

**BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL,
PRINCIPAL BENCH, NEW DELHI.
ORIGINAL APPLICATION NO. 298 OF 2023**

IN THE MATTER OF:

Dr. Raja Singh

...Applicant

Vs.

Union of India & Ors.

...Respondents

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1.	Sur-Rejoinder on behalf of Respondent No. 4 to Applicant's filed on 02.05.2024.	
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3.	Annexure- B A copy of Environmental Health Criteria 203: Chrysotile asbestos. Geneva: World Health Organisation, International Program on Chemical Safety: 1998	

4.	Annexure- C A copy of the World Health Assembly resolution being WHA 60.26 dated 23.05.2007	
5.	Annexure- D (Colly) Copies of letters dated November 2, 2004, and on June 24, 2005, issued by the Ministry of Chemicals and Fertilizers, Government of India, to the answering Respondent	
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Date: 17.09.2024

Place: New Delhi

A. Virmani

(RASHMI VIRMANI) (ANKIT VIRMANI)

E.NO. D-89/88; E.NO. D/2234-B/2009

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**BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL,
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IN THE MATTER OF:

Dr. Raja Singh

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**SUR-REJOINDER ON BEHALF OF RESPONDENT NO. 4 TO THE
APPLICANT'S REJOINDER FILED ON 02.05.2024**

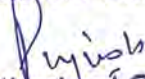
MOST RESPECTFULLY SHOWETH:

PRELIMINARY SUBMISSIONS –

1. Before setting out its paragraph-wise reply, the answering Respondent, an association of the leading manufacturers of fibre cement products in India, begs to make the following preliminary submissions for consideration of this Hon'ble Tribunal, each of which submission is without prejudice to the others.

2. That the captioned Sur-Rejoinder is being filed on behalf of the answering Respondent in view of the permission granted by this Hon'ble Tribunal vide order dated 18.07.2024, to deal with the new facts and documents sought to be introduced by the Applicant in his

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rejoinder dated 01.05.2024 to answering Respondent Reply and in his application dated 23.07.2024 seeking to place on record additional documents.

3. At the outset, all that is set out in answering Respondent's reply dated 01.04.2024 to the captioned OA is reiterated, and anything contrary thereto or inconsistent therewith, is denied. It is submitted that nothing be deemed to be denied for want of specific traverse.

THE MANUFACTURING PROCESS FOLLOWED BY MEMBERS OF THE ANSWERING RESPONDENT ENSURES THAT ASBESTOS FIBRES ARE LOCKED-IN AND NOT RELEASED INTO THE ENVIRONMENT.

4. The manufacturers follow a wet process of manufacture. During the manufacturing process, the asbestos fibres are firmly 'locked' into the cement matrix and cannot be emitted into the atmosphere under normal use. Asbestos cement roof sheets are a high-density material having density of 1.4 gram per cc and chrysotile fibre is firmly locked in Fibre Cement matrix with cement. As such, even after fixing the sheet on the roof, there is virtually no chance of fibre being air borne even on weathering or breakage. A note containing the wet process of manufacture is attached to the Reply of the answering Respondent.¹,
5. The key ingredients of asbestos cement (also known as 'fibre cement') products, including roofing sheets, manufactured by the members of Applicant, are as under (concentration by weight):

¹ Annexure A @ p.513 of R4's Reply.

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- i. Chrysotile (white asbestos) fibres - 7-9%.
 - ii. Cement - about 40%.
 - iii. Fly Ash - about 30%; and
 - iv. The rest comprising of wood pulp and water
6. Full precautions and safety measures are taken by members of the answering Respondent during this manufacturing process to ensure *inter alia* that:
 - a. The exposure of workers to asbestos fibre is minimized and concentration levels of asbestos are below the prescribed standard; and
 - b. Emissions from the units are below prescribed standards. All directions of the Hon'ble Supreme Court as well as all relevant laws in this regard are rigorously followed and implemented.

ASBESTOS USE IS REGULATED, AND NOT BANNED, IN INDIA.

7. It is submitted that the use of asbestos in India is regulated, and the Government of India has not banned the use of asbestos. Pertinently, in response to a Question posed in Lok Sabha *inter alia* regarding the types of asbestos used and whether the Government intends to impose ban on use of asbestos, the Minister of Chemicals and Fertilizers has given the following response on 01.04.2022 *inter alia* explaining some of the regulation on asbestos to ensure safe use:²

“(a) to (d): There are six known varieties of Asbestos, namely, Crocidolite, Actinolite, Anthophyllite, Amostile, Tremolite and Chrysotile. Out of these varieties of asbestos, Chrysotile is majorly used in chemical and petrochemical sector.

² Annexure E @ p.568 of R4's Reply.

Government of India has not banned the use of any type of asbestos in the country. The Crocidolite, Actinolite, Anthophyllite, Amostile, Tremolite varieties of asbestos are listed in Annexure-III (List of certain hazardous Chemicals and Pesticides) of the Rotterdam Convention and are subject to Prior Information Consent (PIC) procedure by the exporting country for the imports to India. However, the Chrysotile asbestos is not included in Annexure-III of the Rotterdam Convention and is imported without any prior consent.

However, the pollution emanating from industries/activities engaged in use of asbestos, is regulated through revised emission standards for 'Asbestos Based Products Manufacturing Industries' notified in March, 2006 by Ministry of Environment, Forest & Climate Change under Environmental (Protection) First Amendment Rules, 2006. Further, the 'General Emission Standards – Part D' notified under the Environment (Protection) Rules, 1986 also prescribe concentration based limits of asbestos. All these standards are enforced through the State Pollution control Boards/Pollution Control Committees and are monitored by Ministry of Environment, Forest and Climate Change.

In India, most of the asbestos industry follow the wet processes which minimizes the dispersion of fibres in the air. Therefore, Government of India has not advocated listing of Chrysotile asbestos in Annexure III of the Rotterdam convention in the meeting of Conference of Parties (CoPs) to the Basel, Rotterdam and Stockholm conventions.

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(e) The safe use of Asbestos is regulated as follows:

(i) The First Schedule under Section 2 (cb) of the Factories (Amendment) Act, 1987 enlists Industries involving hazardous process wherein the asbestos fibre related work in asbestos cement product industries is identified as "Hazardous Process."

(ii) Under Section 41C of the Factories (Amendment) Act, 1987 the Occupier of the factory is assigned to specific responsibility in relation to hazardous process. It involves:

a. Maintenance and update of health record of workers.

b. Medical examination of every worker.

c. Appointment of competent person.

(iii) According to the Third Schedule and section 89 of the Factories Act, Asbestosis comes under the list of Notifiable Occupation Diseases. It is also compensable under the Employee's Compensation Act, 1923 and Employees' State Insurance Act, 1948.

(iv) The occupier of the factory carrying a 'Hazardous Process' shall provide and maintain in good order in Occupational Health Centre with the service and facilities as per scale laid down under Factories Act.

(v) Model Rules are framed by Directorate General Factory Advice Service and Labour Institutes (DGFASLI) under the Factories Act. Schedule XIV of Model Rules under Section 87 on "Handling and Processing of Asbestos, Manufacture of any Article or Substance of Asbestos and any other Processes of Manufacture or otherwise in which Asbestos is used in any Form", provides the detailed guidelines on various aspects of safety and health for asbestos handling. The Factories Act,

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1948 and the State Factories Rules framed thereunder are enforced by the respective State Governments.

(f) DGFASLI under the Ministry of Labour and Employment, carried out a "National Study on Occupational Safety, Health and Working Environment in Asbestos Cement Product Industries" from November, 2018 to February, 2019 covering 50 functional asbestos cement product industries of the country. Out of 2603 workers, 10 cases were found to be suspected cases of asbestos related disorders. The concentration of airborne fibres in industries where inbuilt environmental control measures are in place and good practices followed, were found to be quite low as compared to those units where such measures are unavailable. It was also found that the airborne levels of asbestos fibres in 35 industries were well within the permissible limit of exposure i.e. 0.1 fibre/cc and the concentration of asbestos fibre exceeded the permissible limit in 15 industries, where it ranged from 0.185 to 0.400 fibre/cc."

(emphasis supplied)

Requirement of prior Environment Clearance for setting up asbestos manufacturing plant.

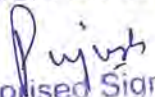
8. The Ministry of Environment, Forest and Climate Change (MoEFCC) requires any industry seeking to engage in manufacture of asbestos-based products to apply for and obtain a prior Environmental Clearance (EC) under the Environment Impact Assessment Notification, 2006 [Item 4(c) in the Schedule]. ECs are granted subject to environmental safeguards.

Regulation under Factories Act, 1948.

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9. Further, the Factories Act, 1948 contains significant regulations governing the asbestos industry.
10. In addition to the above, it is submitted that as per the provisions contained under Section 2(cb) of the Factories Act, 1948 the "*Manufacture, handling and processing of Asbestos and its products*" is declared as a hazardous process and the same is listed in the First Schedule of the Act and accordingly provisions of Chapter IV-A of the Act relating to hazardous processes are applicable to such factories.
11. The permissible levels of asbestos fibre in work environment are given in Second Schedule of the Factories Act (0.1 fibres/cc).
12. Section 7A of the Factories Act provides that every occupier shall ensure, so far as reasonably practicable, the health, safety and welfare of all workers while they are at work in the factory registered under the Factories Act.
13. Further, Section 89 of the Factories Act prescribes that where any worker in a factory registered under the Act contracts any notifiable disease, including Asbestosis, specified under the Act, the manager of the factory shall report the same to the Chief Inspector of Factories and other authorities in their State Factories Rules which is enforced by the State Governments who are empowered under the Act to initiate penal action under Section 92 of the Act for violation of any of the provision of the Act and the Rules framed thereunder.

Concentration limits of asbestos in air are provided under the Environment (Protection) Rules, 1986.

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14. The 'General Emission Standards – Part D' notified under the Environment (Protection) Rules, 1986 ("EP Rules") also prescribe concentration-based limits of asbestos. These are "4 Fibres/cc and dust should not be more than 2 mg/Nm³". Further, item 27 under Schedule I of the EP Rules provides for standards for emission for all types of asbestos manufacturing units (including all processes involving the use of asbestos). These are fixed at "0.5 fibre /cc for one year from the date of notification 0.2 fibre /cc [after one year from the date of notification] 2 mg/m³ (normal)". All these standards are enforced through the State Pollution control Boards/Pollution Control Committees and are monitored by Ministry of Environment, Forest and Climate Change.

Standards for asbestos cement roof sheets are laid down by Bureau of Indian Standards – compliance with these standards shall become mandatory w.e.f. 07.09.2024.

15. The Bureau of Indian Standards ("BIS") has laid down a large number of standards for asbestos-cement products and their safe use and handling (details @ pp.481-484 of Reply of R4).
16. It is further submitted that for laying down specifications for asbestos cement corrugated and semi-corrugated roof sheets, BIS has laid down Indian Standard (IS) 459:1992.³
17. Recently, the Department for Promotion of Industry and Internal Trade, Ministry of Commerce and Industry has notified the 'Asbestos or Fibre Cement based Products (Quality Control) Order, 2024' in the Official Gazette on 07.03.2024 (to come into force w.e.f. 07.09.2024). This order, passed under S.16 of the

³ Annexure D @ p.565 of the answering Respondent's Reply.

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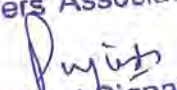
Bureau of Indian Standards Act, 2016, mandates compliance with relevant BIS standards (including IS 459:1992) and provides for penalty for contravention of its provisions.

18. Pertinently, the asbestos-cement products (including roof sheets) manufactured by the members of answering Respondent strictly conform to the applicable BIS specifications.
19. In compliance with IS 459:1992, the members of the answering Respondent provide the safety rules sheet at the time of delivery of every asbestos cement sheet as per clause 13 of the said standard.

Guidelines for Safe Use of Products Containing Asbestos:

20. It is submitted that the Applicant has alleged at para 28 of the Rejoinder that IS 11769 (Part 1) -1987,⁴ being the relevant BIS standard for safe use of asbestos roof sheets in schools, does not consider the weathering of such roofing and talks about manual methods for cutting and drilling of asbestos cement roofing. In this regard, it is submitted that IS 11769 (Part 1) -1987 (a) categorically recognizes that asbestos fibres are bound in cement and "*there is very little possibility of generation of airborne asbestos fibres during any reasonable handling, transport, storage and use of such products...*"; and (b) recommends *inter alia* the following measures for avoiding dust exposure during handling and installation:
 - a. hand tools or slow running tools that produce only coarse dust or chips may be preferred over high-speed machines which generate inhalable dust (Ref.: para 5.2 @ p. 1217 of Rejoinder);

⁴ This IS Standard is at Annexure K @ p.1212 of Applicant's Rejoinder to R4's Reply.

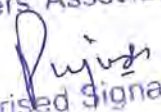
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- b. When high speed tools are used, they shall be fitted with efficient dust extraction equipment designed for the purpose (Ref.: para 5.3 @ p. 1217),
 - c. use of power operated drills for drilling. [Ref.: paras 6.1 and 6.2 (a) @p.1218].
21. It is, therefore, evident that low speed tools are to be preferred, but even high-speed tools can be used with appropriate dust extraction equipment. Pertinently, there is no recommendation to phase out or prohibit use of asbestos roof sheets.

India is opposing the move to include Chrysotile asbestos in Annex III of Rotterdam Convention

22. Under the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, 1998 ('Rotterdam Convention'), certain hazardous chemicals enlisted in Annex III can only be imported into a country after obtaining prior informed consent of the importing country.
23. During the recent Conference of Parties 11 held from 1st May – 12th May 2023 at Geneva (COP 11), India has along with other countries categorically opposed a move to insert chrysotile in Annex III to the Rotterdam Convention on account of *lack of up-to-date scientific literature showing negative impact of chrysotile asbestos on workers' health.*"⁵
24. Pertinently, import of chrysotile asbestos is permitted in India, and

⁵ *Earth Negotiations Bulletin, Vol. 15, No. 301* dated 10 May 2023, Annexure II @ pp.608-611 of R4's Reply

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only the mining of asbestos is banned.

STUDIES ON NON-OCCUPATIONAL EXPOSURE TO ASBESTOS ROOF SHEETS SHOW THAT USE OF ASBESTOS ROOF SHEETS DOES NOT POSE RISK TO HEALTH

25. It is submitted that the only conclusive study on non-occupational exposure to asbestos roof sheets in India is the 2012 study titled '*Study of Health hazards/ Environmental hazards resulting from use of Chrysotile variety of Asbestos in the Country*' conducted by the National Institute of Occupational Health, Indian Council of Medical Research. The objectives of this study were:

“(a) to find out concentrations of chrysotile asbestos fibres in the workplace environment, in the vicinity of the process area and also in the area where chrysotile asbestos products are in use; and

(b) to assess the health status of the workers engaged in the organized and small-scale industries, the residents of the vicinity as well as the end-users of chrysotile asbestos products” (Ann. P to the answering Respondent’s Reply @pp. 819-820).

The study included 135 end-users of chrysotile-asbestos products (Ann. P to the answering Respondent’s Reply @p. 822). In two villages near Hyderabad viz. Velmala and Sandhuguda, indoor samples were taken under the asbestos sheet roof thereby suggesting levels of exposure to end-users, while outdoor samples were taken in the ambient air suggesting the

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exposure to community (**Ann. P to the answering Respondent's Reply @p. 843**). Pertinently, the study highlighted that the asbestos fibre concentrations both indoor and outdoor were found to be significantly lower than not only the then Indian permissible exposure level of 1 fibre/ ml but also the permissible exposure level of 0.1 fibre/ ml recommended by international agencies (**Ann. P to the answering Respondent's Reply @pp. 843-844, Table 25**).

Further, health conditions of these end-users were also examined, and other aspects such as use of tobacco by end-users for smoking (36.7%) and chewing (5.2%) were also considered (**Ann. P to the answering Respondent's Reply @p. 845**). On pulmonary function test, 11.9% of end-users were found to have restrictive disorder, 7.4% were found to have obstructive abnormality, 2.2% were having combined type of abnormality and rest were normal. **There were no cases of interstitial lung fibrosis.** There was no finding that asbestos exposure is causing any of the above conditions.

The relevant portion of the study is as under:

"Fiber concentrations in the factory are shown in Table 24 while the fibre levels in the village situated near the vicinity of the factory are shown in Table 25. Permissible Exposure level (PEL) in India is 1 fiber/ml where as other agencies like OSHA, NIOSH and ACGIH recommend 0.1 fiber/ml. It can be seen from Table 24 and 25 that fiber concentrations are lower than the PELs.

...

Highlights

- *Fiber level in all the workplaces in the vicinity of the factory was below the national and*

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international standards

- ..
- *No subject was found to have radiographic features suggestive of interstitial lung fibrosis.*”
(emphasis supplied)

There is, therefore, no scientific evidence to suggest that non-occupational exposure to asbestos for users of asbestos-cement roof sheets in India is either beyond permissible exposure level or is causing any adverse health effect.

26. Further, in similar conditions, the Sri Lankan Government has published a study in 2021 titled *“Air Quality Study on Concentrations and Significance of Chrysotile Asbestos Fiber in Household Ambient Environment in Sri Lanka”* – conducted by the Environmental Studies and Services Division, National Building Research Organisation, Colombo. The said study was conducted with an aim of assessing the exposure levels of Asbestos fibre in domestic setting, representing different environmental conditions in Colombo and Anuradhapura districts in Sri Lanka. One of the objectives was examination of air-borne Chrysotile fibres in the air within the household indoors and also in the ambient environment at 72 houses representing different environment conditions. These houses included those which used asbestos roof and/ or asbestos ceiling, and also those which did not. The study found the fibre concentrations across all households in both Districts to be below the level of 0.0009 fibre/cc recommended by US-EPA (non-occupational areas). The said technical report has concluded *inter alia* that:

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“... ”

- *The average fiber concentration levels recorded at all selected households in different environmental conditions are below the UA-EPA standard levels (0.0009 f/cc) for asbestos fiber in non-occupational buildings (such as residential houses). The levels also below the lifetime exposure levels (0.0005 f/cc) proposed to WHO by authors in a population of whom 30% are smokers, the excess risk due to lung cancer would be in the order of $10^6 - 10^5$ and the ambient fiber standard levels stipulated in different counties as given in Table 4.1.*
- *The recorded asbestos fiber levels in all environment conditions are well below the maximum exposure levels of 0.1 f/cm³ asbestos fiber recommended by OSHA, NOISH and ACGIH standards for workplaces.*
- *It also represent that the fiber levels are gradually decrease from the house category of having used asbestos ceiling and roofing (AR & AC) to the category of non-asbestos ceiling and roofing (NARO, NAR & NAC). However, there is no significant correlation.*

“... ”

A copy of the technical report titled “*Air Quality Study on Concentrations and Significance of Chrysotile Asbestos Fiber in Household Ambient Environment in Sri Lanka*” is annexed hereto as **Annexure -A**.

STUDIES AND PUBLICATIONS CITED BY THE

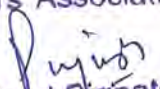
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APPLICANT ARE IRRELEVANT, INAPPLICABLE AND ALSO UNRELIABLE

27. The emphasized portion of the WHO publication titled “*Chrysotile Asbestos*”, which claims that “*in-place materials have the potential to deteriorate and pose a risk to those carrying out alterations, maintenance and demolition.*”, as relied upon by the Applicant, is not a scientific risk assessment and is not based on any evidence whatsoever of exposure to asbestos fibres in India on account of use of asbestos cement roof sheets over time. This document cites ‘*Environmental Health Criteria 203: Chrysotile asbestos. Geneva: World Health Organisation, International Program on Chemical Safety: 1998*’ (at footnote 5) as the source for this above said claim. It is evident from a perusal of this source document that this document was identifying risk in demolition on account of presence of large quantities of materials containing friable asbestos (both chrysotile and amphibole) in buildings (para 9.1 as well as para 10 (c) of the aforesaid Environmental Health Criteria 203); and not on account of asbestos-cement roof sheets where the asbestos is firmly locked with the cement matrix. It is therefore, submitted that the extract mentioned in the paragraph under sur-rejoinder is not relevant to the present case, which relates to asbestos-cement roof sheets.

A copy of *Environmental Health Criteria 203: Chrysotile asbestos. Geneva: World Health Organisation, International Program on Chemical Safety: 1998* downloaded from <https://www.inchem.org/documents/ehc/ehc/ehc203.htm#PartNumber:10> on 29.08.2024 is annexed hereto as **Annexure- B.**

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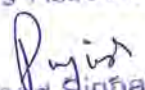
In this regard it is submitted that the World Health Assembly (“WHA”) – the apex decision-making body of WHO, in its 60th meeting, passed a resolution being WHA 60.26 on 23.05.2007 endorsing the Global Plan of Action on Workers’ Health 2008-2017, which advocates a differentiated approach to regulating the various forms of asbestos. As already submitted, India has adopted a differentiated approach to various forms of asbestos – while all other forms of asbestos are prohibited in India, import and use of chrysotile asbestos is permitted. The manufacture of asbestos-based products is highly regulated, requires environmental clearance, and the maximum permissible exposure levels to asbestos fibres are set at 0.1 fibre/cc under the Factories Act, 1948. BIS has laid down standards which give the detailed specifications of asbestos-based products including asbestos-cement roof sheets. These standards must mandatorily be complied with. India has opposed the attempts by certain other countries to place chrysotile asbestos in Annex III of the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, 1998.

A copy of the World Health Assembly resolution being WHA 60.26 dated 23.05.2007 is annexed hereto as **Annexure- C**.

28. As regards the study titled ‘*Releasability of asbestos fibres from weathered roof cement*⁶’ relied upon by the Applicant, it is submitted that:

- i. the study is not an independent and impartial study as it acknowledges that the said study was funded by a law firm representing a plaintiff alleging asbestos exposure.

⁶ Annexure- G @pp. 1171-1191 to the Rejoinder

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- ii. The said study also does not discuss airborne fibre concentrations resulting from release of airborne dust, nor does it discuss the health effects of inhaling the fibres.
- iii. The samples as analysed in the said study were exposed to extreme conditions, as it was heated at 480 degrees for at least 6 hours and later acid washed and therefore the conditions in which this study has been done, does not correspond to natural weathering of asbestos roof sheets.

29. As regards the study titled '*Surface of Asbestos-cement (AC) Roof Sheets and Assessment of the Risk of Asbestos Release*'⁷, relied upon by the Applicant, it is submitted that the said study is also not applicable to India *inter alia* for the following reasons:

- i. Study states that asbestos cement products contain 8-16% of asbestos (as opposed to chrysotile fibres in the range of 6.5 - 7% as used in asbestos cement products by members of answering Respondent)
- ii. The study does not mention the density of the sheets nor the type of asbestos fibre used.
- iii. The samples analysed in the said study were taken from roofs of buildings in a small village, different downs and industrial centres located in Poland, most of these samples were exposed to acid rains and the study also highlights that acid rains accelerated corrosion.
- iv. It is submitted that the climatic conditions in India are different from the climatic conditions in Poland and other Eastern European countries where acid rains are

⁷ Annexure- H @pp. 1192-1200 to the Rejoinder

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more prevalent. Acid rains are not prevalent or common in India.

Further, the answering Respondent craves leave to refer and rely upon the said studies for their true and correct meaning, and interpretation, at the time of hearing.

30. As regard the publication relied upon by the Applicant, titled "*Vision Statement on Environment and Human Health*" by the Ministry of Environment, Forests, and Climate Change it is submitted that the said publication is not a scientific risk assessment of health impact of use of asbestos cement roof sheets in schools, nor is this publication based on any other such risk assessment.

31. As regards the study titled '*Asbestos in Indian Talc*'⁸, relied upon by the Applicant, it is submitted that the said study has been cited out of context for the following reasons:
 - a. The study pertains to the presence of asbestos in commercial talc. It bears no relevance to the context of OA 298/2023, which the Applicant has filed seeking directions to stop the use of asbestos roof sheets in schools across India.
 - b. The study deals with '*tremolite*' variety of asbestos. It is reiterated that the Respondent only uses the '*chrysotile*' variety of asbestos.
 - c. The applicant highlighted that the study states '*Further, it has been shown that as little as 0.001% of asbestos in loose clay soil can produce around 0.1 fiber/cc of asbestos in air with respirable dust concentration around 5 mg/m3.*' In this regard, it is submitted that 0.1 fibre/cc is the Permissible exposure limit (PEL) in India. Further, during the

⁸ Annexure- J @pp. 1203-1210 to the Rejoinder

manufacture of asbestos roofing sheets, chrysotile fibre is firmly locked in Fibre Cement matrix with cement. As such, even after fixing of the sheet on the roof, there is virtually no chance of fibre being air borne even on weathering or breakage.

Further, the answering Respondent craves leave to refer and rely upon the said study for its true and correct meaning, and interpretation, at the time of hearing.

32. As regards the study titled '*The natural reduction of threat in selected systems of old buildings containing asbestos*'⁹ relied upon by the Applicant, it is submitted that under the head of 'Research material: building systems tested':

- a. this study focuses on typical Eastern European buildings from 1970 to 1990. It is submitted that the said research study also does not mention the types of asbestos that were being used in these old buildings. That the harmful variety of asbestos are no longer utilized in either Western countries or India, and only Chrysotile is used, that too only 7-9% which is firmly bound in the cement matrix.
- b. It is submitted that building material as mentioned in the said study deals with Asbestos containing material ("ACM") in friable form and these ACMs contained 20% asbestos.
- c. These friable ACMs were used as insulation products which were applied to walls and ceiling where the asbestos was loosely bound. Such products are not used in India due to the weather conditions. It is further reiterated that asbestos cement products as manufactured by the members of answering Respondent are different from friable or crumbly

⁹ Annexure A @ internal pp. 11-24 of the OA

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asbestos which was earlier used in western countries and these products as used in western countries, when dry, are reduced to powder by applying hand pressure. It is also submitted that schools in India use Asbestos Cement sheets that contain only around 7% of chrysotile asbestos which is firmly bound in layers of cement and fly ash matrix, leaving no scope of release of asbestos fibres ordinarily into the environment. Further, it is respectfully submitted that the said research study also encompasses the following conclusions: -

"3. If there is no evidence of an increase in the concentration of asbestos in the air, the removal of ACM from such facilities should be postponed until the building is no longer used.

...

5. The reduction of asbestos dust in buildings can be a normal and natural process after proper and long service life (if the operation is not accompanied by the destruction of asbestos). Such conditions are met by many buildings with non-friable ACM, in which asbestos is insulated from the internal air. An example of this construction is BISTYP."

Further, the answering Respondent craves leave to refer and rely upon the purported study cited in this paragraph for its true and correct meaning, and interpretation, at the time of hearing.

33. As regards the study titled '*Cancer mortality in chrysotile miners and millers, Russian Federation: main results (Asbestos Chrysotile Cohort-Study)*'¹⁰, the Applicant has highlighted that the study states, '*we observed an increased risk of mesothelioma with high exposure to chrysotile fibres*' It is submitted that the said statement has been cited wholly out of context, as the said statement is in reference to chrysotile miners and millers in the world's largest

¹⁰ Annexure- L/@pp. 1232-1241 to the Rejoinder

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active chrysotile mine, and does not relate to weathering of asbestos cement roof sheets.

Further, the answering Respondent craves leave to refer and rely upon the purported studies cited in this paragraph for their true and correct meaning, and interpretation, at the time of hearing.


THE ISSUE OF WHETHER OR NOT USE OF ASBESTOS SHOULD BE PROHIBITED HAS ALREADY BEEN DECIDED ON MERITS BY THE HON'BLE SUPREME COURT AND OTHER COURTS/ FORA

Judgments of Hon'ble Supreme Court

34. That the issue of whether or not use of asbestos should be prohibited has already been decided on merits *inter alia* by the Hon'ble Supreme Court in *Kalyaneshwari vs, UOI and Ors, (2011) 3 SCC 287*¹¹ wherein the Hon'ble Supreme Court was pleased to decline the prayer for ban on use of asbestos by holding *inter alia* as under:

"21. As already noticed, there is no law banning the use of asbestos in various manufacturing processes despite its adverse effects on human health. It is not for this Court to legislate and ban an activity under relevant laws. Every factory using or manufacturing asbestos, obtains a licence under the Factories Act as well as permission from the competent authorities including permission under the Environmental Laws. Once all the laws in force have been complied with and directions of this Court as contained in the case of Consumer Education and Research Centre (supra) are carried out in their true spirit, we see no reason as to why this Court, in exercise of its extraordinary jurisdiction under Article 32 of the Constitution, should ban such an activity when admittedly large number of families are

¹¹ Annexure- I (@ pp. 612-631 to the R4's Reply.

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dependent upon such processes. What has to be ensured is that proper precautions are taken. The Court had already made ILO guidelines as one of the safety measures to be complied with by the industries and it is expected of each State Government and the Union Government to ensure safe and controlled use of asbestos. What is required is better supervision and regulatory control rather than banning of the activity."

(emphasis supplied)

Judgments of Hon'ble Kerala High Court

35. Four petitions were filed by one Mr. Mukesh Jain before the Hon'ble Kerala State Human Rights Commission, Thiruvananthapuram ("KSHRC") claiming *inter alia* that asbestos is non-biodegradable and a health hazard to school children and if any damage is caused to asbestos roof sheets used in schools, it can result in release of small asbestos fibres that become airborne, and these fibres can cause serious lung diseases. In these petitions, KSHRC passed an order dated 31.01.2009¹² holding *inter alia* as under: -

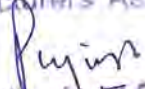
"1. The State Government will replace asbestos roofs of all schools buildings under its control with country tiles in a phased manner."

"2. The Government should see that in the future no new school is allowed to commence its functions with asbestos roofing.

..."

36. On coming to know of the above order, a member of the answering Respondent - M/s. Vishaka Industries Ltd. – filed a petition before the KSHRC seeking recall of the above order. On this petition, the

¹² Annexure- J (@pg 632-648) to the R4's Reply.

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KSHRC passed an order dated 07.05.2009¹³ clarifying that the above order dated 31.01.2009 is only recommendatory in nature and that KSHRC has no jurisdiction to recall its order.

37. Aggrieved by the above, Vishaka Industries Ltd. filed a writ petition before the Hon'ble High Court of Kerala. This writ petition was allowed vide judgment and order dated 07.08.2017,¹⁴ whereby the KSHRC order of 31.01.2009 was set aside and it was held *inter alia* as under (para 5 @ p.654 of Reply of the answering Respondent): -

"5... There are no data available before the commission to arrive that the asbestos sheet is hazardous to the health of children. If it would pose a threat to the health of the children, certainly, that could have been a matter for a decision by the commission. On mere surmises and conjunctures, the commission could not have ordered recommendation for replacement of asbestos sheet. The Commission relied upon the report of the World Health Organisation (WHO). All that could be seen that the asbestos sheet referred by WHO may depend upon the environmental setting it is used. It is necessary to verify what is the nature of the mixture that is used for the asbestos sheet. The asbestos sheet as such is not a threat as revealed from the judgment of the Hon'ble Supreme Court in Kalyaneshwari v. Union of India and Others [(2011) 3 SCC 387] relied by the learned counsel for the petitioner. In the absence of any evidence to show that the asbestos sheet would cause a serious threat to the life of the children, the Commission could not have made such recommendation as referred above. It is to be noted that the industrial rivalry and competition sometimes used as a platform to settle a score. The Commission should have been careful while entertaining such complaint especially when it appears that the complainant never

¹³ Annexure- K (@pg 649) to the R4's Reply.

¹⁴ Annexure- L (@pg 650-657) to R4's Reply.

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appeared before the Commission and also before this Court. In view of the above, the impugned order is set aside. The writ petition is disposed of as above."

(emphasis supplied)

38. The Applicant has, in fact, placed reliance on the above KSHRC order in support of his case without disclosing that the said order had been set aside by the Hon'ble High Court of Kerala.

Judgment of Hon'ble National Human Rights Commission of India

39. Before the Hon'ble National Human Rights Commission of India ("NHRC"), a complaint was filed by one Mr. Gopal Krishna seeking ban on asbestos usage. This complaint was disposed of by the Hon'ble NHRC vide order dated 08.08.2016¹⁵ by holding as under: -

"Pursuant to the directions of the Commission, Dr. Rohit Misra, Assistant Industrial Advisor, Ministry of Chemicals & Fertilizers, Deptt. of Chemicals and Petrochemicals, Govt. of India vide letter dated July, 2016 has informed the Commission that in order to take an appropriate and scientific stand in the International Forum on the issue related to health hazards posed by Chrysotile variety of Asbestos, Department of Chemicals and Petrochemicals had entrusted National Institute of Occupational Health (NIOH) to carry out a study on Health Hazards/Environmental Hazards resulting from the use of Chrysotile variety of Asbestos in the country, Later, with the approval of MoS (md. Charge) Chemicals & Fertilizers, it was decided to set up an Inter-Ministerial Committee for considering the issue of continuance or otherwise of the use of Chrysotile variety of asbestos in India, taking into account of NIOH report and other related issues,

¹⁵ Annexure- M @ pp. 658-659 to the R4's Reply

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On 27.8.2014, a meeting was held under the Chairmanship of Minister (Chemicals & Fertilizer) to consider the NIOH report. It was decided in the meeting that the NIOH report does not indicate any significant health/environment hazards resulting from the use of Chrysotile asbestos under proper conditions, coupled with the fact that asbestos products are quite cost effective for use by the masses, India may not support the inclusion of Chrysotile in Annexure-III at the COP Meeting in 2015. In the light of the above report, no further action by the Commission is called for. The case is closed.

(emphasis supplied)

40. In light of the above, it is humbly submitted that submissions raised by the Applicant that there are health effects on use of asbestos cement roofing in schools are misplaced and misconceived.

SUR-REJOINDER TO PARA WISE REJOINDER:

Without prejudice to all that is set out hereinabove, the para-wise response of the answering Respondent to the captioned Rejoinder is set out below:

41. That as regards the contents of paragraph 1 of the Rejoinder, all that is stated in the Reply of the answering Respondent and in the preliminary submissions hereto is reiterated is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is denied that asbestos cement roofing in schools is causing any adverse health effect, as alleged or at all.
42. That as regards the contents of paragraph 2 of the Rejoinder, all that is stated in the Reply of the answering Respondent and in the preliminary submissions hereto is reiterated is reiterated, and anything contrary thereto or inconsistent therewith is denied.

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43. That the contents of paragraph 3 of the Rejoinder need no sur-rejoinder.
44. That the contents of paragraph 4 of the Rejoinder are entirely misconceived and are denied. All that is stated in the Reply of the answering Respondent and in the preliminary submissions hereto is reiterated is reiterated. There is no scientific evidence of adverse health effects of asbestos cement roofing in schools. Therefore, the question of putting commercial interests at the cost of health and environment does not arise. The members of the answering Respondent are responsible organizations that follow all safety protocols. All that is set out in the Reply in this regard is reiterated. The Applicant is seeking to unfairly paint the members of the answering Respondent in a poor light. It is reiterated that the Fibre Cement industry plays a vital role in helping India accomplish its goals, particularly given its strong contribution to India's policy objectives relating to employment, innovation, and commitment to the environment. The sector contributes significantly to the economy, with a local cement and concrete value chain offering numerous benefits. As one of the important sectors of the Indian economy, the Fibre Cement Industry size is INR 8,000-10,000 crores and provides direct and indirect employment to almost 3 lakh people including manufacturing plants, dealer networks etc. Asbestos cement industry also uses fly ash as a raw material thereby playing a vital role in disposal of fly ash.
45. That as regards the contents of paragraphs 5 and 6 of the Rejoinder, all that is stated in the Reply of the answering Respondent and in the preliminary submissions hereto is reiterated is reiterated., and

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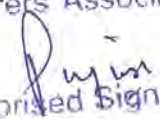
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anything contrary thereto or inconsistent therewith is denied.

Failure of alternatives to meet the Performance Standards set up by roof sheets manufactured using chrysotile asbestos

46. That the contents of paragraph 7, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is submitted that the contents of the Rejoinder are unfounded, misconceived, and incorrect, and therefore, denied. It is denied that companies that answering Respondent represents have made an attempt to switch to new alternatives instead of asbestos. The insinuation that the asbestos-cement products manufactured by such companies have harmful health effects for human beings, is entirely misconceived, incorrect and denied. It is denied that if asbestos would have been the only option, the companies may never have shifted to other alternatives. The suggestion that asbestos-cement products are risking health of Indians, especially Indian children, is incorrect, not backed by any evidence and is entirely misconceived. Without prejudice, it is submitted that while some companies had/ have come out with alternatives to asbestos-cement roof sheets, these alternatives are not viable alternatives for a variety of reasons. Everest Industries Ltd. (a member of the answering Respondent) promoted polycarbonate sheets, however, Everest Industries Ltd. has now stopped manufacturing these polycarbonate sheets since these sheets are not durable and only last for a couple of years and there is hardly any demand for the same. Further, these polycarbonate sheets let in at least 85% of light (**Ref.: Annexure-O of the Rejoinder @pp. 1251-1255**) and also lack the strength that asbestos cement roof sheets provide. Therefore, these

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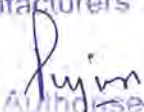

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polycarbonate sheets cannot be used as an alternative to asbestos cement roof sheets. Furthermore, Ramco Industries Ltd. (a member of the answering Respondent) manufactures polypropylene sheets, however, since these sheets are more expensive and less durable when compared to asbestos cement roof sheets, there is hardly demand for the same, the demand is comparable to 1% of total size of the asbestos cement sheet market. It would, therefore, be entirely incorrect to suggest that there are viable alternatives to asbestos cement roofing sheets or that the industry has switched to alternatives.

These alternatives have failed to match the performance standards set by chrysotile asbestos for *inter alia* the following reasons:

- a) The roofing sheets require high strength levels which are provided by chrysotile fibers. These chrysotile fibers are integral to the cement matrix, providing the necessary structural integrity as both cement and chrysotile fibre are silicate mineral. When the industry tried using the alternative fibres and tested the strength of the roofing sheets, they found the strength to be lacking. The requisite strength levels cannot be maintained by using the alternative fibres because polyester fibre does not mix well with cement and other raw materials. Therefore, without chrysotile fibers, desired strength levels cannot be achieved, and thus the products manufactured using alternative fibres cannot be used for roofing sheets as it compromises on safety of the persons who occupy the premises where the roofingsheets are installed.
- b) Chrysotile fibers, being naturally occurring, are more cost-effective compared to their synthetic counterparts. Utilizing

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alternative fibers results in increased production costs for asbestos cement products, ultimately burdening consumers with significantly higher prices.

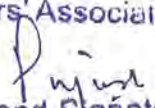
Therefore, in summary, the limitations of alternative fibers in replicating the performance and cost-effectiveness of chrysotile asbestos make them unsuitable substitutes in the fiber cement industry.

47. That as regards the contents of paragraphs 8 and 9 of the Rejoinder, it is denied that in schools with asbestos roofing, the children are exposed to a carcinogen which may cause disease during the breadwinning period of the child's life. It is submitted that there is no evidence that the health of children is getting adversely affected by the use of asbestos cement roof sheets. All that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated

Incorrect Paragraph Numbering in the Rejoinder: Numbering Restarts from Paragraph 9 after Paragraph 14.

48. That the contents of paragraphs 10 to 14 and wrongly numbered paragraphs 9-14 (which appear immediately after the correctly numbered paragraph 14) of the Rejoinder are unfounded, misconceived, and denied. All that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. The answering Respondent craves leave to refer to and rely on the relevant provisions and judicial precedents for their true and correct interpretation.

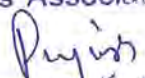
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49. That the contents of paragraph 15 of the Rejoinder are unfounded, misconceived, and incorrect, and therefore, denied and all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated. The purported decisions by the organizations/authorities mentioned in paragraph 15 of the Rejoinder to not use asbestos cement roofing sheets are not on account of any health risk posed by asbestos cement roofing nor are these purported decisions not supported by any scientific risk assessment regarding the likelihood or levels of exposure to asbestos fibers from such roofing. For instance, the Applicant has alleged at para 15(a) that a decision was taken by Western Railways to *'phase out the use of asbestos roofing'* which was based on the recommendations in a guideline submitted by the Railway Design Standard Organisation (**Annexure B of the Rejoinder @pp. 1039-1072**). In the said Guidelines titled *'Standardization of Specification of flooring, Roofing material for platform covering in Station Premises & Standardization of Specification of Workshop flooring'*, it is mentioned at page 1 of the said Guidelines (**@pg. 1044 of the Rejoinder**) that the *"there is large variation in flooring, roofing standards in Railway and nothing has been laid down for different categories of stations. At Railway workshops type of flooring is also not specified. Hence, need to standardize the different type of flooring, roofing at different category of stations and Workshop was felt."*

(emphasis supplied).

It is therefore clear that since there was use of different types of materials in flooring, walling, ceiling, etc. for various areas on the station premises that is why a need was felt to have standard materials. Further, there is nothing in the said Guidelines that show

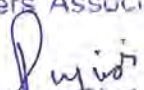
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that asbestos roofing is a health hazard. In fact, asbestos cement roofing is widely used across the country, including by a host of governmental organisations and authorities.

As regards the contents of paragraph 15 (e), it is submitted that the Order dated passed by the Hon'ble National Human Rights Commission in case No. 693/30/97-98 is not supported by any scientific risk assessment regarding the likelihood or levels of exposure to asbestos fibers from asbestos cement roofing. The answering Respondent craves leave to refer and rely upon the ruling given by the Hon'ble National Human Rights Commission in case No. 693/30/97-98 for its true and correct meaning, interpretation, scope and legal effect thereof, at the time of hearing.

50. That as regards the contents of paragraph 16 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied.
51. That as regards the content of paragraphs 17 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied.
52. That as regards the contents of paragraph 18 of the Rejoinder, to the best of the knowledge of the answering Respondent, asbestos roof sheets used in schools in India have at all times been made using chrysotile asbestos, and not the other varieties of asbestos. In any

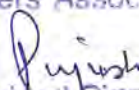
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case, the answering Respondent is not advocating for use for any other variety of asbestos, besides chrysotile, in the roof sheets. All that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated

53. That the contents of paragraph 19 of the Rejoinder are unfounded, misconceived, and incorrect, and therefore, denied and all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. The answering Respondent craves leave to refer and rely upon the ruling given by the Hon'ble Supreme Court in the judgement of *Kalyaneshwari v. Union of India & Ors. (2011) 3 SCC 287* for its true and correct meaning, interpretation, scope and legal effect thereof, at the time of hearing.
54. That as regards the contents of paragraphs 20 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras are reiterated, and anything contrary thereto or inconsistent therewith is denied.
55. That the contents of paragraphs 21 and 22 of the Rejoinder are unfounded, misconceived, and incorrect, and therefore, denied. The answering Respondent received two letters from the Ministry of Chemicals and Fertilizers, Government of India, dated November 2, 2004, and June 24, 2005, **requesting consideration for partial financial support for the NIOH study. The answering Respondent, having no prior involvement in the study or its initiation, provided financial support solely in response to these**

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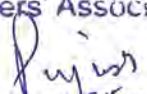

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requests. Notably, out of the total study cost of approximately Rs. 58 lakhs, the answering Respondent contributed only Rs. 16 lakhs, a minor portion, at the specific request of the Ministry. This funding was extended as part of the answering Respondent's social responsibility activities and not due to any direct interest or stake in the outcome of the study. At no point did the answering Respondent influence or interfere with the scope, methodology, or findings of the NIOH study. It is further reiterated that the NIOH study also covered non-occupational exposure to asbestos roof sheets, and was not limited to only occupational exposure as is sought to be incorrectly portrayed in the Rejoinder.

Copies of letters dated November 2, 2004, and on June 24, 2005 issued by the Ministry of Chemicals and Fertilizers, Government of India, to the answering Respondent, are annexed hereto as **Annexure- D (Colly).**

56. That the contents of paragraph 23 of the Rejoinder are unfounded, misconceived, and incorrect, and therefore, denied. All that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated. The answering Respondent craves leave to refer and rely upon the said study titled '*National Study of Occupational Safety, Health and Working Environment in Asbestos-Cement Product Industries*' carried out by the Director General Factory Advice Service and Labour Industries (DGFASLI), Ministry of Labour and Employment, Government of India for its true and correct meaning, and interpretation, at the time of hearing. It is reiterated that Members of the answering Respondent maintain health records of every worker up to a minimum period of 40 years from start of

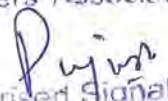
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employment or 15 years after retirement or cessation of employment, whichever is later, in accordance with the directions laid down by the Hon'ble Supreme Court in *Consumer Education and Research Centre v. Union of India*, (1995)3 SCC 42. It is further submitted that the contents of paragraph 7 of the additional documents filed in addition to the Rejoinder dated 23.07.2024 i.e., "7. In the same judgment, i.e., *Consumer Education & Research Centre & Ors vs. Union of India & Ors 1995 3 SCC 42* the Hon'ble Supreme Court had stated that recommendations by ILO will be kept into consideration in the future...." are unfounded, misconceived, and incorrect, and therefore, denied.

57. That the contents of paragraphs 24 and 25 of the Rejoinder are unfounded, misconceived, and incorrect, and therefore, denied. All that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. The answering Respondent craves leave to refer and rely upon the said study for its true and correct meaning, and interpretation, at the time of hearing.
58. That the contents of paragraph 26 are entirely speculative, not based on a shred of evidence and are entirely baseless and denied. All that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied.
59. That as regards the contents of paragraph 27 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is


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reiterated, and anything contrary thereto or inconsistent therewith is denied.

60. That as regards the contents of paragraph 28 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied.
61. That as regards the contents of paragraph 29 of the Rejoinder requires no Sur-Rejoinder.
62. As regards the contents of paragraphs 30 and 31 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. The answering Respondent craves leave to refer and rely upon the said study for its true and correct meaning, and interpretation, at the time of hearing.
63. As regards the contents of paragraph 32 of the Rejoinder, the answering Respondent craves leave to refer and rely upon the ruling given by this Hon'ble Tribunal in the judgement of *Narendra Pratap Singh v. Central Pollution Control Board (O.A. 649/2022)* for its true and correct meaning, interpretation, scope and legal effect thereof, at the time of hearing. It is denied that any number of asbestos fibres are an air pollutant. It is reiterated that the permissible exposure levels of asbestos have been fixed at 0.1 fibre/cc under the Factories Act, 1948. It is denied that asbestos fibres will become either a soil pollutant or a water pollutant, as alleged

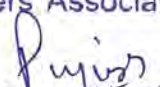
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or at all. There is no shred of evidence in support of these allegations made by the Applicant in the paragraph under sur-rejoinder. All that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied.

64. As regards contents of paragraphs 33 and 34 of the Rejoinder, all that is stated in the Reply of the answering Respondent including at paragraphs 1,2 and 5 of the para-wise reply in the Reply and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. The Applicant's claims as regards his qualification, work experience, etc. are not admitted and the Applicant is put to strict proof thereof.
65. As regards contents of paragraph 35 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is denied that out of the three, the matter OA 206/2022 is directly related to this matter as it deals with indoor air being part of the Air (Prevention and Control of Pollution) Act, 1981, and averments made in paragraph 3 of the para wise reply in the Reply are reiterated. It is submitted that there was no deliberation/discussion on asbestos in OA 206/2022 and the orders passed in OA 206/2022 do not pertain to asbestos cement product and have no application to this present case.
66. As regards contents of paragraph 36 of the Rejoinder, all that is

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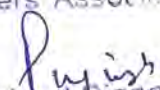

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stated in the Reply of the answering Respondent including at paragraph 4 of the para-wise reply in the Reply and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied.

67. As regards contents of paragraph 37 of the Rejoinder, all that is stated in the Reply of the answering Respondent is reiterated including at paragraph 6 of the para-wise reply in the Reply, and in the preceding paras including preliminary submissions hereto and anything contrary thereto or inconsistent therewith is denied. As regards the study titled '*Asbestos in the Environment*' by W.J Nicholson and F.L. Pundsack, the answering Respondent craves leave to refer and rely upon the purported study cited in this paragraph for its true and correct meaning, interpretation, scope and legal effect thereof, at the time of hearing.

68. As regards contents of paragraphs 38 and 39 of the Rejoinder, all that is stated in the Reply of the answering Respondent including at paragraph 6 of the para-wise reply in the Reply and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. The answering Respondent craves leave to refer and rely upon purported studies cited in this paragraph for its true and correct meaning, and interpretation, at the time of hearing. It is denied that the answering Respondent has not provided the full copy of the study titled '*Biological effect of mineral fibres*' and may have copied out of context without looking at the totality of the issue. In this regard, it is submitted that '*Biological Effect of Mineral Fibres*' is the name of the publication containing the study titled "*Asbestos in the Environment.*" The entire text of this study has been duly annexed

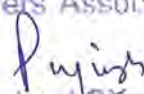
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as **Annexure S** to the Reply of the answering Respondent.

69. As regards contents of paragraph 40 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. The answering Respondent craves leave to refer and rely upon the purported studies cited in this paragraph for their true and correct meaning, and interpretation, at the time of hearing.
70. As regards contents of paragraph 41 of the Rejoinder, all that is stated in the Reply of the answering Respondent including at paragraph 9 of the para-wise reply in the Reply and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is further submitted that it is incorrect to suggest that since the asbestos fibre is only 7-9%, the overall efficiency by using other materials can be studied and optimised in order to do away with a carcinogen. It is denied that the studies cited by Applicant clearly show that asbestos fibres are released by weathering.
71. That as regards the contents of paragraphs 42 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied.
72. As regards contents of paragraph 43 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and

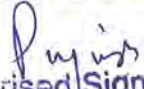
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anything contrary thereto or inconsistent therewith is denied. The answering Respondent craves leave to refer and rely upon purported journal paper cited in this paragraph for their true and correct meaning, and interpretation, at the time of hearing.

73. As regards contents of paragraph 44 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is submitted that the United States chrysotile market is quite small and the use of chrysotile fiber in the asbestos cement products does not exist.
74. As regards contents of paragraph 45 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is submitted that the purported school rule cited in this paragraph is not a scientific risk assessment of health impact of use of asbestos cement roof sheets in schools, nor is this publication based on any other such risk assessment. The answering Respondent craves leave to refer and rely upon the purported school rule for its true and correct meaning, and interpretation, at the time of hearing.
75. As regards contents of paragraph 46 of the Rejoinder, all that is stated in the Reply of the answering Respondent and preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is submitted that the purported article cited in this paragraph is not a piece of scientific evidence, neither a scientific risk assessment of

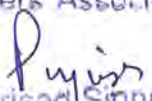
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health impact of use of asbestos cement roof sheets in schools, nor is this publication based on any other such risk assessment and is wholly inadmissible and ought not be relied upon or in any manner considered for adjudicating the present matter.

76. As regards contents of paragraph 47 of the Rejoinder, it is submitted that the contents of paragraph under Sur-Rejoinder are verbatim of paragraph 40 of the Rejoinder and the allegations pertaining to the said paragraph have been duly responded to in the aforesaid paras and is not being repeated herein for the sake of brevity. The answering Respondent reiterates the averments made in the Reply of the answering Respondent and aforesaid paras including the preliminary submissions and disputes and denies all or any allegations to the contrary.
77. As regards contents of paragraph 48 of the Rejoinder, all that is stated in the Reply of the answering Respondent, including at paragraphs 26-28 of the Reply and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied.
78. As regards contents of paragraph 49 of the Rejoinder, all that is stated in the Reply of the answering Respondent, including at paragraphs 26-28 of the Reply and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is further stated that the governmental Order as mentioned in the para under reply was passed based on the recommendations by the Hon'ble Kerala State Human Rights Commission in its Order dated 31.01.2009, passed in HRMP No. 126/2007. That the said Order dated 31.01.2009 was

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not supported by any scientific risk assessment regarding the likelihood or levels of exposure to asbestos fibers from asbestos cement roofing and was accordingly set aside by the Hon'ble High Court of Kerala vide judgment dated 07.07.2017 in the case titled Visaka Industries Ltd v. The Kerala State Human Rights Commission & Ors. [WP(C) No. 25100 of 2009 (F)]¹⁶, whereby it was held inter alia as under: -

"5... There are no data available before the commission to arrive that the asbestos sheet is hazardous to the health of children. If it would pose a threat to the health of the children, certainly, that could have been a matter for a decision by the commission. On mere surmises and conjunctures, the commission could not have ordered recommendation for replacement of asbestos sheet. The Commission relied upon the report of the World Health Organisation (WHO). All that could be seen that the asbestos sheet referred by WHO may depend upon the environmental setting it is used. It is necessary to verify what is the nature of the mixture that is used for the asbestos sheet. The asbestos sheet as such is not a threat as revealed from the judgment of the Hon'ble Supreme Court in Kalyaneshwari v. Union of India and Others [(2011) 3 5CC 387] relied by the learned counsel for the petitioner. In the absence of any evidence to show that the asbestos sheet would cause a serious threat to the life of the children, the Commission could not have made such recommendation as referred above. It is to be noted that the industrial rivalry and competition sometimes used as a platform to settle a score. The Commission should have been careful while entertaining such complaint especially when it appears that the complainant never appeared before the Commission and also before this Court. In view of the above, the impugned order is set aside. The writ petition is

¹⁶ Annexure- L (@pg 650-657) to Reply of R4

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disposed of as above."

