A LITERATURE REVIEW OF AUSTRALIAN AND OVERSEAS STUDIES ON THE RELEASE OF AIRBORNE ASBESTOS FIBRES FROM BUILDING MATERIALS AS A RESULT OF WEATHERING AND/OR CORROSION.

Australian Government
Australian Safety and Compensation Council

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Glossary

Amosite: a form of asbestos with typically brown colouration.

Amphibole: asbestos fibres tending to a long, thin and straight morphology. Both crocidolite and amosite asbestos fibres are included in this category.

Asbestos building material (ABM): any manufactured products containing asbestos fibres with a primary use in commercial or domestic construction.

Asbestosis: pulmonary fibrosis (scarring) as a result of asbestos fibre inhalation.

Aspect Ratio: morphology assessment of asbestos fibres relating to the ratio of length to width.

Chrysotile: a form of asbestos with typically white colouration.

Crocidolite: a form of asbestos with typically blue colouration.

Exposure: the process(es) by which humans are subject to a chemical: the body burden. Without exposure there can be no risk to health.

Fibres per mililitre (f/ml): a commonly used unit of measurement of asbestos fibre concentration in air. This measure is equivalent to fibres/cm^3.

Friable/friability: the potential for release of fibres into the atmosphere relating to a change in the physical state of dry asbestos if it is crumbled, pulverised or reduced to powder by any form of physical disruption (e.g. hand pressure).

Hazard: the intrinsic potential of a substance to cause an adverse health effect (e.g. organ failure or cancer).

Lung cancer: any uncontrolled growths (neoplasias) of lung tissue.

Mesothelioma: a cancer of the pulmonary pleural cavity or, alternatively, of the abdominal cavity (peritoneum).

NIOSH: National Institute of Occupational Safety and Health of the U.S. National Institutes of Health.

REL: recommended exposure level (US NIOSH).

Risk: the probability of damage or harm as a result of a given exposure to the substance.

Serpentine: asbestos fibres with a curly or flexile characteristic (chrysotile asbestos only).

Time Weighted Average (TWA): The average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five-day working week.

Objective

The available literature has been reviewed to determine the extent to which asbestos fibres are released from building materials as a result of the processes of weathering and/or corrosion. Where possible the extent to which fibres are released from weathered/corroded materials is compared to fibre releases from new materials or materials in good condition.

Scope

The following literature review has focussed on the effect of weathering and/or corrosion processes on the release of asbestos fibres from asbestos containing building materials. The currently available peer-reviewed scientific literature, non-peer-reviewed publications and additional information from selected Australian OHS professionals have been utilised.

This literature review is not intended to be a comprehensive analysis of the asbestos literature or the broader body of knowledge relating to asbestos-related health effects. Aspects of asbestos fibre toxicology are covered briefly in so much as these topics relate directly to weathering/corrosion processes and fibre release.

Methodology

The methodology used in this literature review has included:

- an examination of the formal literature on asbestos building products weathering and fibre release.
  The following academic search engines were utilised;
  Medline/PubMed, ISI Web of Science, Google Scholar.
- a review of the non-academic and technical literature,
  The following non-academic search engines were utilised;
  Google, Infoseek, Surfwax.
- Several phone discussions and email correspondences were carried out with Dr. Steven K. Brown (CSIRO Building, Construction and Engineering, Highett, Vic.) from early May to late June 2007 and with Dr. Joe Crea (Chief Advisor, Occupational Hygiene, Safe Work SA) in June 2007. Both are acknowledged Australian specialists in the field of asbestos weathering phenomena and/or abatement processes. I especially thank both colleagues for their assistance and for providing copies of not easily accessible articles for this review.

A. General and brief Introduction

1. Asbestos Building Materials (ABM)

In developed countries the modern industrialised use of asbestos began around 1880 and was maximal in the late 1960s and early 1970s. The number of building materials incorporating asbestos in the USA has recently been estimated as up to 3,000 (ROC 2005). The popularity of asbestos in the building industry has resulted from its cost-effectiveness and its relatively high chemical and physical resilience. For example, asbestos has been used in sheeting/cladding, roofing, thermal and electrical insulation, moulded fittings, water cisterns, rainwater gutters, down pipes, pressure pipes, underground drainage and sewer pipes, sills, copings, chalkboards, fascias, infill panels, cement pipe and sheets, floor tiles, gaskets, friction materials, coatings, plastics, textiles, paper, and other products (ATSDR 2001, NICNAS 1999).

