Metallic friction materials, water combined with oil tends to reduce the friction potential of these materials[64]. Road water generally contains some oil; therefore, there is a potential danger of loss of friction if excessive road water splashes on these linings during operation of the vehicle[65]. Cool and humid air conditions also cause a temporarily low brake effectiveness in Semi-Metallic Linings[66].

The **Non-Asbestos Organic** Friction Materials are composed of fibres and other ingredients. Aramid, fibreglass, mineral wool, wollastonite, steel wool, and processed mineral fibre are among the reinforcement fibres used with binder resin and other fillers and friction modifiers in these brake linings[67]. Non-Asbestos Organic Materials are currently used for passenger cars and light trucks and are becoming increasingly popular in brake blocks on heavy truck drum brakes[68].

One drawback to the use of the Non-Asbestos Organic Friction Materials is that hundreds of fibres and reinforcing agents are available and generally used

(58) Id. at 56.
(59) Id.
(60) Id. at 57.
(61) Id.
(62) Id.
(63) Id.
(64) Id. at 58.
(65) Id.
(66) Id
(67) Id.
(68) Id.

in combination with each other[69]. It is difficult to determine the best combination for the lining process, friction level, friction stability, wear life, fade resistance, recovery, contamination sensitivity, and mechanical properties since there is essentially no technical communication or cooperation among the various lining manufacturers, each working independently of the other[70]. At present, the Non-Asbestos Organic Friction Materials tend to be hard, brittle, low in permeability, highly anistropic, and prone to hot spot, blister and crack; therefore, there is some question as to their effectiveness[71]. Although Non-Asbestos Organic Friction Materials may someday prove to be more effective than asbestos-containing friction materials, this day will not be realized until additional research is completed on these materials.

Sintered Metallic Friction Materials contain an iron or copper base with inorganic filler and friction modifiers[72]. These friction materials have been used extensively in heavy duty brakes and clutches for approximately thirty years[73]. These materials are environmentally sensitive and cause severe galvanic corrosion in moist environments if the typical cast-iron counter surface material is also used[74]. Sintered Metallic Friction Materials are very expensive in addition to their extreme sensitivity to environmental conditions[75].

Carbon-Carbon Friction Materials are space-age components of carbon fibre held in a matrix of morphous carbon[76]. This material is very costly and is extremely difficult to manufacture[77]. Military aircraft, race cars and commercial aircraft use these materials for both stationary and rotating elements in disc brakes[78]. Unfortunately, the high cost of manufacturing and extreme environmental sensitivity give Carbon-Carbon Friction Materials limited use[79].

HAZARDS FROM REPLACEMENT

Many automobile and truck manufacturers contend that vehicle safety may be compromised if vehicle tested friction products containing asbestos are

(69) Id. at 59.
(70) Id.
(71) Id.
(72) Id.
(73) Id.
(74) Id.at 60.
(75) Id.
(76) Id.
(77) Id.
(78) Id.
(79) Id.

replaced with untested asbestos-free friction products[80].Whether on new vehicles or after-market vehicles, asbestos-free friction materials must be capable of providing friction levels and friction stability to achieve proper braking performance[81].

Section 570 of the Code of Federal Regulations was promulgated to insure, among other things, safe braking performance standards under normal and emergency braking conditions for vehicles which are currently in use[82]. Section 571 of the Code of Federal Regulations was promulgated to insure, among other things, safe braking performance standards under normal and emergency braking conditions for motor vehicles and motor vehicle equipment[83]. Each of these sections prescribes stringent performance standards which braking systems should meet[84].

As indicated *supra*, many of the asbestos substitutes currently proffered by the various manufacturers may perform satisfactorily for a short time but then begin to disintegrate due to the friction placed upon them by constant braking. Unfortunately, the tests prescibed by Sections 570 and 571 measure the braking system's performance at a given time and simply measure the overall performance of the braking system[85]. The performance of the individual components of the braking system, including, but not limited to, brake lining, is not analysed[86]. It is quite possible that the overall braking system might be satisfactory at one point in time, but then became unsatisfactory after potentially inferior asbestos-free substitutes become worn away by constant braking. In any event, it is readily apparent that the asbestos-free substitutes may not measure up to the stringent requirements necessary to provide a safe and efficient braking system. At present, there is not enough information regarding the capabilities of these substitutes.

Although the prescriptions of Section 570 apply to the vehicle owner and the prescriptions of Section 571 apply to the manufacturers of motor vehicles and motor vehicle equipment, prudent owners and manufacturers will require competent evidence that individual components used to construct the braking system are safe and effective. Once manufacturers of the asbestos-free substitutes warrant that their products are fit for the purpose intended, they will be subject to liability if theses products are unable to handle the task.

