Institute for Environment and Health

CHRYSOTILE AND ITS SUBSTITUTES: A CRITICAL EVALUATION

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Executive summary

The primary objective of this report, commissioned by the UK Health and Safety Executive, is to provide a reasoned scientific judgement on the substitution of chrysotile in its remaining applications. The report is not intended to be a comprehensive literature review. It includes specific responses to a number of documents, mostly generated by the European Union (EU) on the topic of chrysotile substitution, and addresses issues raised by these documents. Although much of the information drawn on in this report reflects the UK experience, the general principles described here are expected to apply elsewhere in the EU.

Chrysotile asbestos has had many commercial and industrial applications, largely in thermal insulation and fire protection, in asbestos-cement, in friction materials and in gaskets, seals, textiles and composites. For many of these uses numerous substitute materials have been developed over the last three decades and are increasingly being used. Also, alternative technologies which do not rely on the use of fibrous materials are available for certain applications. The two major remaining uses of chrysotile (accounting for approximately 80% of total UK chrysotile imports) are in asbestos-cement and friction linings. The main substitutes for these applications are currently polyvinyl alcohol (PVA), aramid fibres and cellulose fibres.

A major requirement for a substitute is that it should be safer in use than chrysotile. The three parameters of dose, dimension and durability (biopersistence) are of fundamental importance in determining the toxic properties of fibres. To be pathogenic, fibres must be long, thin and durable. Although there is no consensus on the exact values of these parameters that confer toxicity, there is a good measure of agreement. Fibre diameter determines both the concentration in air and respirability, and should be considered a primary component of the intrinsic hazard. Fibre durability determines persistence in the lung and therefore dose integrated over time. Dustiness is determined by both fibre diameter and the propensity for the liberation of respirable fibres, and therefore has a profound influence on the potential for exposure.

The diseases associated with exposure to asbestos are lung fibrosis, lung cancer and mesothelioma. It is generally agreed that chrysotile, whether or not it is contaminated with amphiboles, can cause lung cancer. The presence of varying concentrations of the fibrous amphibole, tremolite (e.g. in Canadian chrysotile) may be partly or entirely responsible for the observed incidence of mesothelioma arising from chrysotile exposure. There is continuing debate about whether the dose–response relationship for asbestos-induced lung disease incorporates a threshold, and regulatory bodies have therefore tended to assume a no-threshold model, even though this might over-estimate the risk at low doses.

Adverse effects associated with the production and use of chrysotile can be reduced only by control of exposure (and therefore dose). General considerations relating to exposure and the potentially exposed population groups are similar for chrysotile and substitute fibres. People who are intermittently exposed, either because of the nature of their work, such as trades people (electricians, plumbers, etc.) or householders engaged in regular D-I-Y activities, should receive special consideration, as control of exposure for these individuals is difficult or impossible. However, fibre characteristics, notably dimension and durability, can be selected or modified to reduce the possibility of adverse health impacts from substitute fibres.

In general terms, substitution with non-respirable materials which do not fibrillate is the single most beneficial change, but other non-respirable fibres and those which do not persist in the lung or the environment will also confer potential benefit. Those evaluated here include PVA, aramid and cellulose fibres, currently the main substitutes for the residual uses of chrysotile.

Lack of a full data set frequently precludes comprehensive assessment of the safety of substitutes. However, application of the basic principles of fibre toxicology will often enable a decision on the relative safety of potential substitutes to be made in such cases.

Due consideration of the hazards of fibrous materials leads to the following conclusions regarding chrysotile and its main substitutes.

- The three parameters of dose, dimension and durability (biopersistence) are key to determining the differential hazard of fibres.

- Substitute fibres can be designed or selected to have particular characteristics. Criteria for the substitution of asbestos by other fibres include:
  - the substitute fibres are not in the respirable range and/or are less durable than chrysotile;
  - other materials (binders, etc.) which have to be incorporated into the replacement product do not, in combination with the replacement fibre, produce an overall more harmful impact than chrysotile alone;
  - the replacement product has an equivalent or acceptable performance; and
  - substitution would result in overall lower fibre exposures during manufacture and use and disposal, taking into account likely exposure scenarios and life cycle analysis.
- The maximum benefits from substitution of chrysotile occur in those uses that have the largest potential for human and environmental exposure over the lifetime of the product.
- It is our judgement that PVA fibres will certainly pose less risk than chrysotile as they are generally too large to be respirable, do not fibrillate, and the parent material causes little or no tissue reaction.
- Aramid fibres have a reduced potential for exposure compared to chrysotile as they are generally of high diameter and the production of respirable fibrils is energy intensive. Experimental evidence also suggests that the potential for fibrosis is less than for chrysotile and the fibrils are biodegradable.
- Cellulose has the benefit of long experience of use in a variety of industries without having raised significant concern. The potential for the generation of respirable fibres seems to be less than is the case for chrysotile, although fibrillation is possible. Cellulose is durable in the lung, and its biological properties should therefore be investigated further. However, exposure levels for current uses are low, and it is biodegradable in the environment.
- Other substitute materials may need to be evaluated using the same general principles.

- The continued use of chrysotile in asbestos-cement products is not justifiable in the face of available and technically adequate substitutes. Likewise, there seems to be no justification for the continued residual use of chrysotile in friction materials.

1 General introduction

1.1 BACKGROUND

There is an historic concern about asbestos, stemming from the identification from the 1930s onwards of exposure related health effects (asbestosis, lung cancer and mesothelioma) in workers in the asbestos industries. It was recognised in the 1960s that the amphibole forms (mainly crocidolite and amosite) are the most hazardous, and the use of these was subsequently banned in the UK and elsewhere. Although some countries have also banned chrysotile, it continues to be used in the UK and some other European Union (EU) member states in a number of applications, in particular asbestos-cement and friction linings. As a consequence of the classification of chrysotile by the EU as a Category 1 carcinogen, there has been continuing progress in replacing chrysotile with substitute fibrous materials (or using alternative technology). However, some of these substitute fibres are also potentially hazardous because of their inherent physical and chemical properties. This has resulted in the current question as to whether further or complete replacement of the remaining uses of chrysotile by substitute materials is scientifically justifiable in health terms.

The Institute for Environment and Health has been commissioned by the Health and Safety Executive to give an expert scientific judgement on the prospect for replacement of chrysotile, in its major remaining uses, by substitute fibres. The report takes particular account of three recent documents:

- a final report produced by Environmental Resources Management (ERM), Oxford, for Directorate-General III of the European Commission, entitled ‘Recent Assessments of the Hazards and Risks Posed by Asbestos and Substitute Fibres, and Recent Regulation of Fibres Worldwide’, November 1997;
- a paper described as a constructive commentary on the June 1997 draft of the ERM report written by Gibbs, Davis, Dunnigan and Nolan, for the Quebec Ministry of Natural

Resources, Department of Natural Resources, Canada, and the Asbestos Institute, September 1997; and

- the conclusions of the DGXXIV Scientific Committee on Toxicity, Ecotoxicity and the Environment, which was asked by DGIII for an opinion on the ERM report and its bearing on current understanding of the human health risks from chrysotile asbestos, February 1998.

1.2 OBJECTIVE

The objective of this document is to present reasoned scientific arguments and judgements on the substitution of chrysotile in its remaining applications. This report presents an expert distillation of current knowledge addressing the critical issues and is not a comprehensive review of available data. Thus the reference list is not exhaustive; specific references are given only to emphasise key points or to support particular statements. The report is written from a European perspective; although drawing largely from UK conditions and experiences, the arguments and conclusions are likely to be relevant to other EU member states.

1.3 STRUCTURE OF THE REPORT

This report briefly reviews the current uses of chrysotile asbestos in the UK (Section 2) and describes the currently favoured substitutes for the main applications (Section 3). General perspectives on comparative fibre hazard and risk assessment, including the key determinants of dimension, durability (biopersistence) and dose, are covered in Section 4. Key issues presented in Sections 5 and 6 include the hazardous properties and characteristics of chrysotile and the possible substitutes. Considerations relevant to the use of substitute fibres are described in Section 7. The report concludes with a discussion and key conclusions (Section 8). Also included, as Annex 1, are specific critiques of the ERM report and the associated commentaries by Gibbs and colleagues and the DGXXIV Scientific Committee, referred to above. Annex 2 is a lay summary of this document.

2 Current uses of chrysotile in the UK[1]

2.1 INTRODUCTION

Chrysotile asbestos is naturally abundant and easy to mine and has had many commercial and industrial applications because it can readily be woven, is resistant to temperature, pressure and corrosive chemicals, has high tensile strength, is durable, and has good thermal and electrical insulation properties. The major applications of chrysotile have been in thermal insulation and fire protection, asbestos-cement, friction materials and gaskets, seals, textiles and composites. Until its use was restricted, chrysotile was a component of very many products, including building materials of various kinds, many of which are still present and can give rise to environmental exposure. However, it is the remaining or residual uses of chrysotile where substitution can be considered that are the focus of this report.

In 1975 the total amount of chrysotile imported into the UK was 191 740 tonnes. By 1990 this had fallen to 15 110 tonnes and in 1996 to 7098 tonnes[2].

2.2 ASBESTOS-CEMENT

Chrysotile has been used in asbestos-cement mostly because it is cost-effective and has good reinforcing properties. Products are mainly in the form of asbestos-cement, asbestos-cement tiles and slates, flat sheets and building board, profiled[3] sheeting and pressure pipes.