Following increasing public health concerns and regulatory controls the demand for asbestos declined rapidly in the USA in the mid-1970's (Kelly & Matos 2006). In Australia mining of asbestos stopped completely in 1983 following similar health concerns, the introduction of substitutes, and subsequent declines in demand (NICNAS 1999). All uses of chrysotile (white) asbestos were prohibited in Australia from December 2003 with only a few specialised exceptions (NOHSC 2003a). These restrictions to the use of chrysotile asbestos were in keeping with earlier prohibitions on the use of all other forms of asbestos in Australia (NOHSC 2003b).

According to Brown (2000) the serpentine chrysotile asbestos form has been favoured in many applications in the past because of its long and easily manipulated fibres. As a result chrysotile has represented over 90% of the total production of asbestos both in Australia and globally (Brown 2000; Leigh et al. 2002). For the period from 1940 to the late 1960s, however, all three forms of asbestos were mined and used in Australia (i.e. chrysotile, crocidolite and amosite). Crocidolite use declined after this period but both amosite and chrysotile asbestos use in Australia continued into the 1980s (Leigh et al. 2002). It has been estimated that over 90% of all consumption of asbestos in this country can be accounted for by the asbestos cement manufacturing industry (Leigh et al. 2002).

Given its widespread use in the past, the amount of asbestos currently in place in commercial and residential buildings may be very high. Furthermore, aging and/or corrosion processes can be expected to alter the physical integrity of ABMs. Consequently, the release of fibres from the support matrices of building materials into which asbestos has been embedded represents an area of potential concern.

The major groupings of building materials containing asbestos and approximate asbestos contents are worthwhile noting (UK DETR 1999).

Although there have been variations in how ABMs have been used in different localities and countries (Dr. SK Brown, *pers. comm*.) the predominant types of ABMs found in industrial, commercial and residential properties may include:

- *Insulating board* (asbestos content approximately 20 – 45%).
  Used for fire protection, heat and sound insulation and generally found in circuit boards, electrical panels, ceiling tiles, wall linings, and partitions.

- *Insulating covers* (e.g. for boilers, pipes; asbestos content 55 – 100%).

- *Sprayed loose insulation or coatings* (asbestos content up to 85%).

- *Asbestos-cement products* (asbestos content mainly 10 – 15%, but sometimes up to 40%).
  The most widely used of the ABMs and found in many types of building as – for example – profiled sheets for roofing and wall-cladding in houses, garages and sheds.

(Source: UK DETR 1999).

2. Asbestos Fibre Characteristics

The term 'asbestos' is a generic one used for a group of six naturally occurring fibrous polysilicate minerals with differing physical characteristics and chemical compositions (ROC 2005). The most common groupings are (ATSDR 2001):

1. Chrysotile or "white" asbestos (CAS No. 12001-29-5) is the form most often used industrially. Its physical properties are serpentine (refer Glossary). Although variability in chemical composition is evident one formula for Chrysotile asbestos is $\{Mg_3(Si_2O_5)(OH)_4\}_n$. Chrysotile fibres are acid labile (Merck Index 2006).

2. Amosite or "brown" asbestos (CAS No. 12172-73-5) is considered particularly hazardous. The general composition is given as $\{(Mg,Fe)_7Si_8O_{22}(OH)_2\}_n$.

3. Crocidolite or "blue" asbestos (CAS No. 12001-28-4) is highly fibrous and often considered the most hazardous of the asbestos forms. A given chemical formula for crocidolite is given as $Na_2Fe^{2+}{}_3Fe^{3+}{}_2Si_8O_{22}(OH)_2$.

4. Tremolite (CAS No. 77536-68-6). Chemical composition of $\{Ca_2Mg_5Si_8O_{22}(OH)_2\}_n$.

5. Actinolite asbestos (CAS No. 77536-66-4). Chemical composition of $\{Ca_2(Mg, Fe)_5Si_8O_{22}(OH)_2\}_n$.

6. Anthophyllite asbestos (CAS No. 77536-67-5). Chemical composition $\{(Mg, Fe)_7Si_8O_{22}(OH)_2\}_n$.

Other natural asbestos minerals, such as richterite, and winchite, may be found as contaminates in products such as mined talc or vermiculite. The available evidence indicates that these minor forms are no less harmful than the major groupings listed above (ATSDR 2001).