(emphasis supplied)

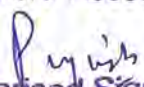
79. As regards contents of paragraphs 50 and 51 of the Rejoinder, all that is stated in the Reply of the answering Respondent including at paragraphs 26-29 of the Reply and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied.
80. As regards contents of paragraph 52 of the Rejoinder, all that is stated in the Reply of the answering Respondent including at paragraph 23 of the Reply and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is denied that other guidelines of the World Health Organisation which lead from the website talk in detail about asbestos cement products, including the ones that are roofing materials and contain chrysotile fibres and the Applicant is put to strict proof the same. It is denied that with respect to the matters related to Chrysotile in Rotterdam convention, something that may be problematic may be hazardous or may not be hazardous, and that is not directly related to the non-occupational use of asbestos roofing in schools. It is incorrect to suggest that in this case, the asbestos fibres, as shown in studies and as stated by the Ministry of Environment, Forests and Climate Change do lead to release and such release can cause health effects as stated before. The allegations pertaining to paragraphs under Sur-Rejoinder have been duly responded to in the aforesaid paras and are not being repeated herein for the sake of brevity. The answering Respondent reiterates the averments made in the aforesaid paras and disputes and denies all or any allegations to the contrary.

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81. As regards contents of paragraphs 53 and 54 of the Rejoinder all that is stated in the Reply of the answering Respondent in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is denied that shifting into non-asbestos alternatives to roof sheets will enable the use of the same employees, factories, agents, distribution networks and all backward and forward linkages. It is denied that the manufactures through alternatives, may be able to achieve economies of large scales and consumers may eventually get safer products. It is submitted that the statements made by the Applicant are baseless and unfounded. The allegations pertaining to paragraphs under Sur-Rejoinder have been duly responded to in the aforesaid paras and are not being repeated herein for the sake of brevity. The answering Respondent reiterates the averments made in the aforesaid paras and disputes and denies all or any allegations to the contrary.
82. The contents of paragraph 55 of the Rejoinder does not pertain to the answering Respondent, therefore, needs no sur-Rejoinder.
83. As regards contents of paragraph 56 of the Rejoinder, all that is stated in the Reply of the answering Respondent and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. That the contents of paragraph under Sur-Rejoinder are legal submissions which will be dealt with by the answering Respondent at the time of hearing. It is denied that the Applicant has in this rejoinder redisplayed the scientific evidence and governmental agency decisions. It is submitted that it is the

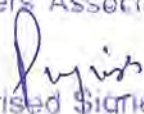
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answering Respondent which has placed on record substantial data to support the submissions made by the answering Respondent. Further, it is reiterated that the act of reopening an issue already decided on merits by the Hon'ble Supreme Court and other fora is an act of misleading this Hon'ble Tribunal by the Applicant. It is denied that the Applicant in the instant petition is praying for schools to not use asbestos sheets and phasing out of asbestos cement sheets in schools. It is denied that there seems to be no repetition of the issue in this petition and the issues raised in the Kalyaneshwari judgment primarily dealt with occupational exposure to asbestos whereas this application deals with the non-occupational exposure of asbestos fibres by school children where asbestos cement roofing is present in schools.

84. As regards contents of paragraph 57 of the Rejoinder, all that is stated in the Reply of the answering Respondent and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. That the contents of paragraph under Sur-Rejoinder are legal submissions which will be dealt with by the answering Respondent at the time of hearing. It is specifically and vehemently denied that there is an attempt to mislead the Hon'ble Tribunal by the answering Respondent by undermining the authority and power given to this Hon'ble Tribunal.
85. As regards contents of paragraph 58 of the Rejoinder, all that is stated in the Reply of the answering Respondent and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. It is submitted that the answering Respondent craves leave

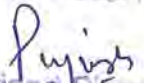
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to refer and rely upon the ruling given by this Hon'ble Tribunal in the judgement in *OA 206/2022* for its true and correct meaning, interpretation, scope, and legal effect thereof, at the time of hearing.

86. As regards contents of paragraph 59 of the Rejoinder, all that is stated in the Reply of the answering Respondent and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. That the contents of paragraph under Sur-Rejoinder are legal submissions which will be dealt with by the answering Respondent at the time of hearing.
87. As regards contents of paragraphs 60 and 61 of the Rejoinder, all that is stated in the Reply of the answering Respondent and in the preceding paras including preliminary submissions hereto is reiterated, and anything contrary thereto or inconsistent therewith is denied. The answering Respondent craves leave to refer and rely upon the said rulings given by the Hon'ble Supreme Court in the judgements in *Vellore Citizens Welfare Forum v. Union of India* and in *T.N. Godavarman Thirumuplad v. Union of India (2022) 9 SCC 306* for their true and correct meaning, interpretation, scope, and legal effect thereof, at the time of hearing.
88. That the contents of paragraphs 62 to 73 of the Rejoinder are verbatim of paragraphs 19, 11, 12, 13, 14, wrongly numbered paragraphs 9, 10, 11, 12, 13 and 14 respectively. The allegations pertaining to the said paragraphs have been duly responded to in the aforesaid paras and are not being repeated herein for the sake of brevity. The answering Respondent reiterates the averments made in the Reply of the answering Respondent and in the aforesaid paras

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including the preliminary submissions and disputes and denies all or any allegations to the contrary.

89. For the aforementioned reasons, it is humbly submitted that the Hon'ble Tribunal be pleased to not grant the relief as prayed for the Applicant.

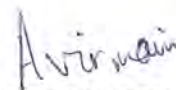
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Dated: 7.09.2024

RESPONDENT NO. 4

Through:


(RASHMI VIRMANI) (ANKIT VIRMANI)

E.NO. D-89/88; E.NO. D/2234-B/2009

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**BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL,
PRINCIPAL BENCH, NEW DELHI.
ORIGINAL APPLICATION NO. 298 OF 2023**

IN THE MATTER OF:

Dr. Raja Singh

...Applicant

Vs.

Union of India & Ors.

...Respondents

AFFIDAVIT

I, Piyush Sharma, son of Shri Vinod Sharma aged about 40 years, residing at 6/242, Geeta Colony, New Delhi - 110031, the Applicant do hereby solemnly affirm and state as under: -

1. I am the Authorized Representative for Defendant No. 4 in the present case and being aware of the facts and circumstances of the present case, I am competent to swear the present affidavit.
2. That I have read and understood the contents of the accompanying Sur-Rejoinder. The contents of the said Sur-Rejoinder have been drafted by my counsel under my instructions. The contents thereof are true and correct based on my knowledge, information and belief and based on record.
3. That no part of this Affidavit is false and nothing material has been concealed therefrom.

17 SEP 2024



Piyush

Pujari
DEPONENT

VERIFICATION

Verified at New Delhi, on this 17 SEP 2024 day of September 2024 that the contents of the above affidavit are true and correct as per my knowledge and belief, no part of it is false and nothing material has been concealed therefrom.



Pujari
DEPONENT

Identified
D/ 7885/2023
HRITHIK SHARMA

Identify the Deponent who
has Signed in My Presence

CERTIFIED THAT THE DEPONENT

Shri/Smt./Kum..... Pujari Shri
S/o, W/o, D/o, Shri..... Vinod Sharma
R/.....
Identified by.....
Has Solemnly Sworn Ad.....
On..... 17 SEP 2024
that the contents of.....
explained to him/her and correct to his/her best knowledge

73

Oath Commissioner, New Delhi

COMPLETION REPORT

**AIR QUALITY STUDY ON CONCENTRATIONS AND SIGNIFICANCE
OF CHRYSOTILE ASBESTOS FIBER IN HOUSEHOLD AMBIENT
ENVIRONMENT IN SRI LANKA**

(FEBRUARY 2019 TO FEBRUARY 2021)

FUNDED BY

**MINISTRY OF SCIENCE, TECHNOLOGY AND RESEARCH
THROUGH
NATIONAL RESEARCH COUNCIL**

ASBESTOS GRANT 19-001

SUBMITTED TO

**NATIONAL RESEARCH COUNCIL
NO. 120/07, VIDYA MAWATHA
COLOMBO 07**

BY

**ENVIRONMENTAL STUDIES AND SERVICES DIVISION
NATIONAL BUILDING RESEARCH ORGANISATION
99/1, JAWATTA ROAD,
COLOMBO – 05
SRI LANKA**

(MAY 2021)

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ACKNOWLEDGEMENT

Our special thanks are given to;

- The Ural Chamber of Commerce and Industry, Russia, who provided the financial and technical assistance to facilitate the research project.
- The National Research Council, Sri Lanka, who selected the NBRO to provide all financial facilities to carry out the research work in Sri Lanka.
- The working group from Sri Lanka, who coordinated all research and administrative activities with the Russian team and the National Research Council, Sri Lanka.
- Director General and all staff of the National Building Research Organisation of Sri Lanka for the facilitate laboratory, personal and all needs for the successfully completion of the project.
- All supportive staff and households for the sampling

.....
HDS Premasiri

ABBREVIATIONS

AC	Asbestos-cement
ACGIH	American Conference of Governmental Industrial Hygienists
AR&AC	Houses with Asbestos roof and Asbestos Ceiling
AR&NAC	Houses with Asbestos roof and non-Asbestos Ceiling
ARO	Houses with Asbestos roof only
LOD	Limit of Detection
NAR&AC	Houses with non-Asbestos roof and Asbestos Ceiling
NAR&NAC	Houses with non-Asbestos roof and non-Asbestos Ceiling
NARO	Houses with non-Asbestos roof only
NBRO	National Building Research Organization
NIOSH	National Institute of Occupational Safety & Health
NRC	National Research Council
OSHA	Occupational Safety and Health Administration
PCM	Phase Contrast Microscope
WHO	World Health Organization

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ABSTRACT

Asbestos is a naturally occurring silicate mineral fibers that have high commercial designation that possess high tensile strength, flexibility, resistance to chemical and thermal degradation, and high electrical resistance and that can be woven, etc. Due to these properties, Asbestos are used in a broad variety of industrial applications to manufacture Asbestos based products. In the meantime, many researchers have shown that some type of Asbestos fiber cause chronic diseases and exposure to Asbestos affects human health that causes cancer of the lung, larynx and ovary, mesothelioma and Asbestosis, etc. It also shown that the health risk is depend on the type of fiber and only the Chrysotile (white) Asbestos fiber is presently using since its health risk is low compared to other fiber in the group. In Sri Lanka, Chrysotile Asbestos fibers are used only in the roofing and ceiling sheets manufacturing industries while used other products in minor quantities. Apart from the important of Asbestos fiber for industries, other products which contain Asbestos are also imported into Sri Lanka.

Therefore, Sri Lankan population may have been exposed to woven Asbestos mainly in their workplaces of asbestos related manufacturing industries. Apart from the workers, other workers may be exposed to Asbestos during their working life involved in the handling of Asbestos products in ports, transport and haulage companies, distributing, construction workers and roofing contractors etc. during the cutting and sawing of Asbestos containing materials. In view of the widespread use of Asbestos in roofing and ceiling materials in Sri Lanka, the presence of Asbestos dust in buildings cannot be disregarded. It is also considered that this exposure would be increased if the Asbestos containing material is damaged or is being removed from existing structures. Therefore, high attention and regular measurement of Asbestos in indoor environment as well as ambient environment is a timely requirement.

Although most of countries have studied and assess the outdoor and indoor exposure levels of Asbestos fibers, only one or two studies were done in Sri Lankan. Therefore, this study was aimed to assess the exposure levels of Asbestos fiber in domestic levels representing different environmental conditions in Colombo and Anuradhapura districts in Sri Lanka. Sampling locations were selected to represent different environment conditions as utilization of the Asbestos in urban, suburban and rural household types that use Asbestos for roofing and ceiling purposes. Sampling locations were selected to represent at least two houses in each six different criteria and the samples were collected from bedroom area, living room area and ambient air to represent the different environmental disciplines. The methodology stipulated by National Institute of Occupational Safety & Health (NIOSH 7400) for the sampling and analysis of Asbestos fiber by using Phase Contrast Microscope (PCM) were used in the study.

The asbestos fiber levels recorded at Colombo District is in the range of 0 – 0.00077 f/cc with average of 0.00034 f/cc and at Anuradhapura District is in the range of 0 – 0.00071 f/cc with the average level of 0.00016 f/cc. The average fiber concentration levels recorded at all selected households in different environmental conditions are below the UA-EPA standard levels (0.0009 f/cc) for asbestos fiber in non-occupational buildings (such as residential houses). The levels also below the lifetime exposure levels (0.0005 f/cc) proposed to WHO by authors in a population of whom 30% are smokers, the excess risk due to lung cancer would be in the order of 10^{-6} - 10^{-5} and the ambient fiber standard levels stipulated in different countries.

The fibers concentration levels are change with the urbanization conditions and decrease as the changing urbanization factor from urban, suburban to rural may be due to the change of air pollution levels in each area with the urbanisation. The recorded fiber level in indoor area are relatively higher than the ambient

environment (outside the premises) in both districts. The fiber levels are gradually decrease from the house category of having used asbestos ceiling and roofing (AR & AC) to the category of non-asbestos ceiling and roofing (NARO, NAR & NAC). However, there is no significant correlation.

Key words: Chrysotile fiber, indoor environment, permissible level

1. INTRODUCTION

1.1 Background

The Government of Sri Lanka was of the view that the importation of Chrysotile Asbestos fiber in to Sri Lanka would be a health hazard, hence it is necessary to reduce its volume gradually. As an initial step, it has been scheduled to commence limited ban from January 2018, aiming to eliminate usage of Asbestos in year 2025. However, the implementation of the above was expected to be executed based on results of a comprehensive study by a group of experts. The Ministry of Science, Technology and Research is in collaboration with the Russian ambassador of Sri Lanka was decided to send a multi-disciplinary scientific delegation to Russia to study the Asbestos related activities, their impacts and related control strategies adopted in Russia due to the fact that most of Sri Lankan Asbestos sheet manufacturing industries use Russian Chrysotile fibers. As per the recommendation of above expert delegation, the Ministry of Science, Technology and Research in collaboration with Ural Chamber of Commerce and Industry, Russia was decided continues further studies on airborne Chrysotile Asbestos level in Sri Lanka due to the lack of adequate scientific evidence on Asbestos in Sri Lanka. In this regards, Ministry of Science, Technology and Research was called proposals for four different thematic research areas in relation with Chrysotile Asbestos. One of the research areas is on “Air Quality Study on Concentrations and Significance of Chrysotile Asbestos Fiber in Household Dust and Household Ambient Environment in Sri Lanka” and the proposal forwarded by the National Building Research Organization (NBRO) was accepted and granted the project to NBRO to proceed with the supervision on National Research Council (NRC).

The instruction of the study consisted in assessing the levels of Asbestos exposure in the general population, particularly in residential household. The study was created to carry out its task to analyzed the existing levels of Asbestos fibers in households at different environmental conditions in Sri Lanka. The study team developed a protocol and environmental assessment tools intended for all households in concerned. The work was carried out in close collaboration with the working group appointed by the Ministry of Science and Technology Sri Lanka, National Research Council of Sri Lanka and the Ural Chamber of Commerce and Industry, Russia.

A dedicated team of Scientists and Technical Assistants were mobilized in this study by NBRO and at the same time, work continued on other relevant aspects: the criteria and standards in effect in Sri Lanka and international organization for the sampling of Asbestos fibers in ambient air, the situation in household such as use of Asbestos and exposure to the level of ambient air in general. Residential houses in Colombo, the commercial capital and higher populated district and Anuradhapura, an ancient city and relatively low population district in Sri Lanka were selected for the study.

The present report sets out the exposure measurement, the Asbestos level and related issues. Then, it summarizes the current knowledge on population exposure in certain environments likely to contain

Asbestos fibers: household buildings and ambient air. Finally, it discusses the situation in different environment conditions in Sri Lanka.

1.2 Scope of the project/ Justification

1.2.1 Asbestos and sources of exposure

The term “Asbestos” applies to a group of fibrous silicate minerals. The term “fiber” applies to all inorganic and organic materials that have a length to diameter ratio greater than 3. Asbestos is one of the so-called natural fibers. Asbestos fibers are used commercially because of their excellent mechanical and thermal resistance as well as their great durability. The macroscopic Asbestos fibers are actually bundles of thinner fibers made up of fibrils which, in the case of Chrysotile, have a diameter of 20-25 nm. Each macroscopic fiber is highly anisotropic and tends to decompose into its thinner constituents under industrial handling or from weathering, giving rise to a fibrous, partially respirable aerosol. The family of Asbestos fibers is divided into two groups: serpentine fibers and amphibole fibers.

Serpentines, whose only fibrous member is Chrysotile fibers consist of aggregates of long, thin, flexible fibrils that resemble scrolls or cylinders of uniform chemical composition. Therefore, it is represented more than 90% of the Asbestos produced in the world. Although Chrysotile is a reasonably well-defined mineral, the five amphibole asbestiform fibers have such variable chemical compositions and physical properties that positive identification is sometimes troublesome. Among the amphiboles, the most common types of fibers are crocidolite (Blue Asbestos), amosite (Brown Asbestos), tremolite, and actinolite. Except for Chrysotile, all forms of Asbestos are on the Rotterdam Convention’s list of banned or severely restricted chemical products, which regulates the international trade of dangerous products. Nevertheless, Chrysotile has not been added into that list due to contradictions in various aspects.

Asbestos fibers released into the environment can contaminate air, soil, water, and food. Environmental contamination may come from natural or industrial sources. The natural erosion of the soil and rocks on the earth’s crust represents a potential source of contamination. At certain locations on the planet, there are exploitable commercial deposits of Asbestos ore. The extraction, processing, and use of Asbestos generate industrial contamination sources. Asbestos mines and mills are unquestionably the largest sources of contamination in the environment in general. Asbestos is found to be used in extremely large variety of applications (in about 3000 different) products manufacturing in consumer products. The principal uses are related to the manufacture of brake pads, Asbestos cement materials, and insulating materials, etc.

The Asbestos fibers contained in the mineral ore are not respirable unless they are released and dispersed in the air by extraction and processing procedures. The Asbestos fibers are trends to fragment and release into the air when manipulated or submitted to mechanical pressure. They can be inhaled only when they are in suspension in the air. Therefore, the population exposure can occur in two types of environment, the workplace and the general environment. At work, the places most at risk are Asbestos mines and mills,

processing plants, construction sites, and buildings undergoing maintenance and repair. The processing industry is made up of several industries such as shipbuilding and repair, transportation equipment, fabrication of metal products, and adhesives, etc.

Asbestos emissions occur during manufacturing and application and demolition activities of roofing and ceiling sheets in which commonly used roofing and ceiling material in worldwide. Use of Asbestos based Brake-linings in vehicle, insulation material sprayed on steelwork or ceilings (such material may become highly friable after some years), Asbestos plasters, low-weight insulation plates, etc. are other sources that released fibers in to air [1,2]. Sometimes such materials have been used in direct or close contact with air-conditioning equipment. Even though some of these materials, such as spray Asbestos, are no longer used, they are still found in many public buildings. Until the mid-1970s electric storage-heaters and some other electrical household equipment contained Asbestos. One of the main forms of use of Asbestos is as Asbestos-cement; in this case the release of fibers to the general environment is minimized, since the fibers are essentially “locked” in the cement matrix. Asbestos cement products, therefore, do not usually pose problems for indoor air quality. However, it may be emitted while fixing, cutting and demolishing. The indoor Asbestos fiber concentrations can be considerably higher than outdoor concentrations due to indoor sources and poor ventilation conditions, etc.

1.2.2 Asbestos sources in Sri Lanka

Although there is no Asbestos mining or milling industries in Sri Lanka, it has been importing Asbestos fiber from various countries for more than 60 years to Sri Lanka. They are mainly used for Asbestos cement-based roofing sheet and ceiling sheet manufacturing industries. Asbestos roofing products became very popular in Sri Lanka as substitute building material due to the lack of other building materials such as timber, clay tiles. Apart from the important of Asbestos fiber, other products which contain Asbestos are also imported into Sri Lanka.

Therefore, Sri Lankan population may have been exposed to woven Asbestos mainly in their workplaces of asbestos related manufacturing industries. Apart from the workers in the Asbestos cement industries and the brake-lining industries, a number of other workers may be exposed to Asbestos during their working life. Workers involved in the handling of Asbestos will include the port workers and transport and haulage companies which distribute the Asbestos materials to the factories and retail outlets, in addition, construction workers and roofing contractors may be exposed to Asbestos fibers during the cutting and sawing of Asbestos containing materials. Boiler men and maintenance engineers may be exposed to Asbestos fibers where Asbestos has been applied for insulation of steam pipes and when this insulation has deteriorated in quality allowing Asbestos fibers to be emitted. The exposure to Asbestos product in early 1990's may be high since many more materials containing Asbestos were used and lack of awareness and

management. Also, in early days some Asbestos produces were used in households for the lighting purposes such as wicks of lamps & mantles in Petrolmax lamps.

In view of the widespread concern about the use of Asbestos and the health problems associated with such use, the Hon. Prime Minister appointed an expert committee in around 1992, to examine the health hazards arising from Asbestos contamination and to recommend strategies for the regulation and control of Asbestos usage. The expert committee has given their recommendations in five (05) main areas such as 1. Banning of crocidolite (Blue Asbestos), 2. Certification and labelling scheme for Asbestos, 3. Research on substitutes for Asbestos containing materials, 4. Controls in the workplace and 5. Sector usage of Asbestos and environmental considerations. Therefore, as per the recommendations of the above expert committee, the statistics shows that, there are many forms of Asbestos exist in worldwide, only the white Asbestos (Chrysotile) are imported to Sri Lanka for the production of roofing and ceiling sheets. These Asbestoses are mixed with cement acting as a binding agent reducing fiber escape to air. Industrialists have given control measures and health & safety guidance to minimize exposure at workshops and surrounding residential exposure.

In view of the widespread use of Asbestos in roofing and ceiling materials in Sri Lanka, the presence of Asbestos dust in buildings cannot be disregarded. It is also considered that this exposure would be increased if the Asbestos containing material is damaged or is being removed from existing structures. Therefore, high attention and regular measurement of Asbestos in indoor environment as well as ambient environment is a timely requirement.

Furthermore, as there are several factories manufacturing Asbestos cement sheets in Sri Lanka, it is likely that the public living in the neighborhood of the factories would be exposed to airborne Asbestos fiber either from emissions from the process or due to improper solid waste disposal of Asbestos containing materials. It is also likely that the public being unaware of the risk associated with Asbestos contamination may have unnecessarily exposed themselves to Asbestos fiber without taking any precautionary measures. The sawing of ceiling panels and insulation boards within the home environment is a good example of such emission.

1.2.3 Exposure limits and standards for airborne Asbestos

Due to extremely large variety of applications of Asbestos contaminated material, there is a high possibility in Asbestos fiber to be airborne. Asbestos emissions occur during processing. When air filtration is used, the dust emissions from processing can be kept below 100 g per ton [3]. Rain acidity (from carbon dioxide and air pollutants) is known to corrode Asbestos-cement sheets, constituting a further source of emission [4]. Brake-linings in cars are another source in the urban environment. Only a few measurements have been

made of the contribution made by these sources to fiber emissions in the urban air [5,6]. Indoor Asbestos fiber concentrations can be considerably higher than outdoor concentrations [7].

Indoor Asbestos dust originates from insulation material sprayed on steelwork or ceilings (such material may become highly friable after some years), Asbestos plasters, low-weight insulation plates, etc. [8,9]. Sometimes such materials have been used in direct or close contact with air-conditioning equipment. Even though some of these materials, such as spray Asbestos, are no longer used, they are still found in many public buildings. One of the main forms of use of Asbestos is as Asbestos-cement; in this case the release of fibers to the general environment is minimized, since the fibers are essentially “locked” in the cement matrix. Asbestos cement products, therefore, do not usually pose problems for indoor air quality. Therefore, most of countries and international organizations have given their air quality standards and exposure limits for Asbestos based on the environmental condition of the location and the exposure time period.

According to the PCM method, the quantitative working range of the method is 0.04 to 0.5 fiber /cc for a 1000 L air sample. The Limit of Detection (LOD) of the method depends on sample volume and quantity of interfering dust, and the value is <0.01 fiber/cc, if free of interferences.

The maximum permissible level given in Russia is 0.06 fiber/cc and in Europe is 0.01 fiber/cc for residential environment. Hence, the standard level of 0.01 fiber/cc is used as the threshold limit for the study.

1.3 Objectives

The project involves identification of airborne Chrysotile fiber levels at indoor and ambient environment in household at urban, sub urban and rural areas in Sri Lanka. Therefore, the objective of the study is categorized into three sub objectives such as,

- a) Examine air borne Chrysotile fibers in the air within the household indoor and ambient environment at 72 houses representing different environment conditions.
- b) Identifying the possible relations between the use of Chrysotile fiber containing products and the airborne Chrysotile fiber levels.
- c) Establish an evidence-based guideline, if necessary.

2. LITERATURE REVIEW/PREVIOUS WORK

The naturally occurring minerals that have collectively become known as 'Asbestos' have been used for thousands of years owing to their unique fibrous characteristics of flexibility, high tensile strength, large surface area to mass ratio, electrical resistance, and resistance to heat and chemical degradation. The industrial/commercial world that mines and processes those materials uses the term 'Asbestos' to refer to a group of six naturally occurring fibrous silicate minerals. Asbestos was incorporated into thousands of industrial and commercial products beginning in the middle of the nineteenth century, and Asbestos-bearing products became abundant in modern society. Historical records show that Asbestos has been used by man for over 4,000 years; in this century it has been used in over 3,000 products including cement building materials, pipework lagging, insulating mattresses and rope, fire resistant insulation boards, sprayed fire-proofing products, floor tiles and coverings, water and sewage pipes, gas masks, friction materials for vehicle brakes and clutches, lifts and machinery [10].

According to recent studies conducted by three leading toxicology laboratories in Switzerland, Germany and the United States, Chrysotile is the safest fiber of all Asbestos, even when compared to artificial substitutes and natural fibers (cellulose), as it is faster than other fibers derived from the lungs. For example, the half-life of disintegration of Chrysotile fibers (the number of days required to remove 50% of the fibers remaining in the lungs after the exposure period has expired) is about 15 days, amphibole fibers - 466 days and cellulose - 1000 days.

There has been a steep rise in the production and use of Asbestos in the last 100 years. Asbestos consumption has levelled off in recent years to about 4 million tones, because of the relative decline in crocidolite and amosite usage. In many industrialized countries most of the Asbestos used for the building sector (70-90% in several western European countries) and the demand for Asbestos in these countries had already reached a constant level because of the health effects of Asbestos were widely argued. Because of its specific technical properties, Asbestos has found an extremely large variety of applications as mentioned in above (in about 3000 different products). In the future, legislative restrictions and the success in finding substitutes for Asbestos in fibre-cement, brake-linings, insulation and many other applications will most probably lead to declining Asbestos consumption in worldwide [3]

The Asbestos situation in Asian countries was described at the 2002 regional conference, which was the first to discuss the theme. 'A striking feature of the region was the persistent use of Asbestos in most, if not all, countries'. However, the important changes have occurred since that time. Indeed, Japan, which was a major Asbestos user in 2005 and adopted a total Asbestos ban in 2006 (a prohibition in principle was already in effect in 2004). In addition, Korea disseminated a ban, in principle, in 2006 and a total ban in 2009 after recognizing a certain number of mesothelioma cases. Moreover, we are aware that several south-

east Asian countries are considering Asbestos bans, although this information has not been documented. Thus, the Asbestos situation in Asia is unstable and permits a careful description [4].

Since the use of Asbestos roofing and its production process shows many health impacts on the people who involve in the production of Asbestos and also on the users, it is necessary to clearly distinguish on which type of Asbestos and how much of fibers in our breathing atmosphere. The fiber concentrations in urban areas are generally not known and knowledge about duration and frequency of exposure as well as the type of fibers are rarely available with an adequate precision. For this reason, the assessment of environmental exposure to Asbestos fibers is rather difficult [5].

In Sri Lankan scenario, although several commercial products consist of Asbestos fiber, only the roofing and ceiling sheet manufacturing industry use Chrysotile fiber as a raw material. It was estimated that about 40% of the Sri Lankan households use Chrysotile cement-based roofing and ceiling sheet [6]. However, there is no data available on the levels of airborne Chrysotile fiber in indoor and ambient environment to that human are exposed. Therefore, this study intends to highlight the exposure levels of fibers in residential households, which use Chrysotile fiber roofing and ceiling sheets for their households. Hence, the aim of this study was to determine the concentration of respirable Asbestos fibers in urban, s rural environments in Sri Lanka.

3. MATERIALS AND METHODS

3.1 Selection of sampling sites and sampling locations

The project intended to cover the project activities in two districts with different environment conditions. Therefore, Colombo, which is the commercial capital of Sri Lanka where many Chrysotile fiber products are used and Anuradhapura, which is the one of ancient capitals of Sri Lanka where the usage of Chrysotile fiber products are comparatively low, were selected for the measurement of airborne Chrysotile fibers levels (Figure 3.1).

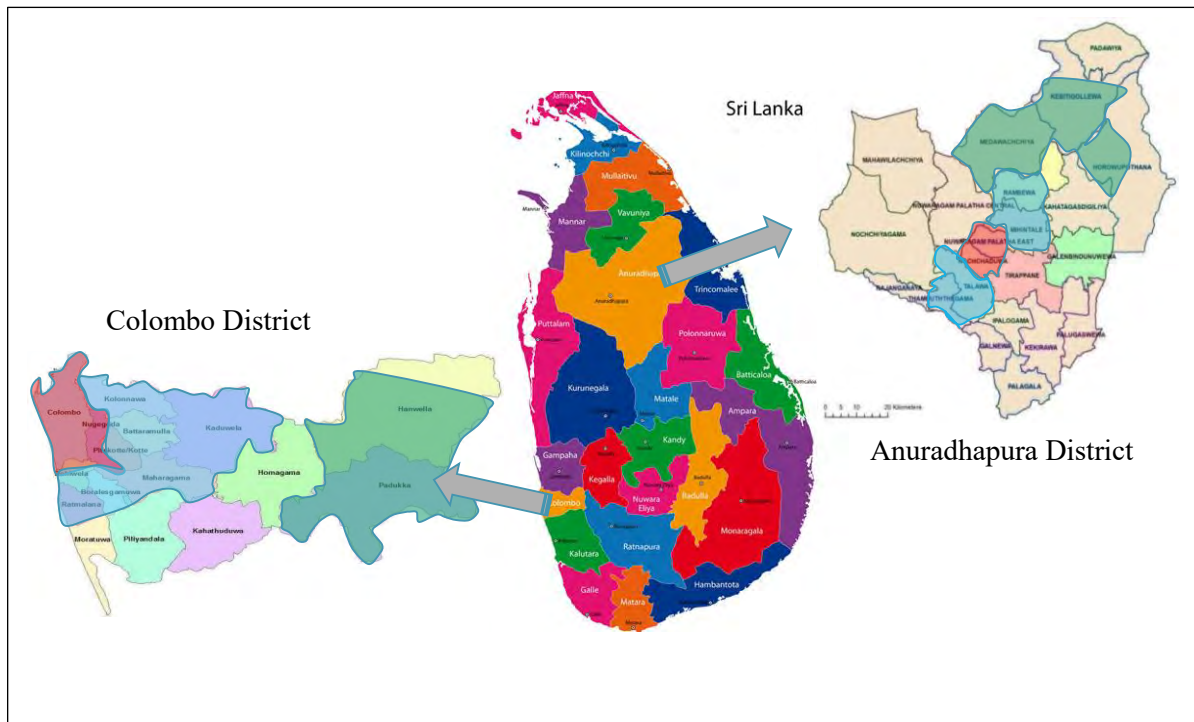


Figure 3.1: Two district selected for the sampling

Among these two districts, the sampling sites were selected by considering the urban, sub urban and rural environmental conditions and then the measurements were undertaken to assess the ambient and indoor Chrysotile fiber levels. Special consideration was given while selecting households to represent different environmental conditions of utilization of the Asbestos as per the developed criteria. The main six criteria used during selection of households are as follows and details are given in Table 3.1.

Main six criteria;

1. Houses with Asbestos roof only (ARO)
2. Houses with non-Asbestos roof only (NARO)
3. Houses with Asbestos roof and Asbestos Ceiling (AR&AC)
4. Houses with Asbestos roof and non-Asbestos Ceiling (AR&NAC)
5. Houses with non-Asbestos roof and Asbestos Ceiling (NAR&AC)

6. Houses with non-Asbestos roof and non-Asbestos Ceiling (NAR&NAC)

- Total number of houses : 36 Houses (in each district)
- Number of samples per house : 3 Samples per house
 - Indoor Environment : 2 Samples (living room & bedroom)
 - Ambient air : 1 Sample (ambient)
- Number of monitoring sessions : 2 (once in six months, covering wet & dry sessions)
- Number of districts : 2 (Colombo and Anuradhapura)
- Total number of Samples : (36 x 3 x 2 x 2) = 432 Samples

Table 3.1: The selection criteria of households in each district

Selection criteria 1(Area)		Selection criteria 2 (Nature of the roof and ceiling)		No. of Houses
1	In urban cities	i	Houses with Asbestos roof only (without ceilings) ARO	12
		ii	Houses with non-Asbestos roof only (without ceilings) NARO	
		iii	Houses with Asbestos roof and Asbestos Ceiling AR&AC	
		iv	Houses with Asbestos roof and non-Asbestos Ceiling AR&NAC	
		v	Houses with non-Asbestos roof and Asbestos Ceiling NAR&AC	
		vi	Houses with non-Asbestos roof and non-Asbestos Ceiling NAR&NAC	
2	In sub-urban cities	i	Houses with Asbestos roof only (without ceilings) ARO	12
		ii	Houses with non-Asbestos roof only (without ceilings) NARO	
		iii	Houses with Asbestos roof and Asbestos Ceiling AR&AC	
		iv	Houses with Asbestos roof and non-Asbestos Ceiling AR&NAC	
		v	Houses with non-Asbestos roof and Asbestos Ceiling NAR&AC	
		vi	Houses with non-Asbestos roof and non-Asbestos Ceiling NAR&NAC	
3	In rural cities	i	Houses with Asbestos roof only (without ceilings) ARO	12
		ii	Houses with non-Asbestos roof only (without ceilings) NARO	
		iii	Houses with Asbestos roof and Asbestos Ceiling AR&AC	
		iv	Houses with Asbestos roof and non-Asbestos Ceiling AR&NAC	
		v	Houses with non-Asbestos roof and Asbestos Ceiling NAR&AC	
		vi	Houses with non-Asbestos roof and non-Asbestos Ceiling NAR&NAC	
Number of houses in one District				36
The total number of houses in both districts				72

3.1.1 The details of sampling locations selected in Colombo District - Urban area

Total of 12 households representing different criteria were selected in the urban area within Colombo District, Colombo, Jayawardanapura and Kesbawa Municipal Council areas. Details of locations selected are summarized in Table 3.2 and Figure 3.2.

Table 3.2: Sampling details of urban areas of Colombo District

Name	Criteria	Sampling Location Details	
AS/CL/U/01	ARO	06°51'56.8"N, 79°54'02.1"E	Nugegoda
AS/CL/U/02	ARO	06°53'10.2"N, 79°52'43.7"E	Colombo 05
AS/CL/U/03	AR & AC	06°53'55.68"N 79°55'19.70"E	Colombo 05
AS/CL/U/04	AR & AC	06°51'48.0"N, 79°54'14.1"E	Colombo 05
AS/CL/U/05	AR & NAC	06°51'38.02"N, 79°54'12.06"E	Colombo 05
AS/CL/U/06	AR & NAC	06°51'48.0"N, 79°55'14.1"E	Nugegoda
AS/CL/U/07	AR&AC	06°51'38.02"N 79°55'12.06"E	Nugegoda
AS/CL/U/08	NAR&AC	6°50'47.35"N 79°54'7.87"E	Boralesgamuwa
AS/CL/U/09	ARO	06°51'46.72"N 79°53'58.11"E	Colombo 05
S/CL/U/10	ARO	06°54'11.90"N 79°52'34.34"E	Colombo 07
AS/CL/U/11	AR&AC	6°50'53.86"N 79°54'44.30"E	Boralesgamuwa
AS/CL/U/12	AR&AC	06°52'22.82"N 79°52'34.35"E	Colombo 05

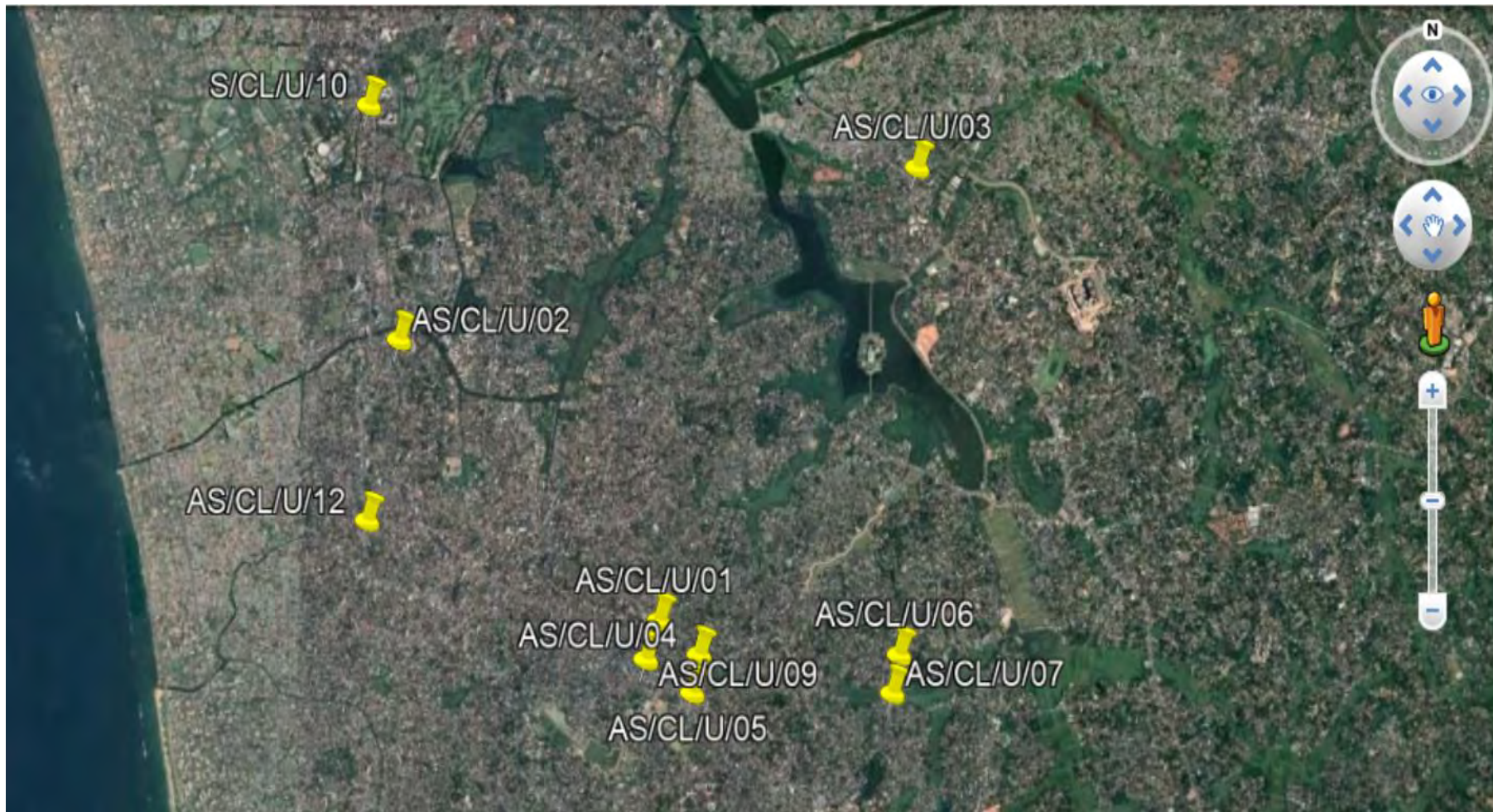


Figure 3.2: Sampling Locations at urban areas of Colombo District

3.1.2. The details of sampling locations in Colombo District - Sub urban area

Total of 12 households representing different criteria were selected in the sub-urban area within Colombo District, Kaduwela and Kesbawa Municipal Council areas. Details of locations selected are summarized in Table 3.3 and Figure 3.3.

Table 3.3: Sampling details of sub-urban areas of Colombo District

Name	Criteria	Sampling Location Details	
AS/CL/SU/01	ARO	06°55'54.72"N, 79°55'48.88"E	Angoda
AS/CL/SU/02	ARO	06°55'58.54"N, 79°55'58.79"E	Angoda
AS/CL/SU/03	AR & AC	06°55'27.50"N 79°58'12.51"E	Kaduwela
AS/CL/SU/04	AR & AC	06°57'36.73"N 79°57'55.69"E	Heiyanthuduwa
AS/CL/SU/05	AR & NAC	06°56'16.99"N 79°57'41.67"E	Kaduwela
AS/CL/SU/06	AR & NAC	06°47'48.68"N 79°55'1.67"E	Piliyandala
AS/CL/SU/07	NAR & AC	06°54'39.02"N 79°57'22.28"E	Malabe
AS/CL/SU/08	NAR & AC	06°50'26.84"N 79°55'50.22" E	Maharagama
AS/CL/SU/09	NARO	06°49'18.52"N 79°54'9.44"E	Werahera
AS/CL/SU/10	NARO	06°57'25.68"N 79°57'59.94"E	Heiyanthuduwa
AS/CL/SU/11	NAR & NAC	06°56'27.29"N 79°57'27.14"E	Kaduwela
AS/CL/SU/12	NAR & NAC	06°48'0.48"N 79°54'55.60"E	Piliyandala



Figure 3.3: Sampling Locations at sub-urban areas of Colombo District

3.1.3 The details of sampling locations in Colombo District - Rural area

Total of 12 households representing different criteria were selected in the rural area within Colombo District, Kaduwela and Kesbawa Municipal Council areas. Details of locations selected are summarized in Table 3.4 and Figure 3.4.

Table 3.4: Sampling details of rural areas of Colombo District

Name	Criteria	Sampling Location Details	
AS/CL/RU/01	ARO	06°42'19.1"N 79°59'01.1"E	Bandaragama
AS/CL/RU/02	ARO	06°54'26.8"N 79°59'18.0"E	Korathota
AS/CL/RU/03	AR & AC	06°42'58.75"N 79°59'10.62"E	Bandaragama
AS/CL/RU/04	AR & AC	6°42'26.92"N 79°59'50.81"E	Bandaragama
AS/CL/RU/05	AR & NAC	06°45'20.4"N 79°59'42.4"E	Gonapala
AS/CL/RU/06	AR & NAC	06°45'34.4"N 80°00'40.5"E	Gonapala
AS/CL/RU/07	NAR & AC	06°44'47.0"N 79°59'29.6"E	Bandaragama
AS/CL/RU/08	NAR & AC	06°50'59.7"N 80°04'11.0"E	Padukka
AS/CL/RU/09	NARO	06°55'25.33"N 80° 5'13.36"E	Korathota
AS/CL/RU/10	NARO	06°55'23.66"N 80° 2'21.37"E	Korathota
AS/CL/RU/11	NAR & NAC	06°49'08.7"N 79°56'09.2"E	Paligedara,
AS/CL/RU/12	NAR & NAC	06°47'54.27"N 80° 1'43.78"E	Watareka, Padukka

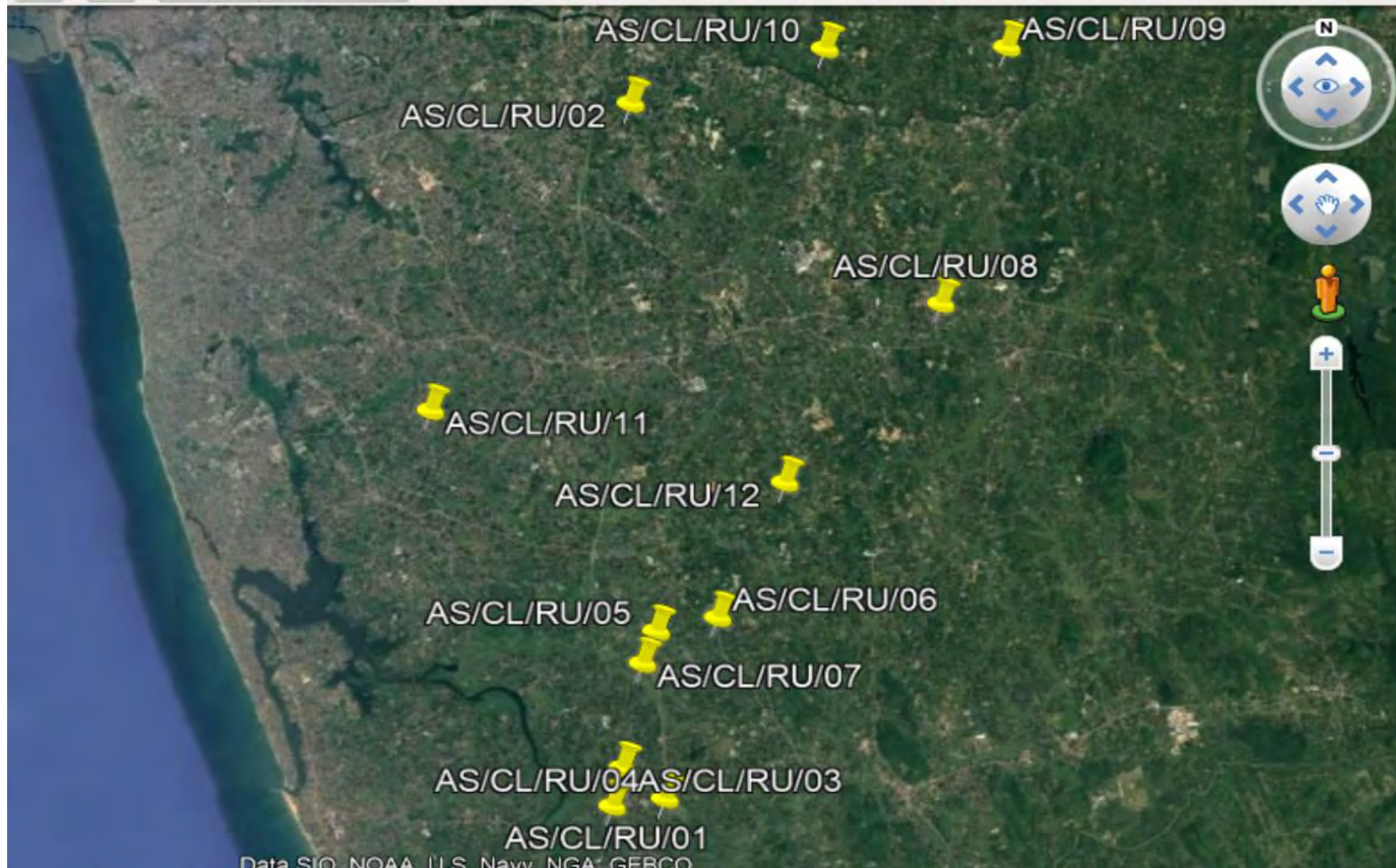


Figure 3.4: Sampling Locations at rural areas of Colombo District

3.1.4 The details of sampling locations in Anuradhapura District - Urban area

Total of 12 households representing different criteria were selected in the urban area within Anuradhapura District, Anuradhapura Urban Council areas. Details of locations selected are summarized in Table 3.5 and Figure 3.5.

Table 3.5: Sampling details of urban areas of Anuradhapura District

Name	Criteria	Sampling Location Details	
AS/AD/U/01	ARO	8°17'49.15"N 80°23'58.77"E	Sawasthipura
AS/AD/U/02	ARO	8° 18' 39.7" N 80° 23' 43.1" E	Yaya 3, Anuradhapura
AS/AD/U/03	AR & AC	8° 18' 27.4" N 80° 23' 54.4" E	Yaya 3, Anuradhapura
AS/AD/U/04	AR & AC	8° 18' 02.5" N 80° 25' 01.4" E	Vanniyankulama, Anuradhapura
AS/AD/U/05	AR & NAC	8° 18' 23.0" N 80° 24' 18.6" E	Yaya 3, Anuradhapura
AS/AD/U/06	AR & NAC	8°19'27.86"N 80°24'58.59"E	1st Stage, Anuradhapura
AS/AD/U/07	NAR & AC	8° 19' 45.0" N 80° 25' 05.1" E	Yaya 1, Anuradhapura
AS/AD/U/08	NAR & AC	8°18'47.39"N 80°23'40.61"E	Yaya 3, Anuradhapura
AS/AD/U/09	NARO	8°18'12.56"N 80°23'58.64"E	Stage 3, Anuradhapura
AS/AD/U/10	NARO	8° 19' 35.8" N 80° 23' 12.4" E	Wessagiriya
AS/AD/U/11	NAR & NAC	8°18'31.35"N 80°24'4.53"E	Yaya 3, Anuradhapura
AS/AD/U/12	NAR & NAC	8°18'32.44"N 80°25'4.07"E	Sawasthipura



Figure 3.5: Sampling Locations at Urban areas of Anuradhapura District

3.1.5 The details of sampling locations in Anuradhapura District - Sub urban area

Total of 12 households representing different criteria were selected in the sub-urban area within Anuradhapura District, Talawa and Eppawela areas. Details of locations selected are summarized in Table 3.6 and Figure 3.6.

Table 3.6: Sampling details of sub urban areas of Anuradhapura District

Name	Criteria	Sampling Location Details	
AS/AD/SU/01	ARO	8° 13' 26.7" N 80° 21' 05.5" E	Talawa
AS/AD/SU/02	ARO	8°13'12.01"N 80°21'8.74"E	Kurunduwewa, Talawa
AS/AD/SU/03	AR & AC	8° 13' 32.9" N 80° 21' 21.9" E	Kurunduwewa, Talawa
AS/AD/SU/04	AR & AC	8° 02' 44.8" N 80° 26' 43.5" E	Thoranegama, Galnewa
AS/AD/SU/05	AR & NAC	8° 13' 13.5" N 80° 20' 31.8" E	Thammennawa, Talawa
AS/AD/SU/06	AR & NAC	8°13'37.30"N 80°20'24.06"E	Thammennawa, Talawa
AS/AD/SU/07	NAR & AC	8° 2'24.03"N 80°26'38.34"E	Galnewa
AS/AD/SU/08	NAR & AC	8° 02' 42.3" N 80° 26' 43.8" E	Thoranegama, Galnewa
AS/AD/SU/09	NARO	8° 9'12.30"N 80°24'16.92"E	Adapola
AS/AD/SU/10	NARO	8° 09' 25.1" N 80° 24' 00.5" E	Eppawala
AS/AD/SU/11	NAR & NAC	8° 09' 24.2" N 80° 23' 52.0" E	Eppawala
AS/AD/SU/12	NAR & NAC	8° 9'37.43"N 80°23'58.97"E	Eppawala



Figure 3.6: Sampling Locations at Sub-Urban areas of Anuradhapura District

3.1.6 The details of sampling locations in Anuradhapura District- Rural area

Total of 12 households representing different criteria were selected in the rural area within Anuradhapura District, Senapura and Malwanegama areas. Details of locations selected are summarized in Table 3.7 and Figure 3.7.

Table 3.7: Sampling details of rural areas of Anuradhapura District

Name	Criteria	Sampling Location Details	
AS/AD/RU/01	ARO	8° 05' 31.4" N 80° 26' 07.5" E	Senapura
AS/AD/RU/02	ARO	8° 05' 39.1" N 80° 26' 06.3" E	Senapura
AS/AD/RU/03	AR & AC	8° 10' 41.1" N 80° 19' 00.8" E	Malwanegama
AS/AD/RU/04	AR & AC	8° 08' 29.0" N 80° 26' 02.09" E	Adagala
AS/AD/RU/05	AR & NAC	8° 05' 18.1" N 80° 26' 08.4" E	Senapura
AS/AD/RU/06	AR & NAC	8°10'29.32"N 80°18'54.71"E	Malwanegama
AS/AD/RU/07	NAR & AC	8° 8'15.40"N 80°25'59.02"E	Adagala
AS/AD/RU/08	NAR & AC	8° 8'10.46"N 80°25'41.60"E	Malwanegama
AS/AD/RU/09	NARO	8° 5'25.37"N 80°25'58.31"E	Senapura
AS/AD/RU/10	NARO	8° 5'44.81"N 80°25'54.78"E	Senapura
AS/AD/RU/11	NAR & NAC	8°10'38.78"N 80°18'40.79"E	Malwanegama
AS/AD/RU/12	NAR & NAC	8°10'3.20"N 80°18'58.23"E	Malwanegama



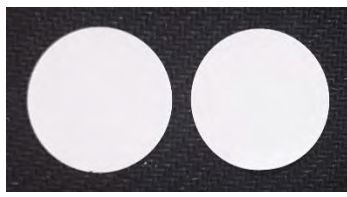
Figure 3.7: Sampling Locations at rural areas of Anuradhapura District

3.2 Sample collection

According to the project plan, the samples were collected from twelve (12) households in each environmental condition of urban, suburban and rural to cover total of 36 houses in each district of Colombo and Anuradhapura. The sampling locations covered each categories of household types and samples, which were collected from three locations (two indoor locations: bedroom and living room and one outdoor location). Therefore, the total of 108 samples were collected from one district and altogether 216 samples from both district in the first phase of the study. Sampling of the same location was repeated after six months as second phase of the project. Total number of samples collected was 432 in all categories. All samples were collected in according to the standard method for the determination of Asbestos and other fibres in air by Phase Contrast Microscope (PCM) stipulated by National Institute of Occupational Safety & Health (NIOSH 7400), America.