In 1996 the UK industrial usage of chrysotile in asbestos-cement was 3500 tonnes (49% of the total UK chrysotile use). An additional 2125 tonnes equivalent was imported as asbestos-cement products; taking this into account, use of chrysotile in the asbestos-cement sector in 1996 accounted for approximately 50–60% of total industrial chrysotile use (compared with around 85% for the rest of Europe).

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1 Production and use data from the Asbestos Information Centre Ltd., Widnes, Cheshire
2 Reported to have fallen further to 4820 tonnes in 1997
3 Profiled — includes corrugated etc.

2.3 FRICTION MATERIALS

Asbestos has been incorporated into friction materials (e.g. brake linings) because it is durable and heat and oil resistant. Although chrysotile use in the private vehicle market has reportedly ceased in preference to substitute materials (see Section 3.4), chrysotile continues to be used to a limited extent in heavy commercial vehicles and other heavy duty applications, mainly on cost grounds.

In 1996, chrysotile in friction materials accounted for approximately 26% of the total UK industrial use of chrysotile (1850 tonnes).

2.4 GASKETS AND SEALING MATERIALS

Major uses are packings (braided asbestos packings, proofed asbestos cloths and tapes, moulded gland* packings and laminated packings) and gaskets (compressed asbestos fibre, comprising asbestos fibre mixed and calendered with various natural and synthetic rubber compounds).

In 1996, chrysotile in gaskets and sealing materials accounted for approximately 21% of the total UK industrial use of chrysotile (1500 tonnes).

2.5 TEXTILES AND COMPOSITES

The main chrysotile asbestos textiles are woven tapes, webbing and cloths, and yarns. Although no longer manufactured in the UK they are still imported. Composites (engineering plastics) have a wide range of applications in various industries, for example the marine, railway, automotive, aerospace and general engineering industries. They are mostly of asbestos cloth or fibre impregnated with resins and cured under heat and pressure to produce sheets, rods, tubes and shaped mouldings. Also chrysotile is used in heavy duty insulation components as a compressed board with or without silicone resin impregnation.

In 1996, chrysotile in textiles and composites accounted for approximately 3.5% of the total UK industrial use of chrysotile (250 tonnes).

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* A gland is a sleeve used to produce a seal around a piston or shaft.

3 Available substitutes for the main uses of chrysotile*

3.1 INTRODUCTION

Some confusion exists regarding the terms 'alternatives' and 'substitutes' for the use of non-asbestos materials in situations where asbestos has been or could be used. *Alternatives* have always been available and are selected based on technical or commercial considerations. They include PVC and sheet metal alternatives to asbestos-cement, metal gaskets, gaskets made from layers of metal and graphite, and calcium silicate insulating boards. *Substitution* of asbestos by other fibres has been occurring partly because of new requirements for technical performance, but mainly because of health concerns. For nearly three decades there has been a requirement for all users of asbestos in the UK to seek substitutes actively. In this document, the term substitute is used to mean a non-asbestos fibrous material used to replace chrysotile asbestos in a particular application.

The UK Report of the Health and Safety Commission's Advisory Committee on Asbestos recommended that an explicit obligation be placed on producers to consider the substitution of asbestos with other materials so far as is reasonably practicable (Health and Safety Commission, 1979). This has been strengthened by subsequent EU directives. Chrysotile has been classified as a Category 1 carcinogen under the Dangerous Substances Directive, 67/548/EEC. For such carcinogens there is an obligation under Article 4 of Directive 90/394/EEC (on the protection of workers from the risks related to exposure to carcinogens at work) as follows:

'The employer shall reduce the use of a carcinogen at the place of work, in particular by replacing it, in so far as is technically possible, by a substance, preparation or process which, under its conditions of use, is not dangerous or is less dangerous to workers' health or safety, as the case may be.'

* The key reference for this section is AA Hodgson, ed (1989) *Alternatives to Asbestos — the Pros and Cons* (Society of Chemical Industry, Critical Reports on Applied Chemistry Volume 26), Chichester, UK, John Wiley & Sons

This is implemented in the UK by the 1992 Control of Asbestos at Work Regulations.

Thus, for many of the established uses of asbestos, it is not surprising that in the UK and elsewhere a wide variety of substitute materials have been developed and are increasingly being used. These uses include fibre-reinforcement, thermal insulation and fire protection, friction materials, heat-resistant textiles, reinforced plastics, gaskets, seals and building materials. It is not the intention of this report to re-evaluate well established substitutes (e.g. those used in insulation).

3.2 AVAILABILITY OF SUITABLE SUBSTITUTE MATERIALS

Materials that can be used as substitutes for chrysotile include natural organic fibres (such as cellulose, cotton and jute), synthetic organic fibres (such as polyvinyl alcohol (PVA), aramid, polyimides and polyacrylonitrile), natural minerals (such as wollastonite and the fibrous clays), and man-made mineral fibres ((MMMF) such as rock wools, slag wools, glass fibres and refractory ceramic fibres (RCF)). There are other speciality fibres, such as silicon carbide whiskers, which may be used for special or high-tech applications, for example in aircraft engines. These special use applications have specific requirements for particular fibre characteristics and the fibres used are thus not strictly replacements for chrysotile asbestos. Also there are other fibres such as metal fibres, carbon fibres and RCF which have a narrow range of applications.

The main non-asbestos fibres that are currently being exploited in the UK as substitutes for remaining uses of chrysotile asbestos are PVA, aramid fibres and cellulose, and also wollastonite. Thus, for the purposes of this report, it is these materials and their uses as chrysotile substitutes that will receive specific attention. It should be noted that part of the reason why many of the substitute fibres have been selected for commercial exploitation is because their fibre diameter was considered to be non-respirable; they would thus not be able to elicit the health effects associated with asbestos (see Section 4). Such substitutes may initially have led to a reduction in technical performance because, as the fibres are not as fine as asbestos, they present a lower surface area per unit volume, which may affect insulation performance as well as other properties such as fibre-reinforcement efficiency. However, many of these technical deficiencies have now been overcome.

3.3 SUBSTITUTES FOR ASBESTOS-CEMENT PRODUCTS

The major asbestos-cement products for which substitutes are used or required are profiled sheet, flat sheet and building board, slates, pressure pipes and moulded goods. To a greater or lesser extent, performance criteria of the major asbestos-cement products are controlled by national or international standards (such as ISO or CEN) and this must be taken into account in the selection of substitute fibres. Most commonly, PVA and cellulose are used as substitutes, particularly for flat and profiled sheets as well as slates. Other fibres such as polyacrylonitrile (PAN) or glass-fibre may also be used. PVA and PAN require the inclusion of cellulose pulp in order to be used in conventional asbestos-cement manufacturing processes.

Polypropylene is suitable for some uses, for example in certain slates, but it requires surface treatment to make it compatible with cement and is now rarely used. High-quality cellulose fibre has a good potential as a substitute product and its reinforcing properties can be improved by increasing the loading relative to the loading used with asbestos, or the incorporation of some synthetic fibre such as PVA into the product. The obvious disadvantage is that the temperature resistance will not be as good as asbestos-cement and, like other organic fibres, it will burn through without the spread of flame. In order to overcome this problem, mica or wollastonite can be added to enhance temperature resistance.

Although substitute fibres can be used to reinforce cement for sheet or board products, these do not appear very promising for pressure pipes because of strength requirements specified by national or international standards. Thus, alternative materials are used for these applications including, for example, unplasticised polyvinyl chloride (uPVC) and polyethylene as well as ductile iron and glass-reinforced plastic.

In the case of substitutes for asbestos in insulating boards, heat-resistant minerals such as vermiculite, mica and wollastonite are available which can be combined with cellulose in an autoclaved calcium silicate process. In addition, gypsum-based composites using glass-fibre are available.

3.4 SUBSTITUTES FOR ASBESTOS IN FRICTION MATERIALS

There are three major friction products — brake linings, brake pads and clutch facings. The composition of asbestos-based products is complex for all these applications, which have been developed over many years to perform under extreme forces and temperatures without failing. A typical asbestos brake lining would be composed of 40% chrysotile with over 20 other components, including phenolic resins. The predominant substitute for chrysotile in friction products is aramid-fibre, although PAN, other fibres and some metal and semi-metallic materials are also used (often in combination).

3.5 SUBSTITUTES FOR ASBESTOS IN GASKETS AND SEALING MATERIALS

Gaskets made from compressed asbestos fibre (CAF) are used widely in turbines, compressors and motor vehicle engines. CAF is composed of chrysotile bonded with polymers (natural or synthetic rubber). A wide range of substitutes has been or is being developed, including aramid-fibre in conjunction with other fibres such as cellulose-pulp, or glass-fibre with mineral fillers such as wollastonite, talc and mica. Semi-metallic and solid metal gaskets are also available, with the former employing materials such as polytetrafluoroethylene (PTFE) and graphite. Asbestos-free gaskets tend to have narrower performance windows than their asbestos-containing counterparts. One consequence of this is that gasket users may have to carry a wider range of asbestos-free counterparts.

Seals include dry packings and impregnated packings. The former, as indicated, are used under dry conditions and act to form barriers to flame spread in static sealing applications where resilience and flexibility are required, such as around furnace and kiln doors and around floodlight lamps. Glass yarn and mineral wools are available as substitutes for such applications. Impregnated packings provide a seal between two surfaces, one of which is moving. They are therefore commonly found in dynamic seals in fluid-handling systems (compressors, pumps and valves). They can take the form of compression packings, moulded packings or 'proofed' asbestos products (e.g. flange joints in autoclaves where the woven or plaited asbestos yarn is coated with chloroprene). For compression packings, carbon-fibre or PTFE or, alternatively, aramid-fibre, with graphite or PTFE, can substitute for asbestos. Glass-fibre impregnated with PTFE is also used. For moulded packings, the common substitutes are aramid and glass-fibre, whilst for the proofed asbestos products, substitutes such as vegetable fibre or neoprene-coated glass-fibre are available.