Fibres form as a consequence of the crystalline structure of asbestos - a result of slow cooling during the initial formation of orientated crystal lattices and the parallel alignment of these polysilicate molecules. As with many minerals these lattices have three cleavage planes which, with sufficient force, can break to produce smaller fragments. Consequently, a larger asbestos fibre can ultimately become the source of hundreds of much thinner and smaller fibres which are typically beyond the size that can be detected by the unaided eye.

This process has important ramifications for human exposure and health. As asbestos fibres become smaller and lighter they can more easily aerosolise. Human respiratory exposures can result, and although most fibres will eventually settle they can also become airborne again with increased air currents or human movement (e.g. the start of morning work shift following settling overnight). Fibre settling is also of potential concern in a residential environment where settling to floor surfaces (the largest accumulation in comparison to walls or ceilings) can lead to a greater exposure for infants and toddlers (ATSDR 2001).

In a related manner, the structure of some asbestos may be so weak that breakdown into smaller fragments can result just from simple handling. In these circumstances the asbestos fibres are readily transferred into the air. This characteristic is termed the “friability” of an asbestos containing product. The smaller the fibres generated from friable asbestos materials the more likely these fragments remain in the atmosphere. The greatest concern is reserved for released asbestos that can be maintained as an aerosol due to the potential for increased respiratory human exposure (ATSDR 2001).

3. Asbestos Fibre Health Risks

The carcinogenic potential of asbestos fibres is well recognised and has been known for some time. Some of the earliest publications of occupational asbestosis include a 1934 report in the medical journal *The Lancet* (Haigh 2006). It was more formally listed in the First Annual Report on Carcinogens in 1980 under the category “Known to be a human carcinogen” (ROC 2005).

Studies in humans have demonstrated that exposure to asbestos causes cancers of the respiratory tract including lung cancer, pleural and peritoneal mesotheliomas and more remote cancers (e.g. lymphoma and cancers of the digestive tract and kidney). The International Agency for Research on Cancer

(IARC) classifies all forms of asbestos under carcinogen Category 1. The Australian Safety and Compensation Council (ASCC) classifies each of the different forms of asbestos as "*Carcinogen Category 1"* with associated Risk Phrases R45 (May cause cancer) and R48/23 (Danger of serious damage to health by prolonged exposure/Toxic by inhalation) (HSIS 2007).

NIOSH considers asbestos to be an occupational carcinogen and debate continues as to whether a threshold exposure level exists for lung carcinogenesis or mesothelioma. Neither epidemiology data nor animal test data are yet sufficient to identify a threshold dose – particularly at low doses (Europa 2007, ATSDR 2001). Consequently, it may be most appropriate in the absence of more definitive information to assume that there is no safe - or threshold - dose of chrysotile and other forms of asbestos fibres.

Nonetheless, regulatory agencies have routinely recommended exposure levels and that exposures should be reduced to the lowest feasible concentration. For example, NIOSH (USA) recommends a Recommended Exposure Limit (REL) of 100,000 fibres per cubic metre of air (100,000 fibres/m^3 or 0.1 fibre/cm^3 [‡]) with a fibre being defined as having an aspect ratio of 3 to 1 or greater. In addition, it is suggested that occupational exposures should be limited to 1.0 fibre/cm^3 of sampled air when averaged over a 30 minute sampling period. Exposures at the REL may still be associated with a residual lung cancer risk as a risk-free level of exposure to asbestos fibres has not been established (ATSDR 2001).

The available data (both epidemiologic and from animal studies) show that the health risk posed by fibre exposures are largely determined by dose, the fibres' dimensional characteristics (length and diameter) and the fibre's ability to accumulate within the body and resist removal (i.e. biopersistence). Smaller fibres appear able to translocate to pleural and peritoneal spaces and be cleared by the lymphatic and circulatory systems. Longer fibre lengths are associated with pathologies although the exact "critical" fibre length is still subject to debate. For example, fibres with lengths ≥ 5 µm have traditionally been of toxicological interest. Nonetheless, the potential adverse health effects of fibres below 5 µm in length is still of interest and the subject of investigation (see, for example, Suzuki et al. 2005 & Tossavainen et al. 1994). This is relevant to the issue of fibre release from aging or corroded materials as Spurny et al. (1979) have shown that asbestos fibres less than 5 µm in length constitute the majority of fibres (67.3%) released from ABM. This also appears to be confirmed by Teichert (1986b).