3.3 Sampling Materials and Equipment

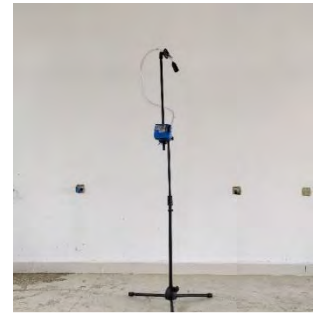
- **Filter paper** – Mixed cellulose ester membrane filters of 0.45 μm pore size with diameter of 25mm were used with a secondary supporting membrane pad (Figure 3.8).
- **Filter holder** – The open-faced filter holder fitted with a protective cowl was used in order to eliminate the accidental contaminations and physical damage. An electrically conductive cowl was required to reduce electrostatic effects on fiber sampling. Cowl was connected to the ground whenever possible, during the sampling.
- **Sampling pump (Air Pump)** – The portable battery operated GilAir3 Personal Air Sampler was used as the sampling pump and it was calibrated for the flow rate of 4 l/min.
- **Rubber tubes** – Rubber tubes with appropriate lengths were used to connect the filter holder with the Personal Air Sampler.
- **Sample stand and stool** – The sampling apparatus must have an appropriate. Therefore, a sample stand with an appropriate height from the floor level (approximately 5 ft.) was used in order to make the height of the sampler.



Filter papers



Filter holder



Sampling arrangement

Figure 3.8: Filter papers, filter holders and sampling arrangement

3.4 Sampling Procedure

To comply with the method, 25 mm, 3-piece open-faced filter holder (Figure 3.8) fitted with 50 mm electrically conductive cylindrical cowl and mixed cellulose ester filter 0.45 μm pore size and backup pad were used for the sampling. Six personal samplers were used to collect samples from two houses simultaneously at a time. Each personal air sampler was calibrated using a flow meter calibrated traceable to international standard of 0.1 l/min. The filter assembling cassettes were tested to ensure the well fitted to filter and shield well to reduce contamination.

Filter cassette was then well fitted to the personal pump using clear tube and tight fit was ensured with no air leak. The filter cassette is placed at about 2 m level of the floor level keeping the open face orienting towards downward (Figure 3.9). Two field blank samples were kept for each set of samplings to represent environmental conditions.

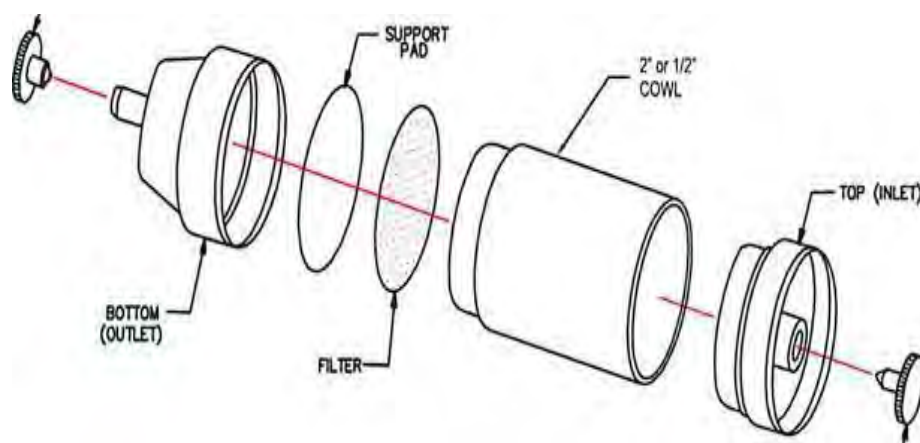


Figure 3.9: Filter holder arrangement

The sampling flow rate of the pump and the sampling period was decided to comply with the test method by using following equation and parameters.

$$t = \frac{AE}{Q * L * 10^3}$$

Where;

E – Fibre density of the filter (f/cc)

t – Sampling time (min)

A – Effective collection area of the filter (385 mm²)

Q – Sampling flow rate (l/min)

L – Expected concentration of fibre in air (f/cc)

By assuming the fibre density of 100, the expected concentration of fibre in air (L) was taken as 0.01 (f/cc) as per the results of previous study [13]. The estimated sampling flow rate of the pump was set in to the level of 4 l/m and the estimated sampling period is about 16 hours at the same rate.

3.5 Sampling details

Three samples from Bed room (B), Living room (L) and Ambient (A) were collected in each selected households for the counting of fiber (Figure 3.10) in urban, sub urban and rural area of Colombo and Anuradhapura districts in both dry and wet seasons as first phase and second phase, respectively. The sampling details are summarized in below tables.



Figure 3.10: Sampling point in each household

3.5.1 Sampling details in Colombo District – 1st Phase

Table 3.8: Sampling details of urban area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/CL/U/01	ARO	B	12.10	960	4	3840
		L	12.10	958	4	3830
		A	12.15	935	4	3740
AS/CL/U/02	ARO	B	10.10	955	4	3820
		L	10.10	928	4	3710
		A	10.20	913	4	3650
AS/CL/U/03	AR & AC	B	10.50	955	4	3820
		L	10.45	928	4	3710
		A	10.40	950	4	3800
AS/CL/U/04	AR & AC	B	10.40	900	4	3600
		L	10.40	930	4	3720
		A	10.40	948	4	3790
AS/CL/U/05	AR & NAC	B	11.10	863	4	3450
		L	11.10	890	4	3560
		A	11.10	910	4	3640
AS/CL/U/06	AR & NAC	B	11.05	938	4	3750
		L	11.10	905	4	3620
		A	11.15	925	4	3700
AS/CL/U/07	NAR & AC	B	11.40	865	4	3460
		L	11.40	878	4	3510
		A	11.40	930	4	3720
AS/CL/U/08	NAR & AC	B	11.37	960	4	3840
		L	11.38	953	4	3810
		A	11.38	925	4	3700
AS/CL/U/09	NARO	B	9.10	913	4	3650
		L	9.10	875	4	3500
		A	9.10	960	4	3840
AS/CL/U/10	NARO	B	9.30	903	4	3610
		L	9.30	810	4	3240
		A	9.30	953	4	3810
AS/CL/U/11	NAR & NAC	B	10.40	938	4	3750
		L	10.40	945	4	3780
		A	10.40	960	4	3840
AS/CL/U/12	NAR & NAC	B	10.10	948	4	3790
		L	10.05	953	4	3810
		A	10.05	925	4	3700

Table 3.9: Sampling details of sub urban area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/CL/SU/01	ARO	B	11.45	960	4	3840
		L	11.50	928	4	3710
		A	11.50	910	4	3640
AS/CL/SU/02	ARO	B	11.05	953	4	3810
		L	11.10	938	4	3750
		A	11.20	923	4	3690
AS/CL/SU/03	AR & AC	B	11.19	960	4	3840
		L	11.21	953	4	3810
		A	11.26	955	4	3820
AS/CL/SU/04	AR & AC	B	10.35	945	4	3780
		L	10.35	953	4	3810
		A	10.40	950	4	3800
AS/CL/SU/05	AR & NAC	B	11.22	978	4	3910
		L	11.20	995	4	3980
		A	11.28	938	4	3750
AS/CL/SU/06	AR & NAC	B	10.26	910	4	3640
		L	10.20	960	4	3840
		A	10.40	930	4	3720
AS/CL/SU/07	NAR & AC	B	12.15	955	4	3820
		L	12.15	923	4	3690
		A	12.20	960	4	3840
AS/CL/SU/08	NAR & AC	B	12.30	960	4	3840
		L	12.30	948	4	3790
		A	12.20	920	4	3680
AS/CL/SU/09	NARO	B	11.15	960	4	3840
		L	11.15	928	4	3710
		A	11.20	995	4	3980
AS/CL/SU/10	NARO	B	10.49	935	4	3740
		L	10.55	910	4	3640
		A	10.55	958	4	3830
AS/CL/SU/11	NAR & NAC	B	12.10	960	4	3840
		L	12.04	948	4	3790
		A	12.16	960	4	3840
AS/CL/SU/12	NAR & NAC	B	12.35	920	4	3680
		L	12.35	953	4	3810
		A	10.10	938	4	3750

Table 3.10: Sampling details of rural area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/CL/RU/01	ARO	B	10.10	955	4	3820
		L	10.10	945	4	3780
		A	10.10	920	4	3680
AS/CL/RU/02	ARO	B	10.25	978	4	3910
		L	10.25	963	4	3850
		A	10.25	905	4	3620
AS/CL/RU/03	AR & AC	B	10.35	960	4	3840
		L	10.35	928	4	3710
		A	10.35	920	4	3680
AS/CL/RU/04	AR & AC	B	11.30	860	4	3440
		L	11.30	890	4	3560
		A	11.30	960	4	3840
AS/CL/RU/05	AR & NAC	B	12.05	953	4	3810
		L	12.05	913	4	3650
		A	12.05	863	4	3450
AS/CL/RU/06	AR & NAC	B	12.20	888	4	3550
		L	12.20	903	4	3610
		A	12.20	863	4	3450
AS/CL/RU/07	NAR & AC	B	11.20	953	4	3810
		L	11.20	960	4	3840
		A	11.20	938	4	3750
AS/CL/RU/08	NAR & AC	B	11.35	865	4	3460
		L	11.30	960	4	3840
		A	11.25	930	4	3720
AS/CL/RU/09	NARO	B	11.20	913	4	3650
		L	11.25	955	4	3820
		A	11.30	960	4	3840
AS/CL/RU/10	NARO	B	10.10	878	4	3510
		L	10.10	905	4	3620
		A	10.10	885	4	3540
AS/CL/RU/11	NAR & NAC	B	11.00	913	4	3650
		L	11.00	838	4	3350
		A	11.00	938	4	3750
AS/CL/RU/12	NAR & NAC	B	11.50	923	4	3690
		L	11.45	950	4	3800
		A	11.50	945	4	3780

3.5.2 Sampling details of Anuradhapura District – 1st Phase

Table 3.11: Sampling details of urban area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/AD/U/01	ARO	B	11.45	953	4	3810
		L	11.50	885	4	3540
		A	11.56	903	4	3610
AS/AD/U/02	ARO	B	12.25	863	4	3450
		L	12.20	928	4	3710
		A	12.30	913	4	3650
AS/AD/U/03	AR & AC	B	9.32	955	4	3820
		L	9.33	948	4	3790
		A	9.37	955	4	3820
AS/AD/U/04	AR & AC	B	10.16	913	4	3650
		L	10.15	865	4	3460
		A	10.25	948	4	3790
AS/AD/U/05	AR & NAC	B	9.08	913	4	3650
		L	9.06	945	4	3780
		A	9.05	953	4	3810
AS/AD/U/06	AR & NAC	B	9.48	960	4	3840
		L	9.45	890	4	3560
		A	9.40	953	4	3810
AS/AD/U/07	NAR & AC	B	9.30	905	4	3620
		L	9.33	898	4	3590
		A	9.35	903	4	3610
AS/AD/U/08	NAR & AC	B	10.15	938	4	3750
		L	10.20	918	4	3670
		A	10.25	960	4	3840
AS/AD/U/09	NARO	B	9.15	953	4	3810
		L	9.18	978	4	3910
		A	9.20	890	4	3560
AS/AD/U/10	NARO	B	10.45	953	4	3810
		L	10.48	945	4	3780
		A	10.50	863	4	3450
AS/AD/U/11	NAR & NAC	B	11.15	903	4	3610
		L	11.20	885	4	3540
		A	11.25	905	4	3620
AS/AD/U/12	NAR & NAC	B	10.05	928	4	3710
		L	10.08	920	4	3680
		A	10.06	923	4	3690

Table 3.12: Sampling details of sub-urban area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/AD/SU/01	ARO	B	9.49	960	4	3840
		L	9.48	953	4	3810
		A	9.52	948	4	3790
AS/AD/SU/02	ARO	B	10.07	913	4	3650
		L	10.05	935	4	3740
		A	10.10	953	4	3810
AS/AD/SU/03	AR & AC	B	9.17	888	4	3550
		L	9.15	935	4	3740
		A	9.25	903	4	3610
AS/AD/SU/04	AR & AC	B	10.05	953	4	3810
		L	10.10	948	4	3790
		A	10.12	940	4	3760
AS/AD/SU/05	AR & NAC	B	9.15	863	4	3450
		L	9.10	945	4	3780
		A	9.10	920	4	3680
AS/AD/SU/06	AR & NAC	B	11.25	928	4	3710
		L	11.28	945	4	3780
		A	11.30	960	4	3840
AS/AD/SU/07	NAR & AC	B	9.20	888	4	3550
		L	9.22	903	4	3610
		A	9.25	935	4	3740
AS/AD/SU/08	NAR & AC	B	10.45	955	4	3820
		L	10.48	920	4	3680
		A	10.50	863	4	3450
AS/AD/SU/09	NARO	B	8.30	888	4	3550
		L	8.32	823	4	3290
		A	8.35	935	4	3740
AS/AD/SU/10	NARO	B	9.20	910	4	3640
		L	9.25	888	4	3550
		A	9.28	940	4	3760
AS/AD/SU/11	NAR & NAC	B	8.45	920	4	3680
		L	8.48	953	4	3810
		A	8.50	950	4	3800
AS/AD/SU/12	NAR & NAC	B	10.05	953	4	3810
		L	10.15	948	4	3790
		A	10.10	920	4	3680

Table 3.13: Sampling details of rural area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/AD/RU/01	ARO	B	9.51	960	4	3840
		L	9.54	913	4	3650
		A	10.00	928	4	3710
AS/AD/RU/02	ARO	B	10.22	955	4	3820
		L	10.24	888	4	3550
		A	10.34	915	4	3660
AS/AD/RU/03	AR & AC	B	9.34	948	4	3790
		L	9.36	873	4	3490
		A	9.32	893	4	3570
AS/AD/RU/04	AR & AC	B	9.53	920	4	3680
		L	9.55	960	4	3840
		A	9.51	888	4	3550
AS/AD/RU/05	AR & NAC	B	10.15	905	4	3620
		L	10.20	953	4	3810
		A	10.22	960	4	3840
AS/AD/RU/06	AR & NAC	B	11.30	878	4	3510
		L	11.32	873	4	3490
		A	11.35	903	4	3610
AS/AD/RU/07	NAR & AC	B	10.05	935	4	3740
		L	10.10	930	4	3720
		A	10.15	928	4	3710
AS/AD/RU/08	NAR & AC	B	8.40	953	4	3810
		L	8.45	888	4	3550
		A	8.47	915	4	3660
AS/AD/RU/09	NARO	B	9.30	898	4	3590
		L	9.35	920	4	3680
		A	9.40	898	4	3590
AS/AD/RU/10	NARO	B	10.35	953	4	3810
		L	10.40	948	4	3790
		A	10.45	915	4	3660
AS/AD/RU/11	NAR & NAC	B	8.30	950	4	3800
		L	8.35	948	4	3790
		A	8.37	928	4	3710
AS/AD/RU/12	NAR & NAC	B	9.30	930	4	3720
		L	9.35	888	4	3550
		A	9.40	903	4	3610

3.5.3 Sampling details of Colombo District – 2nd Phase

Table 3.14: Sampling details of urban area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/CL/U/01	ARO	B	11.45	928	4	3710
		L	11.50	890	4	3560
		A	11.50	955	4	3820
AS/CL/U/02	ARO	B	11.05	953	4	3810
		L	11.10	913	4	3650
		A	11.20	888	4	3550
AS/CL/U/03	AR & AC	B	11.19	853	4	3410
		L	11.21	953	4	3810
		A	11.26	913	4	3650
AS/CL/U/04	AR & AC	B	10.35	960	4	3840
		L	10.35	930	4	3720
		A	10.40	928	4	3710
AS/CL/U/05	AR & NAC	B	11.22	960	4	3840
		L	11.20	955	4	3820
		A	11.28	938	4	3750
AS/CL/U/06	AR & NAC	B	10.26	910	4	3640
		L	10.20	955	4	3820
		A	10.40	928	4	3710
AS/CL/U/07	NAR & AC	B	12.15	955	4	3820
		L	12.15	920	4	3680
		A	12.20	960	4	3840
AS/CL/U/08	NAR & AC	B	12.30	928	4	3710
		L	12.30	955	4	3820
		A	12.20	948	4	3790
AS/CL/U/09	NARO	B	11.15	940	4	3760
		L	11.15	955	4	3820
		A	11.20	960	4	3840
AS/CL/U/10	NARO	B	10.49	850	4	3400
		L	10.55	923	4	3690
		A	10.55	955	4	3820
AS/CL/U/11	NAR & NAC	B	12.10	938	4	3750
		L	12.04	953	4	3810
		A	12.16	923	4	3690
AS/CL/U/12	NAR & NAC	B	12.35	945	4	3780
		L	12.35	923	4	3690
		A	12.40	953	4	3810

Table 3.15: Sampling details of sub- urban area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/CL/SU/01	ARO	B	11.45	950	4	3800
		L	11.50	928	4	3710
		A	11.50	930	4	3720
AS/CL/SU/02	ARO	B	11.05	913	4	3650
		L	11.10	960	4	3840
		A	11.20	923	4	3690
AS/CL/SU/03	AR & AC	B	11.19	955	4	3820
		L	11.21	928	4	3710
		A	11.26	913	4	3650
AS/CL/SU/04	AR & AC	B	10.35	950	4	3800
		L	10.35	960	4	3840
		A	10.40	913	4	3650
AS/CL/SU/05	AR & NAC	B	11.22	915	4	3660
		L	11.20	918	4	3670
		A	11.28	928	4	3710
AS/CL/SU/06	AR & NAC	B	10.26	893	4	3570
		L	10.20	960	4	3840
		A	10.40	960	4	3840
AS/CL/SU/07	NAR & AC	B	12.15	953	4	3810
		L	12.15	923	4	3690
		A	12.20	910	4	3640
AS/CL/SU/08	NAR & AC	B	12.30	960	4	3840
		L	12.30	948	4	3790
		A	12.20	955	4	3820
AS/CL/SU/09	NARO	B	11.15	953	4	3810
		L	11.15	948	4	3790
		A	11.20	945	4	3780
AS/CL/SU/10	NARO	B	10.49	913	4	3650
		L	10.55	938	4	3750
		A	10.55	910	4	3640
AS/CL/SU/11	NAR & NAC	B	12.10	945	4	3780
		L	12.04	908	4	3630
		A	12.16	905	4	3620
AS/CL/SU/12	NAR & NAC	B	12.35	855	4	3420
		L	12.35	888	4	3550
		A	12.40	863	4	3450

Table 3.16: Sampling details of rural area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/CL/RU/01	ARO	B	9.17	960	4	3840
		L	9.15	885	4	3540
		A	9.25	903	4	3610
AS/CL/RU/02	ARO	B	10.05	870	4	3480
		L	10.10	928	4	3710
		A	10.12	930	4	3720
AS/CL/RU/03	AR & AC	B	9.15	935	4	3740
		L	9.10	953	4	3810
		A	9.10	955	4	3820
AS/CL/RU/04	AR & AC	B	11.25	923	4	3690
		L	11.28	935	4	3740
		A	11.30	960	4	3840
AS/CL/RU/05	AR & NAC	B	9.20	910	4	3640
		L	9.22	953	4	3810
		A	9.25	928	4	3710
AS/CL/RU/06	AR & NAC	B	10.16	920	4	3680
		L	10.15	955	4	3820
		A	10.25	960	4	3840
AS/CL/RU/07	NAR & AC	B	9.08	910	4	3640
		L	9.06	938	4	3750
		A	9.05	920	4	3680
AS/CL/RU/08	NAR & AC	B	9.48	945	4	3780
		L	9.45	898	4	3590
		A	9.40	935	4	3740
AS/CL/RU/09	NARO	B	9.30	960	4	3840
		L	9.33	863	4	3450
		A	9.35	940	4	3760
AS/CL/RU/10	NARO	B	10.15	935	4	3740
		L	10.20	953	4	3810
		A	10.25	920	4	3680
AS/CL/RU/11	NAR & NAC	B	9.15	955	4	3820
		L	9.18	935	4	3740
		A	9.20	953	4	3810
AS/CL/RU/12	NAR & NAC	B	11.50	930	4	3720
		L	11.45	913	4	3650
		A	11.50	863	4	3450

3.5.3 Sampling details of Anuradhapura District – 2nd Phase

Table 3.17: Sampling details of urban area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/AD/U/01	ARO	B	10.45	953	4	3810
		L	10.50	905	4	3620
		A	10.50	935	4	3740
AS/AD/U/02	ARO	B	11.05	870	4	3480
		L	11.10	905	4	3620
		A	11.20	938	4	3750
AS/AD/U/03	AR & AC	B	10.15	953	4	3810
		L	10.20	948	4	3790
		A	10.25	955	4	3820
AS/AD/U/04	AR & AC	B	10.35	913	4	3650
		L	10.35	935	4	3740
		A	10.40	960	4	3840
AS/AD/U/05	AR & NAC	B	11.15	903	4	3610
		L	11.20	955	4	3820
		A	11.20	910	4	3640
AS/AD/U/06	AR & NAC	B	10.25	920	4	3680
		L	10.20	903	4	3610
		A	10.25	960	4	3840
AS/AD/U/07	NAR & AC	B	12.15	910	4	3640
		L	12.15	938	4	3750
		A	12.20	885	4	3540
AS/AD/U/08	NAR & AC	B	12.30	928	4	3710
		L	12.30	898	4	3590
		A	12.25	870	4	3480
AS/AD/U/09	NARO	B	11.15	935	4	3740
		L	11.10	863	4	3450
		A	11.20	940	4	3760
AS/AD/U/10	NARO	B	10.50	953	4	3810
		L	10.55	905	4	3620
		A	10.55	920	4	3680
AS/AD/U/11	NAR & NAC	B	12.10	955	4	3820
		L	12.05	893	4	3570
		A	12.05	953	4	3810
AS/AD/U/12	NAR & NAC	B	12.30	920	4	3680
		L	12.35	913	4	3650
		A	12.30	890	4	3560

Table 3.18: Sampling details of sub urban area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/AD/SU/01	ARO	B	10.45	950	4	3800
		L	10.50	928	4	3710
		A	10.50	935	4	3740
AS/AD/SU/02	ARO	B	11.05	905	4	3620
		L	11.10	905	4	3620
		A	11.10	925	4	3700
AS/AD/SU/03	AR & AC	B	11.20	953	4	3810
		L	11.25	940	4	3760
		A	11.30	930	4	3720
AS/AD/SU/04	AR & AC	B	10.35	913	4	3650
		L	10.30	933	4	3730
		A	10.40	955	4	3820
AS/AD/SU/05	AR & NAC	B	11.20	948	4	3790
		L	11.25	950	4	3800
		A	11.30	913	4	3650
AS/AD/SU/06	AR & NAC	B	10.35	923	4	3690
		L	10.30	905	4	3620
		A	10.40	958	4	3830
AS/AD/SU/07	NAR & AC	B	12.15	910	4	3640
		L	12.20	938	4	3750
		A	12.20	903	4	3610
AS/AD/SU/08	NAR & AC	B	12.30	948	4	3790
		L	12.30	898	4	3590
		A	12.20	905	4	3620
AS/AD/SU/09	NARO	B	11.10	935	4	3740
		L	11.15	958	4	3830
		A	11.20	930	4	3720
AS/AD/SU/10	NARO	B	10.15	953	4	3810
		L	10.15	913	4	3650
		A	10.20	920	4	3680
AS/AD/SU/11	NAR & NAC	B	12.10	953	4	3810
		L	12.05	900	4	3600
		A	15.05	948	4	3790
AS/AD/SU/12	NAR & NAC	B	11.35	920	4	3680
		L	11.35	915	4	3660
		A	11.30	873	4	3490

Table 3.19: Sampling details of rural area locations

Sample No.	Criteria	Location area	Start Time	Sampling Time (min)	Flow rate (l/min)	V (L)
AS/AD/RU/01	ARO	B	9.20	948	4	3790
		L	9.25	913	4	3650
		A	9.35	920	4	3680
AS/AD/RU/02	ARO	B	10.05	905	4	3620
		L	10.10	930	4	3720
		A	10.15	928	4	3710
AS/AD/RU/03	AR & AC	B	9.45	953	4	3810
		L	9.50	935	4	3740
		A	9.45	928	4	3710
AS/AD/RU/04	AR & AC	B	11.25	908	4	3630
		L	11.30	935	4	3740
		A	11.35	950	4	3800
AS/AD/RU/05	AR & NAC	B	9.20	940	4	3760
		L	9.25	950	4	3800
		A	9.30	920	4	3680
AS/AD/RU/06	AR & NAC	B	10.45	923	4	3690
		L	10.40	913	4	3650
		A	10.35	948	4	3790
AS/AD/RU/07	NAR & AC	B	9.10	910	4	3640
		L	9.06	938	4	3750
		A	9.05	900	4	3600
AS/AD/RU/08	NAR & AC	B	9.40	948	4	3790
		L	9.45	893	4	3570
		A	9.40	903	4	3610
AS/AD/RU/09	NARO	B	9.30	935	4	3740
		L	9.35	950	4	3800
		A	9.35	930	4	3720
AS/AD/RU/10	NARO	B	10.15	953	4	3810
		L	10.20	910	4	3640
		A	10.25	920	4	3680
AS/AD/RU/11	NAR & NAC	B	9.15	950	4	3800
		L	9.20	903	4	3610
		A	9.25	948	4	3790
AS/AD/RU/12	NAR & NAC	B	10.50	920	4	3680
		L	10.55	915	4	3660
		A	10.50	910	4	3640

3.5 Sample transportation

Filter holders were transported to the NBRO while maintaining the vertical arrangement. Transported holders were stored in the same vertical arrangement in order to eliminate disturbances to the samples.

3.6 Sample preparation

Sample fitters were removed carefully from the sampling cassette without disturbing to the fibers on the surface and cut along the diameter to get $\frac{1}{4}$ part of the filter in a clean area free from dust and fibers. The sample part was placed in a previously clean glass slide. Place the glass slide with filter sample in the PERM-OFIX Acetone vaporizer chamber and exposed to acetone vapor for about 3 to 5 seconds. After obtaining clear transparent condition, removed the slide and gently heat to remove excess Acetone if any. After cooling to room temperature, add two drops of triacetin on to the sample and covered by a clean cover slip.

3.7 Sample analysis

The analysis of fibers in filter holders were carried out by using OPTIKA B-383PH, ITALY, Phase Contrast Microscope (PCM) in according to the method stipulated by National Institute of Occupational Safety & Health (NIOSH 7400), America.

3.8 Fiber counting

The fiber counting was done using PCM after the completion of the clearing and mounting process. As per the PCM standard method, fiber in the sample are focused to clear vision, identification and counting of respirable fiber levels in the collected samples were done by using a Walton-Backett graticule (Type G22) with 100 μm projected diameter circular area (Figure 3.11). Fibers larger than 5 μm ($>5 \mu\text{m}$), width lower than 3 μm ($<3 \mu\text{m}$) and equal or greater than the length to width ratio of 3:1 was counted within the projected area. The same procedure was repeated to cover all sample area (about 100 graticule fields) in according to the counting rules of the method.



Counting Criteria:

- $>5 \mu\text{m}$ in length
- $<3 \mu\text{m}$ in width
- Greater than 3:1 ratio (length/width)
- 100 Graticule Areas
- Other counting guidance given in the NIOSH 7400 PCM method

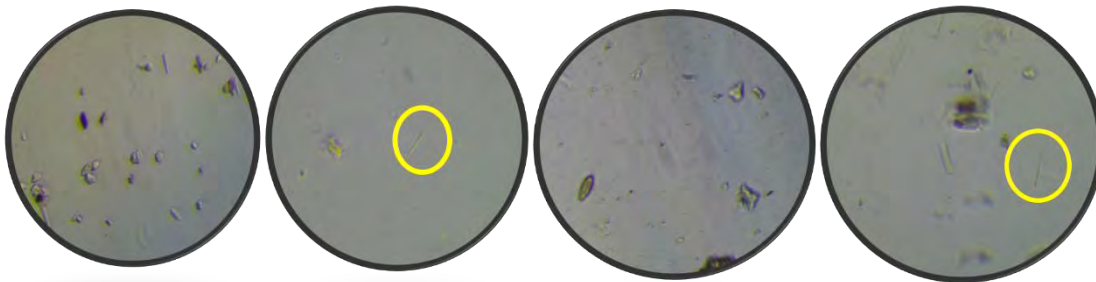


Figure 3.11: Fiber identification criteria and view through PCM

Then, the fibre density of the sample was then calculated using the following equation.

$$E = \frac{(F/n_f) - (B/n_b)}{A_f}$$

Where;

E – Fibre density of the filter (f/cc)

B/n_b – Mean fibre blank counter per graticule field

F/n_f – Mean fibre counter per graticule field

A_f – Graticule field area (mm²)

Then, the fibre concentration of sample C, was calculated using the following equation.

$$C = \frac{EA_c}{V \cdot 10^3}$$

Where;

C – Concentration of fibre (f/cc)

A_c – Effective collection area of the filter (mm²)

E – Fibre density of the filter (f/cc)

V - Air volume of sample (l)

4. RESULTS AND DISCUSSION

The asbestos fiber count levels obtained in each collected samples and fiber concentration calculated in according to the standard according procedure during first phase and second phase from urban, sub urban and rural area of both Colombo and Anuradhapura districts are summarized in following tables. The calculation and other details are given in the annex 1.

The measured concentration of fiber levels asses in the levels recommended by international agencies and countries standard levels since no national standard levels stipulated for Sri Lanka. Some of commonly used international standards levels and standard levels stipulated for different countries for deferent processes are summarized in table 4.1 and can be used to compare the fiber levels obtained by this study to assess the Sri lankan condition.

Table 4.1: The maximum exposure levels of Asbestos fiber recommended by international agencies and countries in their standard

Reference sources	Recommended values (f/cc)
OSHA (Occupational Safety and Health Administration – USA)	0.1
NIOSH (National Institute for Occupational Safety and Health - USA)	0.1
MSHA (The Mine Safety and Health Administration of the United States Department of Labor)	2
ACGIH (The American Conference of Governmental Industrial Hygienists)	2
Indian Industrial Standard	0.5
US – EPA (non-occupational)	0.0009
Russia (Ambient Air quality)	0.06
WHO (proposed by authors in a population of whom 30% are smokers, the excess risk due to lung cancer would be in the order of 10^{-6} - 10^{-5}).	0.0005 (life time exposure)

4.1 Results of fiber levels countered and Fiber concentration

Number of fibers counted in 100 numbers of Walton-Backett Graticule areas of filter samples collected by urban, sub-urban and rural areas of the Colombo District and relevant fiber concentrations are summarized in Table 4.1, Table 4.2 and Table 4.3, respectively.

Table 4.2: Number of Fiber counts and relvent fiber concentrations in urban area of Colombo District during 1st and 2nd stages of the study period

Sample No.	Criteria	Location area	1 st Stage		2 nd Stage	
			No. of fiber count (F)	Fiber Concentration (Fiber/ml)	No. of fiber count (F)	Fiber Concentration (Fiber/ml)
AS/CL/U/01	ARO	B	4	0.00051	5	0.00071
		L	4	0.00051	5	0.00071
		A	4	0.00051	6	0.00071
AS/CL/U/02	ARO	B	6	0.00077	6	0.00081
		L	4	0.00050	5	0.00061
		A	3	0.00040	4	0.00051
AS/CL/U/03	AR & AC	B	6	0.00077	4	0.00060
		L	3	0.00041	4	0.00052
		A	3	0.00042	4	0.00049
AS/CL/U/04	AR & AC	B	4	0.00051	4	0.00050
		L	4	0.00051	3	0.00043
		A	4	0.00051	4	0.00051
AS/CL/U/05	AR & NAC	B	3	0.00041	5	0.00061
		L	4	0.00050	4	0.00051
		A	4	0.00051	3	0.00042
AS/CL/U/06	AR & NAC	B	3	0.00041	5	0.00061
		L	5	0.00051	5	0.00051
		A	0	0.00000	3	0.00039
AS/CL/U/07	NAR & AC	B	2	0.00030	4	0.00051
		L	4	0.00051	4	0.00048
		A	0	0.00000	4	0.00051
AS/CL/U/08	NAR & AC	B	4	0.00051	4	0.00051
		L	4	0.00051	3	0.00033
		A	4	0.00051	4	0.00051
AS/CL/U/09	NARO	B	4	0.00060	4	0.00051
		L	4	0.00050	2	0.00032
		A	0	0.00000	2	0.00031
AS/CL/U/10	NARO	B	2	0.00030	4	0.00052
		L	2	0.00030	3	0.00035
		A	0	0.00000	3	0.00042
AS/CL/U/11	NAR & NAC	B	2	0.00030	3	0.00037
		L	2	0.00032	1	0.00019
		A	4	0.00050	4	0.00051
AS/CL/U/12	NAR & NAC	B	0	0.00000	4	0.00048
		L	4	0.00043	1	0.00015
		A	2	0.00030	4	0.00051

Table 4.3: Number of Fiber counts and relvent fiber concentrations in sub-urban area of Colombo District during 1st and 2nd stages of the study period

Sample No.	Criteria	Location area	1 st Stage		2 nd Stage	
			No. of fiber count (F)	Fiber Concentration (Fiber/ml)	No. of fiber count (F)	Fiber Concentration (Fiber/ml)
AS/CL/SU/01	ARO	B	3	0.00040	5	0.00064
		L	4	0.00050	4	0.00052
		A	4	0.00051	4	0.00049
AS/CL/SU/02	ARO	B	4	0.00051	4	0.00058
		L	3	0.00040	4	0.00051
		A	0	0.00000	4	0.00051
AS/CL/SU/03	AR & AC	B	5	0.00064	2	0.00031
		L	4	0.00051	3	0.00041
		A	2	0.00030	4	0.00055
AS/CL/SU/04	AR & AC	B	3	0.00042	4	0.00051
		L	4	0.00051	3	0.00042
		A	3	0.00041	2	0.00032
AS/CL/SU/05	AR & NAC	B	3	0.00040	4	0.00048
		L	3	0.00040	3	0.00041
		A	4	0.00051	3	0.00037
AS/CL/SU/06	AR & NAC	B	4	0.00050	4	0.00051
		L	3	0.00030	4	0.00038
		A	1	0.00010	3	0.00035
AS/CL/SU/07	NAR & AC	B	4	0.00051	2	0.00032
		L	4	0.00051	2	0.00031
		A	2	0.00020	3	0.00035
AS/CL/SU/08	NAR & AC	B	4	0.00051	4	0.00048
		L	2	0.00020	3	0.00041
		A	2	0.00026	2	0.00026
AS/CL/SU/09	NARO	B	2	0.00030	3	0.00041
		L	2	0.00030	2	0.00021
		A	0	0.00000	1	0.00011
AS/CL/SU/10	NARO	B	1	0.00010	3	0.00038
		L	1	0.00020	1	0.00018
		A	2	0.00020	2	0.00028
AS/CL/SU/11	NAR & NAC	B	3	0.00041	2	0.00031
		L	2	0.00030	1	0.00014
		A	2	0.00021	1	0.00011
AS/CL/SU/12	NAR & NAC	B	2	0.00031	4	0.00051
		L	3	0.00029	0	0.00000
		A	2	0.00021	0	0.00000

Table 4.4: Number of Fiber counts and relvent fiber concentrations in rural area of Colombo District during 1st and 2nd stages of the study period

Sample No.	Criteria	Location area	1 st Stage		2 nd Stage	
			No. of fiber count (F)	Fiber Concentration (Fiber/ml)	No. of fiber count (F)	Fiber Concentration (Fiber/ml)
AS/CL/RU/01	ARO	B	2	0.00020	4	0.00051
		L	2	0.00030	2	0.00023
		A	2	0.00030	3	0.00037
AS/CL/RU/02	ARO	B	2	0.00030	3	0.00042
		L	3	0.00040	4	0.00051
		A	0	0.00000	4	0.00051
AS/CL/RU/03	AR & AC	B	3	0.00035	2	0.00024
		L	3	0.00042	2	0.00022
		A	2	0.00021	3	0.00037
AS/CL/RU/04	AR & AC	B	4	0.00051	2	0.00021
		L	1	0.00020	1	0.00011
		A	2	0.00021	0	0.00000
AS/CL/RU/05	AR & NAC	B	1	0.00010	2	0.00031
		L	3	0.00040	2	0.00031
		A	1	0.00020	2	0.00021
AS/CL/RU/06	AR & NAC	B	1	0.00010	3	0.00041
		L	2	0.00020	1	0.00011
		A	2	0.00020	2	0.00028
AS/CL/RU/07	NAR & AC	B	4	0.00048	2	0.00023
		L	4	0.00051	2	0.00021
		A	1	0.00010	2	0.00021
AS/CL/RU/08	NAR & AC	B	0	0.00000	2	0.00031
		L	1	0.00010	1	0.00014
		A	1	0.00010	1	0.00011
AS/CL/RU/09	NARO	B	1	0.00010	3	0.00033
		L	2	0.00020	2	0.00032
		A	0	0.00000	1	0.00010
AS/CL/RU/10	NARO	B	1	0.00020	2	0.00026
		L	1	0.00010	0	0.00000
		A	0	0.00000	0	0.00000
AS/CL/RU/11	NAR & NAC	B	1	0.00010	2	0.00021
		L	1	0.00021	0	0.00000
		A	0	0.00000	0	0.00000
AS/CL/RU/12	NAR & NAC	B	2	0.00030	2	0.00031
		L	2	0.00021	1	0.00008
		A	0	0.00000	0	0.00000

Number of fibers counted in 100 numbers of Walton-Backett Graticule areas of filter samples collected by urban, sub-urban and rural areas of the Anuradhapura District and relevant fiber concentrations are summarized in Table 4.4, Table 4.5 and Table 4.5 respectively.

Table 4.5: Number of Fiber counts and relevant fiber concentrations in urban area of Anuradhapura District during 1st and 2nd stages of the study period

Sample No.	Criteria	Location area	1 st Stage		2 nd Stage	
			No. of fiber count (F)	Fiber Concentration (Fiber/ml)	No. of fiber count (F)	Fiber Concentration (Fiber/ml)
AS/AD/U/01	ARO	B	5	0.00060	2	0.00026
		L	4	0.00060	1	0.00014
		A	4	0.00050	0	0.00000
AS/AD/U/02	ARO	B	5	0.00071	1	0.00014
		L	4	0.00050	1	0.00014
		A	4	0.00050	2	0.00026
AS/AD/U/03	AR & AC	B	2	0.00030	2	0.00023
		L	2	0.00030	1	0.00013
		A	2	0.00030	0	0.00000
AS/AD/U/04	AR & AC	B	3	0.00040	2	0.00021
		L	4	0.00050	1	0.00011
		A	4	0.00050	0	0.00000
AS/AD/U/05	AR & NAC	B	2	0.00030	2	0.00031
		L	3	0.00040	2	0.00031
		A	5	0.00060	2	0.00021
AS/AD/U/06	AR & NAC	B	4	0.00050	2	0.00027
		L	5	0.00050	1	0.00012
		A	4	0.00050	1	0.00012
AS/AD/U/07	NAR & AC	B	1	0.00020	2	0.00023
		L	4	0.00050	2	0.00021
		A	3	0.00040	1	0.00014
AS/AD/U/08	NAR & AC	B	3	0.00040	2	0.00032
		L	4	0.00050	1	0.00014
		A	3	0.00040	1	0.00012
AS/AD/U/09	NARO	B	2	0.00030	2	0.00026
		L	2	0.00020	0	0.00000
		A	1	0.00020	1	0.00010
AS/AD/U/10	NARO	B	2	0.00020	2	0.00025
		L	2	0.00020	0	0.00000
		A	0	0.00000	0	0.00000
AS/AD/U/11	NAR & NAC	B	0	0.00000	2	0.00021
		L	0	0.00000	0	0.00000
		A	1	0.00020	0	0.00000
AS/AD/U/12	NAR & NAC	B	0	0.00000	2	0.00031
		L	0	0.00000	1	0.00008
		A	2	0.00030	0	0.00000

Table 4.6: Number of Fiber counts and relvent fiber concentrations in sub-urban area of Anuradhapura District during 1st and 2nd stages of the study period

Sample No.	Criteria	Location area	1 st Stage		2 nd Stage	
			No. of fiber count (F)	Fiber Concentration (Fiber/ml)	No. of fiber count (F)	Fiber Concentration (Fiber/ml)
AS/AD/SU/01	ARO	B	0	0.00000	1	0.00013
		L	4	0.00051	1	0.00013
		A	2	0.00030	1	0.00013
AS/AD/SU/02	ARO	B	4	0.00054	1	0.00014
		L	3	0.00040	2	0.00027
		A	4	0.00050	0	0.00000
AS/AD/SU/03	AR & AC	B	0	0.00000	1	0.00013
		L	0	0.00000	2	0.00026
		A	0	0.00000	1	0.00013
AS/AD/SU/04	AR & AC	B	0	0.00000	1	0.00013
		L	0	0.00000	1	0.00011
		A	0	0.00000	0	0.00000
AS/AD/SU/05	AR & NAC	B	1	0.00015	1	0.00013
		L	2	0.00020	2	0.00031
		A	3	0.00040	1	0.00013
AS/AD/SU/06	AR & NAC	B	2	0.00030	2	0.00027
		L	3	0.00030	1	0.00012
		A	3	0.00030	1	0.00012
AS/AD/SU/07	NAR & AC	B	1	0.00010	1	0.00013
		L	3	0.00038	2	0.00021
		A	3	0.00035	1	0.00014
AS/AD/SU/08	NAR & AC	B	2	0.00021	2	0.00031
		L	2	0.00030	1	0.00014
		A	2	0.00025	1	0.00011
AS/AD/SU/09	NARO	B	1	0.00010	2	0.00026
		L	0	0.00000	1	0.00013
		A	0	0.00000	1	0.00010
AS/AD/SU/10	NARO	B	1	0.00010	2	0.00025
		L	0	0.00000	1	0.00013
		A	0	0.00000	0	0.00000
AS/AD/SU/11	NAR & NAC	B	0	0.00000	1	0.00013
		L	0	0.00000	1	0.00014
		A	1	0.00017	0	0.00000
AS/AD/SU/12	NAR & NAC	B	0	0.00000	2	0.00031
		L	0	0.00000	1	0.00008
		A	1	0.00018	0	0.00000

Table 4.7: Number of Fiber counts and relvent fiber concentrations in rural area of Anuradhapura District during 1st and 2nd stages of the study period

Sample No.	Criteria	Location area	1 st Stage		2 nd Stage	
			No. of fiber count (F)	Fiber Concentration (Fiber/ml)	No. of fiber count (F)	Fiber Concentration (Fiber/ml)
AS/AD/RU/01	ARO	B	0	0.00000	1	0.00013
		L	1	0.00010	1	0.00013
		A	1	0.00010	0	0.00000
AS/AD/RU/02	ARO	B	2	0.00030	1	0.00014
		L	1	0.00010	0	0.00000
		A	0	0.00000	0	0.00000
AS/AD/RU/03	AR & AC	B	0	0.00000	1	0.00013
		L	0	0.00000	1	0.00013
		A	1	0.00014	0	0.00000
AS/AD/RU/04	AR & AC	B	1	0.00013	1	0.00013
		L	1	0.00013	1	0.00013
		A	0	0.00000	0	0.00000
AS/AD/RU/05	AR & NAC	B	1	0.00014	1	0.00013
		L	1	0.00013	1	0.00013
		A	0	0.00000	1	0.00013
AS/AD/RU/06	AR & NAC	B	1	0.00014	1	0.00013
		L	0	0.00000	1	0.00011
		A	0	0.00000	0	0.00000
AS/AD/RU/07	NAR & AC	B	0	0.00000	1	0.00013
		L	1	0.00013	1	0.00013
		A	0	0.00000	1	0.00014
AS/AD/RU/08	NAR & AC	B	1	0.00013	1	0.00013
		L	0	0.00000	1	0.00014
		A	1	0.00013	1	0.00014
AS/AD/RU/09	NARO	B	1	0.00014	0	0.00000
		L	0	0.00000	1	0.00013
		A	0	0.00000	1	0.00013
AS/AD/RU/10	NARO	B	1	0.00013	1	0.00013
		L	0	0.00000	1	0.00013
		A	0	0.00000	0	0.00000
AS/AD/RU/11	NAR & NAC	B	1	0.00013	1	0.00013
		L	0	0.00000	1	0.00014
		A	0	0.00000	0	0.00000
AS/AD/RU/12	NAR & NAC	B	1	0.00012	1	0.00013
		L	0	0.00000	1	0.00011
		A	0	0.00000	1	0.00013

4.2 Assessment of fiber concentration in Colombo District

According to the fiber concentrations levels obtained by the study, the average fiber level in indoor (bedroom and Living Rooms) areas of the households in rural areas were relatively lower than that of the urban and sub-urban areas in both Colombo and Anuradhapura districts. Also, the indoor fiber levels in all three environmental conditions of urban, suburban, rural shown in Figure 4.1 are below the maximum recommended levels of US-EPA (non-occupational) areas.

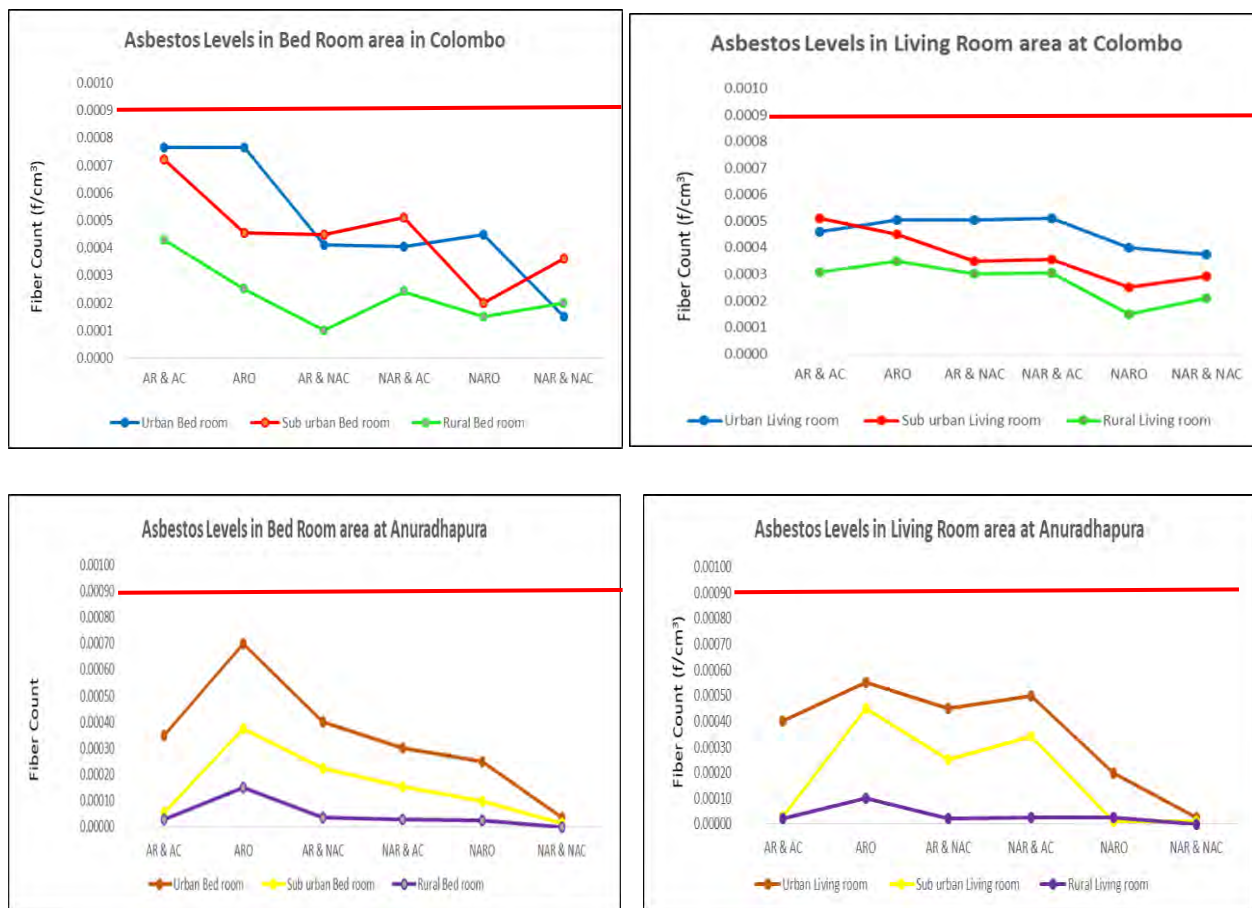


Figure 4.1: Variation of fiber concentration in bedrooms and living rooms in Colombo and Anuradhapura District

According to the ambient fiber concentrations levels obtained by the study, shown in Figure 4.2, the average fiber level in ambient air is increasing with the urbanisation but are well below the maximum recommended levels of US-EPA (non-occupational) areas. This increase of fiber level with the urbanization could be due to the changes of air pollution conditions in the urban and sub-urban areas. Furthermore, it may be due to the usage of vehicles that could contribute fibers from brake pads or other uses such as insulates in commercial and industrial buildings, etc.

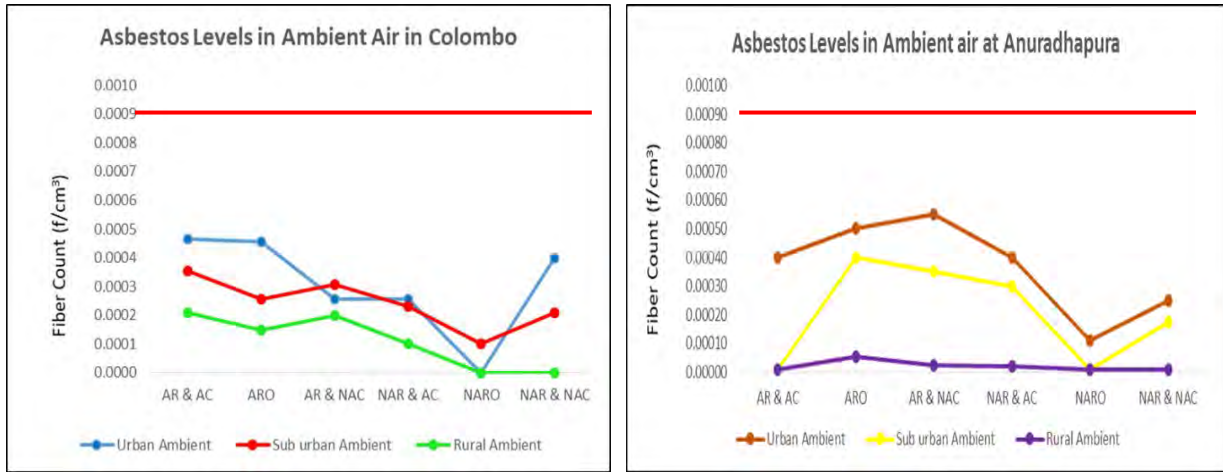


Figure 4.2: Variation of fiber concentration in ambient air in Colombo and Anuradhapura

As shown in Figure 4.3, the indoor fibre concentration is relatively high in Colombo compared to Anuradhapura, specially in rural areas, where as the ambient fiber concentrations does not show such variation as shown in Figure 4.5. This variation clearly indicates the ambient air quality contribution to indoor air quality in urban areas are higher than that of rural areas where pollutant distribuion dominated by wind is low in urban areas due to high building density. Also, the airborne ability of pollutants including fibers are relatively high in urban areas with heat island effects and space useage, etc.