3.6 SUBSTITUTES FOR ASBESTOS IN COMPOSITES

Asbestos and a range of other fibres are used in the production of thermosetting and thermoplastic composites which have important engineering applications. Although no single fibre type would match asbestos in all properties, numerous substitutes are continually being developed and introduced for a variety of purposes. Some of these may offer superior performance in particular applications. They include aramid-fibre, glass-fibre, carbon-fibre, cotton, organic fibres and MMMF (occasionally in blends) and a range of particulate mineral fillers.

3.7 SUBSTITUTES FOR ASBESTOS IN TEXTILES

Temperature-resistant fibres which can be woven into textiles must extend over a service range of 200 ºC–1200 ºC and withstand extreme conditions such as molten metal splash, welding sparks and naked flame. They require heat resistance as well as strength and flexibility (and possibly bulk) to provide thermal insulation. Asbestos is in the middle of the range with a service temperature of around 600 ºC. Refractory fibres are used at the higher end of the temperature range and synthetic organic fibres are used at lower temperatures. To meet specific thermal (and chemical resistance) requirements of the product, various blends of organic, glass, metal and synthetic fibres have been developed for particular applications.

3.8 THE IMPORTANCE OF TECHNICAL PERFORMANCE

A key requirement in the selection of suitable substitutes for asbestos-containing products is that the product is able to meet the technical performance criteria of the applications. An obvious example of this would be a friction material incorporated into a braking system on a vehicle where technical performance would have serious implications for public safety. Another requirement is that the product should not have a much shorter life than the asbestos-containing original. For example, it would be unacceptable if a substitute fibre-reinforced cement product crumbled or developed structural weaknesses necessitating regular replacement. Many of the properties that make asbestos fibres so useful are related to their intrinsic temperature resistance, reinforcing strength (fine fibre size and ability to bond with matrix) and corrosion and chemical resistance (not universal). These and other properties need to be matched against candidate substitutes in relation to specific production uses. This report does not attempt to address the specific technical requirements for all existing asbestos uses and match these against those of the available substitutes. This is a complex process and requires detailed knowledge of specific properties needed for particular applications. It is, however, appropriate to describe a few general principles. It is important to note that many of the fibres identified in this report were used in preference to asbestos even prior to the 1979 Recommendations of the Advisory Committee on Asbestos to seek substitutes. This mostly reflects technical and economic considerations rather than a response to health concerns, although media attention and public opinion on health effects played a part from the mid 1960s onwards. The last three decades have seen wide-ranging advances in material sciences and development of many alternative products.

3.9 TECHNICAL PROPERTIES OF SUBSTITUTES

Clearly, all the essential properties which chrysotile imparts to the products into which it is incorporated need to be met by its substitutes. Often there will not be an exact match, but a compromise or trade-off between the required properties such as temperature resistance, toughness, wear resistance, flexibility and cost.

The following examples illustrate the relative technical attributes of some of the substitute fibres.

Reinforcing strength		
Good	-	aramid fibres, carbon fibres, glass-fibre, PVA.
Moderate	-	cellulose fibre, polypropylene fibre, RCF, mineral wools.
Poor	-	PTFE
Heat resistance		
Good	-	(above 400 ºC) mineral wool, RCF.
Moderate	-	(200 ºC–400 ºC) aramid-fibre, glass-fibre, PVA, polyacrylonitrile fibre.
Chemical resistance		
Good	-	polybenzimidazole fibre, polyacrylonitrile fibre, PTFE, carbon-fibre, most mineral fibres (not in acids)
Moderate	-	aramid fibres
Poor	-	cellulose fibre

4 General perspectives on fibre hazards and risks

4.1 INTRODUCTION

It is generally accepted that to be pathogenic, fibres must be long, thin and durable; while there is no consensus on actual values of these various parameters, there is a large measure of agreement. Each of the properties of importance is detailed below. Other factors such as fibre chemistry may also contribute to pathogenicity.

4.1.1 Fibre diameter and length

According to the standard (WHO) definition, a fibre has an aspect ratio (the ratio of length to diameter) of 3:1 or more. Fibre diameter is the major determinant of the falling speed in air, which is proportional to the square of the diameter and directly proportional to bulk density. Fibre length is much less significant in this context, with probably the square root or cube root determining the effect. The importance of this is twofold. First, diameter determines the length of time a fibre will remain suspended in air, and is thus a major contributor to the concentration likely to be encountered where aerosols of fibre are generated. Second, diameter determines the probability that individual fibres will deposit in the deep lung (the ‘respirable fraction’). Mineral fibres above about 3 µm diameter are considered non-respirable. This value may be refined by reference to density and length, but as the respirable limit is approached asymptotically, small differences in the limit value have little practical significance. For alveolar accumulation the efficiency of retention is maximal at about 1 µm actual diameter for mineral fibres; for retention in the ciliated airways it is slightly larger and shows greater variation with such physiological changes as breathing rate and nose versus mouth breathing. Since it has such a profound impact on potential dose of fibre, in terms of both generation and deposition, diameter should be considered as a primary component of the intrinsic hazard of a fibre.

Fibre diameter is also associated with the potential for skin irritation (see Section 4.2.3).

A direct effect of fibre diameter on mesothelioma induction has been proposed by several workers in the field, with most associating this tumour to fibres of sub-micron (many believe <0.5 µm) diameter. This is disputed by some, as unequal numbers of fibres were tested in the assays from which the conclusions were drawn.

4.1.2.Fibre durability and biopersistence

Once fibres have been inhaled, durability becomes a major determinant of integrated dose. Long fibres deposited in the alveolar spaces are cleared only slowly by mechanical (macrophage) activity and thus the rate at which they dissolve may be the principal determinant of residence time. However, durability can be viewed in two separate ways. The more obvious of these is the property of a deposited fibre to resist dissolution in the surprisingly aggressive environment of the lung. This is largely determined by the chemical composition of the fibres concerned. Thus the ultimate lung burden after continuing exposure to a soluble fibre will be less than after similar exposure to a durable fibre; for intermittent exposures the residence time of fibres in the lung — the biopersistence — may be reduced.

The second aspect of dissolution is fibre fragmentation. If a filament breaks transversely into shorter pieces it is obvious that it will ultimately no longer meet the aspect ratio (length:diameter) greater than 3:1 needed to justify the definition of a fibre. In practice other factors are also involved. A considerable body of work shows that for mesothelioma induction a minimum fibre length is essential. This is universally accepted as at least 8 µm but most workers would accept a figure of 10 µm, with a high probability that the true value may be closer to 20 µm long. The biological reason for this is sometimes explained as exceeding the maximum size for complete entrapment within a macrophage but, although plausible, this is not established with certainty. The induction of a fibrotic response is also much more rapid with long fibres. Fibres may break transversely either by mechanical flexure within the lung tissue or by partial dissolution — usually within the acidic environment within the macrophage, which will partially engulf longer fibres. This may be an important means by which toxicity of deposited fibre is reduced over time. The extent of breakage would be expected to reflect the mechanical properties of the fibre and thus be related to composition, but the available evidence is limited to too few fibre types to allow generalisation of these properties.

4.1.3 Fibre dustiness

The majority of fibrous products are produced in bulk form often as ‘wool’ or ‘blanket’ with staple lengths which may be measured in centimetres. The ability of these products to fragment and release dust into the air is an important determinant of hazard. There is general agreement on both the importance of this factor and the properties of fibres which can influence it. As yet there is no universally accepted assay, although several centres have developed useful ‘dustiness’ tests. All involve the principle of a standard input of energy to ‘work’ on the fibre with measurement of the associated fibre release. The factors of importance are the breakage rate of the filaments, which is a function of both stiffness and resistance to shear, the way in which the fractures are propagated (lengthways or transverse), and the respirability of the resulting fibrous dust. Dustiness will profoundly influence the potential for exposure. Thus, for example, mineral wool or glass fibres, which are normally supplied as wool or blanket, do not give rise to fibre counts at the levels seen when asbestos is similarly treated, and this is an intrinsic property of the material. The effect of fibre geometry and composition on dustiness is not always easy to predict. An example is the vitreous MMMF, which are all manufactured by a route which produces a fibre with a small degree of lengthways taper. It may be expected that shear forces would result in a disproportionate breakage in the area with smaller diameter, resulting in fragments with smaller mean diameter than the bulk. This is often seen but modification of the fibre composition could give the opposite effect if the areas with fine diameters then become more flexible and the thicker areas more brittle. Dustiness is therefore difficult to predict.

It should be noted that the dustiness described here relates to preparations of pure fibre without binders or dust suppression.

4.2 HEALTH EFFECTS

The diseases associated with exposure to natural fibrous minerals in the asbestiform series are lung fibrosis (asbestosis), lung cancer and mesothelioma. MMMF are known to cause irritation of the skin and mucous membranes. Local or systemic toxicity from the material of which the fibre is composed (or from binders, additives or breakdown products) is also at least a theoretical possibility. The features which are believed to be important in the genesis of each of these conditions are considered separately.