The current Australian exposure standards for *each* of the forms of asbestos is uniformly 0.1 fibres/ml of sampled air as an 8 hour TWA (HSIS 2007). This places the Australian exposure standard guidelines at the lowest level adopted by any regulatory agency or jurisdiction.

[‡] Measurement units of fibre/cm^3 are identical to fibre/millilitre which are used elsewhere in this review.

4. Asbestos Fibre Measurement

The inhalation of micron-scaled asbestos fibres is the major exposure pathway for this material. Consequently, the determination of risk and occupational exposure limits is based in large part on the accurate determination of fibre concentrations in the air. However, all measurement procedures are complicated by the considerable variation in physical structure and chemical composition that are found with the different forms of asbestos. Parameters that are generally considered important for impacting on human health include:

- the respirability of the fibres,
- a low fibre diameter,
- the *number* of respirable fibres (in comparison to absolute fibre *mass*),
- fibre durability,and,
- a high length to width ratio (or aspect ratio).

A fibre is traditionally defined as having an aspect ratio of 3:1, a length of 5 μm and a diameter less than 3 μm (Brown 2000).

There are two broad analytical techniques described by NIOSH for the determination of occupational asbestos fibre levels. These are:

1. Phase contrast microscopy (<u>PCM</u>) Analytical Method 7400 – Asbestos and Other Fibers measured by PCM (NIOSH 1994a) count all fibers that are longer than 5 μm and have an aspect ratio equal to or greater than 3:1 (aspect ratio).
2. Transmission electron microscopy (<u>TEM</u>) – Analytical Method 7402 – Asbestos measured by TEM (NIOSH 1994b) quantify the asbestos fibre fraction of all fibres in air samples when there is any uncertainty as to the composition of the samples. This count can be used to proportionally reduce fiber counts obtained by PCM Method 7400 to yield a more accurate measurement of ambient asbestos fibres.

PCM is the predominant method used in all workplace determinations principally because of its relative ease of use and cost advantage ((J Crea, *pers comm*.). There are limitations with each of these procedures. For example, PCM may underestimate the concentration of relevant fibres as this visual procedure cannot accurately determine fibres below 0.2 μm in diameter. Importantly, all of the asbestos types can produce fibres below this size which cannot be easily determined by optical resolution (Brown 2000).

In addition, PCM procedures routinely count only fibers longer than 5 μm in length. Furthermore, PCM techniques are not able in some situations to accurately distinguish morphologically non-asbestos fibres from asbestos fibres. Fibres below 5 μm in length may still be very relevant to asbestos mediated health effects in humans (Suzuki et al. 2005; Tossavainen et al. 1994) and are best evaluated using electron microscopy methods (SK Brown, *pers. comm.*). However, the more sensitive analytical methods utilizing electron microscopy are time and labour intensive and suffer from standardisation problems between laboratories (Wagner 2002).

The membrane filter method using PCM has been used for many years as the standard procedure for the determination of asbestos fibres in air in Australia (J Crea, *pers comm*.). The Australian National Occupational Health and Safety Commission (NOHSC) has published a Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres (2^{nd}. Ed.) (NOHSC 2005). "Countable fibres" are defined as any fibrous objects having a maximum width less than 3 μm, a length greater than 5 μm and a length/width ratio greater than 3:1. These guidelines do not place a requirement on the quantification of fibres below 5 μm in length in occupational settings even though the available evidence indicates that such fibres represent the majority of fibres released from ABM (Spurny et al. 1979; Teichert 1986b).