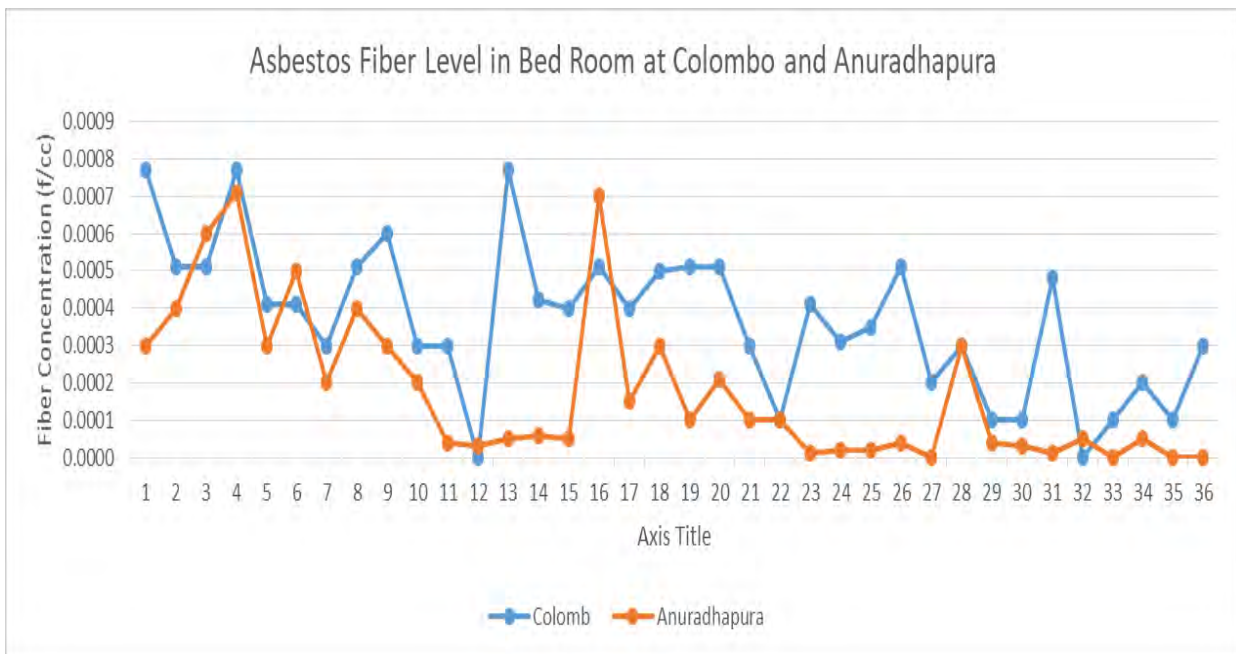


Figure 4.3: Variation of fiber concentration in indoor environment in Colombo and Anuradhapura districts

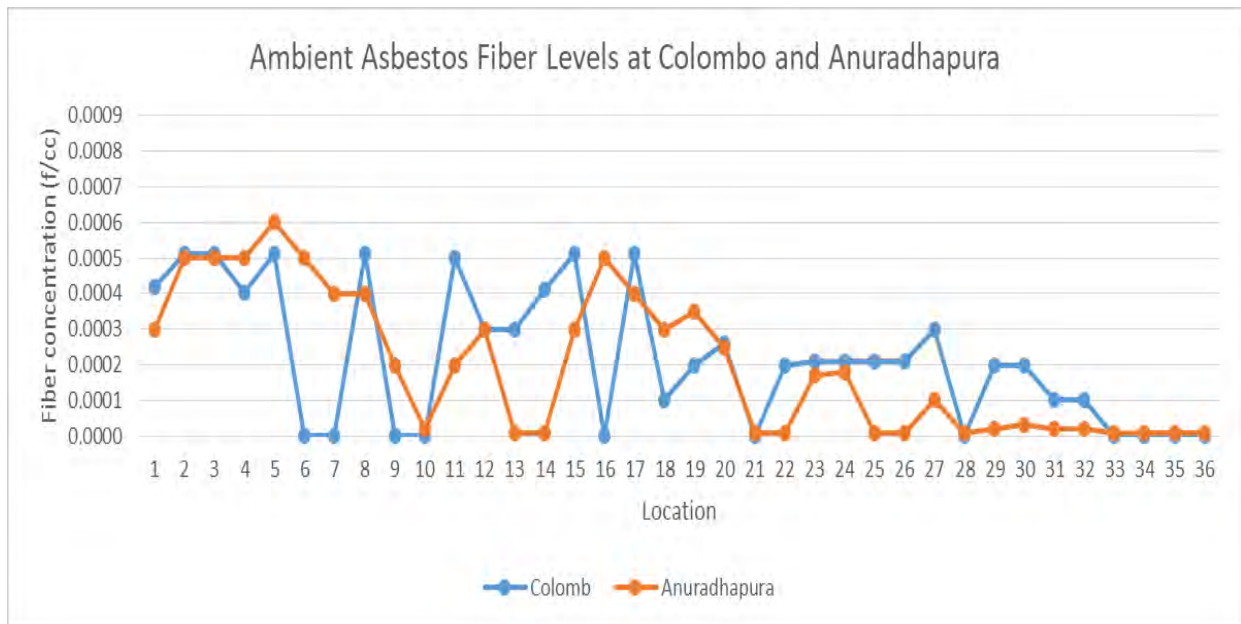


Figure 4.4: Variation of fiber concentration in ambient environment in Colombo and Anuradhapura districts

When compared the fiber concentrations in households that use Chrysotile fiber sheets only as roofing (ARO) materials with non-asbestos (NARO), clay tiles, as roofing materials the indoor fiber level in newly built asbestos roofing houses are comparatively high whereas no clear variations in houses older than 5 years as shown in Figure 4.5. Similar variation can be observed in houses used Chrysotile fiber sheet as roofing as well as ceiling (AR & AC) materials compared to houses used non-asbestos roofing (clay tile) and ceiling (wood) materials as presented in Figure 4.6. This relatively high fiber levels in newly built houses used Chrysotile roofing materials should be due to the contribution of air borne fibers while cutting and damaging intervention during roof and ceiling construction.

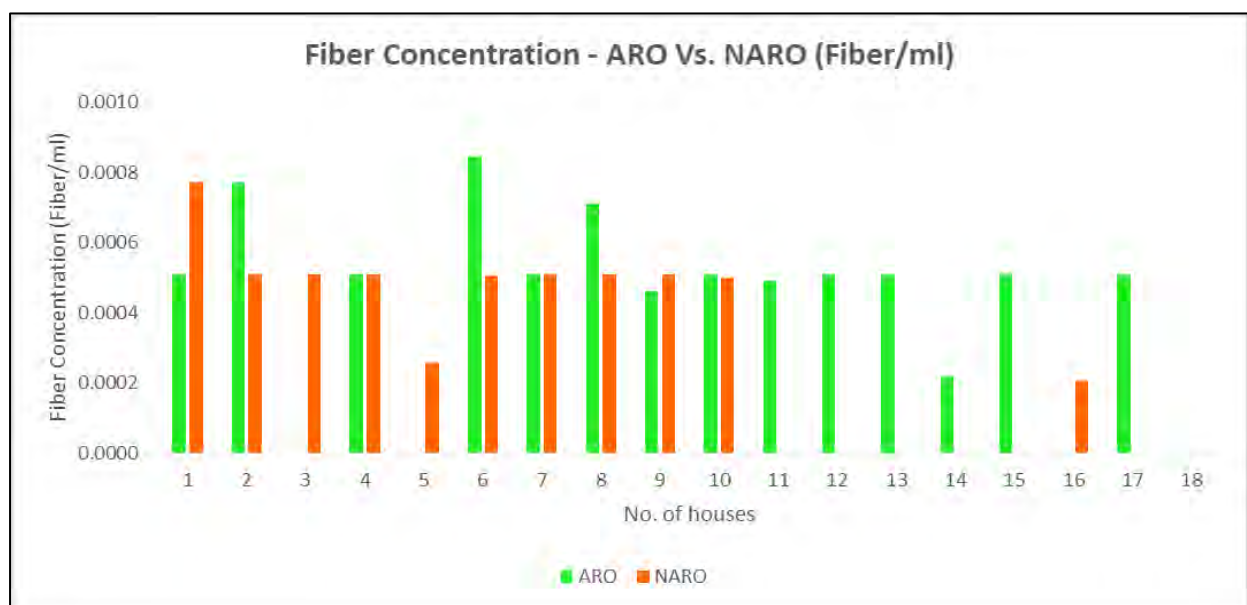


Figure 4.5: Variation of indoor fiber concentration in ARO and NARO category of houses

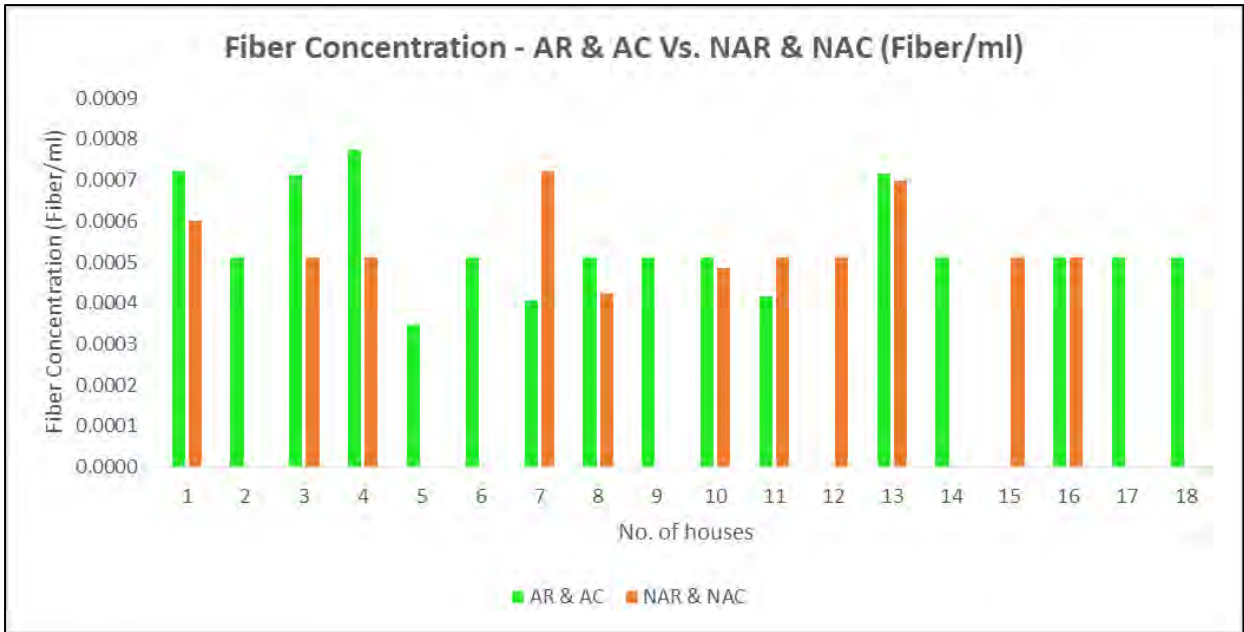


Figure 4.6: Variation of indoor fiber concentration in AR & AC and NAR & NAC category of houses

According to the results, it is noticed that the indoor fiber levels gradually decrease from the category of houses that used chrysotile for roofing and ceiling (AR & AC), ceiling only (NAR & A C) and roof (ARO) only, to the category of non Asbestos used houses. However, levels are decrease with the time and no visible change after 5 years.

According to Figure 4.7, it is clear that indoor fiber levels in non asbestoes used (NARO) houses in Colombo District are comparatively higher than that of in Anuradhapura District. This variation would be due to the poor ventilation and outdoor contribution of fibers due to urbanisation, vehicular fleet, building density and industrial usage of asbestores related product in Colombo than the Anuradhapura District.

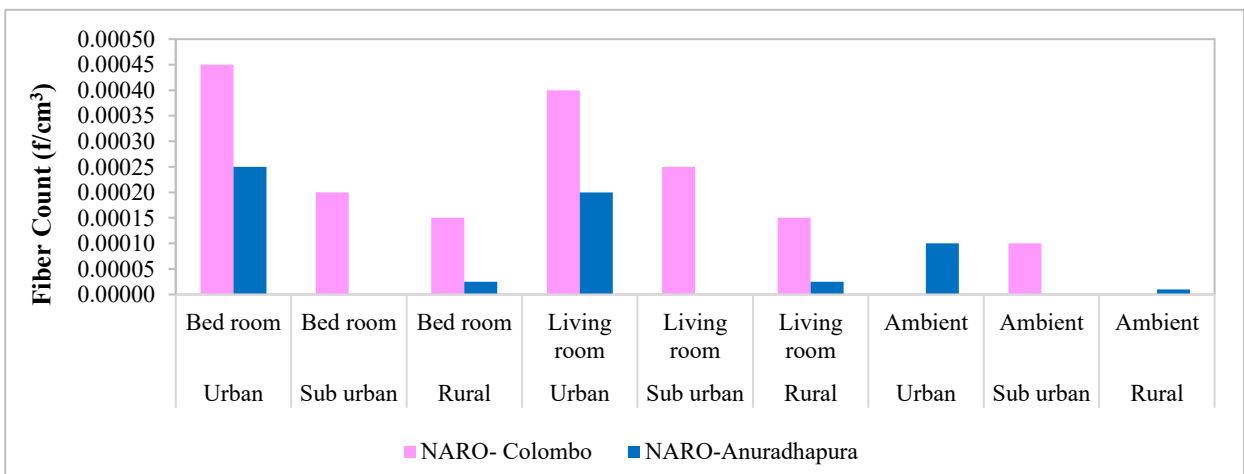


Figure 4.7: Comparison of Asbestos fiber levels of NARO category households in Colombo and Anuradhapura districts

However, as presented in Figure 4.8, the difference in indoor fiber levels in asbestoses used (ARO) houses in urban areas of Colombo and Anuradhapura districts is not considerable. This indicates that the use of Asbestoses as roofing material may equally contribute to the indoor fiber levels in both districts rather than other factors such as urbanisation, vehicle density, building density, industrial and commercial usage, etc.

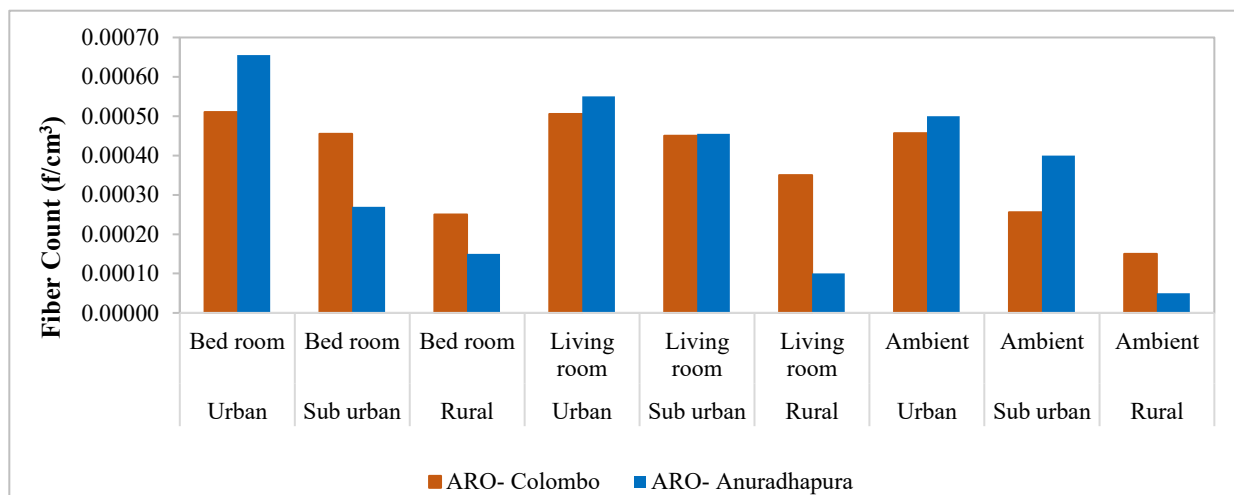


Figure 4.8: Comparison of Asbestos fiber levels of ARO category households in Colombo and Anuradhapura districts

The results further indicate that usage of Asbestoses related materials for both roofing and ceiling would not significantly differ in indoor fiber levels in houses in urban areas of Colombo and Anuradhapura districts whereas a significant difference in rural areas of Colombo and Anuradhapura districts are shown in Figure 4.9. Relatively low density of AR & AC category houses in Anuradhapura District compared to Colombo District would be the reason behind this significant change in rural areas.

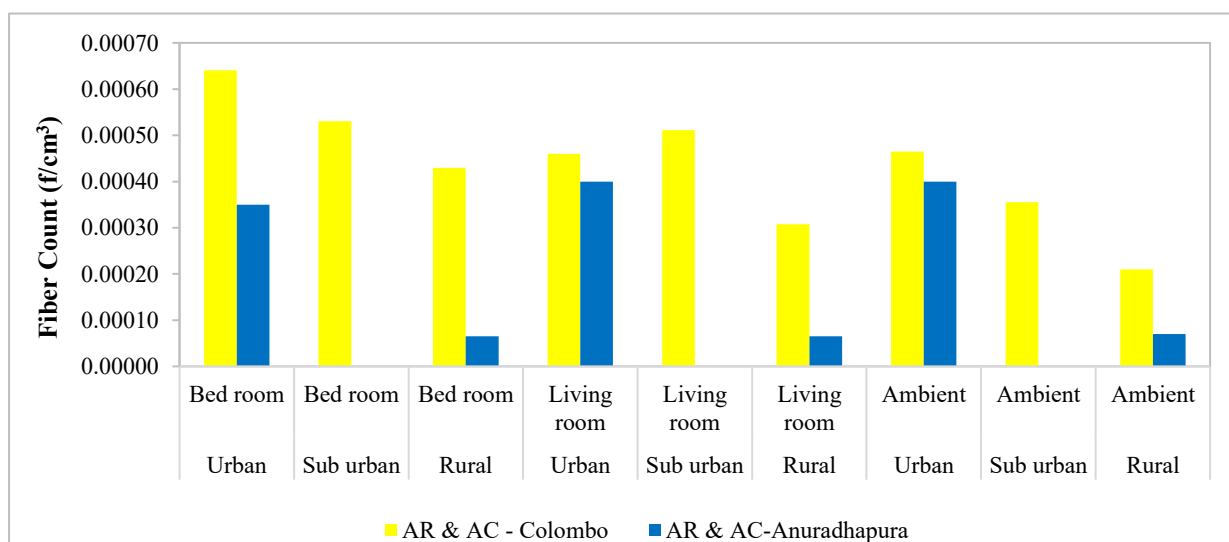


Figure 4.9: Comparison of Asbestos fiber levels in AR & AC category households in Colombo and Anuradhapura districts

According to the Figure 4.10, the average level of fiber concentration in indoor and ambient environment in all categories of houses at Colombo District is in the range of 0 – 0.00077 f/cc with average of 0.00034 f/cc. The average level of fiber concentration in indoor and ambient environment in all categories of houses in Anuradhapura District is in the range of 0 – 0.00071 f/cc with the average level of 0.00016 f/cc. The average levels in both districts are well below the maximum recommended levels of US–EPA (non-occupational) areas as well as the lifetime exposure levels proposed to WHO by authors in a population of whom 30% are smokers, the excess risk due to lung cancer would be in the order of 10^{-6} - 10^{-5} . The fiber levels also below the ambient fiber standard levels stipulated in different counties as given in Table 4.1.

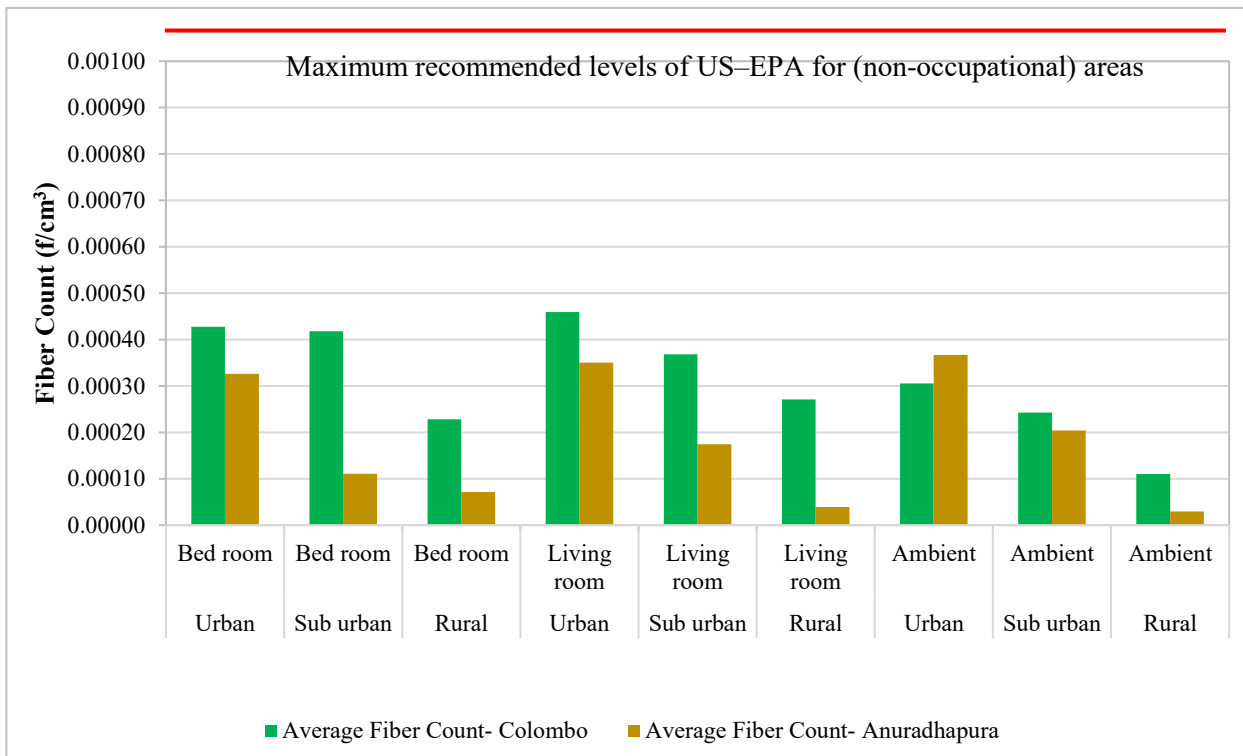


Figure 4.10: Average Asbestos fiber concentrations in each location in different areas in Colombo and Anuradhapura districts

5. CONCLUSIONS AND RECOMMENDATIONS

Following conclusions and recommendations can be presented based on the results obtained by the study and literature review.

- The asbestos fiber levels recorded at Colombo District is in the range of 0 – 0.00077 f/cc with average of 0.00034 f/cc and at Anuradhapura District is in the range of 0 – 0.00071 f/cc with the average level of 0.00016 f/cc.
- The average fiber concentration levels recorded at all selected households in different environmental conditions are below the UA-EPA standard levels (0.0009 f/cc) for asbestos fiber in non-occupational buildings (such as residential houses). The levels also below the lifetime exposure levels (0.0005 f/cc) proposed to WHO by authors in a population of whom 30% are smokers, the excess risk due to lung cancer would be in the order of 10^6 - 10^5 and the ambient fiber standard levels stipulated in different counties as given in Table 4.1.
- The recorded asbestos fiber levels in all environment conditions are well below the maximum exposure levels of 0.1 f/cm³ asbestos fiber recommended by OSHA, NOISH and ACGIH standards for workplaces.
- The fibers concentration levels are change with the urbanization conditions and decrease as the changing urbanization factor from urban, suburban to rural. It may be due to the change of air pollution levels in each area with the urbanisation, vehicular density, building density, industrial and commercial useage, etc. It is further confirmed by relatively high fiber levels at all house types in Colombo area compared to the Anuradhapura.
- The recorded fiber level in indoor area are relatively higher than the ambient environment (outside the premises) in both districts. This could be the reason of the ventilation condition and dispersion changes from indoor to outdoor environments.
- It also represent that the fiber levels are gradually decrease from the house category of having used asbestos ceiling and roofing (AR & AC) to the category of non-asbestos ceiling and roofing (NARO, NAR & NAC). However, there is no significant correlation.
- The measuring results futher indicate that usage of asbestoes releted materials for both roofing and ceiling would not significantly the differenet in indoor fiber levels in houses in urban areas of Colombo and Anuradhapura districts whereas a significant diffrence in rural area of Colombo and

Anuradhapura districts as shown in Figure 4.9. Relatively low density of AR & AC category houses in Anuradhapura District compared to Colombo District would be the reason behind this significant changes in rural areas.

- It is recommended to incorporate asbestos fiber measurements in the national air quality monitoring programme of the country to assess the trends, special distribution, source identification and risk, etc.
- It is recommended to consider asbestos fibre as one parameter and provide national ambient air quality standard for fiber concentration.
- More research, studies and assessment on asbestos useage, fiber concentration, etc are recommended.

6. LIST OF PUBLICATIONS/COMMUNICATIONS

Premasiri H D S , Kumarapeli H D, Liyanarachchi P D, Kaushalya L K G, “*Air Quality Study on Concentrations and Significance Of Chrysotile Asbestos Fiber In Household dust and Household Ambient Environment In Sri Lanka*”, Symposium on Chrysotile Asbestos Fiber in the Ambient Environment of Sri Lanka and their health significance, Colombo, Sri Lanka, 2019.

N K P M M Perera, H D Kumarapeli, D M M R Dissanayake, H D S Premasiri “*Exposure Levels and Seasonal Variation of Airborne Asbestos Fiber Concentration in Colombo, Sri Lanka*” submitted to 11th Annual Symposium of National Building Research Organisation 2020.

H D Kumarapeli, H D S Premasiri, D M M R Dissanayake, N K P M M Perera “*Assessment of domestic chrysotile asbestos fiber levels in different environment conditions in Sri Lanka*” submitted to 11th Annual Symposium of National Building Research Organisation 2020.

7. REFERENCES

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12. Study on use of Environmentally Friendly Alternative Fiber materials for Asbestos Roofing sheets in Sri Lanka, Peiris and Weerasinghe / OIDA International Journal of Sustainable Development 12:02 (2019).
13. Report on “Study on Airborne Chrysotile Fiber in Roofing Industry in Sri Lanka” The Chrysotile information Center of Sri Lanka and National Building Research Organisation of Sri Lanka, 2016.

Annex 1.

Location details in Colombo District

Sampling location details in urban areas

Name	Criteria	Sampling Location Details	
AS/CL/U/01	ARO	No. 10/26, 1st Lane, Old Kesbewa Road, Gangodawila, Nugegoda 06°51'56.8"N, 79°54'02.1"E	
AS/CL/U/02	ARO	Mr. S Ashokan, No. 30/3, Kalinga Mawatha, Polhengoda, Colombo 05 06°53'10.2"N, 79°52'43.7"E	
AS/CL/U/03	AR & AC	No. 46 Fife Rd, Colombo 05 6°56'16.99"N, 79°57'41.67"E	
AS/CL/U/04	AR & AC	Mr. Amila Thushara, No. 30/44, , Kalinga Mawatha, Polhengoda, Colombo 05 06°51'48.0"N, 79°54'14.1"E	
AS/CL/U/05	AR & NAC	Mr. Pradeep Sanjeewa No. 19/12, Station Road, Gangodawila 06°51'38.02"N, 79°54'12.06"E	
AS/CL/U/06	AR & NAC	Mr. Damitha Pushpakumara No. 41/21/A, Station Road, Gangodawila 06°51'48.0"N, 79°54'14.1"E	

Name	Criteria	Sampling Location Details	
AS/CL/U/07	NAR & AC	No. 75/A, Rubber Watte Road, Gangodawila, Nugegoda 06°51'19.3"N 79°54'06.9"E	
AS/CL/U/08	NAR & AC	Mr. S S Satharasinghe, No. 25/9, Vijaya Kumarathunga Mawatha, Colombo 05 06°53'09.2"N, 79°52'40.7"E	
AS/CL/U/09	NARO	Mr. Chinthana Alwis, No. 67/5, Raththanapitiya, Boralesgamuwa 6°50'53.86"N, 79°54'14.30"E	
AS/CL/U/10	NARO	Mr. Anura Gunawardhena, No. 26, G H Perera Mw, Raththanapitiya, Boralesgamuwa 6°50'47.35"N, 79°54'7.87"E	
AS/CL/U/11	NAR & NAC	No. 46 Fife Rd, Colombo 05 6°56'16.99"N 79°57'41.67"E	
AS/CL/U/12	NAR & NAC	Mr. W W Karunawathi No. 102/2, Kalinga Mawatha, Polhengoda, Colombo 05 06°51'38.02"N 79°54'12.06"E	

Sampling location details – Sub urban area

Name	Criteria	Sampling Location Details	
AS/CL/SU/01	ARO	Ms. W A Bandaramanike No 499/3/E, Siri Parakum Mawatha, Angoda 6°55'54.72"N, 79°55'48.88"E	
AS/CL/SU/02	ARO	Mr. Chaminda Kumara No. 603/ 7A, Siri Parakum Mawatha, Angoda 6°55'58.54"N, 79°55'58.79"E	
AS/CL/SU/03	AR & AC	Mr. Moris Fernando No.148B, Church Rd, Welivita, Kaduwela 6°56'15.15"N 79°57'40.26"E	
AS/CL/SU/04	AR & AC	Ms. L M Kusum Wasanthi, No. 148/2/1, Mabima Road, Heiyanthuduwa 6°57'36.73"N 79°57'55.69"E	
AS/CL/SU/05	AR & NAC	Ms. Nirmala Kavirathna No.145, Church Rd, Welivita, Kaduwela (House 2) 6°56'16.99"N 79°57'41.67"E	
AS/CL/SU/06	AR & NAC	Mr. K A D Nihal No. 48/2, Baudhaloka Mw, Suwarapola, Piliyandala 6°47'48.68"N 79°55'1.67"E	

Name	Criteria	Sampling Location Details	
AS/CL/SU/07	NAR & AC	<p>Ms. P. H. Moses No.154/ 3A, Bathalawatta, Thaladena, Malabe 6°54'39.02"N 79°57'22.28"E</p>	
AS/CL/SU/08	NAR & AC	<p>Mr. H M K Bandara No. 62, Mahamegawatta Rd, Maharagama 6°50'26.84"N 79°55'50.22" E</p>	
AS/CL/SU/09	NARO	<p>Mr. B Suriyaarachchi, No. 36/2/A, Gangarama Road, Werahera, Boralesgamuwa 6°49'18.52"N 79°54'9.44"E</p>	
AS/CL/SU/10	NARO	<p>Mr. Janaka Bandara, No. 148/2, Mabima Road, Heiyanthuduwa 6°57'35.88"N 79°57'56.21"E</p>	
AS/CL/SU/11	NAR & NAC	<p>Ms. Nirmala Kavirathna No. 145, Church Rd, Welivita, Kaduwela (House 1) 6°56'16.45"N 79°57'41.85"E</p>	
AS/CL/SU/12	NAR & NAC	<p>Mr. K A D Nihal No. 78, Baudhaloka Mw, Suwarapola, Piliyandala 6°47'48.81"N 79°55'1.20"E</p>	

Sampling location details – Rural area







Name	Criteria	Sampling Location Details	
AS/CL/RU/01	ARO	Mr. A L K D Perera, No. 226, Wadupasala Road, Maswila, Bandaragama 06°42'19.1"N 79°59'01.1"E	
AS/CL/RU/02	ARO	Mr. A M Sripalika, No. 663/B, Thunhandahena, Korathota, Kaduwela 06°54'26.8"N 79°59'18.0"E	
AS/CL/RU/03	AR & AC	Mr. S P Silva, No. 226/2, Wadupasala Road, Maswila, Bandaragama 06°42'19.7"N 79°59'00.8"E	
AS/CL/RU/04	AR & AC	Mr. Rasika Chandima Peiris, No. 231/F/1, Wadupasala Road, Maswila, Bandaragama 06°42'18.6"N 79°59'02.3"E	
AS/CL/RU/05	AR & NAC	Mr. K Seelawathi, No. 162, Giraliyadda Road, Godigamuwa, Gonapala 06°45'20.4"N 79°59'42.4"E	
AS/CL/RU/06	AR & NAC	Mr. H F Weerasinghe, No. 252/D, Kopiwatta, Gonapala 06°45'34.4"N 80°00'40.5"E	

Name	Criteria	Sampling Location Details	
AS/CL/RU/07	NAR & AC	<p>Mrs. Beylin Nona, No. 215/1, Hongoda, Bandaragama 06°44'47.0"N 79°59'29.6"E</p>	
AS/CL/RU/08	NAR & AC	<p>Mr. W P D Wimalaratne, No. 232/8, Watareka, Padukka 06°50'59.7"N 80°04'11.0"E</p>	
AS/CL/RU/09	NARO	<p>Mr. P Budhi Ravinath Perera, No. 661, Thunhandahena, Korathota, Kaduwela 06°54'26.8"N 79°59'18.0"E</p>	
AS/CL/RU/10	NARO	<p>Mr. Yasasri Madusanka, No. 662/A, Thunhandahena, Korathota, Kaduwela 06°54'27.4"N 79°59'17.6"E</p>	
AS/CL/RU/11	NAR & NAC	<p>Mr. A D U Suminda, No. 156/4, Paligedara, Piliyandala 06°49'08.7"N 79°56'09.2"E</p>	
AS/CL/RU/12	NAR & NAC	<p>Mr. W P D Wimalaratne, No. 232/8, Watareka, Padukka 06°50'59.7"N 80°04'11.0"E</p>	

Location details in Anuradhapura District

Sampling location details – Urban area

Name	Criteria	Sampling Location Details	
AS/AD/U/01	ARO	Ms. Iresha, Wanigarathna,5-Ela, Rabewa, Sawasthipura 8° 18' 22.1" 80° 22' 28.9"	
AS/AD/U/02	ARO	Mr. S M S Senavirathna, 3185/36, Yaya 3, Anuradhapura 8° 18' 39.7" 80° 23' 43.1"	
AS/AD/U/03	AR & AC	Mr. W M Gunasena, 2528, Yaya 3, Anuradhapura 8° 18' 27.4" 80° 23' 54.4"	
AS/AD/U/04	AR & AC	Mr. G G Gunarathna, Nagasena Mawatha, Vanniyankulama, Anuradhapura 8° 18' 02.5" 80° 25' 01.4"	
AS/AD/U/05	AR & NAC	Mr. K C Senevirathna, No 2726, Yaya 3, Anuradhapura 8° 18' 23.0" 80° 24' 18.6"	
AS/AD/U/06	AR & NAC	Mr. Gihan Weerasekara, 394/24A, Muditha Mawatha, 1st Starge, Anuradhapura 8° 19' 41.6" 80° 25' 04.5"	

Name	Criteria	Sampling Location Details	
AS/AD/U/07	NAR & AC	Mr. Sarath Wijeweera, 394/22/A, Muditha Mawatha, Yaya 1, Anuradhapura 8° 19' 45.0" 80° 25' 05.1"	
AS/AD/U/08	NAR & AC	Ms. Shama Gunarathna, Yaya 3, Anuradhapura 8° 18' 42.8" 80° 23' 40.9"	
AS/AD/U/09	NARO	Mr. K U Piyadasa, Stage 3, Anuradhapura 8° 18' 27.6" 80° 23' 55.1"	
AS/AD/U/10	NARO	Mr. W Warnapura Balasooriya, 296, Old Kurunegala Road, Wessagiriya 8° 19' 35.8" 80° 23' 12.4"	
AS/AD/U/11	NAR & NAC	Mr. S D S Samaradasa, 2539, Yaya 3, Anuradhapura 8° 18' 27.9" 80° 23' 56.5"	
AS/AD/U/12	NAR & NAC	Mr. Hettiarachchi, 5-Ela, Rabewa, Sawasthipura 8° 18' 22.7" 80° 22' 29.3"	

Sampling location details – Sub urban area

Name	Criteria	Sampling Location Details	
AS/AD/SU/01	ARO	Ashan Shivantha, 89, Kurunduwewa, Talawa. 8° 13' 26.7" 80° 21' 05.5"	
AS/AD/SU/02	ARO	Athula Nanayakkara, No 83, Kurunduwewa, Talawa 8° 13' 26.4" 80° 21' 04.2"	
AS/AD/SU/03	AR & AC	Ms. K K Sidawathi, 139, Kurunduwewa, Talawa 8° 13' 32.9" 80° 21' 21.9"	
AS/AD/SU/04	AR & AC	W A Chameera Prasanna, 19, Thoranagama, Galnawa 8° 02' 44.8" 80° 26' 43.5"	
AS/AD/SU/05	AR & NAC	Mr. E A Indrapala, Thammennawa, Talawa 8° 13' 13.5" 80° 20' 31.8"	
AS/AD/SU/06	AR & NAC	Mr. AA Upul Pushpakumara, Thammennawa, Talaw 8° 13' 14.5" 80° 20' 32.0"	

Name	Criteria	Sampling Location Details	
AS/AD/SU/07	NAR & AC	W A S Jayalath, 10, Thoranegama, Galnewa $8^{\circ} 02' 43.4''$ $80^{\circ} 26' 44.2''$	
AS/AD/SU/08	NAR & AC	W A Siripala Gunarathna, 10, Thoranegama, Galnewa $8^{\circ} 02' 42.3''$ $80^{\circ} 26' 43.8''$	
AS/AD/SU/09	NARO	L M Rathnawathi, Mihidupura, Adapola $8^{\circ} 08' 12.8''$ $80^{\circ} 25' 29.2''$	
AS/AD/SU/10	NARO	D K A K Dissanayake, Eliyadiulwewa, Eppawala $8^{\circ} 09' 25.1''$ $80^{\circ} 24' 00.5''$	
AS/AD/SU/11	NAR & NAC	N V K Rathnayaka, Eliyadiulwewa, Eppawala $8^{\circ} 09' 24.2''$ $80^{\circ} 23' 52.0''$	
AS/AD/SU/12	NAR & NAC	D T Jayawardana, Eliyadiulwewa, Eppawala $8^{\circ} 09' 23.1''$ $80^{\circ} 23' 49.4''$	

Sampling location details – Rural area

Name	Criteria	Sampling Location Details	
AS/AD/RU/01	ARO	Mr. Ranjith Senevirathna, Yaya 4, Akkara 70 Junction, Senapura 8° 05' 31.4" 80° 26' 07.5"	
AS/AD/RU/02	ARO	Mr. W M S Wijesingha, Dikwewa, Senapura 8° 05' 39.1" 80° 26' 06.3"	
AS/AD/RU/03	AR & AC	Mr. D C Pushpakumara, Rajapakshagama, Malwanegama, Talawa 8° 10' 41.1" 80° 19' 00.8"	
AS/AD/RU/04	AR & AC	Mr. Dilip Madumal, Meegaswewagama, Adagala, Eppawala 8° 08' 29.0" 80° 26' 02.0"9"	
AS/AD/RU/05	AR & NAC	Mr. D M Gnanawathi kumari, Yaya 4, Akkara 70 Junction, Senapura 8° 05' 18.1" 80° 26' 08.4"	
AS/AD/RU/06	AR & NAC	Mr. D Abewickrama, Rajapakshagama, Malwanegama, Talawa 8° 10' 40.2" 80° 19' 00.8"	

Name	Criteria	Sampling Location Details	
AS/AD/RU/07	NAR & AC	<p>Mr. W A Emanis, No 49, Meegaswewagama, Adagala, Eppawala</p> <p>8° 08' 26.4" 80° 26' 03.0"</p>	
AS/AD/RU/08	NAR & AC	<p>Mr. Upul Karunanayaka, Malwanegama, Talawa</p> <p>8°35'16.0" 80° 39' 08.3"</p>	
AS/AD/RU/09	NARO	<p>Mr. R J Nissanka, Dikwewa, Senapura</p> <p>8° 05' 34.1" 80° 26' 07.5"</p>	
AS/AD/RU/10	NARO	<p>Mr. D M Muthubanda, Dikwewa, Senapura</p> <p>8° 05' 35.8" 80° 26' 07.0"</p>	
AS/AD/RU/11	NAR & NAC	<p>Mr. S A Kapila Bandara, Rajapakshagama, Malwanegama, Talawa</p> <p>8° 10' 41.1" 80° 19' 02.2"</p>	
AS/AD/RU/12	NAR & NAC	<p>Mr. G Karunarathna, Malwanegama, Talawa</p> <p>8°03'56" 80°38'58.0"</p>	

Annex 2

Annex 2. The detail fiber concentration calculation sheet – Colombo district (Urban area) – 1st stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/CL/U/01	ARO	B	4	100	100	0	0.00785	0.04000	0	0.04000	5.09554	385	3840	1961.783	3840000	0.00051
		L	4	100	100	0	0.00785	0.03990	0	0.03990	5.08227	385	3830	1956.675	3830000	0.00051
		A	4	100	100	0	0.00785	0.03896	0	0.03896	4.96285	385	3740	1910.695	3740000	0.00051
AS/CL/U/02	ARO	B	8	100	100	0	0.00785	0.07958	0	0.07958	10.13800	385	3820	3903.132	3820000	0.00102
		L	4	100	100	0	0.00785	0.03782	0	0.03782	4.81818	385	3710	1855.000	3710000	0.00050
		A	3	100	100	0	0.00785	0.02993	0	0.02993	3.81284	385	3650	1467.943	3650000	0.00040
AS/CL/U/03	AR & AC	B	8	100	100	0	0.00785	0.07958	0	0.07958	10.13800	385	3820	3903.132	3820000	0.00102
		L	3	100	100	0	0.00785	0.03092	0	0.03092	3.93843	385	3710	1516.295	3710000	0.00041
		A	3	100	100	0	0.00785	0.03248	0	0.03248	4.13736	385	3800	1592.882	3800000	0.00042
AS/CL/U/04	AR & AC	B	4	105	100	0	0.00785	0.03750	0	0.03750	4.77707	385	3600	1839.172	3600000	0.00051
		L	4	100	100	0	0.00785	0.03875	0	0.03875	4.93631	385	3720	1900.478	3720000	0.00051
		A	4	100	100	0	0.00785	0.03948	0	0.03948	5.02919	385	3790	1936.239	3790000	0.00051
AS/CL/U/05	AR & NAC	B	3	100	100	0	0.00785	0.02890	0	0.02890	3.68192	385	3450	1417.540	3450000	0.00041
		L	4	100	100	0	0.00785	0.03629	0	0.03629	4.62338	385	3560	1780.000	3560000	0.00050
		A	4	100	100	0	0.00785	0.03792	0	0.03792	4.83015	385	3640	1859.607	3640000	0.00051
AS/CL/U/06	AR & NAC	B	3	100	100	0	0.00785	0.03142	0	0.03142	4.00209	385	3750	1540.804	3750000	0.00041
		L	5	125	100	0	0.00785	0.03771	0	0.03771	4.80361	385	3620	1849.390	3620000	0.00051
		A	0	107	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3700	0.000	3700000	0.00000
AS/CL/U/07	NAR & AC	B	2	100	100	0	0.00785	0.02116	0	0.02116	2.69610	385	3460	1038.000	3460000	0.00030
		L	4	100	100	0	0.00785	0.03656	0	0.03656	4.65764	385	3510	1793.193	3510000	0.00051
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3720	0.000	3720000	0.00000
AS/CL/U/08	NAR & AC	B	4	100	100	0	0.00785	0.04000	0	0.04000	5.09554	385	3840	1961.783	3840000	0.00051
		L	4	100	100	0	0.00785	0.03969	0	0.03969	5.05573	385	3810	1946.457	3810000	0.00051
		A	4	100	100	0	0.00785	0.03854	0	0.03854	4.90977	385	3700	1890.260	3700000	0.00051
AS/CL/U/09	NARO	B	4	100	100	0	0.00785	0.04465	0	0.04465	5.68831	385	3650	2190.000	3650000	0.00060
		L	4	100	100	0	0.00785	0.03568	0	0.03568	4.54545	385	3500	1750.000	3500000	0.00050
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3840	0.000	3840000	0.00000
AS/CL/U/10	NARO	B	2	100	100	0	0.00785	0.02208	0	0.02208	2.81299	385	3610	1083.000	3610000	0.00030
		L	2	100	100	0	0.00785	0.01982	0	0.01982	2.52468	385	3240	972.000	3240000	0.00030
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3810	0.000	3810000	0.00000
AS/CL/U/11	IAR & NAC	B	2	100	100	0	0.00785	0.02294	0	0.02294	2.92208	385	3750	1125.000	3750000	0.00030
		L	2	100	100	0	0.00785	0.02480	0	0.02480	3.15912	385	3780	1216.261	3780000	0.00032
		A	4	100	100	0	0.00785	0.03915	0	0.03915	4.98701	385	3840	1920.000	3840000	0.00050
AS/CL/U/12	IAR & NAC	B	0	106	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3790	0.000	3790000	0.00000
		L	4	120	100	0	0.00785	0.03307	0	0.03307	4.21311	385	3810	1622.048	3810000	0.00043
		A	2	100	100	0	0.00785	0.02263	0	0.02263	2.88312	385	3700	1110.000	3700000	0.00030

The detail fiber concentration calculation sheet – Colombo district (Sub urban area) – 1st stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/CL/SU/01	ARO	B	3	100	100	0	0.00785	0.03132	0	0.03132	3.98961	385	3840	1536.000	3840000	0.00040
		L	4	100	100	0	0.00785	0.03782	0	0.03782	4.81818	385	3710	1855.000	3710000	0.00050
		A	4	100	100	0	0.00785	0.03792	0	0.03792	4.83015	385	3640	1859.607	3640000	0.00051
AS/CL/SU/02	ARO	B	4	100	100	0	0.00785	0.03969	0	0.03969	5.05573	385	3810	1946.457	3810000	0.00051
		L	3	100	100	0	0.00785	0.03058	0	0.03058	3.89610	385	3750	1500.000	3750000	0.00040
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3690	0.000	3690000	0.00000
AS/CL/SU/03	AR & AC	B	8	100	100	0	0.00785	0.08000	0	0.08000	10.19108	385	3840	3923.567	3840000	0.00102
		L	4	100	100	0	0.00785	0.03969	0	0.03969	5.05573	385	3810	1946.457	3810000	0.00051
		A	2	100	100	0	0.00785	0.02337	0	0.02337	2.97662	385	3820	1146.000	3820000	0.00030
AS/CL/SU/04	AR & AC	B	3	105	100	0	0.00785	0.03251	0	0.03251	4.14094	385	3780	1594.261	3780000	0.00042
		L	4	100	100	0	0.00785	0.03969	0	0.03969	5.05573	385	3810	1946.457	3810000	0.00051
		A	3	100	100	0	0.00785	0.03184	0	0.03184	4.05545	385	3800	1561.348	3800000	0.00041
AS/CL/SU/05	AR & NAC	B	3	100	100	0	0.00785	0.03189	0	0.03189	4.06234	385	3910	1564.000	3910000	0.00040
		L	3	100	100	0	0.00785	0.03246	0	0.03246	4.13506	385	3980	1592.000	3980000	0.00040
		A	4	100	100	0	0.00785	0.03906	0	0.03906	4.97611	385	3750	1915.804	3750000	0.00051
AS/CL/SU/06	AR & NAC	B	4	100	100	0	0.00785	0.03711	0	0.03711	4.72727	385	3640	1820.000	3640000	0.00050
		L	3	125	100	0	0.00785	0.02349	0	0.02349	2.99221	385	3840	1152.000	3840000	0.00030
		A	1	107	100	0	0.00785	0.00758	0	0.00758	0.96623	385	3720	372.000	3720000	0.00010
AS/CL/SU/07	NAR & AC	B	4	100	100	0	0.00785	0.03979	0	0.03979	5.06900	385	3820	1951.566	3820000	0.00051
		L	4	100	100	0	0.00785	0.03844	0	0.03844	4.89650	385	3690	1885.151	3690000	0.00051
		A	2	100	100	0	0.00785	0.01566	0	0.01566	1.99481	385	3840	768.000	3840000	0.00020
AS/CL/SU/08	NAR & AC	B	4	100	100	0	0.00785	0.04000	0	0.04000	5.09554	385	3840	1961.783	3840000	0.00051
		L	2	100	100	0	0.00785	0.01546	0	0.01546	1.96883	385	3790	758.000	3790000	0.00020
		A	2	100	100	0	0.00785	0.01966	0	0.01966	2.50422	385	3680	964.124	3680000	0.00026
AS/CL/SU/09	NARO	B	2	100	100	0	0.00785	0.02349	0	0.02349	2.99221	385	3840	1152.000	3840000	0.00030
		L	2	100	100	0	0.00785	0.02269	0	0.02269	2.89091	385	3710	1113.000	3710000	0.00030
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3980	0.000	3980000	0.00000
AS/CL/SU/10	NARO	B	1	100	100	0	0.00785	0.00763	0	0.00763	0.97143	385	3740	374.000	3740000	0.00010
		L	1	100	100	0	0.00785	0.01484	0	0.01484	1.89091	385	3640	728.000	3640000	0.00020
		A	2	100	100	0	0.00785	0.01562	0	0.01562	1.98961	385	3830	766.000	3830000	0.00020
AS/CL/SU/11	NAR & NAC	B	3	100	100	0	0.00785	0.03217	0	0.03217	4.09814	385	3840	1577.783	3840000	0.00041
		L	2	100	100	0	0.00785	0.02318	0	0.02318	2.95325	385	3790	1137.000	3790000	0.00030
		A	2	100	100	0	0.00785	0.01651	0	0.01651	2.10333	385	3840	809.783	3840000	0.00021
AS/CL/SU/12	NAR & NAC	B	2	106	100	0	0.00785	0.02333	0	0.02333	2.97154	385	3680	1144.042	3680000	0.00031
		L	3	120	100	0	0.00785	0.02226	0	0.02226	2.83576	385	3810	1091.769	3810000	0.00029
		A	2	100	100	0	0.00785	0.01597	0	0.01597	2.03387	385	3750	783.041	3750000	0.00021

The detail fiber concentration calculation sheet – Colombo district (Rural area) – 1st stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/CL/RU/01	ARO	B	2	100	100	0	0.00785	0.01558	0	0.01558	1.98442	385	3820	764.000	3820000	0.00020
		L	2	100	100	0	0.00785	0.02312	0	0.02312	2.94545	385	3780	1134.000	3780000	0.00030
		A	2	100	100	0	0.00785	0.02251	0	0.02251	2.86753	385	3680	1104.000	3680000	0.00030
AS/CL/RU/02	ARO	B	2	100	100	0	0.00785	0.02392	0	0.02392	3.04675	385	3910	1173.000	3910000	0.00030
		L	3	100	100	0	0.00785	0.03140	0	0.03140	4.00000	385	3850	1540.000	3850000	0.00040
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3620	0.000	3620000	0.00000
AS/CL/RU/03	AR & AC	B	3	100	100	0	0.00785	0.02721	0	0.02721	3.46635	385	3840	1334.547	3840000	0.00035
		L	3	100	100	0	0.00785	0.03142	0	0.03142	4.00247	385	3710	1540.950	3710000	0.00042
		A	2	100	100	0	0.00785	0.01582	0	0.01582	2.01569	385	3680	776.042	3680000	0.00021
AS/CL/RU/04	AR & AC	B	4	105	100	0	0.00785	0.03583	0	0.03583	4.56476	385	3440	1757.431	3440000	0.00051
		L	1	100	100	0	0.00785	0.01452	0	0.01452	1.84935	385	3560	712.000	3560000	0.00020
		A	2	100	100	0	0.00785	0.01635	0	0.01635	2.08269	385	3840	801.834	3840000	0.00021
AS/CL/RU/05	AR & NAC	B	1	100	100	0	0.00785	0.00777	0	0.00777	0.98961	385	3810	381.000	3810000	0.00010
		L	3	100	100	0	0.00785	0.02977	0	0.02977	3.79221	385	3650	1460.000	3650000	0.00040
		A	1	100	100	0	0.00785	0.01407	0	0.01407	1.79221	385	3450	690.000	3450000	0.00020
AS/CL/RU/06	AR & NAC	B	1	100	100	0	0.00785	0.00724	0	0.00724	0.92208	385	3550	355.000	3550000	0.00010
		L	2	125	100	0	0.00785	0.01472	0	0.01472	1.87532	385	3610	722.000	3610000	0.00020
		A	2	107	100	0	0.00785	0.01407	0	0.01407	1.79221	385	3450	690.000	3450000	0.00020
AS/CL/RU/07	NAR & AC	B	4	100	100	0	0.00785	0.03744	0	0.03744	4.76956	385	3810	1836.280	3810000	0.00048
		L	4	100	100	0	0.00785	0.04000	0	0.04000	5.09554	385	3840	1961.783	3840000	0.00051
		A	1	100	100	0	0.00785	0.00765	0	0.00765	0.97403	385	3750	375.000	3750000	0.00010
AS/CL/RU/08	NAR & AC	B	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3460	0.000	3460000	0.00000
		L	1	100	100	0	0.00785	0.00783	0	0.00783	0.99740	385	3840	384.000	3840000	0.00010
		A	1	100	100	0	0.00785	0.00758	0	0.00758	0.96623	385	3720	372.000	3720000	0.00010
AS/CL/RU/09	NARO	B	1	100	100	0	0.00785	0.00744	0	0.00744	0.94805	385	3650	365.000	3650000	0.00010
		L	2	100	100	0	0.00785	0.01558	0	0.01558	1.98442	385	3820	764.000	3820000	0.00020
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3840	0.000	3840000	0.00000
AS/CL/RU/10	NARO	B	1	100	100	0	0.00785	0.01431	0	0.01431	1.82338	385	3510	702.000	3510000	0.00020
		L	1	100	100	0	0.00785	0.00738	0	0.00738	0.94026	385	3620	362.000	3620000	0.00010
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3540	0.000	3540000	0.00000
AS/CL/RU/11	NAR & NAC	B	1	100	100	0	0.00785	0.00744	0	0.00744	0.94805	385	3650	365.000	3650000	0.00010
		L	1	100	100	0	0.00785	0.01440	0	0.01440	1.83494	385	3350	706.452	3350000	0.00021
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3750	0.000	3750000	0.00000
AS/CL/RU/12	NAR & NAC	B	2	106	100	0	0.00785	0.02257	0	0.02257	2.87532	385	3690	1107.000	3690000	0.00030
		L	2	120	100	0	0.00785	0.01634	0	0.01634	2.08142	385	3800	801.348	3800000	0.00021
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3780	0.000	3780000	0.00000