4.2.1 Pulmonary fibrosis

This is the accumulation of scar tissue in the lung following tissue damage attributable to inhaled materials. ‘Asbestosis’ is diffuse interstitial fibrosis (‘honeycomb lung’ — after its appearance on X-ray); ‘silicosis’ is the nodular equivalent. These are often considered ‘progressive’ diseases which may worsen even in the absence of further exposure. Fibrosis should be distinguished from the ‘foreign body’ response where extraneous material is rendered innocuous by encapsulation. True fibrosis will generally result in a deterioration in lung function.

The factors which cause fibrosis are not fully understood. Surface chemistry is an important determinant so that isometric particles as well as fibres may cause it. Additionally some fibres, notably the aluminosilicate RCF, have induced low grade fibrosis in experimental animals at very high exposure levels whereas particles may not. Fibre length can be important in the induction of fibrosis, possibly indicating mechanical damage as an aetiological factor. The occurrence of fibrosis has been associated with incidence of lung cancer (see also Sections 4.2.2 and 5.4).

4.2.2 Carcinogenesis

Asbestos exposure can give rise both to lung tumours, which occur in the lung parenchyma and the airways, and to mesothelioma, which is a tumour of the chest lining and is quite different in appearance and behaviour.

The lung tumours seen are identical to the tumours commonly associated with cigarette smoking. There is a possible association with fibrosis, although there is no agreement as to whether the two diseases run in parallel due to a common cause (inflammation; Egilman & Reinert, 1996) or whether the development of frank fibrosis is a prerequisite for increased cancer incidence (Browne, 1994). There is an accepted synergistic interaction between asbestos exposure and cigarette smoking in the induction of lung cancer (see also Section 5.3.3).

Mesothelioma occurs in the pleural or, more rarely, the peritoneal cavity and arises from the cells lining these areas. Once diagnosed it is almost invariably rapidly fatal. There appears to be no association between mesothelioma occurrence and cigarette smoking, but various experiments have shown the importance of fibre size. The current view of the majority of workers in the field is that tumour induction is maximal with fibres at least 10 µm long and with a diameter in the region of 0.25 µm, with activity falling sharply as diameters are increased. Some workers consider that the tumour may also result from coarser fibres (>1 µm diameter), but the aerodynamic properties of these mean that exposure will be at a lower level (see Section 4.1).

4.2.3 Irritation of skin and mucous membranes

Although not a long-term health risk, irritation is of practical importance because of the discomfort caused to those who must handle the materials. The severity of response is size-dependant and probably also related to fibre stiffness. Glass fibres with diameters less than 5 µm are considered non-irritant whereas those with diameter above 10 µm are highly irritant. Length is unimportant. The response is probably due to localised histamine release following mechanical penetration of the skin by the fibre. This property does not pose a direct long-term health risk but may be of overriding practical significance for those workers whose skin does not adapt to the effect.

4.2.4 Systemic or local toxicity from dissolved components, additives, binders etc.

This is a largely theoretical possibility with substitute fibres in current use, although there are isolated reports of reaction to glass fibres which may represent a hypersensitivity to a partially cured resin which is commonly applied to suppress dust and enhance cohesion. The search for increased fibre solubility may lead to the incorporation of significant quantities of barium in some glasses and significant local concentrations as a result of rapid dissolution could theoretically induce effects on smooth muscle in the lung.

4.3 DETERMINANTS OF RISK

As indicated above there are properties of fibres, especially diameter, which can be considered as intrinsic indicators of hazard. This section deals briefly with other exposure considerations more properly regarded as determinants of risk.

4.3.1 Potential for fibre release from the product

Although superficially related to dustiness, this is actually a fundamentally different risk parameter related to the properties of the product rather than the intrinsic character of the fibres. Many composite materials bind fibres so that they cannot be released in normal use, although some fibres may be released when the material is subjected to more vigorous attack such as cutting or abrasion. Similarly, many fibre preparations contain a binder or dust suppression agents which reduce the potential for fibre release. These are important factors for risk assessment in terms of their ability to limit exposure.

4.3.2 Exposure conditions

This consideration relates to such factors as the frequency with which the target population may be exposed to the fibre, the probable location of exposure and the extent of distribution of the product and its use (see also Section 7.3). For the example of a fibre/cement composite, such features as the weathering rate and the effect of this on the ability to release fibre, the extent to which the composite may be used in a given situation or location and whether the material is intended for indoor or outdoor use, will have major consequences on both the exposure potential and the likely exposure rate. In general, indoor uses have the potential to generate greater personal exposures than outdoor uses (IEH, 1997), particularly when there is no local mechanical extract ventilation. However, if installed outdoors, materials intended for indoor use may weather rapidly and result in significant potential for exposure.

4.4 THRESHOLD OF EFFECT

The possibility that threshold levels of fibre exposure exist, below which pathological effects do not occur, has been debated at length. This is difficult to prove experimentally and probably impossible to verify by epidemiological investigation. Experimental studies with intrapleural and intraperitoneal injection of mineral fibres have produced results consistent with a threshold for the induction of mesothelioma. The fact that the excess mesothelioma observed in epidemiological studies is confined to populations where there has been relatively substantial exposure to asbestos (or erionite) is also consistent with a threshold; exposure from natural sources is universal, if low, and in the absence of a threshold any additional exposure should produce an excess of these tumours, although the evidence for amphibole asbestos is that duration of effective exposure may be short. The probability of an association of lung cancer with fibrosis or inflammatory change has been discussed earlier. If it is the case that inflammation and fibrosis, which themselves almost certainly have a threshold of effect, are necessary precursors to lung cancer, then a threshold effect for lung cancer is also plausible, but this is a matter of continuing debate (see Section 5).

5 Hazardous properties of chrysotile

5.1 INTRODUCTION

It is not intended to attempt a complete review of the toxicological properties and health effects of chrysotile, but to present an evaluation of the current evidence, based on primary sources as well as on reviews. It is also not appropriate to discuss in depth the possible mechanistic basis for the effects that chrysotile has on the lung. It is evident that, both in mining and in its subsequent use, chrysotile gives rise to respirable-sized fibres that can remain in the lung long enough to cause certain pathological effects. As described in Section 4, the possible effects to be considered are lung cancer, mesothelioma and asbestosis.

5.2 AMPHIBOLE CONTAMINATION

The carcinogenicity of chrysotile cannot be considered without taking into account the presence of varying concentrations of the fibrous amphibole tremolite in the Canadian product. Few would dispute that tremolite is more carcinogenic than chrysotile on a weight-for-weight basis, partly or perhaps mainly because of its greater durability. However, it has been claimed that mesotheliomas arising in asbestos workers are mainly attributable to tremolite, and some would extend this to include lung tumours. This 'amphibole hypothesis' is not universally accepted, especially for lung tumours, as further discussed below.

It should be borne in mind that some chrysotile produced elsewhere, for example in Zimbabwe, contains very little tremolite. Thus there is a problem in assessing hazards based solely on Canadian material.

5.3 CANCER

There is general agreement that chrysotile itself, whether or not it is contaminated with amphiboles, can cause lung cancer, and it has been classified as an EU Category 1 carcinogen. The evidence for this comes from epidemiological studies of workers who have been exposed to high levels of asbestos, and from studies on experimental animals that have used even higher dust concentrations (see below). Recent debate has focused on whether chrysotile can also cause mesothelioma, and on the significance of any cancer risk at levels to which workers or the general population might be exposed in the future, taking due account of possible asbestos–smoking interactions.

5.3.1 Epidemiological studies

The largest relevant epidemiological study is the cohort study of McDonald and co-workers on 11 000 Quebec miners and millers. This study has recently been updated and is now essentially complete (Liddell *et al.*, 1997). The study shows a clear excess of lung cancer in workers in the three highest exposure groups. However, the 38 mesothelioma cases observed could not be related to exposure levels in the same way (McDonald *et al.*, 1997). From the latest analyses, McDonald has again argued for the 'amphibole hypothesis', on the basis of the tremolite lung burdens in the mesothelioma cases, and on the relative incidence of mesothelioma among those who worked in the more contaminated central Thetford mines compared with those who worked only in the surrounding mines where the tremolite levels are four times lower. This evidence relating to mesothelioma does indeed provide support for the amphibole hypothesis. It has to be said, however, that it is not completely proven, and cannot be proven from such evidence. Specifically, this is because we do not know the time-integrated lung doses of tremolite and chrysotile over the lifetimes of these workers and because epidemiological evaluations provide proof of association not cause.

A higher rate of lung cancer was found in the study of textile workers in Charleston, South Carolina. These people were exposed to chrysotile from Quebec. The excess lung cancer was best described by a dose–response relationship in which the relative risk increased linearly with exposure (Stayner *et al.*, 1997). The slope of the dose–response curve was over ten times greater than the slope derived from the study of the Quebec workers, and this has never been fully explained. There were hardly any cases of mesothelioma, which, bearing in mind that most of the tremolite was removed during processing, does support the contention that this type of tumour is not caused by chrysotile.

Among asbestos-cement workers there have been some reported increases in the incidence of both lung cancer and mesothelioma, but at least some of these may be attributed to previous or concomitant crocidolite exposure. Most studies have not found increases in mesothelioma in either the asbestos-cement or the friction material industries (reviewed by Meldrum, 1996).