B. Literature Review of Aging, Weathering and/or Corrosion Specific Articles.

1. ABM Integrity as a Product of Aging and Weathering.

As can be expected the physical and structural properties of all building materials will be altered with age due to weathering (sun, rain, wind and/or frost) and/or from corrosion (e.g. H_2SO_3 or H_2CO_3). These processes will also be relevant to ABMs (SK Brown *pers. comm*.; Brown 1982; Brown & Angelopoulos 1991). The majority of studies reviewed were conducted overseas and reported observations of fibre release from asbestos embedded into cement usually as roofing or sheeting building products. These studies are relevant to Australian conditions as roofing and sheeting products constitute by far the biggest use for ABM in the ACT region (>95%; ACT Asbestos Taskforce 2005, figure Pg. 41; Leigh et al. 2002; URS 2005) and this is likely to be the case elsewhere in the country.

Erosion removes cement particles and can result in the release of asbestos fibres leaving the material with less reinforcement. For ABM used in roofing applications this effect becomes noticeable after approximately 15 years (Brown 1998). It has been estimated from European studies that the loss of sheet thickness is of the order of 0.01 to 0.02 mm per year (Bornemann & Hildebrandt 1986; Brown 1998). An Australian asbestos survey of the ACT reports more generally that "*material of an unstable nature such as highly weathered roof sheeting ...... was found to be a rare occurrence*" (URS 2005 pg. 3-23). The same report also indicated that in approximately 90% of all residential buildings containing ABMs in the ACT, ABMs were found to be in good condition with a minimal potential to release fibres.

Furthermore, at least one Australian study indicated that chrysotile and crocidolite roofing sheets, which had weathered for 25 to 27 years, maintained a static strength greater than 5000 Newton when tested according to AS 1611-1973 (Brown 1998). This compares with the recommended static strength under these test guidelines of 4900 N per metre width. This finding provides some circumstantial evidence for the view that weathering phenomena do not deplete internal fibre concentrations to such an extent that ABM structural integrity is compromised. A commonly under-appreciated point is that during manufacture asbestos fibre bundles are impregnated with cement matrix which provides considerable bonding strength and reduces the likelihood of fibre release (J Crea, *pers. comm.*). However, the exact contribution of such interstitial cement in the maintenance of ABM integrity is not known and has not been fully evaluated (SK Brown, *pers. comm.*).

Erosion can become a more serious problem with regular and extremely harsh weather conditions. Although more rare, flaking can occur when elements permeate beneath the surface of ABMs. The effects of cyclic expansion and contraction of permeated materials during freeze-thaw cycles on ABM structural integrity has not been studied (SK Brown, *pers. comm.*). However, it is known that as the moisture content increases, severe deterioration is more likely to occur (Brown 1998). An important point is that asbestos-cement products are inherently brittle and even with low impact forces are susceptible to cracking and chipping. The release of fibres from ABM sheeting during machining, hammering, or similar forcible manipulations has been studied (Lohrer 1979) and can be considered more relevant to situations of ABM handling during demolition and renovation (ATSDR 2001; Sebastien et al 1982).

Biological growth on the exterior of asbestos-cement is also an important consideration and can be a problem in sheltered environments. Such growths can stimulate surface disintegration and dissolution. Anecdotally, and for unknown reasons, the presence of dark lichen growth is especially prevalent in Australia in comparison to other countries (SK Brown, *pers comm.*).

Aside from the removal of aged asbestos materials by approved abatement procedures the deterioration of asbestos-cement products can be prevented by appropriate encapsulation methods. In these situations encapsulation refers to the application of an additional layer of material - without prior physical disruption from preparation such as sanding - so as to stabilise the ABM and prevent fibre release. In general terms this can be viewed as a *painting* step. Although these procedures have been - and are being - used they are still undergoing refinement. According to Dr. Brown (CSIRO) encapsulation procedures can be very effective in preventing continued degradation of ABMs – and, consequently, release of asbestos fibres (SK Brown, *pers. comm.*). Preliminary studies by the CSIRO suggest that aqueous based encapsulation procedures are the most effective. To date there has been a reliance on organic solvent-based encapsulation paints in Australia and this has been primarily due to cost (SK Brown, *pers. comm.*).

2. Controlled Laboratory Studies

The available literature relating to laboratory studies on the influence of aging, weathering and/or corrosion specifically on ABMs is very limited. Moreover, the published reports and secondary (i.e. non-peer reviewed) literature which are available mostly date from the late 1970s to late 1980s. No studies which deal with this topic have been found to have been published in the last 5 or so years. This older - but peer-reviewed - literature is discussed first and then followed by the secondary literature.