The detail fiber concentration calculation sheet – Anuradhapura district (Urban area) – 1st stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf - B/nb	(F/nf - B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/AD/U/01	ARO	B	5	100	100	0	0.00785	0.04661	0	0.04661	5.93766	385	3820	2286.000	3820000	0.00010
		L	4	100	100	0	0.00785	0.04331	0	0.04331	5.51688	385	3620	2124.000	3620000	0.00011
		A	4	100	100	0	0.00785	0.03680	0	0.03680	4.68831	385	3580	1805.000	3580000	0.00011
AS/AD/U/02	ARO	B	6	100	100	0	0.00785	0.05628	0	0.05628	7.16883	385	3610	2760.000	3610000	0.00011
		L	4	100	100	0	0.00785	0.03782	0	0.03782	4.81818	385	3730	1855.000	3730000	0.00010
		A	4	100	100	0	0.00785	0.03721	0	0.03721	4.74026	385	3680	1825.000	3680000	0.00010
AS/AD/U/03	AR & AC	B	2	100	100	0	0.00785	0.02337	0	0.02337	2.97662	385	3810	1146.000	3810000	0.00010
		L	2	100	100	0	0.00785	0.02318	0	0.02318	2.95325	385	3800	1137.000	3800000	0.00010
		A	2	100	100	0	0.00785	0.02337	0	0.02337	2.97662	385	3840	1146.000	3840000	0.00010
AS/AD/U/04	AR & AC	B	3	105	100	0	0.00785	0.02977	0	0.02977	3.79221	385	3640	1460.000	3640000	0.00011
		L	4	100	100	0	0.00785	0.03527	0	0.03527	4.49351	385	3510	1730.000	3510000	0.00011
		A	4	100	100	0	0.00785	0.03864	0	0.03864	4.92208	385	3620	1895.000	3620000	0.00011
AS/AD/U/05	AR & NAC	B	2	100	100	0	0.00785	0.02233	0	0.02233	2.84416	385	3610	1095.000	3610000	0.00011
		L	3	100	100	0	0.00785	0.03083	0	0.03083	3.92727	385	3700	1512.000	3700000	0.00010
		A	5	100	100	0	0.00785	0.04661	0	0.04661	5.93766	385	3820	2286.000	3820000	0.00010
AS/AD/U/06	AR & NAC	B	4	100	100	0	0.00785	0.03915	0	0.03915	4.98701	385	3840	1920.000	3840000	0.00010
		L	5	125	100	0	0.00785	0.03629	0	0.03629	4.62338	385	3570	1780.000	3570000	0.00011
		A	4	107	100	0	0.00785	0.03884	0	0.03884	4.94805	385	3810	1905.000	3810000	0.00010
AS/AD/U/07	NAR & AC	B	1	100	100	0	0.00785	0.01476	0	0.01476	1.88052	385	3640	724.000	3640000	0.00011
		L	4	100	100	0	0.00785	0.03660	0	0.03660	4.66234	385	3600	1795.000	3600000	0.00011
		A	3	100	100	0	0.00785	0.02944	0	0.02944	3.75065	385	3640	1444.000	3640000	0.00011
AS/AD/U/08	NAR & AC	B	3	100	100	0	0.00785	0.03058	0	0.03058	3.89610	385	3750	1500.000	3750000	0.00010
		L	4	100	100	0	0.00785	0.03741	0	0.03741	4.76623	385	3680	1835.000	3680000	0.00010
		A	3	100	100	0	0.00785	0.03132	0	0.03132	3.98961	385	3800	1536.000	3800000	0.00010
AS/AD/U/09	NARO	B	2	100	100	0	0.00785	0.02331	0	0.02331	2.96883	385	3710	1143.000	3710000	0.00010
		L	2	100	100	0	0.00785	0.01594	0	0.01594	2.03117	385	3800	782.000	3800000	0.00010
		A	1	100	100	0	0.00785	0.01452	0	0.01452	1.84935	385	3560	712.000	3560000	0.00011
AS/AD/U/10	NARO	B	2	100	100	0	0.00785	0.01554	0	0.01554	1.97922	385	3820	762.000	3820000	0.00010
		L	2	100	100	0	0.00785	0.01541	0	0.01541	1.96364	385	3780	756.000	3780000	0.00010
		A	0	100	100	0	0.00785	0.00141	0	0.00141	0.17922	385	3640	69.000	3640000	0.00011
AS/AD/U/11	NAR & NAC	B	0	100	100	0	0.00785	0.00294	0	0.00294	0.37506	385	3630	144.400	3630000	0.00011
		L	0	100	100	0	0.00785	0.00289	0	0.00289	0.36779	385	3540	141.600	3540000	0.00011
		A	1	100	100	0	0.00785	0.01476	0	0.01476	1.88052	385	3640	724.000	3640000	0.00011
AS/AD/U/12	NAR & NAC	B	0	106	100	0	0.00785	0.00227	0	0.00227	0.28909	385	3710	111.300	3710000	0.00010
		L	0	120	100	0	0.00785	0.00075	0	0.00075	0.09558	385	3610	36.800	3610000	0.00011
		A	2	100	100	0	0.00785	0.02257	0	0.02257	2.87532	385	3600	1107.000	3600000	0.00011

The detail fiber concentration calculation sheet – Anuradhapura district (Sub urban area) – 1st stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/AD/SU/01	ARO	B	0	100	100	0	0.00785	0.00391	0	0.00391	0.49870	385	3840	192.000	3840000	0.00005
		L	4	100	100	0	0.00785	0.03884	0	0.03884	4.94805	385	3810	1905.000	3810000	0.00050
		A	2	100	100	0	0.00785	0.02318	0	0.02318	2.95325	385	3790	1137.000	3790000	0.00030
AS/AD/SU/02	ARO	B	5	100	100	0	0.00785	0.05210	0	0.05210	6.63636	385	3650	2555.000	3650000	0.00070
		L	3	100	100	0	0.00785	0.03050	0	0.03050	3.88571	385	3740	1496.000	3740000	0.00040
		A	4	100	100	0	0.00785	0.03884	0	0.03884	4.94805	385	3810	1905.000	3810000	0.00050
AS/AD/SU/03	AR & AC	B	0	100	100	0	0.00785	0.00362	0	0.00362	0.46104	385	3550	177.500	3550000	0.00005
		L	0	100	100	0	0.00785	0.00381	0	0.00381	0.48571	385	3740	187.000	3740000	0.00005
		A	0	100	100	0	0.00785	0.00074	0	0.00074	0.09377	385	3610	36.100	3610000	0.00001
AS/AD/SU/04	AR & AC	B	0	105	100	0	0.00785	0.00466	0	0.00466	0.59377	385	3810	228.600	3810000	0.00006
		L	0	100	100	0	0.00785	0.00077	0	0.00077	0.09844	385	3790	37.900	3790000	0.00001
		A	0	100	100	0	0.00785	0.00077	0	0.00077	0.09766	385	3760	37.600	3760000	0.00001
AS/AD/SU/05	AR & NAC	B	1	100	100	0	0.00785	0.01055	0	0.01055	1.34416	385	3450	517.500	3450000	0.00015
		L	2	100	100	0	0.00785	0.01541	0	0.01541	1.96364	385	3780	756.000	3780000	0.00020
		A	3	100	100	0	0.00785	0.03001	0	0.03001	3.82338	385	3680	1472.000	3680000	0.00040
AS/AD/SU/06	AR & NAC	B	2	100	100	0	0.00785	0.02269	0	0.02269	2.89091	385	3710	1113.000	3710000	0.00030
		L	3	125	100	0	0.00785	0.02312	0	0.02312	2.94545	385	3780	1134.000	3780000	0.00030
		A	3	107	100	0	0.00785	0.02349	0	0.02349	2.99221	385	3840	1152.000	3840000	0.00030
AS/AD/SU/07	NAR & AC	B	1	100	100	0	0.00785	0.00724	0	0.00724	0.92208	385	3550	355.000	3550000	0.00010
		L	3	100	100	0	0.00785	0.02797	0	0.02797	3.56312	385	3610	1371.800	3610000	0.00038
		A	3	100	100	0	0.00785	0.02669	0	0.02669	3.40000	385	3740	1309.000	3740000	0.00035
AS/AD/SU/08	NAR & AC	B	2	100	100	0	0.00785	0.01636	0	0.01636	2.08364	385	3820	802.200	3820000	0.00021
		L	2	100	100	0	0.00785	0.02251	0	0.02251	2.86753	385	3680	1104.000	3680000	0.00030
		A	2	100	100	0	0.00785	0.01759	0	0.01759	2.24026	385	3450	862.500	3450000	0.00025
AS/AD/SU/09	NARO	B	1	100	100	0	0.00785	0.00724	0	0.00724	0.92208	385	3550	355.000	3550000	0.00010
		L	0	100	100	0	0.00785	0.00067	0	0.00067	0.08545	385	3290	32.900	3290000	0.00001
		A	0	100	100	0	0.00785	0.00076	0	0.00076	0.09714	385	3740	37.400	3740000	0.00001
AS/AD/SU/10	NARO	B	1	100	100	0	0.00785	0.00742	0	0.00742	0.94545	385	3640	364.000	3640000	0.00010
		L	0	100	100	0	0.00785	0.00072	0	0.00072	0.09221	385	3550	35.500	3550000	0.00001
		A	0	100	100	0	0.00785	0.00077	0	0.00077	0.09766	385	3760	37.600	3760000	0.00001
AS/AD/SU/11	NAR & NAC	B	0	100	100	0	0.00785	0.00075	0	0.00075	0.09558	385	3680	36.800	3680000	0.00001
		L	0	100	100	0	0.00785	0.00078	0	0.00078	0.09896	385	3810	38.100	3810000	0.00001
		A	1	100	100	0	0.00785	0.01317	0	0.01317	1.67792	385	3800	646.000	3800000	0.00017
AS/AD/SU/12	NAR & NAC	B	0	106	100	0	0.00785	0.00155	0	0.00155	0.19792	385	3810	76.200	3810000	0.00002
		L	0	120	100	0	0.00785	0.00077	0	0.00077	0.09844	385	3790	37.900	3790000	0.00001
		A	1	100	100	0	0.00785	0.01351	0	0.01351	1.72052	385	3680	662.400	3680000	0.00018

The detail fiber concentration calculation sheet – Anuradhapura district (Rural area) – 1st stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/AD/RU/01	ARO	B	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3840	0.000	3840000	0.00000
		L	1	100	100	0	0.00785	0.00744	0	0.00744	0.94805	385	3650	365.000	3650000	0.00010
		A	1	100	100	0	0.00785	0.00756	0	0.00756	0.96364	385	3710	371.000	3710000	0.00010
AS/AD/RU/02	ARO	B	2	100	100	0	0.00785	0.02337	0	0.02337	2.97662	385	3820	1146.000	3820000	0.00030
		L	1	100	100	0	0.00785	0.00724	0	0.00724	0.92208	385	3550	355.000	3550000	0.00010
		A	0	100	100	0	0.00785	0.00075	0	0.00075	0.09506	385	3660	36.600	3660000	0.00001
AS/AD/RU/03	AR & AC	B	0	100	100	0	0.00785	0.00155	0	0.00155	0.19688	385	3790	75.800	3790000	0.00002
		L	0	100	100	0	0.00785	0.00213	0	0.00213	0.27195	385	3490	104.700	3490000	0.00003
		A	0	100	100	0	0.00785	0.00073	0	0.00073	0.09273	385	3570	35.700	3570000	0.00001
AS/AD/RU/04	AR & AC	B	0	105	100	0	0.00785	0.00300	0	0.00300	0.38234	385	3680	147.200	3680000	0.00004
		L	0	100	100	0	0.00785	0.00078	0	0.00078	0.09974	385	3840	38.400	3840000	0.00001
		A	0	100	100	0	0.00785	0.00072	0	0.00072	0.09221	385	3550	35.500	3550000	0.00001
AS/AD/RU/05	AR & NAC	B	0	100	100	0	0.00785	0.00295	0	0.00295	0.37610	385	3620	144.800	3620000	0.00004
		L	0	100	100	0	0.00785	0.00155	0	0.00155	0.19792	385	3810	76.200	3810000	0.00002
		A	0	100	100	0	0.00785	0.00157	0	0.00157	0.19948	385	3840	76.800	3840000	0.00002
AS/AD/RU/06	AR & NAC	B	0	100	100	0	0.00785	0.00215	0	0.00215	0.27351	385	3510	105.300	3510000	0.00003
		L	0	125	100	0	0.00785	0.00142	0	0.00142	0.18130	385	3490	69.800	3490000	0.00002
		A	0	107	100	0	0.00785	0.00221	0	0.00221	0.28130	385	3610	108.300	3610000	0.00003
AS/AD/RU/07	NAR & AC	B	0	100	100	0	0.00785	0.00076	0	0.00076	0.09714	385	3740	37.400	3740000	0.00001
		L	0	100	100	0	0.00785	0.00152	0	0.00152	0.19325	385	3720	74.400	3720000	0.00002
		A	0	100	100	0	0.00785	0.00151	0	0.00151	0.19273	385	3710	74.200	3710000	0.00002
AS/AD/RU/08	NAR & AC	B	0	100	100	0	0.00785	0.00388	0	0.00388	0.49481	385	3810	190.500	3810000	0.00005
		L	0	100	100	0	0.00785	0.00217	0	0.00217	0.27662	385	3550	106.500	3550000	0.00003
		A	0	100	100	0	0.00785	0.00149	0	0.00149	0.19013	385	3660	73.200	3660000	0.00002
AS/AD/RU/09	NARO	B	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3590	0.000	3590000	0.00000
		L	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3680	0.000	3680000	0.00000
		A	0	100	100	0	0.00785	0.00073	0	0.00073	0.09325	385	3590	35.900	3590000	0.00001
AS/AD/RU/10	NARO	B	0	100	100	0	0.00785	0.00388	0	0.00388	0.49481	385	3810	190.500	3810000	0.00005
		L	0	100	100	0	0.00785	0.00386	0	0.00386	0.49221	385	3790	189.500	3790000	0.00005
		A	0	100	100	0	0.00785	0.00075	0	0.00075	0.09506	385	3660	36.600	3660000	0.00001
AS/AD/RU/11	NAR & NAC	B	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3800	0.000	3800000	0.00000
		L	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3790	0.000	3790000	0.00000
		A	0	100	100	0	0.00785	0.00076	0	0.00076	0.09636	385	3710	37.100	3710000	0.00001
AS/AD/RU/12	NAR & NAC	B	0	106	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3720	0.000	3720000	0.00000
		L	0	120	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3550	0.000	3550000	0.00000
		A	0	100	100	0	0.00785	0.00074	0	0.00074	0.09377	385	3610	36.100	3610000	0.00001

The detail fiber concentration calculation sheet – Colombo district (Urban area) – 2nd stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/CL/U/01	ARO	B	5	100	100	0	0.00785	0.05377	0	0.05377	6.85031	385	3710	2637.369	3710000	0.00071
		L	5	100	100	0	0.00785	0.05160	0	0.05160	6.57334	385	3560	2530.737	3560000	0.00071
		A	6	100	100	0	0.00785	0.05530	0	0.05530	7.04468	385	3820	2712.200	3820000	0.00071
AS/CL/U/02	ARO	B	6	100	100	0	0.00785	0.06299	0	0.06299	8.02456	385	3810	3089.457	3810000	0.00081
		L	5	100	100	0	0.00785	0.04546	0	0.04546	5.79147	385	3650	2229.716	3650000	0.00061
		A	4	100	100	0	0.00785	0.03698	0	0.03698	4.71072	385	3550	1813.628	3550000	0.00051
AS/CL/U/03	AR & AC	B	4	100	100	0	0.00785	0.04172	0	0.04172	5.31429	385	3410	2046.000	3410000	0.00060
		L	4	100	100	0	0.00785	0.04030	0	0.04030	5.13316	385	3810	1976.266	3810000	0.00052
		A	4	100	100	0	0.00785	0.03647	0	0.03647	4.64545	385	3650	1788.500	3650000	0.00049
AS/CL/U/04	AR & AC	B	4	105	100	0	0.00785	0.03915	0	0.03915	4.98701	385	3840	1920.000	3840000	0.00050
		L	3	100	100	0	0.00785	0.03247	0	0.03247	4.13614	385	3720	1592.413	3720000	0.00043
		A	4	100	100	0	0.00785	0.03865	0	0.03865	4.92304	385	3710	1895.369	3710000	0.00051
AS/CL/U/05	AR & NAO	B	5	100	100	0	0.00785	0.04783	0	0.04783	6.09294	385	3840	2345.783	3840000	0.00061
		L	4	100	100	0	0.00785	0.03979	0	0.03979	5.06900	385	3820	1951.566	3820000	0.00051
		A	3	100	100	0	0.00785	0.03211	0	0.03211	4.09091	385	3750	1575.000	3750000	0.00042
AS/CL/U/06	AR & NAO	B	5	100	100	0	0.00785	0.04534	0	0.04534	5.77560	385	3640	2223.607	3640000	0.00061
		L	5	125	100	0	0.00785	0.03979	0	0.03979	5.06900	385	3820	1951.566	3820000	0.00051
		A	3	107	100	0	0.00785	0.02950	0	0.02950	3.75818	385	3710	1446.900	3710000	0.00039
AS/CL/U/07	NAR & AC	B	4	100	100	0	0.00785	0.03979	0	0.03979	5.06900	385	3820	1951.566	3820000	0.00051
		L	4	100	100	0	0.00785	0.03608	0	0.03608	4.59647	385	3680	1769.642	3680000	0.00048
		A	4	100	100	0	0.00785	0.04000	0	0.04000	5.09554	385	3840	1961.783	3840000	0.00051
AS/CL/U/08	NAR & AC	B	4	100	100	0	0.00785	0.03865	0	0.03865	4.92304	385	3710	1895.369	3710000	0.00051
		L	3	100	100	0	0.00785	0.02552	0	0.02552	3.25069	385	3820	1251.516	3820000	0.00033
		A	4	100	100	0	0.00785	0.03948	0	0.03948	5.02919	385	3790	1936.239	3790000	0.00051
AS/CL/U/09	NARO	B	4	100	100	0	0.00785	0.03917	0	0.03917	4.98938	385	3760	1920.913	3760000	0.00051
		L	2	100	100	0	0.00785	0.02499	0	0.02499	3.18381	385	3820	1225.766	3820000	0.00032
		A	2	100	100	0	0.00785	0.02427	0	0.02427	3.09195	385	3840	1190.400	3840000	0.00031
AS/CL/U/10	NARO	B	4	100	100	0	0.00785	0.03617	0	0.03617	4.60777	385	3400	1773.992	3400000	0.00052
		L	3	100	100	0	0.00785	0.02647	0	0.02647	3.37144	385	3690	1298.003	3690000	0.00035
		A	3	100	100	0	0.00785	0.03271	0	0.03271	4.16727	385	3820	1604.400	3820000	0.00042
AS/CL/U/11	AR & NAO	B	3	100	100	0	0.00785	0.02853	0	0.02853	3.63416	385	3750	1399.151	3750000	0.00037
		L	1	100	100	0	0.00785	0.01458	0	0.01458	1.85673	385	3810	714.840	3810000	0.00019
		A	4	100	100	0	0.00785	0.03844	0	0.03844	4.89650	385	3690	1885.151	3690000	0.00051
AS/CL/U/12	AR & NAO	B	4	106	100	0	0.00785	0.03715	0	0.03715	4.73200	385	3780	1821.821	3780000	0.00048
		L	1	120	100	0	0.00785	0.01096	0	0.01096	1.39678	385	3690	537.759	3690000	0.00015
		A	4	100	100	0	0.00785	0.03969	0	0.03969	5.05573	385	3810	1946.457	3810000	0.00051

The detail fiber concentration calculation sheet – Colombo district (Sub urban area) – 2nd stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/CL/SU/01	ARO	B	5	100	100	0	0.00785	0.04963	0	0.04963	6.32268	385	3800	2434.232	3800000	0.00064
		L	4	100	100	0	0.00785	0.03935	0	0.03935	5.01335	385	3710	1930.140	3710000	0.00052
		A	4	100	100	0	0.00785	0.03723	0	0.03723	4.74306	385	3720	1826.078	3720000	0.00049
AS/CL/SU/02	ARO	B	4	100	100	0	0.00785	0.04323	0	0.04323	5.50705	385	3650	2120.216	3650000	0.00058
		L	4	100	100	0	0.00785	0.04000	0	0.04000	5.09554	385	3840	1961.783	3840000	0.00051
		A	4	100	100	0	0.00785	0.03844	0	0.03844	4.89650	385	3690	1885.151	3690000	0.00051
AS/CL/SU/03	AR & AC	B	2	100	100	0	0.00785	0.02405	0	0.02405	3.06405	385	3820	1179.658	3820000	0.00031
		L	3	100	100	0	0.00785	0.03108	0	0.03108	3.95940	385	3710	1524.369	3710000	0.00041
		A	4	100	100	0	0.00785	0.04100	0	0.04100	5.22264	385	3650	2010.716	3650000	0.00055
AS/CL/SU/04	AR & AC	B	4	105	100	0	0.00785	0.03958	0	0.03958	5.04246	385	3800	1941.348	3800000	0.00051
		L	3	100	100	0	0.00785	0.03295	0	0.03295	4.19788	385	3840	1616.183	3840000	0.00042
		A	2	100	100	0	0.00785	0.02388	0	0.02388	3.04212	385	3650	1171.216	3650000	0.00032
AS/CL/SU/05	AR & NAC	B	4	100	100	0	0.00785	0.03597	0	0.03597	4.58178	385	3660	1763.986	3660000	0.00048
		L	3	100	100	0	0.00785	0.03068	0	0.03068	3.90831	385	3670	1504.700	3670000	0.00041
		A	3	100	100	0	0.00785	0.02799	0	0.02799	3.56545	385	3710	1372.700	3710000	0.00037
AS/CL/SU/06	AR & NAC	B	4	100	100	0	0.00785	0.03719	0	0.03719	4.73726	385	3570	1823.846	3570000	0.00051
		L	4	125	100	0	0.00785	0.02975	0	0.02975	3.79013	385	3840	1459.200	3840000	0.00038
		A	3	107	100	0	0.00785	0.02740	0	0.02740	3.49091	385	3840	1344.000	3840000	0.00035
AS/CL/SU/07	NAR & AC	B	2	100	100	0	0.00785	0.02486	0	0.02486	3.16675	385	3810	1219.200	3810000	0.00032
		L	2	100	100	0	0.00785	0.02339	0	0.02339	2.97961	385	3690	1147.151	3690000	0.00031
		A	3	100	100	0	0.00785	0.02612	0	0.02612	3.32765	385	3640	1281.146	3640000	0.00035
AS/CL/SU/08	NAR & AC	B	4	100	100	0	0.00785	0.03765	0	0.03765	4.79632	385	3840	1846.583	3840000	0.00048
		L	3	100	100	0	0.00785	0.03175	0	0.03175	4.04478	385	3790	1557.239	3790000	0.00041
		A	2	100	100	0	0.00785	0.02041	0	0.02041	2.59949	385	3820	1000.803	3820000	0.00026
AS/CL/SU/09	NARO	B	3	100	100	0	0.00785	0.03192	0	0.03192	4.06612	385	3810	1565.457	3810000	0.00041
		L	2	100	100	0	0.00785	0.01623	0	0.01623	2.06727	385	3790	795.900	3790000	0.00021
		A	1	100	100	0	0.00785	0.00855	0	0.00855	1.08865	385	3780	419.131	3780000	0.00011
AS/CL/SU/10	NARO	B	3	100	100	0	0.00785	0.02835	0	0.02835	3.61095	385	3650	1390.216	3650000	0.00038
		L	1	100	100	0	0.00785	0.01376	0	0.01376	1.75325	385	3750	675.000	3750000	0.00018
		A	2	100	100	0	0.00785	0.02085	0	0.02085	2.65560	385	3640	1022.407	3640000	0.00028
AS/CL/SU/11	NAR & NAC	B	2	100	100	0	0.00785	0.02389	0	0.02389	3.04364	385	3780	1171.800	3780000	0.00031
		L	1	100	100	0	0.00785	0.01036	0	0.01036	1.32000	385	3630	508.200	3630000	0.00014
		A	1	100	100	0	0.00785	0.00818	0	0.00818	1.04257	385	3620	401.390	3620000	0.00011
AS/CL/SU/12	NAR & NAC	B	4	106	100	0	0.00785	0.03563	0	0.03563	4.53822	385	3420	1747.213	3420000	0.00051
		L	0	120	100	0	0.00785	0.00120	0	0.00120	0.15264	385	3550	58.765	3550000	0.00002
		A	0	100	100	0	0.00785	0.00422	0	0.00422	0.53766	385	3450	207.000	3450000	0.00006

The detail fiber concentration calculation sheet – Colombo district (Rural area) – 2nd stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/CL/RU/01	ARO	B	4	100	100	0	0.00785	0.04000	0	0.04000	5.09554	385	3840	1961.783	3840000	0.00051
		L	2	100	100	0	0.00785	0.01669	0	0.01669	2.12613	385	3540	818.561	3540000	0.00023
		A	3	100	100	0	0.00785	0.02730	0	0.02730	3.47761	385	3610	1338.881	3610000	0.00037
AS/CL/RU/02	ARO	B	3	100	100	0	0.00785	0.02996	0	0.02996	3.81639	385	3480	1469.311	3480000	0.00042
		L	4	100	100	0	0.00785	0.03865	0	0.03865	4.92304	385	3710	1895.369	3710000	0.00051
		A	4	100	100	0	0.00785	0.03875	0	0.03875	4.93631	385	3720	1900.478	3720000	0.00051
AS/CL/RU/03	AR & AC	B	2	100	100	0	0.00785	0.01811	0	0.01811	2.30751	385	3740	888.393	3740000	0.00024
		L	2	100	100	0	0.00785	0.01673	0	0.01673	2.13113	385	3810	820.485	3810000	0.00022
		A	3	100	100	0	0.00785	0.02889	0	0.02889	3.67991	385	3820	1416.766	3820000	0.00037
AS/CL/RU/04	AR & AC	B	2	105	100	0	0.00785	0.01587	0	0.01587	2.02117	385	3690	778.151	3690000	0.00021
		L	1	100	100	0	0.00785	0.00846	0	0.00846	1.07713	385	3740	414.695	3740000	0.00011
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3840	0.000	3840000	0.00000
AS/CL/RU/05	AR & NAC	B	2	100	100	0	0.00785	0.02307	0	0.02307	2.93924	385	3640	1131.607	3640000	0.00031
		L	2	100	100	0	0.00785	0.02415	0	0.02415	3.07651	385	3810	1184.457	3810000	0.00031
		A	2	100	100	0	0.00785	0.01589	0	0.01589	2.02364	385	3710	779.100	3710000	0.00021
AS/CL/RU/06	AR & NAC	B	3	100	100	0	0.00785	0.03083	0	0.03083	3.92738	385	3680	1512.042	3680000	0.00041
		L	1	125	100	0	0.00785	0.00864	0	0.00864	1.10017	385	3820	423.566	3820000	0.00011
		A	2	107	100	0	0.00785	0.02192	0	0.02192	2.79273	385	3840	1075.200	3840000	0.00028
AS/CL/RU/07	NAR & AC	B	2	100	100	0	0.00785	0.01722	0	0.01722	2.19311	385	3640	844.346	3640000	0.00023
		L	2	100	100	0	0.00785	0.01612	0	0.01612	2.05404	385	3750	790.804	3750000	0.00021
		A	2	100	100	0	0.00785	0.01582	0	0.01582	2.01569	385	3680	776.042	3680000	0.00021
AS/CL/RU/08	NAR & AC	B	2	100	100	0	0.00785	0.02412	0	0.02412	3.07260	385	3780	1182.951	3780000	0.00031
		L	1	100	100	0	0.00785	0.01057	0	0.01057	1.34683	385	3590	518.530	3590000	0.00014
		A	1	100	100	0	0.00785	0.00846	0	0.00846	1.07713	385	3740	414.695	3740000	0.00011
AS/CL/RU/09	NARO	B	3	100	100	0	0.00785	0.02591	0	0.02591	3.30022	385	3840	1270.583	3840000	0.00033
		L	2	100	100	0	0.00785	0.02251	0	0.02251	2.86753	385	3450	1104.000	3450000	0.00032
		A	1	100	100	0	0.00785	0.00767	0	0.00767	0.97662	385	3760	376.000	3760000	0.00010
AS/CL/RU/10	NARO	B	2	100	100	0	0.00785	0.01951	0	0.01951	2.48514	385	3740	956.778	3740000	0.00026
		L	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3810	0.000	3810000	0.00000
		A	0	100	100	0	0.00785	0.00375	0	0.00375	0.47792	385	3680	184.000	3680000	0.00005
AS/CL/RU/11	NAR & NAC	B	2	100	100	0	0.00785	0.01651	0	0.01651	2.10312	385	3820	809.700	3820000	0.00021
		L	0	100	100	0	0.00785	0.00159	0	0.00159	0.20285	385	3740	78.095	3740000	0.00002
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3810	0.000	3810000	0.00000
AS/CL/RU/12	NAR & NAC	B	2	106	100	0	0.00785	0.02358	0	0.02358	3.00384	385	3720	1156.478	3720000	0.00031
		L	1	120	100	0	0.00785	0.00602	0	0.00602	0.76679	385	3650	295.216	3650000	0.00008
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3450	0.000	3450000	0.00000

The detail fiber concentration calculation sheet – Anuradhapura district (Urban area) – 2nd stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/AD/U/01	ARO	B	4	100	100	0	0.00785	0.04000	0	0.04000	5.09554	385	3810	1961.783	3810000	0.00051
		L	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3540	1471.338	3540000	0.00042
		A	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3610	980.892	3610000	0.00027
AS/AD/U/02	ARO	B	5	100	100	0	0.00785	0.05000	0	0.05000	6.36943	385	3450	2452.229	3450000	0.00071
		L	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3710	1471.338	3710000	0.00040
		A	4	100	100	0	0.00785	0.03721	0	0.03721	4.74026	385	3650	1825.000	3650000	0.00050
AS/AD/U/03	AR & AC	B	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3820	1471.338	3820000	0.00039
		L	2	100	100	0	0.00785	0.02318	0	0.02318	2.95325	385	3790	1137.000	3790000	0.00030
		A	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3820	980.892	3820000	0.00026
AS/AD/U/04	AR & AC	B	3	105	100	0	0.00785	0.02857	0	0.02857	3.63967	385	3650	1401.274	3650000	0.00038
		L	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3460	980.892	3460000	0.00028
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3790	490.446	3790000	0.00013
AS/AD/U/05	AR & NAC	B	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3650	1471.338	3650000	0.00040
		L	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3780	980.892	3780000	0.00026
		A	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3810	1471.338	3810000	0.00039
AS/AD/U/06	AR & NAC	B	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3840	1471.338	3840000	0.00038
		L	2	125	100	0	0.00785	0.01600	0	0.01600	2.03822	385	3560	784.713	3560000	0.00022
		A	1	107	100	0	0.00785	0.00935	0	0.00935	1.19055	385	3810	458.361	3810000	0.00012
AS/AD/U/07	NAR & AC	B	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3620	980.892	3620000	0.00027
		L	4	100	100	0	0.00785	0.03660	0	0.03660	4.66234	385	3590	1795.000	3590000	0.00050
		A	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3610	980.892	3610000	0.00027
AS/AD/U/08	NAR & AC	B	4	100	100	0	0.00785	0.04000	0	0.04000	5.09554	385	3750	1961.783	3750000	0.00052
		L	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3670	1471.338	3670000	0.00040
		A	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3840	980.892	3840000	0.00026
AS/AD/U/09	NARO	B	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3810	1471.338	3810000	0.00039
		L	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3910	1471.338	3910000	0.00038
		A	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3560	980.892	3560000	0.00028
AS/AD/U/10	NARO	B	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3810	1471.338	3810000	0.00039
		L	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3780	1471.338	3780000	0.00039
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3450	490.446	3450000	0.00014
AS/AD/U/11	NAR & NAC	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3610	490.446	3610000	0.00014
		L	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3540	980.892	3540000	0.00028
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3620	0.000	3620000	0.00000
AS/AD/U/12	NAR & NAC	B	1	106	100	0	0.00785	0.00943	0	0.00943	1.20178	385	3710	462.685	3710000	0.00012
		L	1	120	100	0	0.00785	0.00833	0	0.00833	1.06157	385	3680	408.705	3680000	0.00011
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3690	490.446	3690000	0.00013

The detail fiber concentration calculation sheet – Anuradhapura district (Sub urban area) – 2nd stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/AD/SU/01	ARO	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3810	490.446	3810000	0.00013
		L	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3790	980.892	3790000	0.00026
		A	2	100	100	0	0.00785	0.02318	0	0.02318	2.95325	385	3650	1137.000	3650000	0.00031
AS/AD/SU/02	ARO	B	4	100	100	0	0.00785	0.04000	0	0.04000	5.09554	385	3620	1961.783	3620000	0.00054
		L	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3710	980.892	3710000	0.00026
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3790	490.446	3790000	0.00013
AS/AD/SU/03	AR & AC	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3610	490.446	3610000	0.00014
		L	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3840	490.446	3840000	0.00013
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3590	490.446	3590000	0.00014
AS/AD/SU/04	AR & AC	B	1	105	100	0	0.00785	0.00952	0	0.00952	1.21322	385	3620	467.091	3620000	0.00013
		L	0	100	100	0	0.00785	0.00077	0	0.00077	0.09844	385	3780	37.900	3780000	0.00001
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3720	490.446	3720000	0.00013
AS/AD/SU/05	AR & NAC	B	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3520	0.000	3520000	0.00000
		L	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3820	490.446	3820000	0.00013
		A	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3590	980.892	3590000	0.00027
AS/AD/SU/06	AR & NAC	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3800	490.446	3800000	0.00013
		L	1	125	100	0	0.00785	0.00800	0	0.00800	1.01911	385	3790	392.357	3790000	0.00010
		A	2	107	100	0	0.00785	0.01869	0	0.01869	2.38109	385	3810	916.721	3810000	0.00024
AS/AD/SU/07	NAR & AC	B	1	100	100	0	0.00785	0.00724	0	0.00724	0.92208	385	3640	355.000	3640000	0.00010
		L	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3700	980.892	3700000	0.00027
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3720	490.446	3720000	0.00013
AS/AD/SU/08	NAR & AC	B	2	100	100	0	0.00785	0.01636	0	0.01636	2.08364	385	3810	802.200	3810000	0.00021
		L	3	100	100	0	0.00785	0.03000	0	0.03000	3.82166	385	3700	1471.338	3700000	0.00040
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3560	490.446	3560000	0.00014
AS/AD/SU/09	NARO	B	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3610	980.892	3610000	0.00027
		L	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3420	490.446	3420000	0.00014
		A	0	100	100	0	0.00785	0.00076	0	0.00076	0.09714	385	3710	37.400	3710000	0.00001
AS/AD/SU/10	NARO	B	1	100	100	0	0.00785	0.00742	0	0.00742	0.94545	385	3680	364.000	3680000	0.00010
		L	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3590	490.446	3590000	0.00014
		A	0	100	100	0	0.00785	0.00077	0	0.00077	0.09766	385	3810	37.600	3810000	0.00001
AS/AD/SU/11	NAR & NAC	B	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3700	980.892	3700000	0.00027
		L	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3800	490.446	3800000	0.00013
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3780	0.000	3780000	0.00000
AS/AD/SU/12	NAR & NAC	B	1	106	100	0	0.00785	0.00943	0	0.00943	1.20178	385	3670	462.685	3670000	0.00013
		L	1	120	100	0	0.00785	0.00833	0	0.00833	1.06157	385	3710	408.705	3710000	0.00011
		A	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3800	0.000	3800000	0.00000

The detail fiber concentration calculation sheet – Anuradhapura district (Rural area) – 2nd stage

Sample No.	Criteria	Location area	F	nf	nb	B	Af (mm ²)	F/nf	B/nb	F/nf -B/nb	(F/nf -B/nb)/Af (fiber/mm ²)	Ac (mm ²)	V (L)	(E) *(Ac) (Fiber)	V*1000 (ml)	(E) *(Ac)/V*1000 (Fiber/ml)
AS/AD/RU/01	ARO	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3810	490.446	3810000	0.00013
		L	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3600	0.000	3600000	0.00000
		A	1	100	100	0	0.00785	0.00756	0	0.00756	0.96364	385	3710	371.000	3710000	0.00010
AS/AD/RU/02	ARO	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3800	490.446	3800000	0.00013
		L	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3620	0.000	3620000	0.00000
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3680	490.446	3680000	0.00013
AS/AD/RU/03	AR & AC	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3800	490.446	3800000	0.00013
		L	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3620	490.446	3620000	0.00014
		A	0	100	100	0	0.00785	0.00073	0	0.00073	0.09273	385	3450	35.700	3450000	0.00001
AS/AD/RU/04	AR & AC	B	1	105	100	0	0.00785	0.00952	0	0.00952	1.21322	385	3710	467.091	3710000	0.00013
		L	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3820	490.446	3820000	0.00013
		A	0	100	100	0	0.00785	0.00072	0	0.00072	0.09221	385	3620	35.500	3620000	0.00001
AS/AD/RU/05	AR & NAC	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3610	490.446	3610000	0.00014
		L	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3800	490.446	3800000	0.00013
		A	0	100	100	0	0.00785	0.00157	0	0.00157	0.19948	385	3820	76.800	3820000	0.00002
AS/AD/RU/06	AR & NAC	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3620	490.446	3620000	0.00014
		L	0	125	100	0	0.00785	0.00142	0	0.00142	0.18130	385	3530	69.800	3530000	0.00002
		A	1	107	100	0	0.00785	0.00935	0	0.00935	1.19055	385	3620	458.361	3620000	0.00013
AS/AD/RU/07	NAR & AC	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3700	490.446	3700000	0.00013
		L	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3720	490.446	3720000	0.00013
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3840	490.446	3840000	0.00013
AS/AD/RU/08	NAR & AC	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3830	490.446	3830000	0.00013
		L	0	100	100	0	0.00785	0.00217	0	0.00217	0.27662	385	3600	106.500	3600000	0.00003
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3620	490.446	3620000	0.00014
AS/AD/RU/09	NARO	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3580	490.446	3580000	0.00014
		L	0	100	100	0	0.00785	0.00000	0	0.00000	0.00000	385	3640	0.000	3640000	0.00000
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3610	490.446	3610000	0.00014
AS/AD/RU/10	NARO	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3800	490.446	3800000	0.00013
		L	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3570	490.446	3570000	0.00014
		A	0	100	100	0	0.00785	0.00075	0	0.00075	0.09506	385	3810	36.600	3810000	0.00001
AS/AD/RU/11	NAR & NAC	B	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3790	490.446	3790000	0.00013
		L	2	100	100	0	0.00785	0.02000	0	0.02000	2.54777	385	3820	980.892	3820000	0.00026
		A	1	100	100	0	0.00785	0.01000	0	0.01000	1.27389	385	3640	490.446	3640000	0.00013
AS/AD/RU/12	NAR & NAC	B	1	106	100	0	0.00785	0.00943	0	0.00943	1.20178	385	3840	462.685	3840000	0.00012
		L	1	120	100	0	0.00785	0.00833	0	0.00833	1.06157	385	3620	408.705	3620000	0.00011
		A	0	100	100	0	0.00785	0.00074	0	0.00074	0.09377	385	3710	36.100	3710000	0.00001



ANNEXURE- B

UNITED NATIONS ENVIRONMENT PROGRAMME
INTERNATIONAL LABOUR ORGANISATION
WORLD HEALTH ORGANIZATION

INTERNATIONAL PROGRAMME ON CHEMICAL SAFETY

ENVIRONMENTAL HEALTH CRITERIA 203

CHRYSOTILE ASBESTOS

This report contains the collective views of an international group of experts and does not necessarily represent the decisions or the stated policy of the United Nations Environment Programme, the International Labour Organisation, or the World Health Organization.

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World Health Organization

Geneva, 1998

The International Programme on Chemical Safety (IPCS), established in 1980, is a joint venture of the United Nations Environment Programme (UNEP), the International Labour Organisation (ILO), and the World Health Organization (WHO). The overall objectives of the IPCS are to establish the scientific basis for assessment of the risk to human health and the environment from exposure to chemicals, through international peer review processes, as a prerequisite for the promotion of chemical safety, and to provide technical assistance in strengthening national capacities for the sound management of chemicals.

The Inter-Organization Programme for the Sound Management of Chemicals (IOMC) was established in 1995 by UNEP, ILO, the Food and Agriculture Organization of the United Nations, WHO, the United Nations Industrial Development Organization, the United Nations Institute for Training and Research, and the Organisation for Economic Co-operation and Development (Participating Organizations), following recommendations made by the 1992 UN Conference on Environment and Development to strengthen cooperation and increase coordination in the field of chemical safety. The purpose of the IOMC is to promote coordination of the policies and activities pursued by the Participating Organizations, jointly or separately, to achieve the sound management of chemicals in relation to human health and the environment.

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NOTE TO READERS OF THE CRITERIA MONOGRAPHS

Every effort has been made to present information in the criteria monographs as accurately as possible without unduly delaying their publication. In the interest of all users of the Environmental Health Criteria monographs, readers are requested to communicate any errors that may have occurred to the Director of the International Programme on Chemical Safety, World Health Organization, Geneva, Switzerland, in order that they may be included in corrigenda.

* * *

A detailed data profile and a legal file can be obtained from the International Register of Potentially Toxic Chemicals, Case postale 356, 1219 Châtellaine, Geneva, Switzerland (telephone no. + 41 22 - 9799111, fax no. + 41 22 - 7973460, E-mail irptc@unep.ch).

* * *

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Environmental Health Criteria

PREAMBLE

Objectives

In 1973 the WHO Environmental Health Criteria Programme was initiated with the following objectives:

- (i) to assess information on the relationship between exposure to environmental pollutants and human health, and to provide guidelines for setting exposure limits;
- (ii) to identify new or potential pollutants;
- (iii) to identify gaps in knowledge concerning the health effects of pollutants;
- (iv) to promote the harmonization of toxicological and epidemiological methods in order to have internationally comparable results.

The first Environmental Health Criteria (EHC) monograph, on mercury, was published in 1976 and since that time an ever-increasing number of assessments of chemicals and of physical effects have been produced. In addition, many EHC monographs have been devoted to evaluating toxicological methodology, e.g., for genetic, neurotoxic, teratogenic and nephrotoxic effects. Other publications have been concerned with epidemiological guidelines, evaluation of short-term tests for carcinogens, biomarkers, effects on the elderly and so forth.

Since its inauguration the EHC Programme has widened its scope, and the importance of environmental effects, in addition to health effects, has been increasingly emphasized in the total evaluation of chemicals.

The original impetus for the Programme came from World Health Assembly resolutions and the recommendations of the 1972 UN Conference on the Human Environment. Subsequently the work became an integral part of the International Programme on Chemical Safety (IPCS), a cooperative programme of UNEP, ILO and WHO. In this manner, with the strong support of the new partners, the importance of occupational health and environmental effects was fully recognized. The EHC monographs have become widely established, used and recognized throughout the world.

The recommendations of the 1992 UN Conference on Environment and Development and the subsequent establishment of the Intergovernmental Forum on Chemical Safety with the priorities for action in the six programme areas of Chapter 19, Agenda 21, all lend further weight to the need for EHC assessments of the risks of chemicals.

Scope

The criteria monographs are intended to provide critical reviews on the effect on human health and the environment of chemicals and of combinations of chemicals and physical and biological agents. As such, they include and review studies that are of direct relevance for the evaluation. However, they do not describe every study carried out. Worldwide data are used and are quoted from original studies, not from abstracts or reviews. Both published and unpublished reports are considered and it is incumbent on the authors to assess all the articles cited in the references. Preference is always given to published data. Unpublished data are only used when relevant published data are absent or when they are pivotal to the risk assessment. A detailed policy statement is available that describes the procedures used for unpublished proprietary data so that this information can be used in the evaluation without compromising its confidential nature (WHO (1990) Revised Guidelines for the Preparation of Environmental Health Criteria Monographs. PCS/90.69, Geneva, World Health Organization).

Avramani

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In the evaluation of human health risks, sound human data, whenever available, are preferred to animal data. Animal and *in vitro* studies provide support and are used mainly to supply evidence missing from human studies. It is mandatory that research on human subjects is conducted in full accord with ethical principles, including the provisions of the Helsinki Declaration.

The EHC monographs are intended to assist national and international authorities in making risk assessments and subsequent risk management decisions. They represent a thorough evaluation of risks and are not, in any sense, recommendations for regulation or standard setting. These latter are the exclusive purview of national and regional governments.

Content

The layout of EHC monographs for chemicals is outlined below.

- * Summary -- a review of the salient facts and the risk evaluation of the chemical
- * Identity -- physical and chemical properties, analytical methods
- * Sources of exposure
- * Environmental transport, distribution and transformation
- * Environmental levels and human exposure
- * Kinetics and metabolism in laboratory animals and humans
- * Effects on laboratory mammals and *in vitro* test systems
- * Effects on humans
- * Effects on other organisms in the laboratory and field
- * Evaluation of human health risks and effects on the environment
- * Conclusions and recommendations for protection of human health and the environment

- * Further research
- * Previous evaluations by international bodies, e.g., IARC, JECFA, JMPR

Selection of chemicals

Since the inception of the EHC Programme, the IPCS has organized meetings of scientists to establish lists of priority chemicals for subsequent evaluation. Such meetings have been held in: Ispra, Italy, 1980; Oxford, United Kingdom, 1984; Berlin, Germany, 1987; and North Carolina, USA, 1995. The selection of chemicals has been based on the following criteria: the existence of scientific evidence that the substance presents a hazard to human health and/or the environment; the possible use, persistence, accumulation or degradation of the substance shows that there may be significant human or environmental exposure; the size and nature of populations at risk (both human and other species) and risks for environment; international concern, i.e. the substance is of major interest to several countries; adequate data on the hazards are available.

If an EHC monograph is proposed for a chemical not on the priority list, the IPCS Secretariat consults with the Cooperating Organizations and all the Participating Institutions before embarking on the preparation of the monograph.

Procedures

The order of procedures that result in the publication of an EHC monograph is shown in the flow chart. A designated staff member of IPCS, responsible for the scientific quality of the document, serves as Responsible Officer (RO). The IPCS Editor is responsible for layout and language. The first draft, prepared by consultants or, more usually, staff from an IPCS Participating Institution, is based initially on data provided from the International Register of Potentially Toxic Chemicals, and reference data bases such as Medline and Toxline.

The draft document, when received by the RO, may require an initial review by a small panel of experts to determine its scientific quality and objectivity. Once the RO finds the document acceptable as a first draft, it is distributed, in its unedited form, to well over 150 EHC contact points throughout the world who are asked to comment on its completeness and accuracy and, where necessary, provide additional material. The contact points, usually designated by governments, may be Participating Institutions, IPCS Focal Points, or individual scientists known for their particular expertise. Generally some four months are allowed before the comments are considered by the RO and author(s). A second draft incorporating comments received and approved by the Director, IPCS, is then distributed to Task Group members, who carry out the peer review, at least six weeks before their meeting.

The Task Group members serve as individual scientists, not as representatives of any organization, government or industry. Their function is to evaluate the accuracy, significance and relevance of the information in the document and to assess the health and environmental risks from exposure to the chemical. A summary and recommendations for further research and improved safety aspects are also required. The composition of the Task Group is dictated by the range of expertise required for the subject of the meeting and by the need for a balanced geographical distribution.

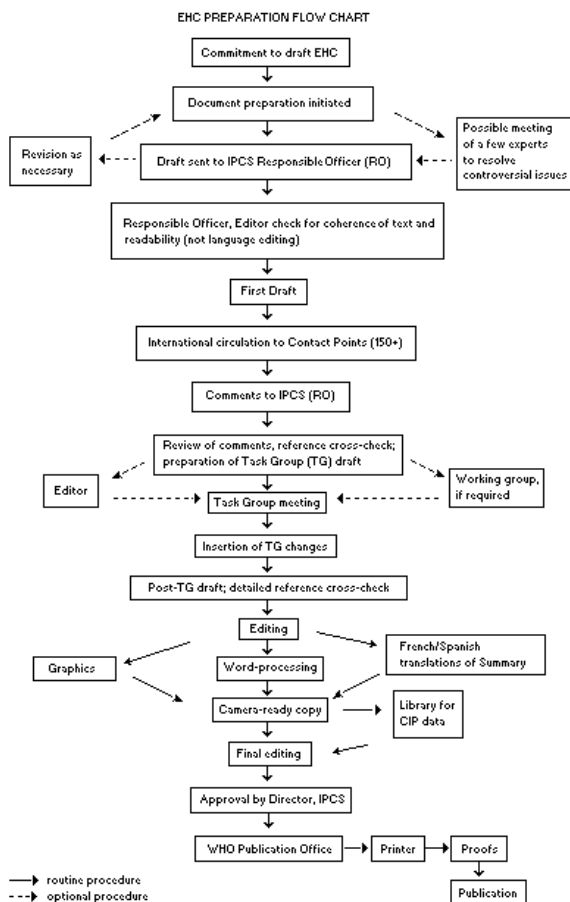
The three cooperating organizations of the IPCS recognize the important role played by nongovernmental organizations. Representatives from relevant national and international associations may be invited to join the Task Group as observers. While observers may provide a valuable contribution to the process, they can only speak at the invitation of the Chairperson. Observers do not participate in the final evaluation of the chemical; this is the sole responsibility of the Task Group members. When the Task Group considers it to be appropriate, it may meet *in camera*.

All individuals who as authors, consultants or advisers participate in the preparation of the EHC monograph must, in addition to serving in their personal capacity as scientists, inform the RO if at any time a conflict of interest, whether actual or potential, could be perceived in their work. They are required to sign a conflict of interest statement. Such a procedure ensures the transparency and probity of the process.

When the Task Group has completed its review and the RO is satisfied as to the scientific correctness and completeness of the document, it then goes for language editing, reference checking, and preparation of camera-ready copy. After approval by the Director, IPCS, the monograph is submitted to the WHO Office of Publications for printing. At this time a copy of the final draft is sent to the Chairperson and Rapporteur of the Task Group to check for any errors.

It is accepted that the following criteria should initiate the updating of an EHC monograph: new data are available that would substantially change the evaluation; there is public concern for health or environmental effects of the agent because of greater exposure; an appreciable time period has elapsed since the last evaluation.

All Participating Institutions are informed, through the EHC progress report, of the authors and institutions proposed for the drafting of the documents. A comprehensive file of all comments received on drafts of each EHC monograph is maintained and is available on request. The Chairpersons of Task Groups are briefed before each meeting on their role and responsibility in ensuring that these rules are followed.



WHO TASK GROUP ON ENVIRONMENTAL HEALTH CRITERIA FOR CHRYSOTILE ASBESTOS

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^b Not present at the last session

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^a Present only during first two days of the meeting (i.e. before the
discussions on Chapters 9, 10 and 11 were held)

^b Not present during the discussions on Chapters 9, 10 and 11, which
were held *in camera*

IPCS TASK GROUP ON ENVIRONMENTAL HEALTH CRITERIA FOR CHRYSOTILE
ASBESTOS

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A Task Group on Environmental Health Criteria for Chrysotile Asbestos met at WHO Headquarters, Geneva, Switzerland, from 1 to 6 July 1996. Dr M. Mercier, Director IPCS, opened the Meeting and welcomed the participants on behalf of the heads of the three cooperating organizations of the IPCS (UNEP/ILO/WHO). The Task Group reviewed and revised the third draft of the monograph, made an evaluation of the risks for human health and the environment from exposure to chrysotile asbestos, and made recommendations for health protection and further research.

The first drafts were prepared by Dr G. Gibbs, Canada (Chapter 2), Mr B.J. Pigg, USA (Chapter 3), Professor W.J. Nicholson, USA (Chapter 4), Dr A. Morgan, UK and Professor M. Lippmann, USA (Chapter 5), Dr J.M.G. Davis, UK and Professor B.T. Mossman, USA (Chapter 6), Professor J.C. McDonald, UK, Professor P.J. Landrigan, USA and Professor W.J. Nicholson, USA (Chapter 7), Professor H. Schreier, Canada (Chapter 8).

In the light of international comments, the second draft was prepared under the coordination of Professor F. Valiè, Croatia. Chapter 8 was modified by a group of experts in risk assessment (Professors J. Hughes, USA, J. Peto, UK, and J. Siemiatycki, Canada).

Professor F. Valiè was responsible for the overall scientific content of the monograph and for the organization of the meeting, and Dr P.G. Jenkins, IPCS Central Unit, for the technical editing of the monograph.

The efforts of all who helped in the preparation and finalization of the monograph are gratefully acknowledged.