As already mentioned, there is continuing debate about whether the dose–response relationship for asbestos-induced lung disease incorporates a threshold, that is, the dose–response relationship does not simply extrapolate down to zero effect at zero dose. WHO has stated that 'no threshold has been identified for carcinogenic risks.' It is claimed, however, that the Quebec data show a discernible increase in the lung cancer rate only in the three highest exposure groups (Liddell *et al.,* 1997), although the discontinuity in the dose–response is not robust. In contrast, the Carolina lung cancer data were fitted better by a model with zero threshold than by one with any threshold value (Stayner *et al.,* 1997). Although there is no consensus on this point, regulatory authorities have generally assumed a no-threshold model, even though this might over-estimate the risk at very low doses.

5.3.2 Animal studies

Both lung cancer and mesothelioma have been induced in rats by inhaled asbestos fibres. In order to produce a detectable response in reasonably sized groups of animals, extremely high levels of exposure were used. When the various studies were evaluated in terms of exposure to the numbers of fibres above a certain size, it was found that the lung cancer dose–response for chrysotile, whether from Quebec or Zimbabwe, was approximately the same as for various amphiboles (Lippmann, 1994). This is not easy to explain; it has been attributed to the phenomenon of particle overload. The process of particle overload, whereby non-fibrous particles of otherwise non-toxic substances can induce lung cancer at sufficiently high doses, following the inhibition of particle clearance, appears to be peculiar to the rat (Levy, 1995).

The results for mesothelioma are somewhat different. In experiments where the fibres were given by inhalation, there were insufficient data to define a dose–response function, but amphiboles were more effective than chrysotile at inducing the disease, and Quebec chrysotile was more potent than Zimbabwe chrysotile (Lippmann, 1994). This is clearly more consistent with the results from epidemiological studies.

The question of whether there is a threshold dose has not been settled by experimental work, any more than by epidemiological studies. Much of the lung cancer data can be fitted by simple dose–response curves that do not include a threshold. However, there have been other experiments where chrysotile failed to produce any tumours even at high doses (reviewed by Meldrum, 1996). The statistical requirements to demonstrate a threshold in a convincing manner are not easily met as very large numbers of animals are needed for the low-dose groups. This has been well illustrated in a study by Sanders *et al.* (1993) for lung cancer induced by inhaled plutonium dioxide in which a threshold was clearly demonstrated, but only by having very large numbers of animals (over 1000) in both the zero dose (control) group and the lowest dose group. No such study has been undertaken for asbestos or any other type of mineral fibre. Nevertheless, as already discussed, much experimental work such as that with injected fibres can be seen as consistent with the existence of a threshold.

5.3.3 Interaction with other factors

A number of epidemiological studies have investigated whether there is an interaction between asbestos exposure and cigarette smoking in lung cancer incidence. Most of these studies involved populations exposed to amphiboles as well as chrysotile. The data from these studies are best described by a multiplicative (synergistic) interaction between asbestos and cigarette smoke (Saracci, 1977).

There have been few experimental studies in this area that have used inhaled, as opposed to instilled, fibres. Recently it has been shown in rats that injected *N*-nitrosoheptamethyleneimine, a specific lung carcinogen, and inhaled chrysotile produce pulmonary tumours and hyperplastic responses in an apparently synergistic fashion (Harrison *et al.,* 1997).

Unlike lung cancer, mesothelioma is not caused, nor is the incidence from other causes increased, by cigarette smoking.

5.4 FIBROSIS

The production of pulmonary interstitial fibrosis, that is asbestosis, by inhaled mineral fibres represents an important end-point in its own right. There is no doubt that high doses of chrysotile are both inflammatory and fibrogenic.

As with lung cancer, there is conflicting epidemiological evidence regarding the existence or otherwise of a threshold of effect.

The relationship between asbestosis and cancer is relevant to our understanding of the overall hazard of chrysotile. It is generally agreed that asbestos will not cause cancer without prior chronic inflammation, but there is less consensus on whether this must progress to fibrosis. While both asbestosis and lung cancer in man can be induced by exposure to chrysotile, there is uncertainty and debate regarding whether these two pathological end-points are independent or whether fibrosis is a necessary prerequisite for cancer (Egilman & Reinert, 1996). Asbestosis and lung cancer have broadly similar dose–response relationships, similar latent periods, and depend in the same way on fibre length (reviewed by Meldrum, 1996).

5.5 CONCLUSIONS

Chrysotile *per se* can cause lung cancer and asbestosis; it is less clear that it can also cause mesothelioma in man, and indeed it may not, whereas tremolite (a common contaminant of chrysotile) and other amphiboles can do so.

There is no definitive evidence for a threshold exposure level for lung cancer induction, although some studies suggest that a threshold does exist. Given this doubt, it is difficult to assess the exact risk for current levels of occupational or environmental exposure to chrysotile, though the resulting disease incidence (if any) is unlikely to be detectable by epidemiological studies.

6 Hazardous properties of selected substitutes

6.1 INTRODUCTION

A very wide range of fibrous materials with a variety of physical and chemical properties have been considered for use as asbestos substitutes, and it is necessary to consider each potential substitute fibre on its own merit, using the principles outlined in Section 4 of this report. The output of such review will be a judgement of whether such substitution will offer increased safety (and/or other advantages) over the whole life cycle of the product. Performance issues are product-specific and will not be considered here; rather this section will exemplify the process of evaluation of potential toxicity, by reference to some of those materials currently in use as substitutes. In this process it is important to realise that the volume of information available will always be less than that for chrysotile and that, in particular, human experience with using these materials will generally be limited. Identification of major areas of uncertainty may help to focus additional investigations should the available information be deemed inadequate for a decision on substitution.

6.2 POLYVINYL ALCOHOL (PVA) FIBRES

The predominant use of PVA fibres is in cement reinforcement. The diameter of these fibres is such that, as manufactured, they are well above the respirable limit and most of them will not be inhalable. When assessing this property it is necessary to consider their lower density (circa 1.3) compared with mineral fibres, which means that the respirable limit for these fibres will be about 7 µm rather than the 3 µm usually assumed for minerals. Nevertheless, the fibres as produced are mostly in the range 10–16 µm diameter so the respirable fraction will be small. There is evidence that the fibres do not fibrillate (split lengthways) and the nature of the material does not suggest that this would be a usual fracture mode. In addition, many of the particles seen in the atmosphere are too short to meet the agreed (WHO) criterion of a 3:1 aspect ratio and so do not qualify as fibres by this definition. Although the published toxicological information on PVA is relatively sparse, the parent material has been used extensively in surgery and has food contact clearance (IARC, 1979), presumably based on unpublished studies. Indications of an accumulation of oligomers in the kidney in some circumstances (e.g. Carver *et al.*, 1985) mean that the spectrum of molecular weight of material in the fibres (as used) should be considered, especially if a smaller diameter material were to be produced. The material will degrade only slowly (if at all) in the lungs. It will burn, but the chemical composition does not suggest special toxicity from the degradation products, though interactions with other components of the final product need to be considered. Flammability is not expected in cement mixtures.

Thus this material should result in reduced exposures if substituted for asbestos fibres in products such as asbestos-cement. This prediction has been confirmed in industrial application where very low fibre counts have been reported. Misuse of installed material would not result in significant exposure. Factors to consider when specifying supply quality would include diameter range and degree of polymerisation.

6.3 ARAMID FIBRES

Aramid fibres are used in friction lining, gaskets and seals. They are of predominantly coarse diameter (10–12 µm diameter as made) and thus above the respirable limit, corrected for density, of 6–7 µm diameter. Fibrils are present on the surface of the fibre as made and can be liberated in operations with a high energy input. The fibres do not fibrillate under pressure although there is the potential to liberate fibrous wear fragments when shear forces are applied. Animal experiments have shown fibrosis in response to high doses, but the associated 'proliferative keratinising cysts' are generally considered to be of no relevance for human exposures, as they occur in rats only at levels where lung clearance mechanisms are severely inhibited (IARC, 1997a). Mesothelioma incidence in rats following intraperitoneal injection of fibrils was below the level normally considered 'positive' but some researchers consider there was a marginal effect. In this respect the fibre can be considered as no worse than chrysotile where mesothelioma induction by 'pure' fibre is at worst a weak association and may not occur at all. The fibrils are reported as biodegradable in the lung at a rate much faster than chrysotile (Searl, 1994). Their polyamide structure would not be expected to persist in the environment. As organic materials the fibres will burn, but they do not support flame spread or combustion in the absence of external heat input. When overheated they may release toxic off-gases.

On balance the use of this material should result in reduced levels of fibre exposure compared with chrysotile asbestos and the fibrils released will be no more toxic and will be less biopersistent. Use in confined spaces where there is an oxidising environment and possible external sources of heat, may need careful consideration. The predicted reduction in absolute exposure levels has been achieved in industrial practice. Misuse of installed material would not be expected to give significant exposures.

6.4 CELLULOSE FIBRES

These are mainly used in cement reinforcement. Cellulose fibres are produced from a variety of natural sources and are reported to be predominantly non-respirable although experimental studies as well as industrial surveys have shown some potential to produce respirable fibres (Ubersax-Ingold & Gruber, 1992). The extent of fibrillation is not established but it remains a possibility. Recent communications suggest that in the UK fibre-cement industry the process is less dusty than processes using chrysotile, and the majority of fibre counts are less than 0.05 f/ml, although occasional peaks up to 0.2 f/ml may occur. For a material with such wide application there is surprisingly little experimental evidence on its toxicological properties. Use in the paper industry over hundreds of years has produced little evidence of disease, even at relatively high exposure levels. Although there is limited epidemiological evidence of an increase in the lung cancer rate, smoking was not corrected for so the aetiology is uncertain (see Davis, 1996). Wood dust (which is primarily lignified material) has been associated with nasal cancer. This is best established for certain hardwoods, with softwood much less potent or inactive, suggesting that the cellulose content is not the primary cause. Similarly extensive reports of lung disease (byssinosis) in the cotton processing industry are associated with contaminants rather than the pure (cellulose) fibre. Recent experimental evidence has shown that cellulose fibre is more biopersistent than chrysotile in the rat lung (Muhle & Bellmann, 1997), but persistence in the environment will be short, as many microflora are known to degrade cellulose. The material is combustible but not likely to be flammable in the applications envisaged. Structural and experimental investigations indicate no special toxicity from combustion products, though interactions with other components of the final product should be considered.