Before summarising these studies it should be emphasised that variations in the determination of air fibre concentrations are possible and even likely. Given this proviso, and the fact that it is not possible to return to the raw data for any of these studies to critically examine the derived figures, the stated fibre concentrations are taken at face value for this literature review. There are, however, consistencies throughout the literature which are evident.

In the oldest study found Lohrer et al (1979) examined fibre release from asbestos containing cement and floor coverings subject to various machining processes with or without air extraction controls. Levels of asbestos fibres, as measured by electron microscopy, were found to be very high and dependent on the type of power tool or machinery used. These ranged from 0.8 f/ml in the vicinity of a power drill and increased to 100 f/ml with a power saw. These values can be viewed as possible ambient air concentrations under severe conditions (e.g. demolition or installation procedures and without adequate ventilation controls). The authors concluded that without physical disruption of ABMs by power tool and machinery use the release of asbestos fibres into the air was very low.

Using similar techniques Spurny and colleagues (1979) found fibre concentrations of 0.0003 f/ml and 0.0000035 f/ml at 0.5 and 100 metres respectively from 70 year old asbestos cladding. In addition, the size distribution of asbestos fibres was presented. Approximately one-third of all fibres were greater than or equal to 5 μm in length. However, the majority of fibres in this study were in the 2 - 3 μm size range. Similarly Felbermayer & Ussar observed fibre concentrations of 0.0004 to 0.021 f/ml from 30 year-old sheeting or asbestos tiles from buildings in Austria (*cited in* Brown 1982).

Sebastien and colleagues (1982) measured concentrations of airborne asbestos using both electron and fluorescence microscopy inside and outside of an office building which contained ceilings sprayed with a crocidolite-containing material and floors covered with vinylchrysotile tiles. Results were presented as nanograms of asbestos fibre per cubic metre of air. Using an approximate conversion factor of 2000 fibres per nanogram of asbestos (Tilkes & Beck 1989) the reported concentrations in the air ranged from 0.0004 to 0.034 f/ml (see also Summary table). It was concluded that airborne fibre concentrations were the highest where human activity (such as walking) and similar forces (scraping and machine scrubbing) were the greatest.

Teichert (1986a&b) concluded that despite evidence of "considerable erosion", only "very low" (i.e. in most cases undetectable) asbestos fibre emissions were observed from asbestos cement roofing. A strength of this work was that fibre concentrations were related to the prevailing weather conditions at the time of measurement. The proportion of released fibres in the external air that were asbestos in nature were reported to be very low at 1.1 % for shorter fibres of 2.5 μm to 5.0 μm in length and less than 0.2% for fibres greater than or equal to 5.0 μm in length (Teichert 1986b).

A linear relationship between the corrosion and aging of asbestos cement products over 50 years and a loss of sheeting thickness was reported by Bornemann & Hildebrandt (1986). This was also apparent for mass loss from these ABMs (in g/dm^2). Furthermore, this equated to approximately 0.0001 f/ml of released asbestos fibres under the sampling conditions used. This level of fibre release was very low (by a factor of 20-40 fold) in comparison to other environmental high release scenarios for atmospheric asbestos such as heavy traffic situations or in the vicinity of an asbestos mine.

In a review of their previous work Spurny (1989) concludes that asbestos-cement corrodes in response to "aggressive" atmospheric pollution (e.g. to acids arising for sulphur dioxide and other industrial gases). The extent of corrosion is dependent on several factors including the concentrations of these pollutant gases, the relative time of exposure and the prevailing weather conditions. Spurny (1989) indicates, however, that only about 20% of free asbestos is released into the air. The remaining 80% is hypothesised to be removed by rain. It is not known if these northern European findings can be directly related to the drier conditions found in Australia.

Many of these reports have been reviewed and critically examined by Brown (1998). The final conclusion reached by this author is as follows:

> *" It is clear that there is an environmental release of asbestos fibres from weathered AC sheet at extremely low but measurable levels (by SEM). However, the significance of this emission to environmental pollution by asbestos is a matter of dispute ...."*

(cont. next page)

A summary of these (mostly) peer-reviewed reports is provided in the table below.