ABBREVIATIONS

ACM	asbestos-containing material
AOS	activated oxygen species
ATEM	analytical transmission electron microscopy
BAL	bronchoalveolar lavage
BP	benzo (a)pyrene
CI	confidence interval
EDXA	energy-dispersive X-ray analyser
f	fibre
FGF	fibroblast growth factor
LDH	lactate dehydrogenase
mpcf	millions of particles per cubic foot
mpcm	millions of particles per cubic metre
NHMI	N-nitrosoheptamethyleneimine
OR	odds ratio
p	particle
PCOM	phase contrast optical microscopy
PDGF	platelet-derived growth factor
PMR	proportional mortality ratio
RR	relative risk
SAED	selected area electron diffraction
SEM	scanning electron microscopy
SMR	standardized mortality ratio
TEM	transmission electron microscopy
TPA	12-O-tetradecanoylphorbol-13-acetate
TWA	time-weighted average
UICC	Union Internationale Contre le Cancer (reference asbestos samples)

INTRODUCTION

As early as 1986 the International Programme on Chemical Safety (IPCS) published the Environmental Health Criteria (EHC 53) on the health effects of natural mineral fibres with particular emphasis on asbestos (IPCS, 1986). During the next 7 years, efforts were focused on possible reduction of environmental asbestos exposure (IPCS, 1989; WHO/OCH, 1989), including the evaluation of a number of possible substitute fibres such as man-made mineral fibres (IPCS, 1988), and selected organic synthetic fibres (IPCS, 1993).

In 1992, four WHO Member States invited the Director-General of WHO to request the IPCS to update that part of EHC 53 concerning the health effects of chrysotile asbestos. The Director-General accepted the request and instructed the IPCS to develop an EHC specifically for chrysotile asbestos taking into consideration that (a) the International Labour Organisation had recommended the discontinuation of the use of crocidolite asbestos; (b) amosite asbestos was, for all practical purposes, no longer exploited; and (c) there was still wide-spread production and use of chrysotile asbestos in the world.

A number of reputable scientists (selected solely on the basis of their contributions to the open scientific literature) were approached with the request to develop individual scientific chapters for the first draft. Chapters 5, 6 and 7 were drafted by two or three authors independently. On the basis of these texts a coherent draft was prepared by the IPCS.

The drafts of chapters 5, 6 and 7 were sent for preliminary review to a limited number of recognized experts proposed by IPCS participating institutions. The full draft of the document was submitted to the standard IPCS worldwide evaluation procedure by

circulating it for comments to more than 140 IPCS Contact Points.

Taking into account all the relevant comments, a second draft was developed by the IPCS. Chapter 7, drafted independently by three authors, was modified by a working group of experts and focuses on lung cancer and mesothelioma risks in populations exposed almost exclusively to chrysotile. The discussion in this chapter has been restricted primarily to direct observation from epidemiological studies.

The third draft was submitted for evaluation, modification and finalization to a Task Group of experts appointed by WHO. None of the primary authors was appointed to be a member of the Task Group.

1. SUMMARY

1.1 Identity, physical and chemical properties, sampling and analysis

Chrysotile is a fibrous hydrated magnesium silicate mineral that has been used in many commercial products. It is widely used in global commerce today. Its physical and chemical properties as a mineral are observed to vary among the exploited geological deposits. The minerals that accompany the fibre in ores are many, and among these may be some varieties of fibrous amphibole. Tremolite is thought to be especially important in this respect; its form and concentration range greatly.

Analysis of chrysotile in the workplace currently entails the use of light and electron microscopes. Various instruments and devices have been previously used to monitor environments for the presence and concentration of both total dust and fibres. The membrane filter technique and phase contrast optical microscopy are commonly used today for workplace assay (expressed as fibres per ml air); and the transmission electron microscopy is also employed. Environmental assays require the use of transmission electron microscopy. Tissue burden studies have been employed to improve information regarding exposures. Depending on the degree of attention to detail in these studies, inferences regarding mechanisms and etiology have been drawn.

Gravimetric and thermal precipitator and midget impinger techniques were previously used for workplace characterization, and these dust (not fibre) values are the only early exposure indices available for gauging exposure-response relationships. There have been many attempts to convert these values to fibres per volume of air, but these conversions have had very limited success. Conversion factors have been found to be industry-specific and even operation-specific; universal conversion factors carry high variances.

1.2 Sources of occupational and environmental exposure

Low concentrations of chrysotile are found throughout the crustal environment (air, water, ice caps and soil). Both natural and human activities contribute to fibre aerosolization and distribution. Anthropogenic sources include dusts from occupational activities, which cover ore recovery and processing, manufacturing, application, usage and, ultimately disposal.

Production occurs in 25 countries, and there are seven major producers. Annual world production of asbestos peaked at over 5 million tonnes in the mid-1970s but has since declined to a current level of about 3 million tonnes. Manufacturing of chrysotile products is undertaken in more than 100 countries, and Japan is the leading consumer country. The current main activities resulting in potential chrysotile exposure are: (a) mining and milling; (b) processing into products (friction materials, cement pipes and sheets, gaskets and seals, paper and textiles); (c) construction, repair and demolition; (d) transportation and disposal. The asbestos-cement industry is by far the largest user of chrysotile fibres, accounting for about 85% of all use.

Fibres are released during processing, installation and disposal of asbestos-containing products, as well as through normal wear of products in some instances. Manipulation of friable products may be an important source of chrysotile emission.

1.3 Occupational and environmental exposure levels

Based on data mainly from North America, Europe and Japan, in most production sectors workplace exposures in the early 1930s were very high. Levels dropped considerably to the late 1970s and have declined substantially to present day values. In the mining and milling industry in Quebec, the average fibre concentrations in air often exceeded 20 fibres/ml (f/ml) in the 1970s, while they are now generally well below 1 f/ml. In the production of asbestos-cement in Japan, typical mean concentrations were 2.5-9.5 f/ml in 1970s, while mean concentrations of 0.05-0.45 f/ml were reported in 1992. In asbestos textile manufacture in Japan, mean concentrations were between 2.6 and 12.8 f/ml in the period between 1970 and 1975, and 0.1-0.2 f/ml in the period between 1984 and 1986. Trends have been similar in the production of friction materials: based on data available from the same country, mean concentrations of 10-35 f/ml were measured in the period between 1970 and 1975, while levels 0.2-5.5 f/ml were reported in the period between 1984 and 1986. In a plant in the United Kingdom in which a large mortality study was conducted, concentrations were generally above 20 f/ml in the period before 1931 and generally below 1 f/ml during 1970-1979.

Few data on concentrations of fibres associated with the installation and use of chrysotile-containing products are available, although this is easily the most likely place for workers to be exposed. In the maintenance of vehicles, peak concentrations of up to 16 f/ml were reported in the 1970s, while practically all measured levels after 1987 were less than 0.2 f/ml. Time-weighted average exposures during passenger vehicle repair in the 1980s were generally less than 0.05 f/ml. However, with no controls, blowing off debris from drums resulted in short-term high concentrations of dust.

There is potential for exposure of maintenance personnel to mixed asbestos fibre types due to large quantities of friable asbestos in place. In buildings with control plans, personal exposure of building maintenance personnel in the USA, expressed as 8-h time-weighted averages, was between 0.002 and 0.02 f/ml. These values are of the same order of magnitude as typical exposures during telecommunication switchwork (0.009 f/ml) and above-ceiling work (0.037 f/ml), although higher concentrations were reported in utility space work (0.5 f/ml). Concentrations may be considerably higher where no control plans have been introduced. In one case, short-term episodic concentrations were 1.6 f/ml during sweeping and 15.5 f/ml during dusting of library books in a building with a very friable chrysotile-containing surface formulation. Most other 8-h time-weighted averages are about two orders of magnitude less.

Based on surveys conducted before 1986, fibre concentrations (fibres > 5 µm in length) in outdoor air, measured in Austria, Canada, Germany, South Africa and the USA, ranged between 0.0001 and about 0.01 f/ml, levels in most samples being less than 0.001 f/ml. Means or medians were between 0.00005 and 0.02 f/ml, based on more recent determinations in Canada, Italy, Japan, the Slovak Republic, Switzerland, United Kingdom and USA.

Fibre concentrations in public buildings, even those with friable asbestos-containing materials, are within the range of those measured in ambient air. Concentrations (fibres > 5 µm in length) in buildings in Germany and Canada reported before 1986 were generally less than 0.002 f/ml. In more recent surveys in Belgium, Canada, the Slovak Republic, United Kingdom and USA, mean values were between 0.00005 and 0.0045 f/ml. Only 0.67% of chrysotile fibres were longer than 5 µm.

1.4 Uptake, clearance, retention and translocation

The deposition of inhaled chrysotile asbestos is dependent upon the aerodynamic diameter, the length and the morphology of the fibre. Most airborne chrysotile fibres are considered respirable because their fibre diameters are less than 3 µm, equal to an aerodynamic diameter of about 10 µm. In laboratory rats, chrysotile fibres are deposited primarily at alveolar duct bifurcations.

In the nasopharyngeal and tracheobronchial regions, chrysotile fibres are cleared via mucociliary clearance. At the alveolar duct bifurcations the fibres are taken up by epithelial cells. Fibre length is an important determinant of alveolar clearance of chrysotile fibres. There is extensive evidence from animal studies that short fibres (less than 5 µm long) are cleared more rapidly than long fibres (longer than 5 µm). The mechanisms of the relatively more rapid clearance of chrysotile fibres compared to those of amphiboles are not completely known. It has been hypothesized that short chrysotile fibres are cleared through phagocytosis by alveolar macrophages, while long chrysotile fibres are cleared mainly by breakage and/or dissolution. To what extent chrysotile fibres are translocated to the interstitium, pleural tissue and other extrathoracic tissues is not fully understood.

Analyses of human lungs of workers exposed to chrysotile asbestos indicate much greater retention of tremolite, an amphibole asbestos commonly associated with commercial chrysotile in small proportions, than of chrysotile. The more rapid removal of chrysotile fibres from the human lung is further supported by findings from animal studies showing that chrysotile is more rapidly cleared from the lung than are amphiboles including crocidolite and amosite.

Available data from studies in humans and animals are insufficient to evaluate the possible uptake, distribution and excretion of chrysotile fibres from ingestion. Available evidence indicates that, if penetration of chrysotile fibres across the gut wall does occur, it is extremely limited. One study indicated an

increased level of chrysotile fibres in the urine of workers occupationally exposed to chrysotile.

1.5 Effects on animals and cells

Various experimental samples of chrysotile fibres have been shown in numerous long-term inhalation studies to cause fibrogenic and carcinogenic effects in laboratory rats. These effects include interstitial fibrosis and cancer of the lung and pleura. In most cases, there appears to be an association between fibrosis and tumours in the rat lung. Fibrogenic and carcinogenic effects have also been found in long-term animal studies (mainly in rats) using other modes of administration (e.g., intratracheal instillation and intrapleural or intraperitoneal injection).

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Exposure/dose-response relationships for chrysotile-induced pulmonary fibrosis, lung cancer and mesothelioma have not been adequately investigated in long-term animal inhalation studies. Inhalation studies conducted to date, mainly using a single exposure concentration, show fibrogenic and carcinogenic responses at airborne fibre concentrations ranging from 100 to a few thousand fibres/ml. When data from various studies are combined, there appears to be a relationship between airborne fibre concentrations and lung cancer incidence. This type of analysis, however, may not be scientifically sound as different experimental conditions were used in available studies.

In non-inhalation experiments (intrapleural and intraperitoneal injection studies), dose-response relationships for mesothelioma have been demonstrated for chrysotile fibres. Data from these types of studies, however, may not be suitable for the evaluations of human risk from inhalation exposure to fibres.

Tremolite asbestos, a minor component mineral of commercial chrysotile, has also been shown to be carcinogenic and fibrogenic in a single inhalation experiment and an intraperitoneal injection study in rats. Exposure/dose-response data are not available to allow direct comparison of the cancer potency of tremolite and chrysotile.

The ability of fibres to induce fibrogenic and carcinogenic effects appears to be dependent on their individual characteristics, including fibre dimension and durability (i.e. biopersistence in target tissues), which are determined in part by the physico-chemical properties. It has been well documented in experimental studies that short fibres (shorter than 5 µm) are less biologically active than long fibres (longer than 5 µm). It is still uncertain, however, whether short fibres have any significant biological activity. Furthermore, it is not known how long a fibre needs to remain in the lung in order to induce preneoplastic effects, since the appearance of asbestos-related cancer generally occurs later in the animal's life.

The mechanisms by which chrysotile and other fibres cause fibrogenic and carcinogenic effects are not completely understood. Possible mechanisms of fibrogenic effects of fibres include chronic inflammation process mediated by production of growth factors (e.g., TNF-alpha) and reactive oxygen species. With regard to fibre-induced carcinogenicity, several hypotheses have been proposed. These include: DNA damage by reactive oxygen species induced by fibres; direct DNA damage by physical interactions between fibres and target cells; enhancement of cell proliferation by fibres; fibre-provoked chronic inflammatory reactions leading to prolonged release of lysozymal enzymes, reactive oxygen species, cytokines and growth factors; and action by fibres as co-carcinogens or carriers of chemical carcinogens to the target tissues. It is likely, however, that all these mechanisms contribute to the carcinogenicity of chrysotile fibres, as such effects have been observed in various *in vitro* systems of human and mammalian cells.

Overall, the available toxicological data provide clear evidence that chrysotile fibres can cause fibrogenic and carcinogenic hazard to humans. The data, however, are not adequate for providing quantitative estimates of the risk to humans. This is because there are inadequate exposure-response data from inhalation studies, and there are uncertainties concerning the sensitivities of the animal studies for predicting human risk.

Chrysotile fibres have been tested in several oral carcinogenicity studies. Carcinogenic effects have not been reported in available studies.

1.6 Effects on humans

Commercial grades of chrysotile have been associated with an increased risk of pneumoconiosis, lung cancer and mesothelioma in numerous epidemiological studies of exposed workers.

The non-malignant diseases associated with exposure to chrysotile comprise a somewhat complex mixture of clinical and pathological syndromes not readily definable for epidemiological study. The prime concern has been asbestosis, generally implying a disease associated with diffuse interstitial pulmonary fibrosis accompanied by varying degrees of pleural involvement.

Studies of workers exposed to chrysotile in different sectors have broadly demonstrated exposure-response or exposure-effect relationships for chrysotile-induced asbestosis, in so far as increasing levels of exposure have produced increases in the incidence and severity of disease. However, there are difficulties in defining this relationship, due to factors such as uncertainties in diagnosis and the possibility of disease progression on cessation of exposure.

Furthermore, some variation in risk estimates are evident among the available studies. The reasons for the variations are not entirely clear, but may relate to uncertainties in exposure estimates, airborne fibre size distributions in the various industry sectors and statistical models. Asbestotic changes are common following prolonged exposures of 5 to 20 f/ml.

The overall relative risks for lung cancer are generally not elevated in the studies of workers in asbestos-cement production and

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In some of the cohorts of asbestos-cement production workers. The exposure-response relationship between chrysotile and lung cancer risk appears to be 10-30 times higher in studies of textile workers than in studies of workers in mining and milling industries. The relative risks of lung cancer in the textile manufacturing sector in relation to estimated cumulative exposure are, therefore, some 10-30 times greater than those observed in chrysotile mining. The reasons for this variation in risk are not clear, so several hypotheses, including variations in fibre size distribution, have been proposed.

Estimation of the risk of mesothelioma is complicated in epidemiological studies by factors such as the rarity of the disease, the lack of mortality rates in the populations used as reference, and problems in diagnosis and reporting. In many cases, therefore, risks have not been calculated, and cruder indicators have been used, such as absolute numbers of cases and deaths, and ratios of mesothelioma over lung cancers or total deaths.

Based on data reviewed in this monograph, the largest number of mesotheliomas has occurred in the chrysotile mining and milling sector. All the observed 38 cases were pleural with the exception of one of low diagnostic probability, which was pleuro-peritoneal. None occurred in workers exposed for less than 2 years. There was a clear dose-response relationship, with crude rates of mesotheliomas (cases/ 1000 person-years) ranging from 0.15 for those with cumulative exposure less than 3530 million particles per m³ (mpcm)-years (< 100 million particles per cubic foot (mpcf)-years) to 0.97 for those with exposures of more than 10 590 mpcm-years (> 300 mpcf-years).

Proportions of deaths attributable to mesotheliomas in cohort studies in the various mining and production sectors range from 0 to 0.8%. Caution should be exercised in interpreting these proportions as studies do not provide comparable data stratifying deaths by exposure intensity, duration of exposure or time since first exposure.

There is evidence that fibrous tremolite causes mesothelioma in humans. Since commercial chrysotile may contain fibrous tremolite, it has been hypothesized that the latter may contribute to the induction of mesotheliomas in some populations exposed primarily to chrysotile. The extent to which the observed excesses of mesothelioma might be attributed to the fibrous tremolite content has not been resolved.

The epidemiological evidence that chrysotile exposure is associated with an increased risk for cancer sites other than the lung or pleura is inconclusive. There is limited information on this issue for chrysotile *per se*, although there is some inconsistent evidence for an association between asbestos exposure (all forms) and laryngeal, kidney and gastrointestinal tract cancers. A significant excess of stomach cancer has been observed in a study of Quebec chrysotile miners and millers, but possible confounding by diet, infections or other risk factors has not been addressed.

It should be recognized that although the epidemiological studies of chrysotile-exposed workers have been primarily limited to the mining and milling, and manufacturing sector, there is evidence, based on the historical pattern of disease associated with exposure to mixed fibre types in western countries, that risks are likely to be greater among workers in construction and possibly other user industries.

1.7 Environmental fate and effects on biota

Serpentine outcroppings occur world-wide. Mineral components, including chrysotile, are eroded through crustal processes and are transported to become a component of the water cycle, sediment population and soil profile. Chrysotile presence and concentrations have been measured in water, air and other units of the crust.

Chrysotile and its associated serpentine minerals chemically degrade at the surface. This produces profound changes in soil pH and introduces a variety of trace metals into the environment. This has in turn produced measurable effects on plant growth, soil biota (including microbes and insects), fish and invertebrates. Some data indicate that grazing animals (sheep and cattle) undergo changes in blood chemistry following ingestion of grasses grown on serpentine outcrops.

2. IDENTITY, PHYSICAL AND CHEMICAL PROPERTIES, SAMPLING AND ANALYSIS

2.1 Identity

2.1.1 Chemical composition

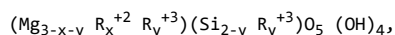
Chrysotile, referred to as white asbestos, is a naturally occurring fibrous hydrated magnesium silicate belonging to the serpentine group of minerals. The chemical composition, crystal structure and polytypic forms of the serpentine minerals have been described by Langer & Nolan (1994).

The composition of chrysotile is close to the ideal unit cell formula (Mg₃Si₂O₅(OH)₄); substitution by other elements in the crystal structure is possible. According to Skinner et al. (1988) substitution possibilities are:

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where $\text{R}^{2+} = \text{Fe}^{2+}$, Mn^{2+} or Ni^{2+} and $\text{R}^{3+} = \text{Al}^{3+}$ or Fe^{3+} .

Results of a typical chemical analysis are shown in Table 1 of Environmental Health Criteria 53 (IPCS, 1986).

Trace amounts of some other elements, such as Na, Ca and K, are probably due to the presence of other minerals admixed in the ore (see section 2.1.6).

2.1.2 Structure

Chrysotile is a sheet silicate with a basic building block of $(\text{Si}_2\text{O}_5)_n$ in which three of the oxygen atoms in each tetrahedron base are shared with adjacent tetrahedra in the same layer. The apical oxygens of the tetrahedra in the silica sheet become a component member of the overlying brucite layer $(\text{Mg}(\text{OH})_2)$ (Speil & Leineweber, 1969). As the dimensions of the cations in the silica and brucite sheets are different, strain is produced, which is accommodated by the formation of a scroll structure. Yada (1967) produced transmission electron micrographs that permitted visualization of this morphological feature. The curvature occurs with the brucite layer on the outer surface. The resulting capillaries are common to most specimens although solid cores have been found.

When more than one structure occurs, they are called polytypes: orthochrysotile (orthorhombic structure), clinochrysotile (monoclinic structure) and parachrysotile (cylindrical or polygonal Povlen-type structures) (Wicks, 1979). Most chrysotile is a mixture of the ortho- and clino-polytypes in various proportions (Speil & Leineweber, 1969).

2.1.3 Fibre forms in the ore

Chrysotile can occur in the host rock as "cross-fibre" (fibre axes at right angles to the seam or vein), "slip-fibre" (fibre axes parallel to the seam) or massive fibre (in which there is no recognizable fibre orientation, as in the New Idria deposit in USA).

2.1.4 Fibre properties

Depending on the relative flexibility, fibres may be "harsh" or "soft". Chrysotile fibres generally occur with properties between these end-types (Badollet, 1948). While amphibole fibres are generally harsh, most chrysotile fibres are soft, although fibres displaying intermediate properties also occur. Harshness has been reported to be related to the water content of the fibre, i.e. the higher the water content the "softer" the fibre (Woodroffe, 1956), relative contents of clino- and ortho-chrysotile, and the presence of fine mineral intergrowth (Speil & Leineweber, 1969).

Harsh chrysotile fibres tend to be straighter and less flexible than the soft fibres. Inhalation of respirable straight fibres is reported to be associated with greater penetration to the terminal bronchioles than in the case of "curly" fibres (Timbrell, 1965, 1970).

The fibres can be classified into crude chrysotile (hand-selected fibres in essentially native or unfiberized form) and milled fibres (after mechanical treatment of the ore). Fibre grades used for different products vary from country to country. The Canadian system has been described by Cossette & Delvaux (1979). The Canadian grading system is widely used internationally.

At the turn of this century, the fibres of major commercial importance were several centimetres long. With time, as new applications developed, shorter fibres became important. This change is likely to have altered the nature of exposure in some circumstances.

2.1.5 UICC samples

Two UICC (Union Internationale Contre le Cancer) standard reference samples of chrysotile asbestos were available for use in experimental work. One was from Zimbabwe (Chrysotile A) and the other was a composite sample of fibres from Canadian mines in the eastern townships of Quebec (Chrysotile B). The physico-chemical properties of these samples are well characterized and details of their composition and properties have been reported (Timbrell et al., 1968; Rendall, 1970). These mixtures were artificial and did not reflect any one commercially available fibre.

2.1.6 Associated minerals in chrysotile ore

The mineral dusts to which miners or millers might be exposed are determined by the minerals associated with each of the chrysotile ore deposits. These depend on the composition of the original rock types and on the materials added or removed during geological events, surface weathering processes, etc. The spacial relationships among these components within ore bodies vary significantly from deposit to deposit.

Iron is ubiquitous in chrysotile deposits derived from ultramafic rocks. In some of these, magnetite occurs in intimate association with

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in fibres (e.g., in Quebec). In other deposit types, e.g., in carbonate rocks, the iron content is low (e.g., in Arizona). Brucite, or nemalite (the fibrous form of brucite), is found in some deposits. Micas, feldspars, altered feldspars, talc and carbonate minerals may be present. Langer & Nolan (1994) listed minerals likely to be associated with ultramafic rocks in which chrysotile is found, and Gibbs (1971a) listed more than 70 minerals occurring in the Quebec chrysotile mining region. Minerals such as magnetite, calcite and zeolites may also occur in a fibrous form.

Amphiboles may also be encountered, some in fibrous form. These latter minerals have been found in studies of lung tissues of exposed workers. Tremolite, ferro-tremolite, actinolite, anthophyllite and other amphibole minerals have been described. Their occurrence in ore bodies is both heterogeneous in distribution and variable in concentration. Addison & Davies (1990) found tremolite in 28 out of 81 ore samples (34.6%) at concentrations (when detected) from 0.01 to about 0.6%. The average concentration was about 0.09%. The form of the amphibole, whether asbestos or massive, was not given. This information may be crucial in considering the mineral type as an agent of disease, especially for mesothelioma.

Trace metals have been described in association with fibres, particularly chromium, cobalt, nickel, iron and manganese (Cralley et al., 1967; Gibbs, 1971a; Morgan & Cralley, 1973; Oberdörster et al., 1980). Concentrations in mills in the late 1960s were several times higher than those measured at textile plants at that time (Gibbs, 1971a).

Naturally occurring chrysotile has been shown to contain trace quantities of organic compounds, predominantly straight-chain alkanes (Gibbs, 1971b). Processed fibres may also contain organic compounds including polycyclic aromatic hydrocarbons (Gibbs, 1971a; Gibbs & Hui, 1971). Concentrations of polycyclic aromatic hydrocarbons in the air of chrysotile mills were found to be lower than levels in urban areas (Gibbs, 1971a). Fibres can also be contaminated by alkanes and by antioxidants from storage in polyethylene bags (Commins & Gibbs, 1969; Gibbs & Hui, 1971).

Radon concentrations in the Quebec chrysotile mines were reported to be below 0.3 Standard Working Level (Gibbs, 1971a). This has been rejected as an agent of disease among miners, especially for lung cancer.

2.2 Physical and chemical properties

The mineralogy and properties of chrysotile have been summarized by Wicks (1979), Pooley (1987), and Langer & Nolan (1994).

2.2.1 Physical properties

The physical properties of chrysotile, as they affect human health, have been described in Langer & Nolan (1986, 1994) and IPCS (1986).

Harshness has been discussed in section 2.1.4.

Heating of chrysotile fibre at 700°C for an hour converts it to an amorphous, anhydrous magnesium silicate material (Speil & Leinweber, 1969). Intensive dry grinding also destroys the structure of chrysotile. Analysis of wear debris from brake linings made with asbestos has shown that virtually all of the chrysotile fibre is converted to amorphous material, in association with the mineral forsterite (a recrystallization product). The conversion is explained by localized temperatures above 1000°C at the point of contact between the brake lining and the drum (Lynch, 1968; Rowson, 1978; Williams & Muhlbaier, 1982). The fibres found in the brake wear debris are predominantly (99%) less than 0.4 µm in length (Rohl et al., 1977; Williams & Muhlbaier, 1982). Rodelsperger et al. (1986) found less than 1% of fibres longer than 5 µm.

Size and shape are the most important characteristics for defining the respirability of fibres. For workplace regulatory purposes a fibre has been defined most frequently as having an aspect ratio (ratio of fibre length to fibre diameter) of at least 3:1. Regulatory definitions usually impose a length of 5 µm or greater for workplace assay.

Chrysotile bundles may be split longitudinally to form thinner fibres. The ultimate fibre is called a fibril. Yada (1967), by means of high resolution transmission electron microscopy, showed that basic spiral elements of chrysotile consist of 5 silica-magnesia units with approximately 10 silica-magnesia units forming the 0.007 µm wall of a single fibril. The diameter of the ultimate fibril is about 0.03 µm.

The fibres of significance in health risk evaluation are those that can be inhaled. Timbrell (1970, 1973) showed that chrysotile fibres less than about 3.5 µm in diameter can enter the conducting airways of the lung. The radius of curvature of the chrysotile fibre may play a role in the ability of a fibre to penetrate to distant sites along the conducting airways.

As it is possible to have long narrow fibres and short narrow fibres, descriptions of fibrous aerosols by "mean or median diameter", or "mean or median length" do not provide sufficient information.

Comparisons of fibrous aerosols to which subjects are exposed may therefore be limited. The measurements of dimensions are time-consuming and complete data sets are scant.

Results of most distributions reported are incomplete. Unless specific steps have been taken to evaluate very long fibres, transmission electron microscopy (TEM) will understate the number of long fibres (>20 µm). Because the proportion of very long fibres is low, random scanning rarely encounters them. Scanning electron microscopy (SEM) usually requires coating of the specimen. Most preparation techniques obscure single chrysotile fibrils. In addition, if chemical analysis of individual fibres is not made, other fibres may be erroneously reported as chrysotile.

It has been noted that the vast majority of airborne chrysotile fibres are short, the percentage of fibres more than 5 µm long in mining and milling being about 1.3 and 4.1%, respectively (Gibbs & Hwang, 1980), while data show that up to 24% of fibres may be longer than 5 µm in certain textile spinning operations (Gibbs, 1994). Virtually all airborne fibres have a diameter of less than 3 µm and are thus respirable.

The cross-section of a chrysotile fibril is approximately circular (see figure in Yada, 1967). This is important in calculating the mass of individual fibres. Generally, the surface area depends on the degree of fibre openness. The New Idria (Coalinga) material has a surface area of about 78 m²/g and an average fibril diameter of 0.0275 µm, while the Canadian 7R has a surface area of about 50 m²/g and an average fibril diameter of 0.0375 µm (Speil & Leineweber, 1969). It has been suggested that surface area plays a role in imparting biological potential.

Timbrell (1975) reported the magnetic properties of fibres. Chrysotile showed no preferred orientation in magnetic fields.

It has been observed that industrial processing of fibres from different sources may affect total airborne dust concentrations.

2.2.2 Chemical properties

Chrysotile exhibits significant solubility in aqueous neutral or acidic environments (Langer & Pooley, 1973; Jaurand et al., 1977; Spurny, 1982). In contact with dilute acids or aqueous medium at pH less than 10, magnesium leaches from the outer brucite layer (Nagy & Bates, 1952; Atkinson, 1973; Morgan & Cralley, 1973). Magnesium loss has also been demonstrated *in vivo*. The surface area of leached chrysotile is greatly increased (Badollet & Gannt, 1965). The solubility of the outer brucite layer of chrysotile in body fluids greatly affects bioaccumulation in lung tissues. The role of chemical properties in the biological behaviour of chrysotile has been recently discussed (Langer & Nolan, 1986, 1994).

The adsorption of polar organic agents on the surface of chrysotile is reported to be higher than that of less polar or non-polar agents (Speil & Leineweber, 1969; Gorski & Stettler, 1974). The binding of carcinogens such as benzo (*a*)pyrene, nitrosonornicotine and *N*-acetyl-2-aminofluorene to chrysotile has been studied by Harvey et al. (1984). Adsorption of components of cigarette smoke onto the surface of chrysotile fibres has been suggested to play a role in the etiology of lung cancer in fibre-exposed cigarette smokers. The fibre may act as a vehicle which transports polycyclic aromatic hydrocarbons across membranes of the target cells (Gerde & Scholander, 1989).

2.3 Sampling and analytical methods

The collection of samples from air, water, biological specimens, soils or sediments must follow an appropriate sampling strategy. A review of methods for sampling asbestos fibres has been published (IPCS, 1986).

The most commonly used analytical methods involve phase-contrast optical microscopy (PCOM) (in the workplace) and transmission electron microscopy (TEM) (in the general environment). PCOM is resolution-limited and non-specific for fibre characterization. TEM overcomes both limitations (Dement & Wallingford, 1990).

2.3.1 Workplace sampling

The most widely used method for the last 20 years has been the membrane filter method. Several attempts have been made to standardize the method (CEC, 1983; ILO, 1984; AIA, 1988; NIOSH, 1989a; ISO, 1993). A recommended method for the determination of airborne fibre concentration by PCOM (membrane filter method) has been published (WHO, 1997).

A known volume of air is drawn through a membrane filter on which the number of fibres is determined using a phase contrast microscope (see section 2.3.3.2). Special attention should be given to flow rates, sampling time, face velocity through the filter, and where, when and how to sample. Preference should be given to assessing individual exposure by personal sampling. The sampling strategy should be selected to yield the best estimate of an 8-h time-weighted average concentration. Excursions may be evaluated for regulatory purposes. If

The purpose of the measurement is evaluation of control measures, other methods may also be used.

2.3.2 Sampling in the general environment

Methods for sampling ambient air depend on the method of analysis, but generally involve filtering airborne particles from relatively large volumes of air using membrane filters. Strategies and sampling methods have been described by Rood (1991) and reviewed in detail in the Health Effects Institute study of asbestos in public buildings (HEI, 1991).

For analysis of water, sample specimens are collected and filtered through polycarbonate filters. If there is much organic debris, this must be removed to improve particle detection. The fibres must be re-prepared before analysis. The instrumental method is the same as that used for air samples.

2.3.3 Analytical methods

Analyses are performed to identify the fibre or fibres present and to determine their concentrations.

2.3.3.1 Fibre identification

Several methods have been developed to identify chrysotile asbestos using dispersion staining methods and polarization microscopy (Julian & McCrone, 1970; McCrone, 1978; Churchyard & Copeland, 1988; NIOSH, 1989a). NIOSH (1989b) described the procedure specifically for the analysis of asbestos bulk samples.

The limit of visibility of fibres, depending on the microscope and light source used, is in the range 0.2-0.3 μm . With most high quality research microscopes, chrysotile fibres of 0.22 μm are generally reported as being observable. The experience and expertise of the microscopist and the quality of the laboratory set-up both influence the outcome.

Fibres with diameters less than about 0.22 μm cannot be seen with a light optical microscope. When fibres with diameters less than this value need to be analysed, TEM is used. This method is generally applied to the identification and characterization of fibres in water and in ambient air (Chatfield, 1979, 1987; Rood, 1991; ISO, 1991; HEI, 1991). The most reliable method of identifying chrysotile fibres is the combination of morphology, chemistry and electron diffraction (Skikne et al., 1971; Langer & Pooley, 1973). Several methods for the determination of amphibole fibres in chrysotile have been described (Addison & Davies, 1990).

Analytical methods using scanning electron microscopy (SEM) have also been developed (AIA, 1984; WHO, 1985; ISO, 1992).

2.3.3.2 Measurement of airborne fibre concentrations

a) Workplace

In the PCOM method, the membrane filter is dissolved or collapsed using a solvent with a refractive index which matches the refractive index of the filter medium, rendering it invisible. Fibres entrained on the filter are made readily visible.

The number of fibres of specified length and diameter in a known area of the filter is counted at magnifications of 400 to 500. A graticule has been designed for this purpose. Development of the HSE/NPL slide (LeGuen et al., 1984), which permits laboratories to standardize the limit of visibility of their microscopes and microscopists, has improved the potential for interlaboratory agreement in counts.

Improvements in the mounting techniques and counting strategy has resulted in higher fibre counts than those found using the same techniques in the early 1970s (HSE, 1979; Gibbs, 1994). This change was estimated in the United Kingdom to cause a two-fold increase in the reported fibre concentrations (HSE, 1979).

Instrumentation for automatic counting has been developed (e.g., Kenny, 1984) but has failed to receive wide international recognition.

b) Ambient air

The diameter of most chrysotile fibres found in the non-occupational environment is below the resolution of the light optical microscope (Rooker et al., 1982).

The most reliable method for determining the concentration of chrysotile fibres in ambient air is TEM. Most currently available transmission electron microscopes have a resolution of about 0.2 nm; in combination with an energy-dispersive X-ray analyser (EDXA), TEM can chemically characterize fibres down to a diameter of 0.01 μm . The disadvantage of TEM is the small area that can be scanned when employing very high magnifications. This makes analysis of the long fibres (>5 μm) more limited in accuracy (Coin et al., 1992). A review of the use of TEM and a comparison of direct and indirect methods of filter preparation have been published recently (HEI, 1991).

SEM has been used in the measurement of chrysotile. Most SEMs have a resolution intermediate between that of TEM and PCOM.

2.3.3.3 Lung tissue analysis

Several methods have been described (Langer & Pooley, 1973; Gaudichet et al., 1980; Rogers et al., 1991a,b). All methods use ashing or digestion of tissues, TEM, SAED and EDXA. International standardization of these methods has not as yet been carried out. For this reason comparison of results from different laboratories is often difficult to make.

2.3.3.4 Gravimetric analysis

Gravimetric methods have been applied in some countries for the evaluation of workplace conditions and emissions (Rickards, 1973; Middleton, 1982). Relatively large samples of dust are needed and the methods do not distinguish between the fibres and non-fibrous dusts nor among mineral components of each group. In view of this and the

current belief that counts of fibres better define the health risk, gravimetric methods are limited in application. However, it must also be recognized that bulk dust assay is a useful index for control evaluation and should be used if membrane filter techniques are unavailable.

2.4 Conversion factors

The concentrations of airborne chrysotile fibres in the workplace are expressed as the number of fibres per millilitre (f/ml) of air, fibres per litre (f/litre) of air or fibres per cubic metre (f/m³) of air, or in milligrams per cubic metre (mg/m³) of air. Concentrations are expressed as number of fibres per cubic metre or nanograms per cubic metre (ng/m³) in the general environment.

The number of fibres per millilitre, obtained by the method of membrane filtration and PCOM, is currently used by regulatory agencies in most countries for the workplace. It is for this reason that the conversion of results obtained by different methods into membrane filter equivalents has been performed. Critiques of such conversions have been published (Walton, 1982; Valiø, 1993; Gibbs, 1994).

2.4.1 Conversion from airborne particle to fibre concentrations

In almost all epidemiological studies in which health effects have been related to exposure, concentration measurements were made using methods quite different from the membrane filter technique. The early instruments employed were the thermal precipitator in the United Kingdom, and the midget impinger in North America. Gravimetric measurements have also been used.

Attempts to convert the midget impinger count to an equivalent membrane filter fibre count have shown that no single conversion factor applies. Large variations in the ratios of midget impinger to membrane filter counts occur in different industries, between jobs within a single industry, or at a single plant site (Ayer et al., 1965; Gibbs & Lachance, 1974). Similar conversion problems were encountered in other countries where attempts were made to convert konimeter or thermal precipitator results to membrane filter equivalents (DuToit & Gilfillan, 1979; DuToit et al., 1983; Valiø & Cigula, 1992).

Side-by-side study of conversion factors has shown the correlation between particle and fibre counts to be limited. Both industry and operation-specific correlations have been made but are only site-specific. Although some comparisons made for epidemiological studies have yielded valuable data, no universal factor has ever been found. High variance exists. Temporal change in dust conditions in plants may have also affected conversion factors (Dagbert, 1976). The range of conversion ratios between work sites has been large (Doll & Peto, 1985). For purposes of exposure-response studies, conversions based on industry- and operation-specific data have proven valuable in some instances.

2.4.2 Conversion from total mass to fibre number concentrations

The conversions from total mass concentrations of dust determined gravimetrically into the fibre number concentrations may also be generally subject to great errors (Pott, 1978; IPCS, 1986). However, in some specific industries a good correlation has been achieved (Fei & Huang, 1989; Huang, 1990).

When measurements of airborne fibre concentrations are made using transmission electron microscopy, determination of fibre lengths and diameters are necessary. If chrysotile is split into fibrils, approximate mass can be calculated by determining the fibre dimensions and using fibre density in the calculation.

3. SOURCES OF OCCUPATIONAL AND ENVIRONMENTAL EXPOSURE

3.1 Natural occurrence

Chrysotile is present in most serpentine rock formations. As a result, chrysotile originating from serpentine rock is often found in

and water due to natural weathering (Nicholson & Pundsack, 1973; Neuberger et al., 1996).

Workable deposits are present in over 40 countries. Twenty-five of these currently produce chrysotile. Canada, South Africa, Russia and Zimbabwe have 90% of the established world reserves (Shride, 1973).

Chrysotile is emitted from both natural and industrial sources. No measurements concerning the extent of release of airborne fibres through natural weathering processes are available. A study of the mineral content of the Greenland ice cap showed that airborne chrysotile existed long before it was used commercially on a large scale. Ice core dating showed the presence of chrysotile as early as 1750 (Bowes et al., 1977).

Chrysotile is introduced into water by the weathering of chrysotile-containing rocks and ores, in addition to the effects of industrial effluents and atmospheric pollution (Canada Environmental Health Directorate, 1979). The largest concentrations of asbestos in drinking-water generally occur from erosion of asbestos deposits (Polissar, 1993; Neuberger et al., 1996). Millette JR ed. (1983) has attributed chrysotile in water supplies to erosion from natural sources in areas such as San Francisco, Sherbrooke and Seattle. Millette et al. (1980) have shown that in the USA asbestos in drinking-water is primarily chrysotile.

3.2 Anthropogenic sources

Chrysotile was at one time used in many applications, which included both friable and non-friable products (Shride, 1973). Currently, the human activities resulting in potential chrysotile exposure can be divided into broad categories: (a) mining and milling, (b) processing of asbestos into products (such as friction materials, cement pipe and sheet, gaskets and seals, paper and textiles), (c) construction and repair activities, and (d) transportation and, especially, disposal of chrysotile-containing waste products.

Chrysotile is by far the predominant asbestos fibre consumed today, e.g., in the USA 98.5% asbestos consumption in 1992 was chrysotile (Pigg, 1994).

3.2.1 Production

Although there are 25 countries currently producing chrysotile, seven countries account for the major part of world production (Brazil, Canada, China, Kazakhstan, Russia, South Africa and Zimbabwe) (US Department of Interior, 1993).

World production of asbestos increased 50% between 1964 and 1973 when it reached 5 million tonnes (US Department of Interior, 1991), but production has generally declined since the mid-1970s to its current level of 3.1 million tonnes. Table 1 shows the yearly production levels by countries between 1988 and 1992.

Table 2 shows the decline in major asbestos uses in the USA during the period 1977-1991 (US Department of Interior, 1986, 1991).

Chrysotile ore is usually mined in open-pit operations. Possible sources of emissions are drilling, blasting, loading broken rock and transporting ore to the primary crusher or waste sites. Subsequently, the ore is crushed and emissions may result during unloading, primary crushing, screening, secondary crushing, conveying and stockpiling. A drying step follows, involving conveying the ore to the dryer building, screening, drying, tertiary crushing, conveying ore to dry rock storage building and dry rock storage. The next step is the milling of the ore. In well-controlled mills, this is largely confined in the mill building, and presents low emissions because the mill air is collected and ducted through control devices (US EPA, 1986). In poorly controlled mills the emissions may be high.

3.2.2 Manufacture of products

Chrysotile use today mainly involves products where it is incorporated into matrices. The asbestos-cement industry is by far the largest user of asbestos fibres world-wide, accounting for some 85% of all use. Asbestos-cement production facilities exist in more than 100 countries and produce 27 to 30 million tonnes annually (Pigg, 1994). Asbestos-cement products contain 10-15% of asbestos, mostly chrysotile, although limited amounts of crocidolite have been used in large diameter, high-pressure pipes.

There are five major asbestos-cement products: (a) corrugated sheets; (b) flat sheets and building boards; (c) slates; (d) moulded goods, including low-pressure pipes; and (e) high-pressure water pipes (Pigg, 1994).

Possible emission sources are: (a) feeding of asbestos fibres into the mix; (b) blending the mix; and (c) cutting or machining end-products. Emissions may vary according to the dust control measures and technology.

Although declining in the North American and Western European markets, asbestos-cement product manufacturing continues to grow in South America, South-East Asia, the eastern Mediterranean region and

eastern Europe (Pigg, 1994). Japan, Thailand, Malaysia, Korea and Taiwan imported 430 000 tonnes, well over 30% of world-wide imports in 1989 (Industrial Minerals, 1990). It has been reported that "asbestos use" (the generic term used by the author) in Japan has reached proportions which indicate that it leads the world in consumption of fibres (Frank, 1995).

Table 1. World production, of asbestos (tonnes)^a (from: US Department of Interior, 1993)

Country ^b	1988	1989	1990	1991	1992
Argentina	2328	225	300 ^e	250 ^e	50
Bosnia & Herzegovina ^c	--	--	--	--	1000
Brazil	227 653	206 195	232 332 ^r	233 100 ^r	233 000
Bulgaria	300	300	500 ^r	500 ^{e,r}	500
Canada	710 357	701 227	685 627	689 000 ^r	585 000
China ^e	150 000 ^r	181 000 ^r	221 000 ^r	230 000	240 000
Columbia ^{e, d}	7600	7900	8000	8000	8000
Cyprus	14 585	--	--	---	--
Egypt	166	312	369	450 ^r	450
Greece	71 114	73 300 ^r	65 993 ^r	5500 ^{e,r}	--
India	31 123	36 502	26 053 ^r	24 094 ^r	25 000
Iran ^e	3410 ^{r,g}	3300	2800 ^r	3000 ^r	3000
Italy	94 549	44 348	3862	3000 ^{e,r}	1500
Japan ^e	5000	5000	5000	5000	5000
Kazakhstan ^f	--	--	--	--	300 000
Korea	2428	2361	1534	1500 ^e	1600
Russia	--	--	--	--	1 400 000
Serbia & Montenegro ^c	--	--	--	--	1700
South Africa	145 678	156 594	145 791	148 525 ^r	123 951 ^g
Swaziland	22 804	27 291	35 938	13 888 ^r	35 000
Turkey	50 ^e	--	--	--	--
Former-USSR ^e	2 600 000	2 600 000	2 400 000	2 000 000	--

Table 1. (continued)

Country ^b	1988	1989	1990	1991	1992
USA (sold or used by producers)	18 233	17 427	W	20 061	15 573
Former-Yugoslavia	17 030	9111	6578	5500 ^e	--
Zimbabwe	186 581	187 006 ^r	160 861 ^r	141 697 ^r	140 000
Total	4 310 989 ^r	4 259 399	4 002 538 ^r	3 533 065 ^r	3 120 524

^a Marketable fibre production. Table includes data available until 19 April 1993

^b In addition to the countries listed, Afghanistan, Czechoslovakia, North Korea and Romania also produce asbestos, but output is not officially reported, and available general information is inadequate for the formulation of reliable estimates of output levels.

^c Formerly part of Yugoslavia; data were not reported separately until 1992.

^d Estimated fibre production (in tonnes), based on reported crude production, was as follows: 1988: 152 896; 1989: 158 149; 1990: 159 600; 1991: 160 332; 1992: 160 000 (estimated).

^e Estimated

^f Formerly part of the USSR; data were not reported separately until 1992.

^g Reported figure.

^r Revised

^w Withheld to avoid disclosing proprietary data; excluded from "total"

Table 2. Demand for asbestos in the USA

(thousands tonnes) (US Department of Interior, 1986, 1991)

	1977	1984	1991
Asbestos-cement pipe	115	37	4
Asbestos-cement sheet	27	12	2
Coating and compounds	36	22	1
Flooring products	150	46	-
Friction products	57	48	10
Installation: electrical	4	1	-
Installation: thermal	17	2	-
Packing and gaskets	28	13	3
Paper products	7	2	-
Plastics	8	1	-
Roofing products	70	7	15
Textiles	10	2	-
Other	143	33	1
Total ^a	672	226	34

^a The totals given are not the exact sums of the values for individual products, owing to independent rounding.

Other asbestos products consume smaller quantities of chrysotile asbestos. Friction products, gaskets and asbestos paper are among them. Production of shipboard and building insulation, roofing and, particularly, flooring felts and other flooring materials, such as vinyl asbestos tiles, has declined considerably, some of them having disappeared completely from the market place. Friable asbestos materials in building construction have been phased out in many countries due to international recommendations.

Moulded brake linings on disc- and drum-type car brakes are among the chrysotile products that are still manufactured. Woven brake linings and clutch facings for heavy vehicle use are made from high-strength chrysotile yarn and fabric reinforced with wire; this material is dried and impregnated with resin. In the moulding process, the fibres are combined with the resin, which is then thermoset. Final treatment involves curing by baking and grinding to customer specifications.

3.2.3 Use of products

Many chrysotile-containing products have entered global commerce. The nature of the product and local work practices determine dust emissions. Non-friable products and appropriate technological controls greatly reduce fibre release. Manipulation of friable products without controls may release high levels of airborne dust. However, some conditions may produce chrysotile aerosols even with non-friable products, e.g., the use of high-speed power tools without controls.

Concern about the possible exposure of inhabitants of buildings with asbestos-containing materials has led to extensive monitoring (HEI, 1991). In this respect the exposure of custodian and maintenance staff is still being studied (see Chapter 4).

Manufacturing data are not available from individual countries concerning specific chrysotile-containing products.

4. OCCUPATIONAL AND ENVIRONMENTAL EXPOSURE LEVELS

Few recent reports of occupational and environmental exposure levels are available, particularly those that differentiate among the forms of asbestos. Workplace concentrations were very high when monitoring first began (in the 1930s). In countries where controls were implemented, the levels generally reduced considerably with time and continue to decline. In contrast, there is less difference between the early results of measurements in both outdoor and indoor non-occupational environments (1970s) and recent data.

Environmental Health Criteria 53 (IPCS, 1986) reported that 58.5% of samples had fibre concentrations of < 0.5 f/ml and 80.7% < 1.0 f/ml in textile industries in the United Kingdom over the period 1972-1978. Corresponding measurements in France in 1984 were 65.3% with < 0.5 f/ml and 85.4% with < 1.0 f/ml. It also reported 86.5% of samples with < 0.5 f/ml and 95.0% with < 1 f/ml in asbestos-cement industries in the United Kingdom during the period 1972-1978. Corresponding measurements in France in 1984 were 93.5% with < 0.5 f/ml and 97.4% with < 1.0 f/ml. In industries manufacturing friction products, 71.0% of samples had < 0.5 f/ml and 85.5% < 1.0 f/ml in the United Kingdom during 1972-1978, while the corresponding results in France in 1984 were 62.8% with < 0.5 f/ml and 85.0% with < 1.0 f/ml. Typical concentrations (fibres > 5 µm in length) in outdoor air measured in various locations in Austria, Canada, Germany, South Africa and the USA ranged from < 0.0001 to about 0.01 f/ml, concentrations in most samples being less than 0.001 f/ml. Concentrations (fibres > 5 µm in length) measured in various buildings in Canada and Germany ranged from values below the limit of detection to 0.01 f/ml. The highest concentrations were found in buildings with sprayed-on friable asbestos.

4.1 Occupational exposure

This section focuses mainly on exposures found in industries where only commercial chrysotile was used. Emphasis is placed on data obtained directly by the membrane filter method, but, in the case of some older studies, data are conversions from original particle counts. In the latter case, fibre concentrations are subject to the limitations discussed in sections 2.4.1 and 2.4.2.

4.1.1 Mining and milling

Several sets of data have been published concerning the exposure levels of mine and mill workers employed in the production facilities of Thetford Mines and Asbestos, Quebec, Canada. A substantial body of exposure data was collected by using midget impingers and enumerating all dust particles (Gibbs & Lachance, 1972). Table 3 lists mean concentrations of dust in the mills in millions of particles per m³ (mpcm) and per cubic foot (mpcf) of air during the period 1949 to 1965. The mill with the highest dust concentrations had more than twice the mean values given in Table 3, and that with the lowest concentrations had less than one half.

Table 3. Mean dust concentrations in asbestos mills of Quebec, Canada (from Gibbs & Lachance, 1972)

Concentration	1949	1951	1953	1955	1957	1959	1961	1963	1965
mpcm	2650	1940	1770	1130	1060	570	350	530	180
mpcf	75	55	50	32	30	16	10	15	5

Studies of the relationships between particle counts and fibre concentrations have shown poor correlation (Gibbs & Lachance, 1974; Dagbert, 1976). Gibbs & Lachance (1974) stated that no single conversion factor could be applied to all mines and mills. Assuming a conversion factor of roughly 106 f/ml for each mpcm (3 f/ml for each mpcf), it can be calculated that mean fibre concentrations in the Quebec mills before mid-1955 were well above 150 f/ml (see discussions in section 2.4).

Nicholson et al. (1979) reported fibre concentrations obtained by the membrane filter method in five mines and mills of Thetford Mines, Quebec, Canada during the period October 1973 to October 1975 (Table 4).

In Zimbabwe, Cullen et al. (1991) reported estimates of fibre levels prior to 1980. After 1980, the measured concentrations were below 10 f/ml in all facilities. In India, the concentrations measured in four mills in 1989 by Mukherjee et al. (1992) are presented in Table 5.

Parsons et al. (1986) reported that the concentrations in refining and bagging areas in a Newfoundland mill were generally less than 0.5 f/ml, but concentrations in the screening area ranged up to 13.9 f/ml.

Average concentrations of asbestos fibres (length > 5 µm) in the Quebec mining industry during the period 1973-1993 are presented in Fig. 1. The average concentrations in Quebec chrysotile mining towns are shown in Fig. 2.

4.1.2 Textile production

Nine textile plants in the USA were studied in 1964 and 1965 by Lynch & Ayer (1966). The results of the membrane filter analysis are presented in Table 6. The presence of small amounts of amosite or crocidolite fibres cannot be excluded due to the non-specificity of the assay instrument (PCOM).

Table 4. Asbestos fibre concentrations^a in five chrysotile mines and mills at Thetford Mines, Quebec, Canada (from Nicholson et al., 1979)

Location		Five mines and mills				
		1	2	3	4	5
General mill air	Number of samples	14	37	5	6	7
	mean	35	12	15	18	9
	range	14-57	7-27	7-27	12-29	5-12
Bagging asbestos	Number of samples	2	6	2	2	
	mean	16	16	9	16	
	range	12-20	10-24	4-13	14-17	
Quality control	Number of samples		2	1	1	
	mean		22	20	9	
	range		21-22	-	-	
Crusher	Number of samples		4			
	mean		26			
	range		8-47			

Dryer	Number of samples	2	
	mean	36	
	range	27-45	
Shops	Number of samples	3	
	mean	10	
	range	6-15	
Non-work location	Number of samples	1	2
	mean	0.8	1.3
	range	-	1-1.7

^a The concentration of fibres (> 5 µm) is given in f/ml.