On balance the coarse fibre structure and the long experience in use indicate that substitution of cellulose fibre for chrysotile asbestos should result in reduced occupational exposures to fibre. This has been confirmed in practice by a source in the industry where exposures are less than in paper making. Misuse could result in higher exposures but experimental evidence suggests that these will be less than with chrysotile. The apparent extreme biopersistence of this fibre in the lung is a potential cause for concern if reports of a potential for limited lung damage are confirmed. Experimental investigation of this would be a priority. Specifications should include criteria for purity and any sources with very low particle diameter may need re-evaluation, depending on the ultimate use.

6.5 WOLLASTONITE

This is a natural or synthetic mineral form of calcium silicate. It is a crystalline material which can exist as acicular particles after crushing. Fibrous forms can be separated from ores. The particles are predominantly coarse (diameter >3.5 µm) in comparison with the respirable limit for mineral fibre (3 µm diameter). As the material is crystalline it is prudent to assume that fibrillation is possible. There are isolated reports of lung fibrosis in miners and workers handling wollastonite and some experimental evidence for fibrogenic potential. All of this information is consistent with contamination of natural material by crystalline silica although this has not been verified in all cases. No lung cancer was seen in an animal experiment at relatively low doses, and pleural tumours were seen at low incidence following intrapleural injection of high doses only of the grades containing the finest fibres (IARC, 1997b). The animal studies have shown very low biopersistence compared with chrysotile (Bellman & Muhle, 1994), and environmental persistence would be expected to be short, especially in acid conditions. The material is non combustible.

Use of wollastonite as a substitute for chrysotile asbestos could potentially reduce fibre exposures if the coarser material predominates. However the major benefit would be expected to accrue from reduced biopersistence leading to lower continuing lung burdens for comparable exposures. Perhaps for this reason the material is less toxic than chrysotile and although misuse of installed material could lead to high transient exposures, deposited material would clear rapidly from the lung. Factors to consider in product specification are size range and silica contamination.

6.6 CONCLUSIONS

The examples discussed in this section illustrate the way in which judgements about the relative hazards of substitute fibres can be made even when the existing toxicological data are incomplete. On the basis of their intrinsic properties, it is our judgement that PVA fibres, aramid fibres, cellulose fibres and wollastonite are less hazardous than chrysotile.

7 Exposure, risk and the case for substitution

7.1 INTRODUCTION

The UK ban on further use of amphiboles and the reduction in the use of chrysotile asbestos referred to in Section 1 has resulted in a substantial reduction in both actual and potential exposures. This reflects both the elimination of the more dusty uses (such as sprayed coatings) and improved industrial hygiene procedures in the remaining processes as well as the effect of reduced volume processed. Products in current applications all have the fibre diluted by additional components and captured in a matrix before release to the ultimate user.

7.2 GENERAL PRINCIPLES

In reaching conclusions about the case for substitution of chrysotile in its remaining applications we accept that factors other than the scientific arguments and judgements presented herein may also need to be considered. Such factors include the *substitution principle* and the *precautionary principle* as well as long-term environmental consequences.

According to the substitution principle, if dangerous materials can be replaced by safer ones, then this should be done (see also Section 3.1). Cost implications are generally overridden by health implications. The most important consideration is that the substitute is indeed ‘safer’, in all material ways, than the substance being replaced, bearing in mind also that the relative performance of the product may itself have health and safety implications.

The precautionary principle is Principle 15 from the United Nations Conference on Environment and Development, Rio de Janeiro 1992 which states the following.

‘In order to protect the environment the precautionary approach should be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.’

It is important that application of the substitution principle should not conflict with the precautionary principle. Clearly it is undesirable to introduce equally or more dangerous or environmentally damaging substitutes, and such decisions should not be taken without a full understanding of available scientific data. Wherever possible the overarching requirements of sustainable development should be followed.

Finally, in reaching a decision about the replacement of chrysotile, due consideration must be given to the long-term impact on human health and the wider environment of chrysotile and of its proposed substitutes. All stages of its life cycle during which exposure is possible, from production (mining) to manufacture of products, primary and secondary uses (both commercial and domestic) and ultimate disposal, must be taken into account.

7.3 EXPOSURE TO CHRYSOTILE

7.3.1 Industrial exposure

Exposure to bulk fibre is restricted to a small number of industrial outlets, where the material is received and prepared for admixture with the other components of the final products. This process is well controlled in the UK and potential exposures from these sources are confined to situations of equipment failure, transport accidents and similar occurrences. These, by their very nature, will tend to be very isolated occurrences of short duration. Occupational exposures in the industries directly handling raw asbestos fibre are generally controlled to a level where future development of asbestos-related disease is predicted to be minimal or absent.

7.3.2 Environmental exposure

The general public is potentially exposed to asbestos in the form of ‘environmental’ exposures from geological outcrops as well as from installed asbestos-containing products. These exposures are usually minimal (except where there is prolonged contact with installed materials in poor condition, where significant fibre release is possible) and are considered to be inconsequential in health terms (see IEH, 1997).

7.3.3 Intermittent, unregulated and uncontrolled exposures

There are potentially exposed groups where the exposures and ensuing risks are more difficult to define and residual concern may be greater. These include individuals exposed in the course of their occupation, typically in building maintenance and related activities, or as a result of home improvement (D-I-Y) as a leisure activity or in the removal and disposal of installed asbestos. Para-occupational activity such as laundry of contaminated clothing also falls into this category. In the past such exposures may have been poorly controlled, probably as a result of an underestimate of their cumulative importance and this has probably contributed to the current elevated incidence of mesothelioma in some building and maintenance trades (Peto *et al.,* 1995). As the risk has been recognised, the level of control has been raised and it is expected that management of installed asbestos materials will be strengthened to minimise such incidents so that future occupational exposures of this type will be reduced. It is a feature of these exposures that control is dependent on recognition of the hazardous nature of the material handled. The very wide historical use of asbestos makes universal recognition difficult and the fundamental properties of the fibre mean that inappropriate handling can lead to relatively high fibre counts, especially if operations are conducted in a confined space with poor ventilation. Even when the asbestos is encapsulated in a medium such as cement there is the potential to generate significant fibre counts if the composite has deteriorated and/or is worked with power tools. In general, indoor exposures, where there is little or no mechanical extract ventilation, are higher than those outdoors. Outdoor exposures are usually at a level where risk is considered minimal or absent (Brown, 1987), except where there are poor working practices (e.g. working overhead) or there is a high energy input in an abrasive process. Thus, circumstances where high fibre counts could be generated can be envisaged, and with installed materials these may be impossible to control.

It is these groups subject to intermittent exposure that give rise to most concern about continued use of asbestos products. The majority of the potential exposure to asbestos-containing products, whether from misuse or ignorance, comes from existing installations, particularly as these deteriorate with time and become subject to modification or remediation. Management systems will need to take account of this potential. After these existing installations reach the end of their useful life and are removed, so the potential for further exposures will reduce.

It is in this context that the effect of continuing use of asbestos composites in building materials should be viewed. The nature of those materials in current production means that their contribution to current potential exposures will be small. Their continued use will inevitably increase this potential (although it will still be small) and removal of older products will ensure that the proportion of exposures resulting from these products will also rise.

These materials must also be safely disposed of at the end of their service life. Chrysotile asbestos is a classified EU Category 1 carcinogen and there are legal requirements for its treatment (and of products containing it) as ‘special waste’. This has consequences for disposal and subsequent land use, now and in the future.

7.3.4 Potential for reducing exposure to chrysotile

Thus the case for substitution of asbestos in building materials, whether locally manufactured or imported, to which the public has direct access when installed, rests on the grounds of both potentially uncontrolled exposures post installation and on the basis of minimising future waste disposal problems. Pressure pipes pose a lesser risk as they are usually buried and kept moist so that the potential for uncontrolled exposure is minimal, even when the product is misused. However, a small potential for exposure may occur following inappropriate disposal or unusual use.

Substitution of asbestos in friction linings would bring less benefit in terms of reduced potential for exposure. Asbestos fibres are strongly encapsulated in a matrix and abrasion in use results in destruction of the fibre to give quantities of Forsterite, usually of very short length. Similarly the burning of linings during metal recovery operations will destroy the chemical integrity of the asbestos content, so the poor control often evident during such operations will not result in significant exposure from this source. Direct exposure to the raw fibre, at least in the UK, is confined to those few individuals involved in the initial mixing operation, where exposures are limited in scope and readily controlled. Although the practice of drilling and filing linings to achieve a good fit has now been discontinued, it is uncertain whether low quality imports could still be treated in this way and the practice may continue elsewhere. A universal requirement for substitution would preclude any problems of this nature. Some potential additional benefit could accrue from substitution in terms of reduced exposure to the breakdown products. Although these are considered not to be carcinogenic there is evidence that they do have the potential to cause fibrosis. As there is an observed synergy between asbestosis and lung cancer, it is possible that high exposures to these breakdown products could potentiate any residual exposures to asbestos fibre, but there is no direct evidence for such an effect.