Study	Ambient asbestos fibre concentrations (f/ml)	Comments
Bornemann & Hildebrandt (1986)	0.0004 0.0046 0.0024	Roof covering (asbestos, 30 yrs. old) High traffic density Asbestos mine
Teichert (1983)	0.0005-0.0004 < 0.00015	100cm distance 0.5 metre distance
Teichert (1986)	0.001	0.5 metre distance
Brown (1998)	0.0004-0.0005	
Brown (1982)	0.0004-0.021	Felbermayer & Ussar (Austria)
Brown (2000)	≤ 0.008 0.0002 (ave.)	Health Effects Inst. (1991) report
Clarke (unk date)	< 0.0002	Study of fibres released from new & 25 year old ABM roofing in Weatern Australian schools.
Sebastien et al (1982)	0.0004 - 0.006 0.0016 – 0.034	crocidolite chrysotile
ATSDR (2001)	0.00059 - 0.00099	WHO study (1998) ABM and non-ABM containing buildings in USA
For comparison: ASCC Exposure Standard	0.1 (TWA)	Refer http://hsis.ascc.gov.au
Lowest anticipated exposure levels (Background)	0.00001 (rural) 0.0001 (urban)	Brown (2000) URS (2005)

In general - and cognisant of the limitations inherent in directly comparing various studies which have used different measurement methodologies – it is apparent that the ambient fibre concentrations from these reports are well below guidelines set by most regulatory authorities (as indicated in Section A.3). For a complete analysis of the potential health effects of asbestos fibre release from aging, weathered and/or corroded ABMs, however, the periods of exposure to these materials must be examined.

For example, the average time spent indoors should be combined with calculated ambient indoor fibre concentrations to more accurately determine lifetime risk (ATSDR 2001, Table 6.4; Brown 2000). Calculations such as these may be complex as particular situations are likely to create variations to exposure pathways (e.g. fibre settling during periods of inactivity followed by increased release of fibres into breathing zones on resumption of human movement and increased air flow).

Brown (2000; Table 38.1 below) has provided an indicator of relative risk following ambient air asbestos exposures in differing environments. The table represents estimates only of the combined risk for mesothelioma and lung cancer for building occupants (averaged for males and females) exposed to asbestos fibres in the air under the different exposure situations listed. These estimates are summarised below. In order to place these into perspective the "current exposure standard" of 0.1 fibres/ml indicated in the table above is equivalent for both Australian regulations (NOHSC Standard, HSIS 2007) and the US NIOSH/OSHA standard≠.

TABLE 38.1 Estimated Lifetime Cancer Risks for Different Scenarios of Exposure to Airborne Asbestos Fibers*

Conditions	Premature cancer deaths (lifetime risks per million exposed persons)
Lifetime, continuous outdoor exposure	
0.00001 f/mL from birth (rural)	4
0.0001 f/mL from birth (high urban)	40
Exposure in a school containing ABM, from age 5 to 18 (180 days/year, 5 h/day)	
0.0005 f/mL (average)	6
0.005 f/mL (high)	60
Exposure in a public building containing ABM, age 25 to 45 (240 days/year, 8 h/day)	
0.0002 f/mL (average)	4
0.002 f/mL (high)	40
Occupational exposure from age 25 to 45	
0.1 f/mL (current occupational levels)	2000
10 f/mL (historical industrial exposure)	200,000

*This table represents the combined risk (average for males and females) estimated for lung cancer and mesothelioma for building occupants exposed to airborne asbestos fibers (TEM measurements) under the circumstances specified. These estimates should be interpreted with caution because of reservations concerning the reliability of the estimates of average levels and of the risk assessment models.

The "average" levels for the sampled schools and public buildings represent the means of building averages; the "high" levels shown as 10 times the average, are approximately equal to the average airborne levels of asbestos recorded in approximately 5 percent of schools and buildings with asbestos building materials.