Table 5. Average personal sample fibre concentrations in four mills in India (from Mukherjee et al., 1992)

Process	Fibre concentration (f/ml)	
	Average	Range
Jaw crusher	1.7	1.3-2.1
Pulverizer	8.9	2.3-15.4
Lime mixer	2.6	2.5-2.6
Huller	12.7	8.9-16.4
Primary eccentric screen	12.9	1.8-25.8
Decorticator	8.8	1.3-18.4

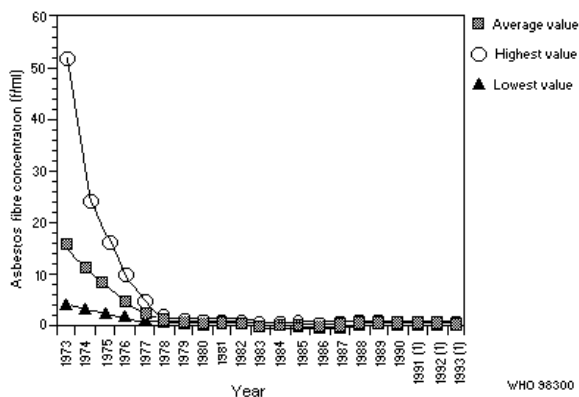


Fig. 1. Average concentrations of asbestos fibres (longer than 5 µm) in the Quebec mining industry (Lebel, 1995a,b)

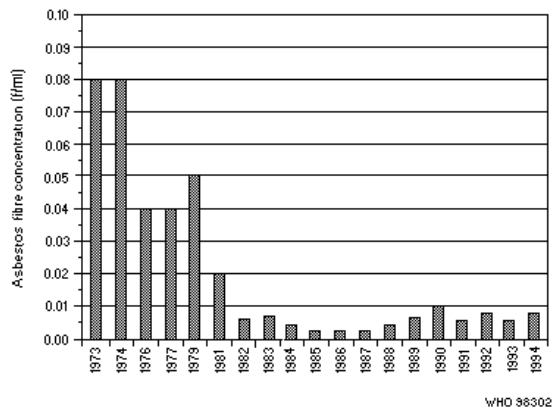


Fig. 2. Asbestos fibre concentrations in Quebec chrysotile mining towns (Lebel, 1995a,b)

Table 6. Mean dust concentrations (f/ml) by plant and operation in nine textile plants in the USA during the period 1964/1965 (from Lynch & Ayer, 1966)

Operation	Fibres ^a	Textile plants								
		1	2	3	4	5	6	7	8	9
Fibre preparation	A	38.1	12.3	23.3	34.0	-	8.1	7.6	35.5	11.8
	B	15.0	10.0	13.3	18.3	-	3.0	4.5	17.0	2.6
Carding	A	18.1	13.6	20.6	32.9	-	6.0	17.2	28.2	8.3
	B	10.2	9.21	3.3	15.2	-	3.5	8.1	13.4	2.0

Spinning	A	9.6	4.1	20.2	29.8	-	5.1	24.8	20.8	7.4
	B	6.6	3.2	18.9	15.7	-	3.5	10.8	10.5	1.8
Twisting	A	9.3	6.9	15.8	51.4	-	4.8	25.9	16.7	3.1
	B	6.4	5.2	7.5	22.4	-	3.3	12.9	7.2	1.1
Winding	A	11.7	4.4	9.6	28.6	-	4.5	25.7	7.9	3.6
	B	7.5	3.9	8.9	17.5	-	3.2	11.7	2.7	1.3
Weaving	A	7.7	7.0	2.9	33.8	4.5	2.9	9.5	8.1	2.9
	B	4.8	3.1	2.3	17.8	3.9	2.2	5.7	3.0	1.5

^a A = total fibres, B = fibres longer than 5 µm

The exposure estimates (1930-1975) in an extensively studied textile plant in South Carolina, USA, in which chrysotile was the predominant fibre used, are presented in Table 7 (Dement et al., 1983a).

Table 7. Exposure estimates in a chrysotile textile plant (1930-1975) (estimated mean exposure to fibres longer than 5 µm in f/ml)^a

Operation	Without controls	With controls
Fibre preparation	26.2-78.0	5.8-17.2
Carding	10.8-22.1	4.3-9.0
Spinning	4.8-8.2	4.8-6.7
Twisting	24.6-36.0	5.4-7.9
Winding	4.1-20.9	4.1-8.4
Weaving	5.3-30.6	1.4-8.2

^a From: Dement et al. (1983a)

Application of controls in the dusty processes at the South Carolina plant led to significant reduction of exposure. Currently available control technology allows much lower levels to be attained.

Table 8 shows a summary of exposure classifications in an English textile plant in the period 1951-1974 (Peto et al., 1985). The early particle count data in this report were based on fibre collection with a thermal precipitator. The conversion factor used, therefore, reflects only a precipitator-membrane filter relationship. Comments on the validity of such conversions have been discussed by Walton (1982).

Kimura (1987) reported geometric mean concentrations of 2.6-12.8 f/ml in the period 1970-1975 and 0.1-0.2 f/ml in the period 1984-1986 in asbestos spinning in Japan.

4.1.3 Asbestos-cement

As mentioned in section 3.2.2, the principal use of chrysotile in the world today is in asbestos-cement products. In the production of asbestos-cement pipes, some crocidolite is still used with chrysotile in certain plants.

Table 9 summarizes the results of the analysis of personal samples, collected in the late 1970s when reportedly only chrysotile was used, in an asbestos-cement facility in the USA (Hammad et al., 1979). In 80% of the samples the concentrations were less than 2 f/ml, and in about 60% they were less than 0.5 f/ml.

Table 8. Mean concentrations of airborne asbestos fibres in a textile plant^a

Period	Very high	High	Medium	Low
1951-1955 ^b	unloading, stacking 28 f/ml	roving, spinning, carding 14 f/ml	doubling, rope spinning 8 f/ml	other areas 4.5 f/ml
1956-1960 ^b	unloading, stacking 28 f/ml	carding 16 f/ml	roving, spinning, mixing 9 f/ml	other areas 4.5 f/ml
1961-1965	unloading, stacking 20 f/ml	carding 15 f/ml	carding, roving, winding, beaming 7.5 f/ml	other areas 2.5 f/ml
1966-1970	unloading, stacking 20 f/ml	carding 15 f/ml	carding, roving, rope cards 7.5 f/ml	other areas 2.5 f/ml
1971-1974	none	none	carding, roving 7.5 f/ml	other areas 2.5 f/ml

^a Peto et al. (1985)

^b Results of particle measurements were converted to fibre concentrations using the relationship 35 p/ml = 1 f/ml
Table 9. Chrysotile fibre concentrations (fibres longer than 5 µm) in selected dust zones of an asbestos-cement production facility^a

Location	Number of samples	Fibre concentration (f/ml) range	mean
Regrinding	4	0.44-1.2	0.86
Mixing	9	0.51-8.9	2.8
Forming	20	0.12-5.0	0.52
Siding and shingle finishing	14	0.14-4.9	0.68
Panel finishing	11	0.33-12.0	2.8
Flat and corrugated finishing	12	0.33-8.0	2.6
Warehouse	5	0.13-2.5	0.63
Maintenance	7	0.20-2.7	0.58

^a From: Hammad et al. (1979)

Exposure estimates in a Canadian plant (Finkelstein, 1983) for the years 1949, 1969 and 1979 were 40, 20 and 0.2 f/ml, respectively, for willow operators, 16, 8 and 0.5 f/ml for forming machine operators, and 8, 4 and 0.3 f/ml for lathe operators. In Japan, Kimura (1987) reported geometric mean concentrations in bag opening and mixing of 4.5-9.5 f/ml in 1970-1975 and 0.03-1.6 f/ml in 1984-1986, whilst in cement cutting and grinding the mean concentrations were 2.5-3.5 f/ml in 1970-1975 and 0.17-0.57 in 1984-1986. Albin et al. (1990) reported fibre concentrations, based on estimates, in a Swedish asbestos-cement plant of 1.5-6.3 f/ml during 1956. Later, based on direct measurements, values were 0.3-5.0 f/ml in 1969 and 0.9-1.7 f/ml in 1975. Higashi et al. (1994) reported geometric average concentrations of 0.05-0.45 f/ml measured in area samples and 0.05-0.78 f/ml in personal samples of an asbestos-cement plant.

Few data are available in the open literature on exposures encountered during installation of asbestos-cement products. It would be expected that cutting, sanding, drilling or otherwise abrading asbestos-cement without efficient ventilation controls would give rise to high exposures (Nicholson, 1978).

Weiner et al. (1994) reported concentrations in a South African workshop in which chrysotile asbestos-cement sheets were cut into components for insulation. The sheets were cut manually, sanded and subsequently assembled. Initial sampling showed personal sample mean concentrations of 1.9 f/ml for assembling, 5.7 f/ml for sweeping, 8.6 f/ml for drilling and 27.5 f/ml for sanding. After improvements and clean-up of the work environment, the concentrations were 0.5-1.7 f/ml.

Nicholson (1978) reported concentrations of 0.33-1.47 f/ml in a room during and after sawing and hammering of an asbestos-cement panel.

4.1.4 Friction products

Skidmore & Dufficy (1983), based on simulated past conditions (Table 10), and McDonald et al. (1984) reported data on workplace exposures during friction product manufacturing.

McDonald et al. (1984) reported that in the 1930s estimated average dust levels were 35-180 mpcm (1-5 mpcf) in 67% of analysed locations, while in the 1960s average dust levels were below 7 mpcm (0.2 mpcf) at 38% of locations and below 18 mpcm (0.5 mpcf) at 67% of locations in which measurements were obtained.

Table 10. Average concentrations of chrysotile fibres (f/ml) longer > 5 µm from woven asbestos products during various periods

	Pre-1931	1932-1950	1951-1969	1970-1979
Storage/distribution	>20	2-5	2-5	0.5-1
Preparation	>20	0-20	2-5	1-2
Impregnation/forming	>20	2-5	1-2	0.5-1
Grinding	>20	5-10	2-5	0.5-1
Drilling, boring	>20	2-5	1-2	1-2
Inspection	>20	2-5	1-2	0.5-1
Packing	>20	1-2	0.5-1	<0.5
Office/laboratory	10-20	<0.5	<0.5	<0.5

* Skidmore & Dufficy (1983)

Kimura (1987) reported geometric mean fibre concentrations of 10.2-35.5 f/ml in 1970-1975, and 0.24-5.5 f/ml in 1984-1986 in spinning and grinding of friction products in Japan.

A considerable number of reports have included airborne asbestos concentrations during maintenance and replacement of vehicle brakes. In the early period, poor or no engineering control measures were utilized, resulting in high total dust exposure. This was particularly so during grinding of brakes and compressed air blowing off dust, both operations of very short duration. Significantly lower levels were

measured when engineering controls were introduced.

An overview of air concentrations measured during maintenance and replacement of asbestos-containing vehicle brakes is presented in Table 11.

Table 11. Asbestos air concentrations measured during maintenance and replacement of vehicle brakes

Mean concentration (f/ml)	Comment	Reference
3.8 ^a	grinding truck brakes	Lorimer et al., 1976
15.9 ^a	blowing off	Lorimer et al., 1976
3.8 ^a	grinding	Rohl et al., 1976
16.0 ^a	blowing off	Rohl et al., 1976
2.5 ^a	dry brushing	Rohl et al., 1976
> 1 ^a	17 of 19 operations	Menichini & Marconi, 1982
> 2 ^a	11 of 19 operations	Menichini & Marconi, 1982
0.09 ^b	fibres longer than 5 µm	Jahn et al., 1985
6.2 ^a	blowing off, grinding	Jahn et al., 1985
0.03 ^b	fibres longer than 5 µm	Elliehausen, 1985
0.06 ^b		Ruhe & Lipscomb, 1985
< 0.5	TWA	Cheng & O'Kelly, 1986
0.13	maximum	Cheng & O'Kelly, 1986
4-5 ^a	fibres longer than 5 µm, blowing off, grinding	Rodelsperger et al., 1986
5-10 ^a	fibres longer than 5 µm, blowing off, grinding, trucks	Rodelsperger et al., 1986
< 0.05 ^b		Kauppinen & Korhonen, 1987
0.01-0.2 ^b	trucks and buses	Kauppinen & Korhonen, 1987
> 1 ^a	blowing off	Kauppinen & Korhonen, 1987
< 0.004		Sheehy et al., 1987
< 0.004 ^b		Godbey et al., 1987
0.09-0.12		Van Wageningen, 1987
0.046 ^b		Cooper et al., 1988
0.03 ^b	TWA < 0.002 f/ml	Moore, 1988

^a These results are mean personal samples obtained by PCOM; fibres $\geq 5 \mu\text{m}$; these represent episodic releases and not time-weighted averages; operation specific.

^b Mean personal air samples (8-h time-weighted average)

4.1.5 Exposure of building maintenance personnel

The subject of asbestos exposure of maintenance personnel in buildings has been raised recently and particularly by US OSHA (1994).

Price et al. (1992) estimated the time-weighted averages (TWAs), of asbestos exposures experienced by maintenance personnel, on the basis of 1227 air samples. The TWAs, obtained by PCOM, were 0.009 f/ml for telecommunication switch work, 0.037 f/ml for above-ceiling maintenance work, and 0.51 f/ml for work in utility spaces. Median concentrations ranged from 0.01 to 0.02 f/ml.

The Health Effects Institute (1991) evaluated an operation and maintenance programme in a hospital on the basis of 394 air samples obtained during 106 on-site activities. The mean asbestos concentration (PCOM) was about 0.11 f/ml for personal samples and about 0.012 f/ml for area samples. Eight-hour TWA concentrations showed that 99% of the personal samples were below 0.2 f/ml, and 95% were below 0.1 f/ml.

Corn et al. (1994) evaluated exposures of building maintenance personnel on the basis of about 500 personal samples collected during maintenance work. However, the building personnel were being monitored during an asbestos "operations and management" programme, so that these values may reflect special work practices and environment conditions. Typical personal exposures are presented in Table 12.

Table 12. Personal asbestos exposures of building maintenance personnel (fibres longer than 5 µm)^a

Activity	Concentration during work (f/ml)	8-h TWA (f/ml)
Electrical/plumbing work	0-0.035	0.0149
Cable running	0.001-0.228	0.0167
HVAC work	0-0.077	0.0023

^a From: Corn (1994)

Published data for custodial workers, as they exist, reflect unusual circumstances. Sawyer (1977) studied fibre release from a friable chrysotile-containing surface formulation during routine custodial activities performed in the Yale Art and Architecture

During the fibre levels, determined by PCOM, ranged from 1.6 f/ml, obtained during sweeping, to 15.5 f/ml, obtained during dusting of library books. These values were obtained as short-term episodes. Most other values, presented as 8-h TWAs, were about two orders of magnitude lower (HEI, 1991).

4.1.6 Various industries

Higashi et al. (1994) reported the results of their environmental evaluations at 510 workplaces in 1985 (roofing materials, asbestos-cement sheets, friction materials, construction materials) and 430 workplaces in 1992. The percentage of workplaces in which exposure concentrations were less than 0.3 f/ml was 70% in 1985 and 98% in 1992. All concentrations in a modernized asbestos-cement plant were less than 0.1 f/ml.

Rickards (1991, 1994) reported the results of the measurement of asbestos fibre concentrations covering exposures of over 39 900 workers in 27 countries in 1989 and over 26 500 workers in 28 countries in 1991 and 1992. His modified results are presented in Table 13. The 1993 data, by industry sector, is shown in Fig. 3 (AIA, 1995). Kogevinas et al. (1994) summarized exposure data obtained from chrysotile-exposed workers in 11 countries. The exposure levels ranged considerably, reflecting industry and other factors.

Table 13. Percentages of over 26 500 workers in 28 countries exposed to various asbestos fibre concentrations in the workplace (members of Asbestos International Association)^a

Percentage of workers	Asbestos fibre concentration (f/ml)			
	< 0.5	0.5-1	1-2	> 2
1989	83.5	11.1	4.5	0.9
1991	84.4	9.4	4.2	2.1
1992	89.1	6.3	3.9	0.8

^a Rickards (1991, 1994)

Fei & Huang (1989) reported fibre concentrations in an asbestos paper factory utilizing chrysotile in the Sichuan Province of west China. The concentration of 135 fibre measurements ranged between 0.6 f/ml and 55.1 f/ml, the latter value being the average of 6 assays in a pulp-reducing area.

4.2 Non-occupational exposure

4.2.1 Ambient air

There are some data concerning fibre levels in the air close to chrysotile mines. Baloyi (1989) found fibre levels around the Shabani Mine (Zimbabwe) to range from below the limit of detection of the method (< 0.01 f/ml) to 0.02 f/ml of air, assayed by PCOM.

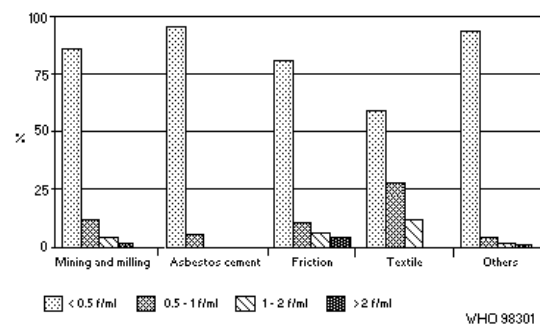


Fig. 3. Percentages of workers exposed to various asbestos fibre concentrations in 1993 (AIA, 1995)

Asbestos concentrations in the outdoor air have been measured in many studies. Chrysotile is the predominant fibre found. Concentrations measured at various locations in Austria, Canada, Germany, South Africa and the USA were reported in Environmental Health Criteria 53 (IPCS, 1986; Table 14). Typical concentrations of fibres longer than 5 μ m ranged from less than 0.0001 f/ml to about 0.01 f/ml, most samples having concentrations less than 0.001 f/ml. Results of some more recent studies are presented in Table 14. Almost all analyses were made by TEM. A review of available data was given in HEI (1991).

Corn (1994) estimated that outdoor air concentrations, expressed as PCOM equivalent fibres (longer than 5 μ m), in remote locations in the USA are generally less than 0.0005 f/ml, in urban areas they are up to 0.002 f/ml, and in suburban locations they are considerably lower.

4.2.2 Indoor air

Concentrations measured in various buildings in Canada and Germany were presented in Environmental Health Criteria 53 (IPCS, 1986, Table 12). Concentration of fibres longer than 5 µm ranged from below the detectable level of the method to 0.01 f/ml. The highest concentrations were found in buildings with sprayed-on asbestos.

The results of some more recent studies are presented in Table 15.

The average airborne fibre concentrations in outdoor air, 71 schools and 49 public buildings in the USA are presented in Table 16.

Corn (1994) estimated an average level of PCOM equivalent fibres (> 0.2 µm width) of 0.00017 f/ml in 71 schools in the USA. Five per cent of the school indoor concentrations exceeded 0.0014 f/ml, the highest value being 0.0023 f/ml.

Lee et al. (1992) found that only 0.67% of chrysotile fibres in indoor air are longer than 5 µm.

Table 14. Asbestos fibre concentrations in outdoor air (f/ml PCOM equivalent fibres^a - TEM)

Environment	Median	Mean	Range ^f	Reference
Rural Japan	0.0218		0.007-0.047	Kohyama, 1989
Urban Switzerland		<0.0004 ^b		Litistorf et al., 1985
USA	0.0003 ^c		ND-0.008	Chesson et al., 1985
Canada	0.0007		0.0006-0.0009	Sebastien et al., 1986a
USA		0.00005 ^c		Tuckfield et al., 1988
Canada	0.0001 ^b		ND-0.003	Nicholson, 1988
Japan		0.0198 ^e	<0.004-0.111	Kohyama, 1989
England		0.00016 ^b	ND-0.00016	Jaffrey, 1988
England		0.0004 ^b		Jaffrey, 1990
Slovak Republic		0.002 ^d	0.001-0.02	Juck et al., 1991
Italy			0.0001-0.012	Chiappino et al., 1993

^a PCOM equivalent fibre: >5 µm long; ≥ 0.25 µm wide; aspect ratio ≥ 3:1

^b total structures >5 µm

^c PCOM analysis

^d near to an asbestos-cement plant

^e residential area

^f ND - not detected

Table 15. Asbestos fibre concentrations (f/ml) in buildings (fibres longer than 5 µm)

Site ^a	Mean ^b	Range ^b	Reference
Canada High-rise office	0.0034	0.0002-0.0065	Chatfield, 1986
Schools	0.0006	ND-0.0014	Chatfield, 1986
United Kingdom Buildings with ACM		ND-0.0017	Burdett & Jaffrey, 1986
Buildings without ACM		ND-0.0007	Burdett & Jaffrey, 1986
Residences with ACM	0.0003	ND-0.0025	Gazzi & Crockford, 1987
Residences without ACM	ND	ND	Gazzi & Crockford, 1987
USA Residences with ACM	0.0001	ND-0.002	CPSC, 1987
Buildings with ACM	0.00005	ND-0.00056	Hatfield et al., 1988; Crump & Farrar, 1989; Chesson et al., 1990
Buildings without ACM	ND	ND	Hatfield et al., 1988; Crump & Farrar, 1989; Chesson et al., 1990
Schools	0.00024	ND-0.0023	Corn et al., 1991
Schools with ACM	0.0002	ND-0.0016	McCrone, 1991
Slovak Republic Buildings	0.0045	0.00085-0.024	Juck et al., 1991
Belgium Public buildings		0.0045-0.0061	Minne et al., 1991

^a ACM = asbestos-containing material

^b ND = not detected

Table 16. Mean concentrations of asbestos fibres longer than 5 μm^a

	Sample size	Mean concentration (f/ml)
Outdoor air	48	0.00039
Schools	71	0.00024
Public buildings (no ACM)	6	0.00099
Public buildings (with ACM in good condition)	6	0.00059
Public buildings (with damaged ACM)	37	0.00073

^a Modified from Mossman et al. (1990)

5. UPTAKE, CLEARANCE, RETENTION AND TRANSLOCATION

5.1 Inhalation

5.1.1 General principles

Factors affecting the inhalation, deposition, clearance and translocation of asbestos and other fibres were discussed in Environmental Health Criteria monographs 53 (IPCS, 1986), 77 (IPCS, 1988) and 151 (IPCS, 1993). The main principles are summarized in this subsection.

It is considered that the potential respiratory health effects related to exposure to fibre aerosols are a function of the internal dose to the target tissue, which is determined by airborne concentrations, patterns of exposure, fibre shape, diameter and length (which affect lung deposition and clearance) and biopersistence. The potential responses to fibres, once they are deposited in the lungs, are a function of their individual characteristics.

Because of the tendency of fibres to align parallel to the direction of airflow, the deposition of fibrous particles in the respiratory tract is largely a function of fibre length. In addition, the shape of the fibres as well as their electrostatic charge may have an effect on deposition (Davis et al., 1988). Fibres of various shapes are more likely than spherical particles to be deposited by interception, mainly at bifurcations.

Since most of the data on deposition have been obtained in studies on rodents, it is important to consider comparative differences between rats and humans in this respect; these differences are best evaluated on the basis of the aerodynamic diameter. The ratio of fibre diameter to aerodynamic diameter is approximately 1:3. Thus, a fibre measured microscopically to have a diameter of 1 μm would have a corresponding aerodynamic diameter of approximately 3 μm . A comparative review of the regional deposition of particles in humans and rodents (rats and hamsters) has been presented by US EPA (1980). The relative distribution between the tracheobronchial and pulmonary regions of the lung in rodents follows a pattern similar to human regional deposition during nose breathing for insoluble particles with a mass median aerodynamic diameter of less than 3 μm . Fig. 4 and 5 illustrate these comparative differences. As can be seen, particularly for pulmonary deposition of particles, the percentage deposition in rodents is considerably less, even within the overlapping region of respiratory tract deposition, than in humans. These data indicate that, although particles with an aerodynamic diameter of 5 μm or more may have significant deposition efficiencies in man, the same particles will have extremely small deposition efficiencies in the rodent.

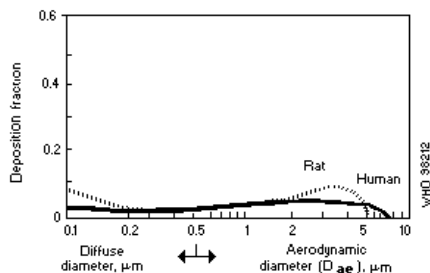


Fig. 4. Tracheobronchial deposition of inhaled monodisperse aerosols in human and rats (US EPA, 1980)

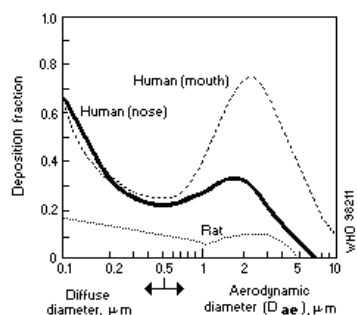


Fig. 5. Pulmonary deposition of inhaled monodisperse aerosols in man and rat (US EPA, 1980)

In the nasopharyngeal and tracheobronchial regions, fibres are generally cleared fairly rapidly via mucociliary clearance, whereas fibres deposited in the alveolar space appear to be cleared more slowly, primarily by phagocytosis and to a lesser extent via translocation and by dissolution. Translocation refers to the movement of the intact fibre after initial deposition at foci in the alveolar ducts and on the ciliated epithelium at the terminal bronchioles. These fibres may be translocated via ciliated mucous movement up the bronchial tree and removed from the lung, or may be moved through the epithelium with subsequent migration to interstitial storage sites or along lymphatic drainage pathways or transport to pleural regions. Fibres short enough to be fully ingested are thought to be removed mainly through phagocytosis by macrophages, whereas longer fibres may be partially cleared at a slower rate either by translocation to interstitial sites, breakage or by dissolution. A higher proportion of longer fibres is, therefore, retained in the lung.

5.1.2 Fibre deposition

The deposition of chrysotile asbestos in the peripheral lung airways of rats exposed *in vivo* for 1 h to 4.3 mg respirable chrysotile/m³ was studied by Brody et al. (1981). In rats killed immediately after exposure, chrysotile fibres were rarely seen by scanning electron microscopy in alveolar spaces or on alveolar duct surfaces, except at alveolar duct bifurcations. Most were less than 10 μm in length and 0.4 μm in diameter, indicating that longer fibres present in the dust cloud had been deposited in the upper airways. Concentrations were relatively high at bifurcations nearest the terminal bronchioles, and lower at the bifurcations of more distal ducts. In rats killed after 5 h the patterns were similar, but the concentrations were reduced. The relative importance of interception, impaction, diffusion and sedimentation on the deposition pattern of chrysotile fibres was considered by Brody & Roe (1983) who concluded that the high deposition observed at alveolar duct bifurcations of rats can be attributed to the high breathing frequency and small airway size of these rodents. They pointed out that the enhanced deposition at alveolar duct bifurcations observed in the rat may not occur in all species.

Coin et al. (1992) examined the patterns of deposition and retention of chrysotile asbestos in the central and peripheral regions of the rat lung in the first month following a single 3-h inhalation exposure. They found that pulmonary deposition did not differ between peripheral and central regions.

Pinkerton & Yu (1988) exposed rats to airborne chrysotile fibres for 7 h/day, 5 days/week for 12 months, and investigated the numbers and lengths of chrysotile fibres found in anatomically distinct regions of the lung parenchyma. The fibre concentration was greatest in the dorsal region and least in the costolateral and caudal regions, in agreement with calculations based on the deposition model for rat lung of Asgharian & Yu (1988). With the exception of the dorsal region, parenchymal changes correlated well with the fibre

concentration. There were differences in the length distributions of fibres in the various regions, fibres in the dorsal region having the greatest proportion of fibres longer than 10 μm. The proportion of fibres longer than 20 μm was greatest in the cranial and lateral regions.

5.1.3 Fibre clearance and retention

5.1.3.1 Fibre clearance and retention in humans

Available data obtained from lung burden studies show that chrysotile fibres deposited in the lung are cleared more rapidly than tremolite fibres, so that the tremolite/chrysotile ratio increases with time after exposure. It has been shown by Sebastien et al. (1989) and Chung et al. (1993) that on average about 75% of the fibres in the lungs of long-term chrysotile miners and millers from the Thetford Mines region of Quebec were tremolite and only about 25% chrysotile, despite the fact that tremolite accounted for only a few percent of the fibres in the chrysotile ambient dust (Sebastien et al., 1986a). Rowlands et al. (1982) found similar quantities of tremolite fibres, compared with chrysotile, in the lung samples of Quebec miners and

1508

Limitations of retention data in lungs with respect to chrysotile exposure have been discussed in a review by Case et al. (1994).

5.1.3.2 Fibre clearance and retention in laboratory animals

Several studies on laboratory animals, mainly rats, have investigated the lung clearance of chrysotile as measured by changes in the lung retention of fibres following acute, short-term and long-term inhalation or single dose via intratracheal exposure. Results of these studies are summarized in Table 17.

Morgan et al. (1977) used a radiotracer technique to study the lung clearance of chrysotile A, chrysotile B, amosite, crocidolite and anthophyllite asbestos following short nose-only inhalation exposures (3 h). There was a rapid decline in fibre lung content followed by a slow phase. The initial decline was assumed to represent mucocilliary clearance of fibres deposited in the smaller conducting airways, and the slow phase to alveolar clearance. Half-times of alveolar clearance, measured over a period of several months following exposure, were in the range of 60-90 days. No significant difference was observed between amphibole and chrysotile asbestos.

Middleton et al. (1979), using UICC samples, exposed rats via inhalation over a 6-week period to concentrations of 1, 5 and 10 mg/m³ and then estimated the amount of asbestos in lung by infrared spectrophotometry after lung ashing. The fractional deposition of chrysotile was lower than for amosite and crocidolite, but the alveolar clearance rates of chrysotile and amphibole fibres were similar. The lower deposition rate of chrysotile was believed to be related to differences in airborne asbestos concentration during exposure and to the curly nature of chrysotile fibres.

Table 17. Studies of chrysotile clearance in experimental animals

Species	Number of animals	Protocol ^a	Results ^a	Reference
Rats	(SPF Wistar) total of 1013 rats: group size of 19-58	Groups exposed to 9.7-14.7 mg/m ³ of UICC amos, anthophyl, croc, chrys A & chrys B for periods of 1 day, 3,6,12 or 24 months.	Linear increase in lung burden of amphiboles with time. Much less chrys found in lung and no clear increase with dose.	Wagner et al.,
Rats (Albino male)	total of 56 rats: group size of 8	Groups exposed nose-only to neutron-activated UICC amos, anthophyl, croc, chrys A & chrys B for 1 h. Deposition measured radiometrically.	Half-time clearance about 3 months. Fibres translocated to subpleural sites.	Morgan et al.,
Rats (SPF Wistar AF/HAN strain)	not specified	Groups exposed to 1, 5 and 10 mg/m ³ of UICC amos, croc and chrys A 7 h/day, 5 days/week for 6 weeks. Asbestos in lung measured by ashing and infrared spectrophotometry.	Deposition rate of chrys 25% of that of amphiboles but clearance rate independent of fibre type.	Middleton et al
Rats (CD-1 strain male)	total of 15 rats: group size of 3	Groups exposed nose-only to 4.3 mg/m ³ chrys for 1 h. Distribution of fibres in lung measured by SEM and TEM at times from 1 h to 8 days.	Most fibres deposited at bifurcations of alveolar ducts. Fibres taken up by Type 1 epithelial cells.	Brody et al., 1
Rats (Wistar female)	unspecified	Groups instilled intratracheally with 2 mg UICC chrys A. Rats killed at 1 day, 1, 6, 12, 18 and 24 months after instillation. Fibre numbers and composition determined after low-temperature ashing of lung using TEM and ATEM.	Number of chrys fibres increased with time and also their mean length.	Bellmann et al.

Table 17. (continued)

Species	Number of animals	Protocol ^a	Results ^a	Reference
Guinea-pigs (Hartley strain female)	total of 18 animals	Animals instilled intratracheally with a mixture of UICC chrys B and amos. Sub-groups of 6 animals killed at 1 day, 1 week and 1 month after administration. Fibre concentration in lung tissue determined using hypochlorite digests of tissue with TEM and EDXA.	Chrys fibre concentration declined more rapidly than that of amos. Concentration ratio declined from 8:1 to 2:1.	Churg et al., 1
Rats	total of 23 animals	Animals exposed to 10 mg/m ³	Deposition similar in central	Coin et al., 19

(SPF Sprague-Dawley male)		chrys for 3 h. Subgroups were killed immediately after exposure and after 1, 8, 15 and 29 days. Peripheral and central regions of the left lung digested and fibres characterized by SEM.	and peripheral regions. Average diameter of fibres decreased with time and length increased.	
Rats (Fischer 344 male)	not specified	Exposures nose-only to 10-15 mg/m ³ . Chrys: 7 h/day, 5 days/week for 6 weeks Croc: 6 h/day, 5 days/week for 90 days Animals sacrificed 90 days after exposure.	In lungs of chrys- and croc-exposed rats longer and narrower fibres than in airborne dust. 90 days post-exposure 95% clearance of chrys, no clearance of croc (by fibre numbers).	Abraham et al.,
Rats (Sprague-Dawley male)	total of 48 rats: group size of 8	Groups exposed to 5 mg/m ³ UICC Canadian chrys for 5 h. Subgroups killed at the end of exposure and after 1, 7, 28 and 90 days. TEM analysis of fibres in lung and BAL.	Progressive increase in mean length, decrease in mean diameter of fibres in lungs. Decrease in mean length and diameter in BAL.	Kauffer et al.,

Table 17. (continued)

Species	Number of animals	Protocol ^a	Results ^a	Reference
Hamsters (Syrian golden, sex not specified)	not specified	Animals instilled with one intratracheal dose of 1 mg UICC Canadian chrys or amos in 0.1 ml saline, killed at 4 and 56 weeks, and 2 years (chrys), 2 years (amos). SEM analysis with EDXA.	Ratio of short chrys fibres 30% to 13% in the lung; 2 years after instillation increased again to 56% (diameter < 0.05 µm). Short amos fibres (< 5 µm) decreased from 41% initially to 4% after 2 years.	Kimizuka et al.
Rats (Barrier derived Fischer 344)	not specified	Rats instilled intratracheally with chrys, croc and erionite at weekly intervals for 21 weeks. Instilled dose of chrys 32 mg. Rats killed at 1 h, 1 day, 1, 4, 8, 12 and 24 months following final instillation. Fibres recovered from lung by low-temperature ashing and analysed by TEM.	Apparent increase in number of chrys fibres between 1 and 10 days followed by gradual decline.	Coffin et al.,
Rats (SPF Wistar AF/HAN strain male)	not specified	Rats exposed to 10 mg/m ³ UICC chrys A for 7 h/day, 5 days/week for up to 18 months. Groups removed from exposure after exposures of 1 day, 4, 13, 26, 52, 65 and 95 weeks, and subgroups killed at 3 and 38 days after removal. Numbers and dimensions of fibres recovered from lung measured by SEM. Fibres with dia > 0.3 µm analysed by EDXA.	Splitting chrys fibres lead to increasing number of long thin fibres with time; after 150 days of exposure lung burden no longer increased.	Jones et al., 1

^a amos = amosite; croc = crocidolite; chrys = chrysotile; anthophyl = anthophyllite.

In contrast, Abraham et al. (1988) found that the alveolar clearance of chrysotile was faster than that of crocidolite. In their study, rats were exposed by inhalation to 10-15 mg/m³ of either chrysotile (6 weeks) or crocidolite (90 days). At the end of exposure, lung fibre concentrations and size distributions were similar for both types of fibres. However, during the subsequent 90 days, 95% of chrysotile (by fibre number) was removed, whereas there was no measurable clearance of crocidolite. Similar findings were reported by Bérubé et al. (1996). The fibre retention of chrysotile in the rat lung after 5 and 20 days of inhalation exposure to 8 mg/m³ was considerably lower than the fibre lung retention of crocidolite asbestos.

Wagner & Skidmore (1965), in a 6-week inhalation exposure study on rats using about 30 mg/m³, reported that, over a period of 2 months, the rate of clearance for chrysotile was higher by a factor of 3 than that for amosite or crocidolite. In addition, the retention of chrysotile, as measured a few days after the end of the 6-week exposure period, was only about one third that of the amphiboles.

In a subsequent study by the same group (Wagner et al., 1974), it was found that, while the lung burden of amphibole fibres increased steadily with time, that of chrysotile appeared to reach a plateau after 3 months of exposure and at a much lower level compared to the simultaneous amphibole level. The difference was attributed to the enhanced clearance rate of chrysotile. This difference in the lung

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Clearance of chrysotile and amphibole fibres has been confirmed by several studies (Davies et al., 1978, 1986a; Davis & Jones, 1988) with amphibole levels at the end of a one-year inhalation period in rats being approximately 10 times those of chrysotile administered at the same mass dose. In their inhalation study of the retention of UICC chrysotile fibres in rat lung (10 mg/m^3 , 7 h/day, 5 days/week, for up to 18 months), Jones et al. (1994) also found that the mass of chrysotile in the lungs increased for several months and then appeared to decline, although exposure continued, in agreement with the Wagner et al. study (1974). Oberdörster (1994), using various types of published data, including a 30-month exposure of baboons (Oberdörster & Lehnert, 1991), calculated that the chrysotile clearance half-times in monkeys are in the order of 90-100 days.

Limited information exists concerning the effect of cigarette smoke on the lung clearance of asbestos fibre. Muhle et al. (1983) investigated the effect of cigarette smoke on the retention of UICC chrysotile A and UICC crocidolite in rats. Results showed a doubling of crocidolite fibres in the lungs of the groups exposed to cigarette smoke compared with animals not exposed to cigarette smoke. A plateau was found for chrysotile, as in the study of Wagner et al. (1974), but this was not influenced by cigarette smoke. This difference between the two fibre types can be explained by a higher deposition rate of chrysotile in the upper airways by interception compared with crocidolite and a decrease in deep lung clearance induced by cigarette smoke. Lippmann et al. (1980) showed that tracheobronchial clearance in humans is influenced by cigarette smoke and Cohen et al. (1979) and

Bohning et al. (1982) showed that long-term smoking reduces long-term deep lung clearance.

Several studies have shown that short fibres are generally cleared at faster rates than long fibres. In their inhalation experiment, Kauffer et al. (1987) exposed rats to UICC Canadian chrysotile for 5 h at 5 mg/m^3 . Animals were killed at different intervals over the subsequent 90 days and their lungs lavaged. In the lung tissue, the prevalence of fibres less than $5 \mu\text{m}$ in length decreased while that of fibres longer than $5 \mu\text{m}$ increased with post-exposure time. An opposite pattern of distribution was observed in the bronchoalveolar lavage (BAL) fluids. This indicates that fibres greater than $5 \mu\text{m}$ in length are cleared less efficiently from the rat lung than fibres less than $5 \mu\text{m}$ in length.

Davis (1989) also found that short fibres ($< 10 \mu\text{m}$ in length) are cleared more rapidly than long fibres ($> 10 \mu\text{m}$ in length). In his study, rats were exposed by inhalation to chrysotile or amosite fibres at 10 mg/m^3 for 12 months. The lung clearance percentages over a 6-month period after exposure were 55 and 90% for long and short chrysotile fibres, respectively. The lung clearance percentages for long and short amosite fibres were 14 and 20%, respectively.

In the study by Abraham et al. (1988), referred to previously in this section, the mean length of chrysotile fibres increased during the 90 days from 5 to $13 \mu\text{m}$ with a reduction in fibre diameter from 0.13 to $0.09 \mu\text{m}$ due to fibre splitting. Crocidolite fibres remained practically unchanged (mean length 6.2 to $5.7 \mu\text{m}$ and mean diameter 0.12 to $0.10 \mu\text{m}$). These findings indicate that shorter chrysotile fibres will be preferentially cleared and that with time the proportion of thinner fibres increases due to fibre splitting.

The observation that chrysotile fibres undergo longitudinal splitting is supported by many other studies. In a study of the number and dimensions of chrysotile fibres in rat lungs following short inhalation exposures, Roggli & Brody (1984) found that the Mg:Si ratio of chrysotile fibres did not differ significantly from that of the original material. Over a period of 1 month there was a decline both in the numbers of fibres in lung and in the estimated total mass of chrysotile remaining. The mean length of the residual fibres appeared to increase. The mean fibre diameter decreased, which suggests that chrysotile fibres were splitting longitudinally into smaller groups of fibrils.

Coin et al. (1992, 1994) found that chrysotile fibres $> 16 \mu\text{m}$ in length were not cleared at a significant rate from the rat lung over a 30-day period following a 3-h inhalation exposure. They found that the average diameter of retained fibres decreased over time, consistent with longitudinal splitting, and that the average length of retained fibres increased over time, consistent with slower clearance of longer fibres. The authors attributed the failure of these long fibres to be cleared from the lung to the inability of pulmonary macrophages to engulf them.

Le Bouffant et al. (1987) exposed rats to 5 mg/m^3 of chrysotile B for 24 months. They found that most of the fibres had undergone splitting by the end of the inhalation period and that chrysotile fibre numbers rapidly declined following inhalation.

Kimizuka et al. (1987), who administered chrysotile and amosite fibres by intratracheal instillation to hamsters, found initially a rapid reduction in the ratio of short to long chrysotile fibres, indicating faster clearance of short fibres. At 2 years, however, the proportion of short fibres had increased again to more than 50%. This is most likely due to breaking up of the longer and thicker fibres in the lungs. This notion was supported by the decrease in diameter of

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chrysotile with time. Amosite showed progressive reduction in the proportion of short fibres in the lung tissue, which was not reversed with time.

The numbers of chrysotile fibres remaining in the lung over a 2-year period, following their administration by intratracheal instillation, were measured by Bellmann et al. (1987). Virgin UICC chrysotile A was used, as well as the same material from which the magnesium had been removed by leaching with oxalic acid *in vitro*. As shown in Fig. 6,

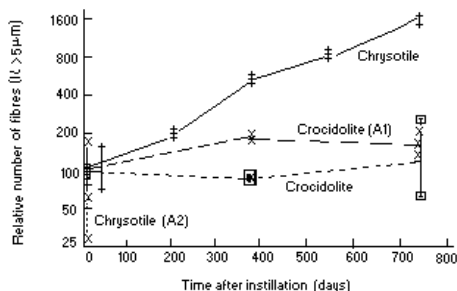


Fig. 6. Relative number of asbestos fibres longer than 5 µm in the lung ash at different sacrifice dates. A1: pretreatment with 0.1 M oxalic acid, 24 h, 20°C; A2: pretreatment with 0.1 M oxalic acid, 39 h, 60°C (Bellman et al., 1987)

the number of intact chrysotile fibres longer than 5 µm increased by a factor of about 15 over the 2-year duration of the study. A significant reduction in the mean diameter of fibres > 5 µm in length was observed, which provides evidence of fibre splitting. The magnesium-leached fibres were removed from the rat lung with a half-time of only 2 days.

Coffin et al. (1992) administered large amounts of chrysotile fibres (6-32 mg) to the rat by intratracheal instillation and measured retention. There was an apparent increase in fibre numbers between 1 and 10 days after instillation, which the authors attributed to the splitting of fibre bundles. After this initial period there was no significant further change in the numbers of Stanton fibres (equal to or greater than 8 µm in length and equal to or less than 0.25 µm in diameter). However, the doses administered may well have been sufficient to overload macrophage-mediated clearance of fibres from the alveolar region of the lung.

5.1.4 Fibre translocation

Available experimental evidence indicates that chrysotile fibres can be transported through the epithelium with subsequent migration to the interstitium. Information on the movement of chrysotile fibres from the lung parenchyma to either the parietal or visceral pleura is conflicting. While chrysotile fibres have been detected in pleural tissues of workers who died of asbestos-related diseases in several studies, other studies did not show this. Additionally, chrysotile fibres were not found in the rat pleura in an acute inhalation study.

5.1.4.1 Fibre translocation in humans

In a study of asbestos fibres in the lung parenchyma and the parietal pleura of 29 asbestos workers, Sebastien et al. (1980) found that chrysotile fibres predominated in the pleura and that amphibole fibres could not be detected. A similar result was reported by Dodson et al. (1990). Kohyama & Suzuki (1991) found short chrysotile fibres in pleural plaques and in mesothelial tumours. In contrast, Boutin et al. (1993) found 0.21×10^6 fibres per g of parietal pleura and 1.96×10^6 in samples of lung parenchyma. Fibre concentrations were higher in subjects with a history of asbestos exposure and most of the fibres were amphiboles. Chung (1994) reported detection of chrysotile fibres in the subpleural parenchyma in chrysotile miners and millers. Kobayashi et al. (1987) reported the detection of few asbestos fibres as asbestos bodies in the extrathoracic organs (pancreas, spleen, etc.) of human subjects exposed to chrysotile.

5.1.4.2 Fibre translocation in animal models

In the inhalation study of Brody et al. (1981), the examination of tissues by electron microscopy revealed that chrysotile fibres deposited at the bifurcations of the alveolar ducts were taken up not only by alveolar macrophages but also by type I epithelial cells during the 1-h inhalation exposure. Some days after exposure, fibres were found in interstitial macrophages and fibroblasts. These observations suggest that there may be direct fibre penetration of the epithelial surface and that chrysotile fibrils can be transported to the interstitium through type I epithelial cells.

Oghiso et al. (1984) exposed rats by intermittent inhalation to chrysotile fibres (95% < 6 µm in length, no fibre > 0.5 µm diameter) or crocidolite fibres (98.7% < 5 µm in length, 4.2% > 0.5 µm diameter) for 3 months and then killed them after 2-16 months.

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Electron microscopy revealed some similarities, but also distinct differences in the pulmonary distribution of the two types of fibre. Thickened alveolar duct bifurcations, associated with aggregates of macrophages, were seen long after exposure ceased, but crocidolite-exposed rats also had subpleural collections of alveolar macrophages, many of which contained crocidolite fibres.

Coin et al. (1992) exposed rats to chrysotile fibres by inhalation for 3 h (see section 5.1.2) killing them at times up to 29 days following exposure. The authors found no evidence of translocation of chrysotile fibres to the pleura. They did find, however, substantial numbers of inhaled fibres deposited within 1-2 mm of the visceral pleura of the rat.

The fate of chrysotile (mean length 3.6 μm , mean diameter 0.05 μm), crocidolite (mean length 2.5 μm , mean diameter 0.14 μm) and glass fibres, following injection into the pleural cavity of rats, was studied by Bignon et al. (1979). By 90 days after injection, fibres were found at similar concentrations in lung, liver, kidney and brain, while in the thoracic lymph nodes the concentrations were higher. The authors concluded that the majority of fibres can migrate rapidly from the site of administration, principally via the pulmonary lymphatics. In the case of chrysotile, particularly, the mean length of fibres found in the lung parenchyma was greater than that of the administered material. In view of the way the fibres were administered in this study, the relevance of the results to prediction of the behaviour of fibres following inhalation may be limited.

5.1.5 Mechanisms of fibre clearance

There is considerable uncertainty about the mechanisms responsible for the more rapid removal of chrysotile fibres from the lung than in the case of amphibole asbestos fibres. It is uncertain whether the more effective removal of chrysotile fibres is due to more rapid fibre dissolution or to more rapid clearance of shorter fibres as a result of breakage. Another explanation may be movement and dispersion in the watery atmosphere in the lung.

Most of the evidence for the preferential dissolution of magnesium from chrysotile is derived from measurement of the magnesium/silicon ratio of fibres recovered from lung using analytical electron microscopy. A reduction in the Mg/Si ratio measured in fibres recovered from human lung was first reported by Langer et al. (1970). Subsequently, Jaurand et al. (1977) found that the extent of magnesium depletion varied from one fibre to another and even along the axis of the same fibre. Sebastien et al. (1986b) examined chrysotile fibres longer than 5 μm and thicker than 0.1 μm and found magnesium depletion as high as 50%. On the other hand, Churg & DePaoli (1988) found only slight magnesium depletion in fibres recovered from the lung of chrysotile miners many years after their last exposure.

One possible explanation for the diversity of results is the impossibility of measuring Mg:Si ratios at a resolution applicable to individual chrysotile fibrils. In relatively thick chrysotile fibres, only the fibrils near the surface of a bundle will be subjected to leaching and those in the interior may remain intact. Another factor is that, once leaching occurs, the unsupported silica structure on the outside of a fibril may disintegrate and this may impose an upper limit to estimates of magnesium depletion based on Mg:Si ratios (Morgan, 1994). Hume & Rimstidt (1992) have proposed that the brucite layer of chrysotile dissolves in the lung leaving the silica layer exposed; this then dissolves at a slower rate and it is suggested that this is the rate-controlling step. These authors developed a "shrinking-fibre model", which predicts that a chrysotile fibre 1 μm in diameter will dissolve completely in 9 ± 4.5 months.

Results of available experimental studies also gave conflicting evidence with regard to magnesium depletion. For example, Jones et al. (1994) obtained values for magnesium depletion ranging from 10 to 40%. Kimizuka et al. (1987) reported magnesium depletion in the lung of hamsters. On the other hand, Coin et al. (1994) found no significant leaching of magnesium over a period of 30 days following administration of chrysotile to rats by inhalation, and Churg et al. (1989) reported a similar result with guinea-pigs following intratracheal instillation.

Bellman et al. (1987) showed that magnesium is removed from chrysotile fibres following their administration to rats by intratracheal instillation and that leaching rates are much greater during the first month than subsequently. These authors also showed that chrysotile fibres, from which the magnesium had been removed by prior treatment with oxalic acid *in vitro*, were removed from the lung with a half-time of only a few days. This explains the observation that the carcinogenic potency of magnesium-leached chrysotile is much reduced, or eliminated completely, compared with that of the untreated fibre (Morgan et al., 1977; Monchaux et al., 1981).

Limited information is available in support of the fibre fragmentation hypothesis. Churg et al. (1993) showed that short chrysotile fibres are present in considerably larger numbers than long fibres in the lungs of chrysotile miners and millers even years after exposure has ceased. While this finding may reflect fragmentation of long inhaled fibres into shorter fibres, it might also reflect retention of some portion of the fibre burden in a sequestration

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compartment with no change in size distribution.

In summary, available data indicates that both fibre breakage and dissolution are likely mechanisms for the rapid removal of chrysotile fibres from the lung.

5.2 Ingestion

An important question in the evaluation of the possible risks associated with the ingestion of chrysotile asbestos is whether fibres can migrate from the lumen into and through the walls of the gastro-intestinal tract to be distributed within the body and subsequently cleared.

Review of the available data has been published in Environmental Health Criteria 53 (IPCS, 1986). The main conclusions were:

- (a) It is not possible to conclude with certainty that chrysotile fibres do not cross the gastrointestinal wall. However, available evidence indicates that, if penetration does occur, it is extremely limited (Cook, 1983).
- (b) There is no available information on bioaccumulation/retention of ingested chrysotile fibres. Simulated gastric juice has been shown to alter the physical and chemical properties of chrysotile fibres (Seshan, 1983).
- (c) There was no difference in the level of urinary chrysotile between subjects drinking water with high compared to those drinking water with much lower natural chrysotile contamination (Boatman et al., 1983).

Finn & Hallenbeck (1985) investigated the number of chrysotile fibres in the urine of six workers occupationally exposed to chrysotile. The levels of chrysotile fibres in the urine of exposed workers were significantly higher than in a control group.

6. EFFECTS ON LABORATORY MAMMALS AND *IN VITRO* TEST SYSTEMS

6.1 Introduction

Several caveats are important in the interpretation of results of inhalation studies in laboratory animals and in cells *in vitro*. A search of the literature on the effects of chrysotile in experimental *in vivo* and *in vitro* models reveals few dose-response studies with appropriate positive and negative "control" dusts. Concentrations of chrysotile and other dusts used in inhalation experiments are several magnitudes higher than concentrations encountered in the workplace and environment today. Moreover, preparations of chrysotile and other dusts used in many experiments are poorly characterized. In the majority of studies before 1980, concentrations are expressed on a mass basis rather than on a fibre number basis. This may be misleading when comparing samples of chrysotile and amphibole asbestos, because the former may contain more than 10 times more fibres per unit weight.

There has been a great deal of debate concerning the relevance of various routes of exposure in experimental animals to risk assessment in humans (McClellan et al., 1992; IPCS, 1993). The general consensus is that all routes of administration should be considered, but that they should be given different weightings in relation to assessment of potential hazard to humans.

Positive results in an inhalation study on animals have important significance for the hazard evaluation of exposure to airborne fibres in humans. Strong arguments would need to be made against the relevance for humans of such a finding. However, the lack of a response in an inhalation study on animals does not mean that the material is not hazardous for humans. For instance, rats, being obligate nose-breathers, have a greater filtering capacity than humans.

As discussed by IPCS (1988), a negative result in a properly conducted intratracheal study would suggest that a given type of fibre may not be hazardous for parenchymal lung tissue. A positive result, however, would require further study since the normal filtering capacity of the respiratory tract has been bypassed. However, pulmonary clearance mechanisms are intact. The results of studies involving intrapleural injection or implantation and intraperitoneal injection should be viewed in a similar way to intratracheal instillation studies. With these methods, both filtering and clearance mechanisms are compromised. Such studies may be more sensitive than inhalation studies because a higher number of fibres can be introduced. Therefore, a negative result would be highly relevant, but a positive result should be confirmed by further investigation.

6.2 Effects on laboratory mammals

6.2.1 Summary of previous studies

The results of early inhalation experiments were presented in Environmental Health Criteria 53 (IPCS, 1986). Fibrosis has been observed in many species following inhalation of chrysotile. In several studies there was progression of fibrosis following cessation of exposure (Wagner et al., 1974, 1980; Wehner et al., 1979). In the majority of the studies only the airborne mass concentrations were

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measured; the numbers and size distributions were not considered. Shorter fibres were found to be less fibrogenic (Davis et al., 1980).