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(80) Id.at 85.
(81) See 49 C.F.R. §§ 570 et seq., 571 et seq. (1986).
(82) 49 C.F.R. § 570, et seq. (1986).
(83) 49 C.F.R. § 570, et seq. (1986).
(84) 49 C.F.R. §§ 570, et seq., 571, et seq. (1986).
(85) Id.
(86) Id.

Without uniform standards, the manufacturers of asbestos-free friction materials face an incalculable risk of liability. If the substitute products are not suitable for braking systems, the litigation resulting against the manufacturers of these products will be staggering. At present, little research has been completed regarding the ability of the substitute products to withstand the tremendous friction placed upon them by constant braking. Furthermore, the various manufacturers of these substitute products conduct their research independently; therefore, there is no uniformity among the manufacturers regarding the quality of these substitute products. It is suggested that the manufacturers of these substitute products pool their existing knowledge concerning safety standards. Without guidelines to follow, many manufacturers will produce an inferior product which will subject them to liability from myriad claimants.

Another issue presented is whether the asbestos-free friction material used to replace asbestos-containing friction material will have harmful effects on those exposed to it. Unfortunately, the Environmental Protection Agency has no regulations regarding the safety of asbestos-free substitutes. Reports of increased lung cancer among mineral wool factory workers and glass fibre workers are prevalent and there is also concern regarding the effect of exposure to ceramic fibres, for which the health data is sparse(87). Any small, inhalable fibre can lodge in the human lungs. Glass-fibre and other insulation products have been shown to cause skin rashes and respiratory irritation(88). Many of the proposed replacement materials share a potentially fatal trait with asbestos, they contain fibres which can be inhaled and become lodged in the human lungs. For example, the United States Navy recently banned shipboard use of ceramic fibres after animal studies suggested that ceramic fibres produced cancerous tumors in animals(89). In a 1986 study by Brown-Ferris Industries, a Houston based waste-management company, printed in The Wall Street Journal on Tuesday, May 12, 1987, it was stated that ceramic fibres used to line industrial furnaces break down into cristobalite, a form af silica, which is linked to silicosis (lung disorder caused by continued, long term inhalation of dust from inorganic compounds)(90).

It stands to reason that many of these substitute materials may be hazardous to humans when they are exposed to these materials. At present, there is no way to ascertain the latency period between exposure to any of these products and the resulting harm. As shown by the tidal wave of litigation regarding exposure to asbestos-containing products and research regarding potentially harmful effects of asbestos exposure, the latency period between exposure to asbestos and any harm resulting therefrom may be as great as 40 years. It is not

(87) Meier, Insulation Peril? Health Studies Suggest Asbestos Substitutes Also Pose Cancer risk, The Wall St. J., (May 12, 1987).
(88) Id.
(89) Id.
(90) Id.; See Supra Note 87.

unlikely that substitute products, if indeed harmful, may also have latency periods equalling, if not exceeding 40 years. To market these substitute products without adequate research is simply an invitation to future litigation which is likely to bring about the financial death of many manufacturers of these substitute products.

CONCLUSION

The number of asbestos cases currently filed in the United States is staggering. These cases range from personal injury lawsuits to property damage lawsuits. At present, there is no proven substitute for asbestos-containing friction materials. The use of asbestos-free friction materials will undoubtedly lead to lawsuits against countless parties if, indeed, theses untested materials are unable to withstand the pressure generated by constant braking. With the number of fatalities annually resulting from driver negligence alone, it is ludicrous to suggest that potentially inferior brake lining should be placed into the market. The end result of this action would be more collisions and increased fatalities.

Until recent times, it was not known that asbestos posed a serious health risk to those exposed. The same can be said for the asbestos-free products which are currently being proffered as replacements to the asbestos friction materials. Studies already suggest that exposure to some of these replacement products causes cancer in laboratory animals. At present, the only valid evidence suggesting that chrysotile asbestos may be hazardous to humans is that chrysotile causes cancer in laboratory animals. In today's litigious society, it stands to reason that the manufacturers of these untested asbestos free friction materials stand to lose far more than they might possibly gain if, indeed, these friction products prove to be improper for the task presented.

Research in the dilemma of the replacement of asbestos containing friction materials with asbestos-free friction materials is in its earliest stages. Additional research is needed to determine whether asbestos-free materials will provide adequate braking control and whether exposure to these products will be safe for humans. Research regarding possible dangers to humans from exposure to chrysotile must also be continued. Presently, it is not known whether the asbestos-free friction materials will provide a safe alternative to asbestos-containing friction materials; therefore, the more prudent course is to fund additional research to answer this question. Replacement of asbestos-containing friction materials with the asbestos-free friction materials, at this time, will simply be replacing one unknown with another. Replacement may pose a far greater health risk than that presumably present with the use of the asbestos-containing friction materials, thereby resulting in floodgates of litigation which can probably be avoided with adequate research and development of proper substitutes.