The concentration shown (0.1 f/mL) represents the permissible exposure limit (PEL) proposed by the U.S. Occupational Safety and Health Administration. Actual worker exposure, expected to be lower, will depend on a variety of factors including work practices, and use and efficiency of respiratory protective equipment, *Source:* Health Effects Institute (1991)

(Brown 2000; p.38.4)

Finally, it is worthwhile mentioning that in relation to the specific processes of weathering and aging on ABMs a single peer-reviewed study has observed that chrysotile fibres released from weathered asbestos cement products appear to be *less* damaging than standard (i.e. un-weathered) fibres (Tilkes & Beck 1989). The authors observed decreased haemolytic activity and

≠ US NIOSH considers asbestos to be a potential occupational carcinogen and recommends that exposures be reduced to the lowest feasible concentration. For asbestos fibres >5 µm in length, NIOSH recommends a REL 0.1 fibres/ml, as determined by NIOSH Analytical Method #7400. Airborne asbestos fibres are defined as those particles having an aspect ratio of 3:1 or greater and the crystal structure and elemental composition consistent with asbestos minerals. In addition, airborne cleavage fragments from the nonasbestos forms of the serpentine minerals are also counted as fibres provided they meet the criteria for a fibre when viewed microscopically. The OSHA Permissible Exposure Limit (PEL) for asbestos fibres is defined as an 8-hour TWA airborne concentration of 0.1 fibre/ml as determined by the membrane filter method at 400X magnification by PCM. OSHA guidelines require no worker exposure in excess of 1 fibre/ml as averaged over a 30 minute sampling period.

macrophage cytotoxicity with size-fractionated asbestos fibres from weathered ABMs and attribute these effects to the leaching of magnesium ions from aged ABMs. As this is a single, and in vitro study, only it is difficult to extrapolate these findings directly to workplace or indoor exposure scenarios.

3. Non-peer reviewed publications.

In perhaps one of the most comprehensive audits of its type Wood and colleagues examined asbestos use in the Australian Capital Territory in response to the ACT Occupational Health and Safety Act (1989) (ACT Asbestos Taskforce 2005; URS 2005). Wood and colleagues acknowledged that the majority of evidence indicates that asbestos materials do not present a health hazard when in a non-friable state. This is so when the asbestos is found in good condition or when contained in a bonded form. However, when asbestos fibres become airborne due to aging, weathering and/or corrosion there is a potential for fibre exposure via inhalation.

C. General Conclusions

The broad consensus from the studies and reports reviewed is that the release of asbestos fibres is exceedingly small from non-friable ABMs as a result of aging, weathering and/or corrosion. In addition, these releases can be measured and quantified with a reasonable level of certainty.

This conclusion is supported by two observations which are evident in many of these studies, namely;

1. Standard and non-standard procedures for the determination of ambient fibre concentrations require a predefined (and generally large, e.g. 300 litre) volume of air to be pumped in order to collect sufficient fibres onto filters for examination and quantification of fibre release, and,
2. When *outside* air fibre concentrations are measured these concentrations are very low and decline rapidly with distance from the non-friable ABM source. The literature indicates an exponential decline of fibres in the air from the ABM source but these observed declines will depend on many other external factors (e.g. wind strength, raining or dry, etc.).

In a review of the area Brown (1998) supports the general professional opinion that the environmental release of asbestos fibres from non-friable ABMs is extremely low. Nonetheless, even though asbestos fibre releases can be measured and quantified by electron microscopy the biological significance of these releases is still uncertain. In comparison to other human activities releasing asbestos fibres (such as machining, polishing, demolition and renovation) the release from weathered asbestos-cement sheeting and similar materials is very small. Basic research into the human health effects of asbestos fibres has failed for many reasons to determine a threshold exposure level (i.e. no observable adverse effect level) (ATSDR 2001). Although weathering and/or corrosion may contribute to the overall body burden of asbestos fibres there are instances of high residential fibre exposure that are more amenable to controls.

Overall, materials containing asbestos are more hazardous in a friable state. Asbestos-cement is considered a non-friable form of asbestos and can be expected to present less of a hazard when not disturbed or otherwise handled (e.g., by using power tools and other machinery). Nonetheless, non-friable ABMs are classified as friable when severe deterioration disturbs the matrix and releases asbestos fibres. Under these circumstances, the extent of degradation of ABMs requires a visual assessment on a case-by-case basis of each building product in each building (J Crea, *pers. comm.*). This should be conducted by a technically competent individual such as an industrial hygienist with specialist knowledge in the area (Brown 2000).

This review of the currently available literature indicates that in most circumstances high levels of asbestos fibre release from aging, weathering and/or corroding ABMs does not appear to be a common event. However, in order to determine any potential risk to human health, such forms of asbestos fibre exposure should also be considered in the context of the length of time of exposure.

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