For other products such as seals and gaskets, the encapsulation of the fibre and the relatively controlled nature of exposures, means that any potential for exposure reduction as a result of substitution will be small and disposal does not create significant problems at the volumes encountered.

7.4 SUBSTITUTE FIBRES

7.4.1 Exposure to substitute fibres

The general considerations relating to exposures, and the potentially exposed groups, are obviously similar to those for chrysotile. The diverse nature of candidate substitutes makes generic comparison impossible. When evaluating potential substitutes, the intermittent exposure group should be specially considered as control of exposure for these individuals is difficult or impossible. In general terms substitution with materials which do not fibrillate is the single most beneficial change, but coarse (non-respirable) fibres and those which do not persist in the lung (or the environment) will also confer potential benefit. Some examples of evaluations of candidate substitutes are given in Section 6. An example of the collective impact of these factors is the glass and mineral wools extensively used for insulation. The potential for exposure is low owing to the inherent properties of the fibre and the use of dust suppression agents. Thus even vigorous misuse gives rise to few fibres within the respirable range, and a high percentage of these are towards the upper end of the range, where the proportion retained in the lung is small. The lung solubility of most of these materials is also greater than for chrysotile although their environmental persistence is similar so potential long-term disposal problems remain. These fibres also illustrate the importance of considering potential for other effects. As they are generally coarse and stiff, handling results in an irritation of the skin and upper respiratory tract and dust generation results in discomfort. This is a problem in occupational use, but paradoxically may be an advantage to those intermittently exposed in that they are more likely to use respiratory protection.

There are a small number of fibres, mainly single crystal whiskers, where exposure may produce responses similar to or more severe than amphibole asbestos (and thus more severe than chrysotile). Although there is only very limited current use of such materials, all of which is in applications to which the public has no access, it is necessary to be vigilant to ensure that these do not come into widespread use without proper evaluation.

We have been given to understand that best practice in UK industry results in minimal fibre exposure levels in the workplace, especially for cellulose. Cellulose is available for supply to the cement industry as sheets or briquettes, which are placed directly into water. PVA is imported and supplied in bales; fibre counts can be readily maintained below 0.05 f/ml.

In friction product manufacture, substitute fibres are generally handled and monitored by the same practices developed for asbestos, and fibre counts kept below the same limits. If this is maintained, exposure to aramid, PAN and glass fibres will be no greater than for asbestos, so that the resultant risk will be less.

7.4.2 Comparative risk evaluation of substitute fibres

In any complex area of risk assessment, the level of scientific understanding pertaining to the key considerations usually falls into the following categories: what is known (generally accepted); what is uncertain (scientifically contentious); what is unknown (data missing but potentially obtainable) and what is unknowable (further research will not answer the question). We believe that new definitive epidemiological studies into the health effects of many of the fibres used as substitutes for chrysotile falls into this last category, for the following reasons.

First, exposure to these new substitute fibres will, in all probability, never reach the high levels to which certain chrysotile-exposed workers were subjected in the past and which account for much of the currently observed ill-health. Thus, no direct comparison at similar exposures will be possible. Second, and more importantly, new substitute fibres are being developed all the time to make products that are both technically superior (for example, improved polymeric fibres which have better reinforcing properties without the need for binders) and intrinsically safer (by making products that are less respirable and less durable). Thus, as new fibres are continually introduced, there will not be cohorts consistently exposed to the same substitute fibres for long periods.

To these considerations must be added the knowledge that the intrinsic hazardous properties of chrysotile can never be ‘engineered out’ and the potential for harm will always remain. Thus, prevention of ill-health will always rely upon the control of exposure, something which history has shown cannot be guaranteed.

8 Discussion and conclusions

8.1 DISCUSSION

Experimental evidence continues to support the proposition that the health risks associated with exposure to a fibre depend predominantly on three key parameters — dose, dimension and durability (biopersistence). These considerations are of essential importance when making risk comparisons between fibres, for example between chrysotile and its substitutes. Certainly it is not appropriate at the outset of the exercise to assume that all possible substitute (non-asbestos) fibres are safer than chrysotile. For example, some man-made fibres (e.g. some silicon carbide whiskers) and some naturally occurring non-asbestos fibres (e.g. erionite) have been shown to have greater pathogenic potency than chrysotile.

Physical and chemical characteristics determine how readily industrial fibres are released from the parent materials and how they fracture (‘dustiness’), which in turn will influence the dimensions of the liberated fibres. Diameter determines exposure potential, and length is important because fibres shorter than about 10 µm have no significant biological activity. Chrysotile is intrinsically hazardous because of its propensity to split longitudinally and to produce thin respirable fibres more readily. Apart from the aramids, man-made fibres do not split longitudinally but usually break to produce shorter fibres. Aramid fibres can give rise to fibrils in the respirable range, although generally more work has to be expended to liberate these respirable fibres than is the case for chrysotile in a similar situation. Other asbestos substitutes are such that they are unlikely to contain (or produce through use) a significant fraction (if any) of respirable fibres.

A fibre’s biopersistence is determined by chemical composition and molecular structure. Chrysotile is more biopersistent than most (but not all) man-made fibres and is persistent in the environment. It is generally less biopersistent than amphibole asbestos. Epidemiological evidence has convincingly demonstrated that exposure to chrysotile at high enough concentrations can lead to asbestosis and lung cancer. Also there is a demonstrated synergistic interaction between chrysotile exposure and smoking in the induction of lung cancer. Whether or not pure chrysotile can cause mesothelioma is the subject of continuing debate, but chrysotile (as used) is often contaminated with tremolite — an amphibole asbestos — and amphiboles certainly are associated with mesothelioma induction. It has been argued that the amphibole contamination is totally or principally the cause of chrysotile-related mesothelioma.

Whether there is a lower limit of exposure below which pathological effects of chrysotile do not occur is uncertain. The answer to this question is currently not known and probably never will be known with certainty. Also there is the question of the association between asbestosis (fibrosis) and lung cancer. Some experts believe that asbestos and cancer induction proceed in parallel, with a common cause, namely inflammation and associated cellular proliferation. Others hold that asbestosis is a necessary precursor for lung cancer.

In comparing the relative risks posed by different fibres it is necessary to take due account of the toxic properties of binders and other materials incorporated into the replacement product and the longer-term risk posed throughout the lifetime of the product — including disposal.

Lack of a full data set frequently precludes comprehensive assessment of the safety of substitutes. However, application of the basic principles of fibre toxicology will often enable a decision on the relative safety of potential substitutes to be made in such cases.

8.2 OVERALL CONCLUSIONS

It is current EU policy that chrysotile should be replaced wherever practicable, and the objective of this report has been to present reasoned scientific arguments and judgements on the substitution of chrysotile in its remaining applications. There are now practicable alternatives for the major remaining uses of chrysotile and, on the balance of evidence, we believe that these substitutes should be used in these applications. Our judgement is based on relative considerations of the intrinsic properties of fibres, the pathogenicity of chrysotile in comparison with that of substitute fibres, potential uncontrollable exposure situations, and possible problems associated with ultimate disposal.

Due consideration of these factors leads us to the following conclusions regarding chrysotile and its main substitutes.

- The three parameters of dose, dimension and durability (biopersistence) are key to determining the differential hazard of fibres.
- Substitute fibres can be designed or selected to have particular characteristics. Criteria for the substitution of asbestos by other fibres include:
  - the substitute fibres are not in the respirable range and/or are less durable than chrysotile;
  - other materials (binders, etc.) which have to be incorporated into the replacement product do not, in combination with the replacement fibre, produce an overall more harmful impact than chrysotile alone;
  - the replacement product has an equivalent or acceptable performance; and
  - substitution would result in overall lower fibre exposures during manufacture and use and disposal, taking into account likely exposure scenarios and life cycle analysis.
- The maximum benefits from substitution of chrysotile occur in those uses that have the largest potential for human and environmental exposure over the lifetime of the product.
- It is our judgement that PVA fibres will certainly pose less risk than chrysotile as they are generally too large to be respirable, do not fibrillate, and the parent material causes little or no tissue reaction.
- Aramid fibres have a reduced potential for exposure compared to chrysotile as they are generally of high diameter and the production of respirable fibrils is energy intensive. Experimental evidence also suggests that the potential for fibrosis is less than for chrysotile and the fibrils are biodegradable.
- Cellulose has the benefit of long experience of use in a variety of industries without having raised significant concern. The potential for the generation of respirable fibres seems to be less than is the case for chrysotile, although fibrillation is possible. Cellulose is durable in

the lung, and its biological properties should therefore be investigated further. However, exposure levels for current uses are low, and it is biodegradable in the environment.

- Other substitute materials may need to be evaluated using the same general principles.
- The continued use of chrysotile in asbestos-cement products is not justifiable in the face of available and technically adequate substitutes. Likewise, there seems to be no justification for the continued residual use of chrysotile in friction materials.

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ANNEX 1: Observations on the environmental resources management report of November 1997 and associated commentaries

Recent Assessments of the Hazards and Risks Posed by Asbestos and Substitute Fibres, and Recent Regulation of Fibres Worldwide, prepared by Environmental Resources Management for the European Commission DGIII, November 1997

This report, commissioned by DGIII and prepared by Environmental Resources Management (ERM), addresses the results of some recent hazard and risk assessments, submitted by member states, in an uncritical manner. Much of the information provided to ERM was in review format and the report is largely a 'review of reviews'. Perhaps understandably, given the very large volume of information available, no attempt has been made to assess the original contributions (i.e. the papers on which the reviews were based) in a critical manner. Inevitably the documents considered by ERM reviewed similar literature but the conclusions were not identical. No attempt has been made in the ERM review to address these inconsistencies in a systematic manner by reference to the original sources and re-evaluation of the conclusions reached. The fact that a large amount of additional submitted information presented as annexes was not reviewed, apparently due to time pressure, also detracts from the utility of the report.