SESSION IV

REGULATORY AND LEGAL ISSUES

Question and Answer Period

Unidenfied voice: You talked about relative risks and lowest feasible levels. You said that for asbestos, 0.2 fibre per cc was an acceptable risk, or words to that effect. At least one Supreme Court judge, in their decision on benzene, said that 1 in 1,000 workers dying from exposure to benzene or other chemicals in the work place was unacceptable. Do you have a comment on that?

Grover Wrenn: I did not say that 0.2 fibre per cc is an acceptable risk. I said that OSHA has never defined acceptable risks or significant risks, and that the Supreme Court has not given a precise formula either. They said that it was a judgment call, and gave some very broad bounds to illustrate their opinion.

If you look at all the standards set by OSHA, as well as their own characterization of the risks remaining in work places that comply with their standards, that may be a useful way of inferring OSHA's rule of thumb on significance of a risk. What you will find is that, for those substances for which specific standards have been set after detailed analysis of risk, the range is 1 in 1,000. The lifetime risk associated with compliance, with the permissible exposure limit for arsenic, benzene, asbestos, and a host of other substances regulated by OSHA, is in the range of plus or minus one excess death per thousand workers exposed.

Contrast that with EPA's and the large number of regulations in which they have described the residual risk in complying with their regulations for cancer-causing substances, or where they decline to regulate because the risk is insufficient. You will find that the rule of thumb implicit in their actions over a period of several years, is about 1 in 100,000.

Obviously, this varies on a case-to-case basis. But there is an interesting dichotomy between what our federal agencies estimate to be a significant risk or, conversely, an acceptable risk: In a work place setting, 1 in 1,000 versus 1 in 100,000 in the general population.

Unidentified voice: Mr. Wrenn, you know, of course, that the service employees in a national union brought suit against the Environmental Protection Agency to set an indoor standard. Essentially they asked the EPA to be the surrogate OSHA. They were not asbestos workers and did not wish to handle asbestos-containing materials. They therefore wanted to be protected under a different standard. What role did this lawsuit play in the political climate which drove EPA to take the leadership in banning asbestos-containing products in the United States?

Grover Wrenn: I honestly do not know. I know something about other factors which, I believe, motivated EPA to try to take action under the Toxic Substances Control Act. This was an Act which had not been the basis for dramatic, significant regulation in its ten-year history. Also, for several years the administration of EPA had been perceived as generally lax in carrying out its mission through direct regulation. In answer to your question, I do not know what role, if any, this suit had in that decision. It was probably one of many factors.

Unidentified voice: Mr. Wrenn, a question to you, as a former regulator and, specifically, to follow-up on some of your comments. Following EPA's legislative hearing and the cross-examination on its proposal to ban certain products and to phase-out remaining uses of asbestos over ten years, the agency's case was clearly demonstrated to be flawed and inadequate. I think inadequate was your word. In fact, as we all know, for some years EPA has been revising its support documents. Yesterday, we heard an EPA spokesman predict that the new regulatory impact analysis would probably be placed in the public record for review and comment in November or December.

In view of the apparent recognition that EPA's previously estimated risks were excessive, do you think that it would be practical for EPA to consider referring its asbestos investigation to OSHA and CPSE again, especially since brake-repair workers present the largest, single employee population exposed to asbestos?

Grover Wrenn: The simple answer is that there is not a simple answer. It is a difficult issue, and I think that one of the most unseemly sights inside the beltway encircling Washington, D.C., is two federal agencies, both with laudatory purposes and separate statutory commands, fighting over their turf. In a sense, that is what is represented by this issue: two agencies with two separate statutes dealing, in large measure, with the same problem but in fundamentally different ways. OSHA, has already issued detailed standards dealing with a host of occupational settings covered by the Occupational Safety and Health Act, yet re-exposure to asbestos may occur. The Environmental Protection Agency must continue to face a significant public-policy dilemma as it seeks to evaluate these new studies and determine what course of action to pursue in further regulation of asbestos.

Personally, I would be surprised if the estimates of risk embodied in EPA's earlier action were not significantly altered by their further scholarship. And I would also be surprised if they did not significantly change, the nature of their proposed regulatory action. But I may be wrong.

Unidentified voice: Mr. Parnell, the billion dollars paid out, are these legal costs, compensation or both? Both, thanks.

ALBERT PARNELL: The harsh reality is that the billion dollars may even be low. I think that indemnity last year was between 400$ and 500$ million in legal costs. There was probably 150$ to 160$ million from one unit alone, not including any other kind of property damage or litigation.

The figures which I have are unofficial and they probably include a predominance of Wellington defendants. I would say that, if you take all the figures in terms of time, support systems, indemnity payments to plaintiffs, and workers'compensation, it is well over a billion dollars.

CHAIRMAN: I would like to thank the panelists for their presentations today. The discussion of risk assessment cannot be more appropriate than here in Atlantic City. And, with that, Ed Drislane of the Friction Materials Standards Institute has some closing comments.

CLOSING REMARKS

Ed Drislane
Friction Materials Standards Institute
Paramus, NJ

The FMSI was honoured to be co-host of this symposium, along with The Asbestos Institute and the SAE.

I just want to thank Pat Couhig of the SAE staff for her work, Phill Dougherty both in his capacity as representative and a member of the SAE, and also the gentlemen from The Asbestos Institute, Claude E. Forget and Scott Houston. And, of course all of you who came here and made this symposium a success. Thank you very much.

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Claude E. Forget
The Asbestos Institute
Montréal, Canada

Looking back over the last day and a half, we managed to squeeze a mountain of information into a very short time. I hope the issues have become a little clearer, although the complexity has not diminished very much.

However complex the issues may be, we must all come to some conclusions. It will not surprise anyone that, at The Asbestos Institute, we have arrived at our own conclusions. I would like, very briefly, to share those with you.

First, we have heard repeatedly that asbestos substitutes may pose a potential occupational health risk. It is not for me to state how large or small that risk may be, but the issue is there and it will not disappear. It is now part of the stock of scientific problems that a lot of scientists around the world will be looking at in the foreseeable future.

Second, within the asbestos family of fibres and products, there appears to be emerging, ever more strongly, an important distinction between fibre types and fibre uses. If we only had to contend with the use of chrysotile asbestos in friction-material products, I believe that it would be very hard to convene a conference about the health implication of those uses, especially if we were to concentrate on present-day technology, dust control, and work practices.

Third, the relative performance of asbestos-containing friction products remains good across a wide spectrum of parameters and criteria. Indeed, we have seen that asbestos-containing friction products remain benchmarks in the studies of all alternatives. And, it is important to note, in this context, that we are comparing a very mature product to new products that have been developed, at great expense, in the past few years. If the same tender loving care had been devoted to developing new mixtures containing asbestos, I am sure that the performance comparisons would be even more favourable to the well-known asbestos fibre.

Fourth, industry's hopes of immunity from regulation and litigation, whether based on health or performance factors, are insupportable after what we have heard in the past day and a half. Friction-product manufacturers must anticipate similar costs for dust control, safe work practices, regulatory compliance, and also legal costs.

Fifth, I must note the faint presence, or perhaps I should say with respect to this very symposium, the absence of the U.S. regulatory agency that has most to do with regulating asbestos and competing products. We have been troubled, in the past, by the selective attention of this agency. In the past, we have attacked its professionalism, or rather its lack of professionalism, and we will continue to do so unless we see a change of behaviour on that front. We should also note the absence of consumer-oriented groups from this gathering.

Lastly, as we said at the outset of this meeting, The Asbestos Institute is quite content to let the chips fall where they may. Our own reading of where the chips have been falling in the past day and a half only strengthens our resolve to keep up the fight for the product that we represent... not only for obviously selfish reasons that anyone can understand, but also because we believe, more than ever before, that absestos continues to represent a valuable resource for the producers as well as for the users of friction products.

In finishing, I would like to join Ed in congratulating the co-sponsoring organizations. I would also like to thank Ed himself, as well as Phil and the staff members who made this conference so successful. Thank you.

Phil Dougherty *
Friction Division Products Inc.
Trenton, NJ

The SAE, the FMSI and The Asbestos Institute have put together an informative program. I should like to make a personal observation. If it appears that an economic struggle is taking place in playing off the governmental agencies as influential bodies by all fibre producers, then those who are playing the role should consider the real impact of the friction compounder. Friction compounders appear to be the least thought of, except for those in the purchasing public. Friction compounders are at risk, whether they use a fibre that needs 20 more years to assess its effects or whether they use a fibre that once presented problems, but needs 20 more years at 0.2 fibre per cc to see if it is now safe.

The friction compounders'main concern should be to develop a product with zero risk in peformance. If they could be left with this concern only, I firmly believe that they could be highly successful. If all fibre suppliers feel that their product is safe, they should be agreeable to accepting the responsibility and indemnifying the compounder.

Another route might be for all fibre manufacturers and governmental agencies to sit back, retreat from the adversarial position and maybe, for the period of one year, to work in concert for the bill-paying public.

Thank you.

* Transcript of oral presentation.

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