No attempt is made to segregate new information from that which has been available for some time. For example the conclusions of the Dutch report submitted to ERM that biological activity reduces rapidly as the aspect ratio drops below 3:1 was a basis for the definition of a fibre agreed more than 30 years ago. The report does not differentiate such basic and well accepted data from the new epidemiological results from the Canadian chrysotile miners which became available only recently.

The report summarises most of the areas where there is general agreement on the factors that determine fibre toxicity, but again there is no substantive critical comment. Thus there is a repeat of various previous recommendations for additional epidemiological investigations of cohorts exposed to chrysotile at low exposure levels, without an evaluation of the probable sensitivity of such studies taking into account the errors inherent in measuring such low exposures and the difficulty of defining a suitable control group, given the ubiquitous distribution of this mineral.

A number of instances where there are differences in interpretation in the various reports reviewed have resulted in incompatible statements in different parts of the ERM report. This also reflects the uncritical nature of the review process.

The report is less than comprehensive when considering potential substitutes, but this partly reflects the relative lack of readily available published data for these materials and the difficulty of accessing information that is not in the public domain. The need for substitutes to be assessed on a case by case basis is well made, but there could have been a clearer exposition of the principles to be applied.

The report does not always differentiate between results obtained for chrysotile asbestos and those for amphiboles, and in several instances this distinction could be important to the overall evaluation. Where the distinction is made, the conclusion reached that the risk of chrysotile is less than one tenth that of amphiboles is not useful. What is needed is the risk relative to substitute fibres.

Finally, although the report concludes that more information on candidate substitutes is needed, there is no specific recommendation for the form this information should take, nor the potential consequences of not obtaining it.

A constructive commentary on the June 1997 Draft Final Report prepared for the European Commission DGIII by Environmental Resources Management, prepared by GW Gibbs, JMG Davis, J Dunnigan and RP Nolan for the Quebec Ministry of Natural Resources, Department of Natural Resources, Canada and the Asbestos Institute, September 1997

This paper comments on the ERM report to DGIII and includes additional information from the authors, who are all experts in the field. The commentary makes at least two important points, namely that recent epidemiological evidence strengthens the case for the amphibole hypothesis for the induction of mesothelioma, and that the term ‘substitutes’ covers such a wide range of materials that generic evaluation is meaningless.

The impact of the commentary is diminished by the very repetitive nature of the conclusions and the unreasonable expectations concerning the extent of experimental evidence on the safety of substitutes required before they can be used. This in particular relates to the respirability of the substitute fibres and other physical characteristics that would suggest that they may be less inherently pathogenic than chrysotile. In this respect, the commentary is somewhat unbalanced in its tone.

A serious weakness in this risk assessment of chrysotile is the concentration on the relative lack of effects of exposure in the current workforce, without consideration of potential for possibly greater exposure of other groups which may occur during the life cycle of the products. The recent epidemiological results from Canada are well summarised and point to the need for a proper understanding of the potential, if any, for ‘pure’ chrysotile to induce mesothelioma in exposed populations. This factor may have wider significance than evaluation of chrysotile alone as it impinges on the sensitivity of animal models to detect real differences in human potency of different fibre types.

One consequence of this concentration on mesothelioma is a relative lack of comment on the potential for lung cancer induction in smokers at these low doses. The debate about whether frank fibrosis is a prerequisite or whether inflammation is the critical factor has considerable practical significance. Omission of substantial discussion of this point in the original ERM report would seem to merit more than the passing comments made.

The authors also fail to mention the status of chrysotile as an EU Category 1 carcinogen. This presumably reflects their opinion that this is unlikely to change as it is firmly based on both epidemiological and experimental evidence, albeit at high doses. The consequences of this classification are that continued use requires demonstration that substitution is not technically feasible. Rather than address this the authors seem to suggest that substitution should not take place until the potential substitutes have been exhaustively evaluated. However desirable this may be in theory it does not accord with EU practice.

An important additional observation is the trend to modify the properties of candidate ‘substitutes’ to improve technical performance. This activity may be essential for product optimisation but the potential health effects of these modifications must also be considered. Changes in particle size, surface chemistry and the total formulation employed, all require an assessment of the potential to cause adverse health effects. The final product mixture could be far removed from the initial form of the candidate substitute that may have been tested experimentally.

Opinion on a study commissioned by Directorate General III of the European Commission; outcome of discussions by the DGXXIV Scientific Committee on Toxicity, Ecotoxicity and the Environment, February 1998

This document is in essence a peer review and commentary of the ERM report. In addition the subgroup of the Scientific Committee that undertook the review also used an unpublished draft of the IPCS Environmental Health Criteria document on Chrysotile (dated July 1996) and the commentary by Gibbs *et al.,* referred to above.

In general the critical comments are pertinent and take due regard of the paper by Gibbs and colleagues. However, the Committee also comments that the conclusion to replace chrysotile with substitute fibres, based on the evidence within the ERM report, is unsound. As a result the Committee recommends a further ‘proper’ evaluation of the public, occupational and para-occupational health risks that may be associated with candidate substitutes as well as an assessment of current exposures to chrysotile and the environmental impact of substitution. It is felt that, in the light of the generally accepted determinants of fibre pathogenicity and the status of chrysotile as an EU Category 1 carcinogen, the Committee could have gone further in the promotion of the use of substitute fibres to replace chrysotile in some or most of the residual applications, despite the limitations of the original ERM report.

The comments on the lack of a defined dose–response relationship for chrysotile are very conservative. The evidence for mesothelioma induction at low doses of chrysotile is patchy, and the recent Canadian results suggest it maybe non-existent. Thus a linear response from high dose exposures and animal experiments will, at the very least, overestimate risk, perhaps substantially. Similarly, for lung fibrosis and lung cancer there is some evidence for a threshold of effect, although this is far from being universally accepted. Some discussion on this, and the practical consequences of adopting a threshold model would have been useful.

The comments on substitutes are also unhelpful. That there is no significant epidemiology on these materials is hardly surprising, given the relatively short span of use. It is unreasonable to expect substantial information of this type when the materials are not yet recommended for use. Similarly, there has been no formal requirement for experimental studies on fibres until recently and the logistical difficulties and expense will deter all but the most determined manufacturer. A discussion of the minimal requirements in this respect, and their relationship to material properties would have been helpful. In particular those determinants which directly influence potential exposure should have been considered. There is an implicit assumption of the need to demonstrate absolute rather than relative safety before substitution, which is at variance with similar situations elsewhere. This may reflect an unintended interpretation of the term ‘proper evaluation’ which is undefined.

Annex 2: Lay summary

Chrysotile asbestos ('white asbestos') has been used for most of this century in a range of products (building materials, insulation and fire proofing, brake linings), but most remaining use is now in asbestos-cement and in brakes and clutches.

Chrysotile asbestos has the ability to split into thin fibres which can be breathed into the lungs. There is no dispute that at high enough exposures chrysotile can cause asbestosis (scarring of the lung) and lung cancer, with cigarette smokers at particularly high risk. Furthermore, chrysotile, as used, is often contaminated with other forms of asbestos known as amphiboles, which can cause the development of mesothelioma (a fatal tumour of the tissue which surrounds the lung). It is possible that those mesotheliomas linked with exposure to chrysotile may result from its contamination with amphibole asbestos.

It is well established that the dose, dimension (which determines the likelihood that the fibre can be breathed into the lung) and durability (the persistence of the fibre in the lung) are three vital factors in determining the ability of fibres to injure the lung. A number of substitute fibres for chrysotile have been developed. In order to be safer than chrysotile, substitute fibres should be too large to be breathed into the lung or be less durable or both. In addition, if and when substitute fibres are used they should result in overall lower fibre exposures in the workplace and in the environment. They must be less harmful than chrysotile when all aspects of their life cycle are considered, and the replacement product(s) should have an equivalent or adequate performance.

It is our judgement that certain substitute fibres meet these criteria. For example, PVA (polyvinyl alcohol) fibres are less harmful than chrysotile because they are too large to be breathed into the lung and they do not break into smaller (thinner) more harmful fibres. Similarly, aramid fibres are usually too large to be inhaled and those fibres which are able to reach the lung tissue are more readily biodegraded than chrysotile fibres. Cellulose has long been used in a variety of industries without having given cause for concern. Cellulose gives rise to few fibres small enough to be inhaled, although it has comparable durability in the lung to that of chrysotile.

These materials — PVA, aramid and cellulose — are three of the main substitutes for chrysotile asbestos. For other substitute fibres the same criteria described before need to be applied.

It should be recognised that the majority of human exposure to chrysotile asbestos will arise from asbestos use which has been largely discontinued (i.e. insulating materials in buildings). The majority of products which now incorporate chrysotile are unlikely to give rise to comparable exposures. However, the persistent nature of asbestos means that issues of waste and disposal will remain important for many years to come. In conclusion, we recommend that wherever it is practicable, appropriate substitutes for chrysotile asbestos should be used. In particular the continued use of chrysotile in asbestos-cement and in brakes and clutches is not justifiable.