Unlike fibrosis, which has been observed in several animal species following inhalation of chrysotile, a consistently increased incidence of lung tumours or pleural mesothelioma has been observed only in the rat. Rats with lung tumours had significantly more fibrosis than those without (Wagner et al., 1974). In a study with exposure to approximately 10 mg/m^3 of three amphibole and two chrysotile asbestos types, Wagner et al. (1974) found 11 mesotheliomas, 4 of which occurred following exposure to Canadian but none following exposure to Rhodesian chrysotile. Davis et al. (1978) compared amosite, crocidolite and Rhodesian chrysotile at 10 mg/m^3 as well as at equal fibre numbers (fibres $> 5 \mu\text{m}$ in length). Both by mass and by fibre number, chrysotile proved the most fibrogenic and carcinogenic, but the authors pointed out that, while numbers of fibres longer than $5 \mu\text{m}$ were roughly equal, the chrysotile dust cloud had many more very long fibres ($> 20 \mu\text{m}$ in length).

Since it became obvious that relatively few mesotheliomas developed in rats following asbestos inhalation and since Wagner (1962) had shown that they could be induced by direct dust injection into body cavities, the injection technique has been frequently used. The results of such early experiments were summarized by IPCS (1986). The major finding from these studies is that, following injection, short fibres are less fibrogenic (Burger & Engelbrecht, 1970; Davis, 1972) and that the most carcinogenic fibres are $> 8 \mu\text{m}$ in length and $< 0.25 \mu\text{m}$ in diameter (Stanton & Wrench, 1972; Pott & Friedrichs, 1972; Pott et al., 1972, 1976; Stanton et al., 1977). Short fibres show little carcinogenicity. The numbers of mesotheliomas produced in these studies were high (up to 90% of animals). Several authors reported a clear dose-response effect (Smith et al., 1968; Stanton & Wrench, 1972; Wagner et al., 1973).

The ability of asbestos to cause gastrointestinal cancer following ingestion has been examined in many experimental studies reviewed extensively by Condie (1983) and Toft et al. (1984). Early studies on ingested asbestos were reviewed by IPCS (1986). There was no conclusive evidence of either histopathological or biochemical effects on the gastrointestinal wall, or of carcinogenicity in the animal species studied.

6.2.2 Recent long-term inhalation studies

The results of the more recent inhalation studies in various animal species are presented in Table 18.

In an inhalation study on rats (10 mg/m^3 UICC chrysotile B for up to 12 months), Wagner et al. (1984) observed a mean fibrosis grade 4.1 and a 25% incidence of adenomas and carcinomas. Le Bouffant et al. (1987), using Canadian chrysotile as a positive control in experiments with MMM(V)Fs in rats (5 mg/m^3 chrysotile B, 5 h/day, 5 days/week for 24 months), reported unquantified fibrosis and pulmonary tumours in 21% of male and 17% of female rats. Muhle et al. (1987), exposing rats to 6 mg/m^3 Calidria chrysotile 5 h/day, four times each week for 12 months, reported the presence of pulmonary fibrosis in 42% of rats, but found no pulmonary tumours.

Davis et al. (1985) examined the effects on rats of tremolite and brucite, two materials frequently found as contaminants of commercially produced chrysotile (10 mg/m^3 , 7 h/day, 5 days/week, for 12 months). A sample of asbestiform tremolite from Korea was highly fibrogenic and carcinogenic, while brucite was less hazardous. However, it was demonstrated that the sample which was supposedly brucite was contaminated with chrysotile fibres, and it was not possible to determine the relative pathogenicity of these two minerals.

The same group (Davis et al., 1986a) examined the long-term effects of dust from samples of wet dispersed chrysotile (WDC) in rats. WDC is a preparation used to produce textile yarn. Raw chrysotile is first separated into individual fibrils by treatment with detergents and then rebound with electrolytes while the slurry is extruded from a narrow nozzle. Handling this material liberates much less dust than standard chrysotile textile yarn. In the experimental studies, however, where respirable dust was produced by milling, both specimens of WDC dust and the parent chrysotile material (5 mg/m^3 , 7 h/day, 5 days/week for 12 months) produced widespread fibrosis and pulmonary tumours in up to 50% of animals. One experimental WDC sample with relatively thick fibres produced as much disease at a dose level of only approximately 100 fibres/ml ($> 5 \mu\text{m}$ in length, measured by PCOM) as was found in the other groups treated with WDC or standard chrysotile where dose levels were 500-650 fibres/ml. The authors concluded that WDC separates into fibrils in lung tissue more rapidly than standard chrysotile. The relatively few thick WDC fibres could generate as many long thin subunits as clouds of similar mass that originally contained more thin fibres.

Platek et al. (1985) treated rats and monkeys with a specially prepared short fibre sample of chrysotile for 18 months (the mass dose level was only 1 mg/m^3 , of which < 1 fibre/ml was longer than $5 \mu\text{m}$ as measured by PCOM). After a total follow-up of 24 months the rats had developed neither fibrosis nor pulmonary tumours. No fibrosis was

found in monkeys by open lung biopsies after 24 months. Davis et al. (1986b), exposing rats to amosite asbestos fibres (all fibres were

< 5 µm in length), found no pulmonary carcinomas, while numbers of benign tumours and levels of pulmonary fibrosis were similar to those in control animals. In contrast, a dust cloud generated from raw amosite with many very long fibres was extremely fibrogenic and carcinogenic. Similar studies examined the importance of fibre length with inhaled Canadian chrysotile (Davis & Jones, 1988). Unfortunately, in this case, the "short" fibre chrysotile preparation did have a small proportion of long fibres, and fibrosis and pulmonary tumours did develop. However, a comparison cloud generated from the same original chrysotile sample, to maximize the number of long fibres, produced 5 times more fibrosis and 3 times more tumours for the same mass dose.

Airborne chrysotile asbestos is able to hold a high electrostatic charge, and there have been reports that this may effect fibre deposition in the lower pulmonary tract (Vincent et al., 1981; Jones et al., 1983). Consequently, Davis et al. (1988) treated rats with equal clouds of UICC Rhodesian chrysotile, either carrying the normal electrostatic charge or discharged by exposure to ionizing radiation from a thallium-204 source. Rats treated with discharged chrysotile had less fibrosis, tumours and retained chrysotile in their lung tissue, but not all these differences were statistically significant.

Davis et al. (1991a) examined the effect on rats of inhaling chrysotile or amosite asbestos (10 mg/m³, 7 h/day, 5 days/week for 12 months) simultaneously with either titanium dioxide (10 mg/m³) or quartz (2 mg/m³). Increased levels of pulmonary fibrosis above levels produced by chrysotile or amosite alone were observed in combination with quartz, but not with addition of titanium dioxide. Tumour production was also increased, but in this case a combination of asbestos and titanium dioxide was as carcinogenic as a combination of asbestos and quartz. Of particular interest in this study was the finding of granulomas on the visceral pleural surface that contained both particles and asbestos fibres in animals treated with asbestos and quartz. Similar granulomas have not been reported in previous experiments with pure asbestos where fibres accumulated beneath the external elastic lamina of the lung and seldom penetrated to the pleural surface. The increased pleural penetration of asbestos fibres in coexposures with quartz dust was associated with increased production of mesotheliomas. The recorded proportions of mesotheliomas were higher than those previously reported in any experiments with commercial varieties of asbestos. Evidence of interspecies differences in response to asbestos and other mineral fibres has been reported. Hamsters treated with respirable refractory ceramic fibre developed no pulmonary carcinomas but 43% developed mesotheliomas. Chrysotile produced neither type of tumour in this species. The mass dose levels were 29 mg/m³ for ceramic fibres and 11 mg/m³ for chrysotile (6 h/day, 5 days/week for 18 months) (Hesterberg et al., 1991). Twenty-one percent of rats treated with Canadian chrysotile (10 mg/m³, 6 h/day, 5 days/week for 24 months) developed both lung tumours (19% of animals) and mesothelioma (one rat) (Bunn et al., 1993; Hesterberg et al., 1993).

Table 18. Long-term inhalation studies

Species	Group size	Protocol ^a	Results ^a	Reference
Rat	24 male, 24 female	Exposure: 10 mg/m ³ UICC chrys B for up to 12 months. Used as a positive control in experiments with MMM(V)F.	Mean fibrosis grade 4.1 (Wagner scale). Adenomas and carcinomas 12/48 (25%).	Wagner et al., 1
Rat (Sprague-Dawley)	150 male	Exposure: 1.0 mg/m ³ chrys 7 h/day, 5 days/week, for 18 months. Ball milled. Concentration of airborne fibres >5 µm in length was 0.79 f/cm ³ .	No fibrosis or tumours at 24 months.	Platek et al., 1
Monkey	10	Exposure: 1.0 mg/m ³ chrys 7 h/day, 5 days/week, for 18 months. Ball milled. Concentration of airborne fibres >5 µm in length was 0.79 f/cm ³ .	No fibrosis (estimated by biopsy) at 28 months.	Platek et al., 1
Rat	24 male, 23 female	Exposure: 5 mg/m ³ chrys B 5 h/day, 5 days/week for 24 months. Used as a positive control in experiments with MMM(V)F.	Fibrosis reported in chrys group but not quantified. Pulmonary tumours in 5/24 (21%) male rats and in 4/23 (17%) female rats.	Le Bouffant et al.
Rat (Wistar)	48 male	Exposure: 10 mg/m ³ tremolite or brucite 7 h/day, 5 days/week for 12 months.	Tremolite very fibrogenic. Pulmonary tumours and mesotheliomas in 20/39 (51%) rats. Brucite caused mild fibrosis. Pulmonary tumours in 5/38 (13%) rats.	Davis et al., 19
Rat (Wistar)	48 male	Exposure: 7 h/day, 5 days/week	All chrys samples very fibrogenic.	Davis et al., 19

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for 12 months; mean conc. of WDC samples 5 mg/m³, concentration of chrys yarn 4.3 mg/m³.

Pulmonary tumours and mesotheliomas in 16/42 (38%) for standard chrys, 18/41 (44%), 18/37 (49%), 21/43 (49%), 21/44 (48%) for WDC preparations.

Table 18. (continued)

Species	Group size	Protocol ^a	Results ^a	Reference
Rat (Wistar)	48 male	Exposure: 10 mg/m ³ of respirable dust 7 h/day, 5 days/week for 12 months. Long fibre amos: cloud generated from raw material. Short fibre amos: very few fibres > 5 µm in length.	Long amos extremely fibrogenic. Pulmonary tumours and mesotheliomas in 13/40 (33%). Short amos no fibrosis. No pulmonary tumours or mesotheliomas.	Davis et al., 19
Rat (Wistar)	50 female	Exposure: 6 mg/m ³ of Calidria chrys 5 h/day, 4 times each week for 12 months. Used as a positive control in experiments with MMM(V)F.	Some septal fibrosis in 21/50 (42%) rats. No pulmonary tumours.	Muhle et al., 19
Rat (Wistar)	48 male	Exposure: 10 mg/m ³ 7 h/day, 5 days/week for 12 months. Long fibre chrys: cloud generated from raw chrys. Short fibre chrys: fibres >5 µm reduced 5 times; fibres >30 µm reduced 80 times.	Long fibre chrys very fibrogenic. Pulmonary tumours and mesotheliomas in 23/40 (58%) rats.	Davis & Jones, 1
Rat (Wistar)	48 male	Exposure: 10 mg/m ³ 7 h/day, 5 days/week for 12 months. Two clouds of UICC chrys A, one of which had reduced electrostatic charge by exposure to ionizing radiation from a thallium-204 source of beta particles.	Interstitial fibrosis reduced by 38% in "discharged" group compared to standard chrys. Pulmonary tumours and mesotheliomas in 11/39 (28%) rats in "discharged" group; 14/36 (11%) rats in standard chrys group.	Davis et al., 19

Table 18. (continued)

Species	Group size	Protocol ^a	Results ^a	Reference
Rat (Wistar)	48 male	Exposure: 10 mg/m ³ 7 h/day, 5 days/week for 12 months. Six treatment groups, UICC chrys A or UICC amosite alone or mixed with either 10 mg/m ³ of titanium dioxide or 2 mg/m ³ of quartz.	Advanced fibrosis increased for both asbestos types by addition of quartz but not by titanium dioxide. Pulmonary tumours and mesotheliomas: chrys 13/37 (35%) rats, chrys + TiO ₂ 26/41 (51%) rats, chrys + quartz 22/38 (58%) rats; amos 14/40 (35%) rats, amos + TiO ₂ 20/40 (50%) rats, amos + quartz 26/39 (67%) rats.	Davis et al., 19
Rat (Fisher 344)	63	Exposure: 10 mg/m ³ chrys A 6 h/day, 5 days/week for 24 months. Used as a positive control in experiments with MMM(V)F.	Mean fibrosis grade 4.0 (Wagner scale). Pulmonary tumours and mesotheliomas 13/63 (21%) rats.	Bunn et al., 199
Hamster	100 male	Exposure: 11 mg/m ³ chrys B 6 h/day, 5 days/week for 18 months. Used as a positive control in experiments with MMM(V)F.	Mean fibrosis grade 4.3 (Wagner scale) at 3 months. No pulmonary tumours or mesotheliomas.	Hesterberg et al.
Baboon		Exposure: 6 h/day, 5 days/week for up to 4 years		Goldstein & Coet
	21	1) UICC chrysotile A, exposure not specified	1) No mesotheliomas	
	18	2) UICC amosite 1100 f/cm ³ , exposure for 4 years	2) 1/18 (5.6%) animals with mesothelioma	
	78	3) UICC crocidolite 1130-14 000 f/cm ³ , exposure for 1.5-3 years	3) 3/78 (3.8%) animals with mesothelioma	

Table 18. (continued)

Species	Group size	Protocol ^a	Results ^a	Reference
Baboon		Exposure: 6 h/day, 5 days/week		Hiroshima et al.
	4	1) UICC chrysotile A 106,074-368,772 f/cm ³ for 8.5-24 months	1) No mesothelioma	
	5	2) UICC amosite 997,678 f/cm ³ for 49 months (dose that produced mesothelioma)	2) 2/5 animals with mesothelioma	

5	3) crocidolite (Transvaal or UICC) 432,291 f/cm ³ for 15 months 769,784 f/cm ³ for 35 months (dose that produced mesothelioma)	3) 2/5 animals with mesothelioma
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^a chrys = chrysotile; MMM(V)F = man-made mineral (vitreous) fibres; WDC = wet dispersed chrysotile; amos = amosite.

Studies in baboons suggest that chrysotile is less apt to cause mesothelioma in comparison to crocidolite and amosite asbestos. In two reports (Goldstein & Coetzee, 1990; Hiroshima et al., 1993), no mesotheliomas nor lung carcinomas were reported after exposure to chrysotile, although mesotheliomas were observed in amosite- and crocidolite-exposed baboons. However, the chrysotile exposure levels were lower than those of amosite or crocidolite in the latter study, while the level of chrysotile in the former study was not specified. Studies in baboons indicate that fibrosis is observed with UICC samples of chrysotile, amosite and crocidolite asbestos (Hiroshima et al., 1993). In all cases, the severity of fibrosis was directly related to cumulative dose.

In experimental inhalation studies with different fibre types it has been an almost universal finding that fibres that are very fibrogenic are also carcinogenic. Davis & Cowie (1990) emphasized this by reporting on advanced fibrosis in 144 rats, aged 2.5 years or more, that had been exposed to a number of different asbestos types, including Rhodesian and Canadian chrysotile. The 85 animals that had pulmonary tumours showed almost twice the level of advanced pulmonary fibrosis as the 59 animals that had not developed tumours.

6.2.3 Intratracheal and intrabronchial injection studies

Table 19 shows the results of intratracheal injection studies with chrysotile documenting fibrosis in sheep, rats and mice.

At high doses (100 mg) of chrysotile administered via intratracheal instillation in sheep, fibrosis appeared to be more marked with chrysotile than with crocidolite (Sebastien et al., 1990). However, the development of fibrosis exhibited evidence of an apparent threshold in this model, as fibrosis was not observed in sheep after injection of 1, 10 or 50 mg of chrysotile (Begin et al., 1987). Repeated instillations of 100 mg chrysotile over a 2-year period in sheep resulted in progression of fibrosis and lung infections (Begin et al., 1991).

Use of an intratracheal injection model in rats has yielded additional data suggesting the decreased fibrogenicity of short-fibre chrysotile (Lemaire, 1985, 1991; Lemaire et al., 1985, 1989). No fibrogenicity was observed with injections of short chrysotile at 1, 5 and 10 mg; however, UICC chrysotile B caused peribronchiolar fibrosis at all concentrations.

Intratracheal studies in mice indicated focal collagen deposition in mice exposed to chrysotile, but more severe fibrosis after exposure to quartz (Bissonnette et al., 1989). Collagen and elastin deposition per unit lung weight was greater after instillation of UICC chrysotile in comparison to UICC crocidolite (injected rats kept for a 12-month period after a single 1.6 mg injection) (Hirano et al., 1988).

Table 19. Intratracheal injection studies (fibrogenicity)

Species	Dose and group size	Protocol	Results	Reference
Rats (Wistar, male)	UICC chrysotile B, short chrysotile (4T30) (1, 5, 10 mg) N = 5/group	Single exposure. Histopathology at 1-60 days and 8 months	Severe peribronchiolar fibrosis at all conc. with chrysotile B. No fibrosis with short chrysotile.	Lemaire, 1985, 1991 Lemaire et al., 1989
Mouse (Balb/c, sex not specified)	UICC chrysotile A (0.5 mg) number not specified	Single exposure. Histopathology at 0.5, 1, 2, 3, 6 and 9 months.	No severe fibrosis until 9 months.	Bissonnette et al.,
Sheep (male)	UICC Canadian chrysotile B (1, 10, 50, 100 mg) N = 6/group	Single exposure. Histopathology at 60 days	Fibrosis only in 100 mg group.	Begin et al., 1987
Sheep (male)	UICC chrysotile A, UICC crocidolite, latex beads (100 mg) N = 15/group	Single exposure. Histopathology at 8 months.	Histological score for fibrosis = 1.9 ± 0.3 in crocidolite and 2.8 ± 1 in chrysotile groups.	Sebastien et al., 1

The rat and sheep intratracheal injection models of fibrosis have also been used to elucidate the time frame of appearance of bombesin and vasoactive intestinal peptide (Day et al., 1985, 1987), populations of cells in bronchoalveolar lavage (BAL) (Lemaire, 1985), pulmonary function and alveolitis (Begin et al., 1985, 1986), and cytokines or inflammatory mediators (Lemaire et al., 1986a; Keith et

in (1987) in relationship to the development of fibrotic disease. The rat intratracheal injection model has also been used to assess the inflammatory and fibrogenic potential of other fibre types (xonotlite, Fibrefrax, attapulgitite) in comparison to UICC chrysotile B and short chrysotile 4T30 (Lemaire et al., 1989). Overall, the order of reactivity was xonotlite < attapulgitite < short chrysotile 4T30 < Fibrefrax < UICC chrysotile B.

Intratracheal and intrabronchial injection studies on carcinogenicity are presented in Table 20. Studies by Coffin et al. (1992) evaluated UICC chrysotile A in comparison to UICC crocidolite and erionite. Large differences in the incidence of mesothelioma in intratracheal injection studies were demonstrated on the basis of tumour-to-fibre ratios based on lung burdens of fibres averaged from 1 day to 1 year. Erionite was 500-800 times more tumorigenic and crocidolite 30-60 times more tumorigenic than chrysotile on fibre number basis.

Other studies have examined the co-carcinogenic effects on rats of chrysotile in combination with benzo (a)pyrene (BP) (Fasske, 1988) or the systemic carcinogen *N*-nitrosoheptamethyleneimine (NHMI) and cadmium (Harrison & Heath, 1988). In the former study, BP appeared to be a weaker lung carcinogen than chrysotile. Synergistic effects of BP and chrysotile were not observed in comparison to chrysotile alone. In the latter study, the lung tumorigenic effects of chrysotile and NHMI appeared to be more than additive in comparison to those observed with NHMI or chrysotile alone.

Kimizuka et al. (1993) explored the co-carcinogenicity of chrysotile and amosite asbestos with BP in hamster lungs. Although tumours were not observed with either type of asbestos or BP alone, lung carcinomas occurred with chrysotile and BP (83%) and with amosite and BP (67%). The incidence of lung carcinomas in rats was higher when chrysotile was instilled repeatedly with the carcinogen *N*-bis(hydroxypropyl)nitrosamine (DHPN) (23/38 rats) than it was with chrysotile alone (1/31 rats) or chrysotile in combination with smoking (4/29 rats) (Yoshimura & Takemoto, 1991). Mesotheliomas were not observed with asbestos, smoking or DHPN alone, but were found in combination groups.

6.2.4 Intraperitoneal and intrapleural injection studies

The results of the most significant intraperitoneal and intrapleural injection studies are presented in Table 21.

Table 20. Intratracheal/intrabronchial injection studies (carcinogenicity)

Species	Dose and group size ^a	Protocol ^a	Results ^a	Reference
Rat (Fischer 344, male)	UICC chrys A (6, 16, 32 mg) ^b ; N = 132 for 6 and 16 mg, 41 for 32 mg	21 weekly intratracheal instillations. Animals kept for lifespan.	At 6, 16 and 32 mg, % mesothelioma were 8.3, 7.5 and 9.8, % carcinoma were 27.3, 14.3 and 2.4, respectively. No dose-response relationship.	Coffin et al., 199
Rat (Wistar, both sexes)	1) Milled UICC chrys B (1 mg) 2) Benzo(a)pyrene (0.5 mg) 3) Chrys (1 mg) + BP (0.5 mg) N = 70-80/group	Single intrabronchial dose. Rats kept for 33 months.	1) 17/70 (24%) lung carcinomas and 1/70 (1.4%) mesothelioma 2) 7/78 (9%) lung carcinomas and 3/78 (4%) mesothelioma 3) 15/78 (19%) lung carcinomas and 1 mesothelioma.	Fasske, 1988
Rat (Lister hooded)	1) UICC chrys B (2 mg) 2) Chrys (2 mg) + cadmium (0.18 mg) 3) Chrys (2 mg) + NHMI (1 mg x10, s.c.) 4) Chrys (2 mg) + NHMI (1 mg x10, s.c.) + cadmium (0.18 mg) 5) NHMI (1 mg x10, s.c.)	Single intratracheal instillation of particular materials. 10 weekly subcutaneous administrations of NHMI	Lung tumours incidence: 1) Chrys alone 1/86 (1.2%) 2) NHMI alone 2/48 (4.2%) 3) Chrys + cadmium 1/94 (1.1%) 4) Chrys + NHMI 8/50 (16.6%) 5) Chrys + NHMI + cadmium 6/44 (13.6%)	Harrison & Heath,

Table 20. (continued)

Species	Dose and group size ^a	Protocol ^a	Results ^a	Reference
Rat (Wistar)	1) Chrys (15 mg), N=31 2) DHPN (1 mg/kg bw) intraperitoneally, N=37 3) DHPN + chrys, N=38 4) chrys + smoke of 10 cigarettes, N=29 5) chrys + DHPN + smoke of 10 cigarettes, N=29	Single intratracheal dose of chrys, DHPN 3 intraperitoneal doses, exposure to smoke of 10 cigarettes/day, 6 days/week throughout lifespan. Lung carcinomas: 1) 1/31 (3.2%)	Yoshimura & Takemoto, 1991	

- 2) 8/37 (21.6%)
- 3) 23/38 (60.5%)
- 4) 4/29 (13.8%)
- 5) 15/29 (51.7%)

Mesotheliomas:

- 1) 0
- 2) 0
- 3) 8/38 (21.1%)
- 4) 2/29 (6.9%)
- 5) 4/29 (13.8%)

Hamster	12/group 1) UICC chrys (0.2 mg) 2) UICC amos (0.2 mg) 3) BP (0.4 mg) 4) Chrys + BP 5) Amos + BP	Weekly intratracheal application through 6 weeks. Tumours examined 18 and 24 months after last instillation.	chrys, amos and BP alone: no tumours. 4) 16 carcinomas in 12 (83% of animals) 5) 11 carcinomas in 12 (68% of animals)	Kimizuka et al., 1
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^a NHMI = *N*-nitrosoheptamethyleneimine, a relative systemic carcinogen; BP = benzo(a)pyrene; chrys = chrysotile; amos = amosite; DHPN = *N*-bis(2-hydroxypropyl) nitrosamine.

^b Accumulated instilled doses. Equivalent to 6.5, 17.4 and 34.8 million fibres, respectively.

Table 21. Intrapleural and intraperitoneal injection studies

Species	Group size	Protocol ^a	Results ^{a,b}	Reference
Rat (Wistar, 20 males, 20 females)	40	Single intrapleural injection of 20 mg chrys, 1% >5 µm in length	Mesotheliomas in 14/32 (44%) rats (sexes unspecified)	Le Bouffant et al.
Rat (Wistar, males)	24	Single intraperitoneal injection of 25 mg of 4 samples of WDC, 1 sample standard chrys	Mesotheliomas reported in 90% of rats in all groups (actual numbers unspecified). Median survival for WDC rats was 310-340 days, for standard chrys rats was 400 days	Davis et al., 1986
Rat (Wistar, females)	32	Single intraperitoneal injection of: Calidrian chrys (0.5 mg) Canadian chrys (1.0 mg)	Mesotheliomas Median survival 2/32 (6%) 812 27/32 (84%) 357	Muhle et al., 1987
Rat (Wistar, male)	24	Single intraperitoneal injection of: long amosite (20 mg) long amosite (10 mg) short amosite (25 mg) short amosite (10 mg)	Mesotheliomas Median survival 20/21 520 21/24 535 1/24 837 0/24	Davis et al., 1986
Rat (Wistar, male)	24	Single intraperitoneal injection of Canadian chrysotile: long fibre (25 mg) long fibre (2.5 mg) long fibre (0.25 mg) short fibre (25 mg) short fibre (2.5 mg) short fibre (0.25 mg)	Mesothelioma Mean induction period 23/24 (96%) 361 22/24 (92%) 511 16/24 (67%) 736 22/24 (92%) 504 8/24 (33%) 675 0/24 (0%)	Davis & Jones, 198

Table 21. (continued)

Species	Group size	Protocol ^a	Results ^{a,b}	Reference
Rat (Wistar, female)	34	Single intraperitoneal injection of: UICC Rhodesian chrys (6 mg)	Mesothelioma Mean survival 26/34 (76%) 497	Pott et al., 1987
	34	UICC Rhodesian chrys (25 mg)	27/34 (79%) 420	
	34	UICC Rhodesian chrys (6 mg) (HCl treated)	0/34 (0%)	
	34	UICC Rhodesian chrys (25 mg) (HCl treated)	0/34 (0%)	
	39	UICC Rhodesian chrys milled (10 mg)	1/39 (2.6%)	
	32	UICC Canadian chrys (1.0 mg)	26/32 (81%) 392	
	30	UICC Canadian chrys (1.0 mg) + separate injection of PVNO	24/30 (80%) 462	
	32	Calidrian chrys (0.5 mg)	2/32 (6%) 742	
	36	UICC Canadian chrys (0.05 mg)	7/36 (19%) 448	
	34	UICC Canadian chrys (0.25 mg)	21/34 (62%) 406	
	36	UICC Canadian chrys (1.0 mg)	31/36 (86%) 245	
Rat (Wistar, female)	50	Single intraperitoneal injection of: UICC Rhodesian chrys (2.0 mg)	Mesothelioma (survival times not recorded)	Tilkes & Beck, 198
	25	UICC Rhodesian chrys (10.0 mg)	25/50 (50%)	
	50	long asbestos-cement chrys (2.0 mg)	14/25 (54%)	
	25	long asbestos-cement chrys (10.0 mg)	19/50 (38%) 8/25 (32%)	

50	short asbestos-cement chrys (2.0 mg)	20/50 (40%)
25	short asbestos-cement chrys (10.0 mg)	8/25 (32%)
50	core asbestos-cement chrys (2.0 mg)	11/50 (22%)
25	core asbestos-cement chrys (10.0mg)	12/25 (48%)

Table 21. (continued)

Species	Group size	Protocol ^a	Results ^{a,b}	Reference	
Rat (Wistar)			Mesothelioma	Mean survival	Yang et al., 1990
	53	Chinese chrys short (50 mg)	26/53 (49.1%)	630	
	52	Chinese chrys long (50 mg)	38/52 (73.1%)	647	
	51	Chinese croc short (50 mg)	23/51 (45.1%)	636	
	54	Chinese croc long (50 mg)	40/54 (74.1%)	492	
	3	UICC chrys (50 mg)	7/13 (53.8%)	550	
	13	UICC croc (50 mg)	8/13 (61.5%)	586	
	14	UICC glass fibre (50 mg)	10/14 (71.4%)	605	
	32	Saline control (2 x 1 ml)	0/32	726	
Rat (Wistar, male)		Single intraperitoneal injection of UICC Rhodesian chrysotile:	Mesothelioma	Median survival	Davis et al., 1991
	24	15.0 mg	19/24 (79%)	476	
	24	10.0 mg	20/24 (83%)	476	
	24	7.5 mg	20/24 (83%)	516	
	24	5.0 mg	19/24 (79%)	506	
	32	2.5 mg	22/32 (69%)	613	
	32	0.5 mg	26/32 (81%)	693	
	32	0.05 mg	12/32 (38%)	903	
	48	0.01 mg	2/48 (4%)	NA	
Rat (Wistar, male)	33 or 36	Single intraperitoneal injection of tremolite:	Mesothelioma	Median survival	Davis et al., 1991
		Californian (asbestiform)	36/36 (100%)	301	
		Swansea (asbestiform)	35/36 (97%)	365	
		Korea (asbestiform)	32/33 (97%)	428	
		Italy (non-asbestiform)	24/36 (67%)	755	
		Carr Brae (non-asbestiform)	4/33 (12%)	NA	
		Shinness (non-asbestiform)	2/36 (6%)	NA	

Table 21. (continued)

Species	Group size	Protocol ^a	Results ^{a,b}	Reference	
Rat (Sprague-Dawley, male)	40	Single intrapleural injection of: Standard Canadian chrys (20 mg)	Mesothelioma 11/40 (28%)	Mean survival 632	Van der Meeren et
		Phosphorylated Canadian chrys (20 mg) (3 samples)	Median survival 11/40 (28%) 13/40 (33%) 16/40 (40%)	612 to 642	
Rat (Fischer 344, male)	50/dose	Single intrapleural injection of: UICC Rhodesian chrys UICC croc UICC erionite	Mesothelioma 118/142 (83%) 65/142 (45%) 137/144 (95%)		Coffin et al., 199
		[NB. Number of chrys fibres (length > 8 µm, diameter < 0.25 µm) was over 100 times higher than for croc or erionite]			

^a chrys = chrysotile; PVNO = polyvinyl-pyridine- N-oxide; asb = asbestos; croc = crocidolite; NA = not assessed.

^b All survival or induction periods are given in days.

When Davis et al. (1986a) treated rats by intraperitoneal injection of a series of four wet dispersed chrysotile (WDC) preparations (see section 6.2.2) and a standard chrysotile sample, mesotheliomas were induced in over 90% of animals. The mean induction period of WDC preparations was 310-340 days, shorter than that for standard chrysotile. It was suggested by the authors that this was due to the rapid separation of WDC fibre bundles in the tissue. Muhle et al. (1987) included two samples of chrysotile in intraperitoneal tests along with man-made fibres. While Canadian chrysotile produced mesotheliomas in 84% of animals (dose of 1.0 mg), a sample of chrysotile from Calidria produced only 6% mesotheliomas (dose of 0.5 mg). Calidrian chrysotile consists of thick and often agglomerated bundles which are difficult to separate and size. Tilkes & Beck (1989) examined the carcinogenicity of chrysotile fibres separated from asbestos-cement sheeting by single intraperitoneal injection in rats. At doses of 2.0 and 10.0 mg both weathered and unweathered chrysotile materials produced similar number of mesotheliomas to raw chrysotile. The incidences of mesothelioma were not dose-related.

Le Bouffant et al. (1985) examined the carcinogenicity of "short" chrysotile fibres by intrapleural injection of 20 mg in 40 rats. Mesotheliomas were induced in 44% of animals, but the dust sample contained over 1% of fibres > 5 µm in length. Davis & Jones (1988) administered to six groups of 24 rats by a single intraperitoneal injection "long" and "short" chrysotile samples at doses of 0.25, 2.5 and 25 mg. All animals were followed practically throughout their life span. At 25 mg, samples of long and short chrysotile produced similar numbers of mesotheliomas (> 90%). At 2.5 mg, the long chrysotile material produced almost the same proportion of mesotheliomas while the short material produced tumours in only 33% of animals. At 0.25 mg, the long chrysotile still produced 67% of mesotheliomas while the short chrysotile produced none. The mean mesothelioma induction period was dose-dependent and significantly longer with short fibre preparations. In fact, it is difficult to conclude whether the zero mesothelioma incidence with short fibre exposure at the dose of 0.25 mg was an exposure threshold or the consequence of an induction period longer than the follow-up period. While in this study samples of long and short chrysotile fibres produced similar number of mesotheliomas at the dose of 25 mg, the same group of authors (Davis et al., 1986b) had previously reported that the intraperitoneal injection of 25 mg of amosite with all fibres shorter than 5 µm produced only a single mesothelioma in 24 rats. The authors attributed this difference to the presence of a small but significant number of long fibres in the "short" chrysotile sample.

Pott et al. (1987) examined the carcinogenicity of many mineral samples, including several chrysotile preparations, in a large intraperitoneal injection study on rats. It was reported that UICC Canadian chrysotile exhibited a clear dose-response effect over a dose range of 0.05 to 1.0 mg, although Rhodesian chrysotile showed no difference between doses of 6 and 25 mg. Milled UICC Rhodesian chrysotile produced only 2.6% mesotheliomas at a dose level of 10 mg, and treatment with hydrochloric acid eliminated the carcinogenic

potential of Rhodesian chrysotile completely. Injecting the animals with polyvinyl-pyrrolidone-*N*-oxide (PVNO) after an injection of UICC Canadian chrysotile had no effect on carcinogenicity. The results were confirmed in a further study by the same group of authors (Pott et al., 1989). These authors emphasized that the maximum carcinogenic potency of fibres is reached at a fibre length of ≥ 20 µm.

Davis et al. (1991b) reported detailed dose-response studies following intraperitoneal injection of UICC Rhodesian chrysotile, UICC crocidolite, UICC amosite and erionite in rats. Dose levels ranged from 0.005 to 25 mg, and a clear dose-response effect was seen for all four minerals. Only two mesotheliomas were recorded with the lowest chrysotile dose (0.01 mg), which contained 55.8×10^6 fibres of all lengths and 872 000 fibres > 8 µm in length. When the dose-response was considered by mass, erionite and chrysotile appeared significantly more carcinogenic than amosite or crocidolite. When considered by fibre number (fibres > 8 µm in length), chrysotile, amosite and crocidolite appeared similar, but erionite showed significantly higher carcinogenicity. In this study, fibres were sized by SEM.

In a similar comparison of fibre number and carcinogenicity by intrapleural injection, Coffin et al. (1992) counted and sized fibres by TEM. A dose level of 20 mg chrysotile produced similar numbers of mesotheliomas in rats (83%) to erionite and twice the proportion of mesotheliomas produced by crocidolite (45%). However, the chrysotile fibre numbers (> 8 µm in length) were reported to be 100 times greater than in the crocidolite preparation and 500 times greater than in erionite.

Van der Meeren et al. (1992) treated rats by intrapleural injection of either standard chrysotile or three samples of phosphorylated chrysotile at the same dose. There were no significant differences in mesothelioma production but the unphosphorylated chrysotile was reported to have at most half the number of "Stanton" size fibres per mg compared to the phosphorylated materials.

Pott (1994) evaluated results from carcinogenicity studies in rats and lung cancer risk data in humans. He concluded that there is no evidence of a lower carcinogenic potency of chrysotile fibre compared to amphibole asbestos fibres.

Because tremolite contamination of chrysotile is believed by some to enhance its pathogenicity, an injection study by Davis et al. (1991c) is of interest. Six tremolite samples (three of asbestiform type and three non-asbestiform varieties) were administered to rats by intraperitoneal injection. The three asbestiform preparations produced mesotheliomas in over 90% of animals, while the non-asbestiform samples produced a lower response which appeared to be related to the number of elongated spicules in the dust. Two preparations, with relatively few of these spicules, produced only a few mesotheliomas similar in numbers to those found in control rats.

6.2.5 Ingestion studies

The main chrysotile-related findings, reported in the Environmental Health Criteria 53 (IPCS, 1986), are as follows:

- (a) There were no consistent pathological findings in the gastrointestinal tract of rats that had consumed up to 250 mg

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chrysotile per week for periods up to 25 months (Bolton et al., 1982), although some evidence of cellular damage was observed in the intestinal mucosa of rats fed 50 mg of chrysotile per day (Jacobs et al., 1978).

- (b) In six identified studies on rats with chrysotile fed in diet (250 mg per week for up to 25 months, or 10% in diet over lifetime, or 1% short-range or 1% intermediate-range chrysotile fed to nursing mothers and over the lifetime of pups) (Donham et al., 1980; Bolton et al., 1982; McConnell, 1982; NTP, 1985), there was no significant treatment-related increase of carcinoma incidence. Only benign tumours of the large intestine were found in rats, fed with an intermediate range of chrysotile fibres, in the NTP study. Of special significance is the finding that no increase in tumour incidence was observed following administration of short-range chrysotile fibres, composed of size ranges similar to those found in drinking-water (McConnell, 1982; NTP, 1985).

Since the publication of Environmental Health Criteria 53 (IPCS, 1986), there have been only a few studies in which possible harmful effects of the ingestion of chrysotile asbestos have been examined in experimental animals. All these studies gave negative findings. McConnell et al. (1983) treated over 3000 hamsters (equal numbers of males and females) with various preparations of chrysotile and amosite in special food pellets containing 1% by weight of asbestos. Neither the male nor the female asbestos-treated groups showed a statistically significant increase in neoplasia in any tissue or organ compared to control groups. A study on Swiss albino male mice, fed orally with chrysotile asbestos suspended in water at a dosage of 20 mg/kg per day during 60 days, did not show induction of chromosomal aberrations or sperm abnormalities (Rita & Reddi, 1986). The most recent completed experimental ingestion study was reported by Truhaut & Chouroulinkov (1989). These authors fed groups of 70 rats with either chrysotile or a mixture of chrysotile and crocidolite (75:25) in palm oil at dose levels of 10, 60 or 360 mg per day for 2 years. No increase in tumour incidence in the treated animals was found compared to controls. Aberrant crypt foci were induced in rats given chrysotile by gavage at a dosage of 70 mg/kg per day (Corpet et al., 1993).

The subject of asbestos ingestion has been reviewed by Davis (1993), Polissar (1993) and Valiæ & Beritiæ-Stahuljak (1993).

6.3 Studies on cells

Cell cultures and cells from bronchioalveolar lavage (BAL) of animals or humans exposed to asbestos have been used to document the cytotoxicity and genotoxicity of asbestos preparations as well as other effects on cells, i.e. proliferative alterations, production of cytokines, which may be predictive of disease. Other studies have focused on perturbations of cell organelles or cell-signalling pathways which are traditionally activated in other experimental models of inflammation, fibrosis and carcinogenesis. These assays have been valuable in determining mechanisms of disease and the properties of fibres, i.e. length and free-radical-generating properties, which are important in cell transformation and proliferation (Mossman & Begin, 1989).

The mechanisms of fibre-induced carcinogenicity have been recently reviewed by IARC (1996).

6.3.1 Genotoxicity and interactions with DNA

Table 22 summarizes results of some key *in vitro* genotoxicity studies.

Many studies have been performed to determine whether or not chrysotile and other types of asbestos interact with DNA either directly by physical association or indirectly via the production of reactive oxygen species (ROS), which may be generated primarily by iron-driven redox reactions on the surface of fibres. The latter mechanism may be particularly relevant to the enhanced biological activities of crocidolite and amosite, which contain approximately 26-36% iron, in comparison to chrysotile (generally < 2% iron by weight), in some preparations (Lund & Aust, 1991). The importance of iron in these reactions is illustrated by the observations that the DNA breakage is also observed with ferric citrate (Toyokuni & Sagripanti, 1993), and that reactivity of fibres is inhibited with iron chelators, such as desferrioxamine (Lund & Aust, 1991). Cell-free assays have shown that UICC samples of Canadian chrysotile, amosite and crocidolite cause lipid peroxidation (Weitzman & Weitberg, 1985), presumably by catalysing the formation of toxic hydroxyl radicals from hydrogen peroxide, a reaction inhibited by desferrioxamine (Weitzman & Graceffa, 1984; Gulumian & Van Wyk, 1987).

Chrysotile asbestos causes breakage of isolated DNA *in vitro* (Kasai & Nishimura, 1984), but this phenomenon is also observed with ferric citrate (Toyokuni & Sagripanti, 1993) and other chemical systems that generate ROS. Oxidative damage to DNA, as indicated by the formation of 8-hydroxydeoxyguanosine from deoxyguanosine (Leanderson et al., 1988), or calf thymus DNA (Adachi et al., 1992) *in vitro* is more potent with chrysotile in comparison to man-made fibres on an equal weight basis. However, the hydroxyl-radical-producing capacity attributed to this activity may be related more directly to the surface area of the material (Leanderson et al.,

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1988).

Table 22. *In vitro* studies on genotoxicity

Species (cell type)	Type of fibres	End-point (change)	Results	Reference
Drosophila (female germ cells)	NIEHS samples of chrysotile, crocidolite, amosite, tremolite	Aneuploidy (+)	Chrysotile and amosite (+) at high dose (25 mg/ml), only chrysotile (+) at low (5 mg/ml) dose. No effects with other types of asbestos.	Osgood & Sterlin 1991
Rat (pleural mesothelial cells)	Canadian chrysotile; UICC crocidolite	Aneuploidy (+); chromosomal aberrations (+)	Chrysotile caused more effects on a weight basis, but crocidolite more effects on a fibre basis. NOEL in 1 of 2 experiments.	Yegles et al., 1
Rat (pleural mesothelial cells)	Canadian chrysotile	Aneuploidy (+)	NOEL	Jaurand et al.,
Rat (pleural mesothelial cells)	UICC chrysotile	Morphologic transformation (+)	Only one dose evaluated.	Paterour et al.,
Rat (lung epithelial cells)	NIEHS intermediate chrysotile	Polyploidy (+); chromosomal aberrations (+)	Dose-dependent increases.	Li, 1986
Rat (bone marrow cells)	Indian chrysotile	Chromosomal aberrations (+)	Increase in chromosomal aberrations; decrease in mitotic index of bone marrow cells. Only one dose evaluated	Fatma et al., 19

Table 22. (continued)

Species (cell type)	Type of fibres	End-point (change)	Results	Reference
Golden Syrian hamster (embryo cells)	UICC chrysotile; glass fibre 100, 110; amosite; crocidolite; anthophyllite; Benzo(a)pyrene (BP)	Morphologic transformation (+)	Chrysotile caused the strongest effects on a weight basis. No synergistic effects of BP	Mikalsen et al.,
Chinese hamster (lung fibroblast)	UICC chrysotile; UICC crocidolite; erionite	Aneuploidy (+); chromosomal aberrations (+)	NOEL, erionite > crocidolite > chrysotile on a fibre basis	Palekar et al.,
Chinese hamster (lung fibroblasts)	35 dusts, including UICC and sized UICC chrysotile	Chromosomal aberrations (+)	Chrysotile more active on a weight basis than other types of asbestos. No dose-response. Shorter preparations less active than long fibres.	Koshi et al., 19
Mouse Balb/3T3 (fibroblasts)	UICC chrysotile; UICC crocidolite TPA ^a	Morphological transformation (+)	With chrysotile, dose-response increases in transformation. Chrysotile and TPA act synergistically.	Lu et al., 1988
Hamster-human hybrid (fibroblasts)	UICC chrysotile	Mutations at HGPRT (-) and S ₁ locus (+)	Dose-response mutations at S ₁ locus.	Hei et al., 1992

Table 22. (continued)

Species (cell type)	Type of fibres	End-point (change)	Results	Reference
Human (bronchial epithelial cells)	UICC chrysotile A; UICC crocidolite	Chromosomal aberrations (-) binuclei and micronuclei (-,+)	No statistically significant effect of chrysotile on numerical or structural chromosome changes. Dose-dependent (NOEL) in micronuclei and binuclei only at 3 days.	Kodama et al., 1
Human (lung	UICC chrysotile A;	Mitotic index (-)	Cytological changes with	Verschaeve et al

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fibroblasts)	glass fibres		chrysotile indicative of cell death (scattered chromatin observed). No effects of glass fibres.	1985
Human (lymphocytes)	Chrysotile (USSR); Clinoptililite; Latex	Chromosomal aberrations (+)	Latex and clinoptililite also + at same weight concentration as chrysotile	Korkina et al.,
Human female (pleural, mesothelial cells)	UICC chrysotile; UICC crocidolite; UICC amosite	Chromosomal aberrations (+)	Only one concentration evaluated. Numerical and structural alterations with all asbestos types, but no breakage nor polyploidy. Aberrations in 2/4 untreated controls.	Olofsson & Mark,

^a TPA = 12-O-tetradecanoylphorbol-13-acetate

Chrysotile asbestos has been shown to induce chromosomal aberrations (Sincock et al., 1982; Lechner et al., 1985; Jaurand et al., 1986), anaphase abnormalities (Palekar et al., 1987; Pelin et al., 1992; Jaurand et al., 1994), and sister chromatid exchange (Livington et al., 1980; Kaplan et al., 1980) in cultured rodent and human cells.

6.3.2 Cell proliferation

Interactions of chrysotile with the DNA of rodent cells may result in chromosomal or mutational events indicative of the initiation of carcinogenesis or genetic damage associated with cytolysis and cell death. However, cell proliferation, a phenomenon intrinsic to the long promotion and progression phases of the carcinogenic process, may be a more important contributing factor to both cancer and fibrosis. Sustained increases in incorporation of tritiated thymidine have been documented in human embryonic lung fibroblasts after exposure to UICC chrysotile at 10 µg/ml medium, but not at 5 µg/ml (Lemaire et al., 1986b). Moreover, effects were not observed with latex beads or titanium dioxide at up to 10-fold higher concentrations. In hamster tracheal epithelial cells, both UICC chrysotile and crocidolite asbestos caused increases in activity of ornithine decarboxylase (ODC), a rate-limiting enzyme in the biosynthesis of polyamines, which accompanied increases in labelling by tritiated thymidine in these cells (Landesman & Mossman, 1982; Marsh & Mossman, 1988, 1991). Elevations in ODC activity were also observed with Code 100 fibreglass and long chrysotile (>10 µm) fibres, but to a lesser extent with short chrysotile (<2 µm) (Marsh & Mossman, 1988).

Both rats (Brody & Overby, 1989; McGavran et al., 1990) and mice (McGavran et al., 1990), following a single exposure to approximately 10 mg/m³ air, exhibited rapid reversible proliferation of epithelial and interstitial cells, as measured by incorporation of tritiated thymidine, which was followed by increased accumulation of alveolar macrophages and localized interstitial fibrosis using morphometric techniques (Chang et al., 1988). In mice, endothelial and smooth muscle cells of arterioles and venules near alveolar duct bifurcations, the site of deposition of asbestos fibres, also incorporate increased levels of tritiated thymidine up to 72 h after initiation of a 5-h exposure to chrysotile (McGavran et al., 1990).

Morphometric analyses of ultrastructural changes in chrysotile-exposed rat lungs have also been used to determine the responses of alveolar type II epithelial cells after inhalation of chrysotile asbestos over a 2-year period (Pinkerton et al., 1990). During this time, type II cell number and volume increased to values more than 4 times those seen in controls. Inhalation of chrysotile over a one-year period resulted in regional differences in the localization and lung burden of fibres, which were proportional to the relative degree of tissue injury at that site (Pinkerton et al., 1986).

The induction of protooncogenes which govern cell division has been compared in cultures of rat pleural mesothelial cells (RPM) and hamster tracheal epithelial cells (HTE) (Heintz et al., 1993). These studies indicated that UICC crocidolite asbestos and UICC chrysotile asbestos cause persistent induction of the protooncogenes c-fos and c-jun in RPM cells in a dosage-dependent fashion. Crocidolite was much more potent than chrysotile in stimulating gene expression of both protooncogenes on a fibre number basis. In HTE cells, only c-fos induction was observed, but patterns of induction by both types of asbestos were similar to those observed in RPM cells. No increases were documented with the use of polystyrene beads or riebeckite.

6.3.3 Inflammation

Using intratracheal injection (1, 10, 25, 50 or 100 mg of UICC Canadian chrysotile) into the isolated tracheal lobe of the lungs of sheep and following pulmonary lavage, Begin et al. (1986) examined the extracted fluid and cells for evidence of inflammation by differential cell counts and estimations of lactate dehydrogenase (LDH), alkaline phosphatase, α-glucuronidase and levels of fibronectin and procollagen. Only the 100 mg dose produced any changes from control levels, a finding which the authors suggested supported the idea of a

"tolerance threshold". Comparing UICC Canadian chrysotile to short Canadian chrysotile and a chrysotile coated with either phosphate or aluminium (intratracheal injection of 100 mg), the UICC chrysotile preparation and the samples of coated chrysotile all produced evidence of similar levels of pulmonary inflammation, but the short chrysotile preparation produced no changes from control values. By administering 100 mg of chrysotile intratracheally at 10-day intervals, Begin et al. (1990) found that normal sheep showed much less evidence of pulmonary inflammation in lavage fluids than those with fibrosis, and the fibre retention was 2.5 times greater when fibrosis was present.

Lemaire et al. (1985) administered, by a single intratracheal injection, 5 mg of either UICC Canadian chrysotile or short fibre preparation (all fibres < 8 µm in length) to rats. Lung morphology was examined at intervals of up to 60 days. The UICC chrysotile produced nodular lesions around the terminal bronchioles with accumulation of inflammatory cells followed by collagen deposition. In contrast, the short fibre preparation produced an accumulation of inflammatory cells but no fibrosis. It was found that standard chrysotile caused an influx of PMN during the first day, which persisted for 7 days. In contrast, the short chrysotile caused only a transient increase in PMN on day 1. Both preparations stimulated an influx of lavageable macrophages, which were frequently binucleate, and frequent mitotic figures were recorded. These studies were extended to include different dose levels and to include attapulgite, xonotlite and aluminium silicate fibres. Intratracheal dose levels were 1, 5 and 10 mg. One month after treatment, UICC Canadian chrysotile and aluminium silicate, which contained long fibres, had produced fibrotic lesions at all doses, while short chrysotile and

attapulgite (a short fibre clay material) produced an accumulation of inflammatory cells but no fibrosis. Xonotlite produced only a minimal response.

Pulmonary lavage was used to examine the inflammatory response to chrysotile and amosite dust in rats following short-term inhalation (Donaldson et al., 1988a; Davis et al., 1989). UICC Rhodesian chrysotile produced a rapid increase in both lavageable macrophages and PMN within 2 days of the start of inhalation at a dose level of 10 mg/m³. Amosite at the same dose had little effect; the chrysotile response was even greater than the early response stimulated by amosite at 50 mg/m³. By 52 days of study, the 50 mg amosite dose had elicited more macrophages than 10 mg of chrysotile, and by 75 days it had elicited more neutrophils as well. By 75 days, the numbers of macrophages in lavage fluids was falling in both chrysotile and amosite treatments, perhaps because macrophages aggregated around fibre deposits were becoming less susceptible to lavage. In contrast to the findings with asbestos, quartz at a concentration 10 mg/m³ produced only minimal increases in macrophages and neutrophils during the first 30 days of dusting, but subsequently a massive influx of both cell types occurred and persisted until the end of the study. In this report, levels of LDH and α-glucuronidase in lavage fluids closely mirrored the numbers of lavage cells for all dust types. Donaldson et al. (1990) used the same experimental procedure to examine leucocyte chemotaxis. Following inhalation for up to 75 days of chrysotile, amosite, quartz or titanium dioxide, chemotactic activity towards zymosan-activated serum was found to be reduced with the first 3 dusts. In contrast, chemotaxis of cells lavaged from animals treated with titanium dioxide showed only a small impairment of chemotaxis. After inhalation of chrysotile (10 mg/m³) for 1 h, cells from BAL exhibited a diminished capacity to secrete superoxide anion, an active oxygen species implicated in bactericidal activity, when incubated with the opsonized zymosan (Petruska et al., 1990).

6.3.4 Cell death and cytotoxicity

Several studies have documented the short-term cytotoxic effects of chrysotile asbestos and other particulates on cells in culture (reviewed in Mossman & Begin, 1989). These studies indicate that geometry and size are important determinants of cytotoxicity in a number of cell types; longer fibres are more potent than short fibres in most of these bioassays (Wright et al., 1986; Mossman & Sesko, 1990).

6.3.5 Liberation of growth factors and other response of cells of the immune system

Macrophages and other cell types of the immune system produce a number of cytokines or growth factors (Rom & Paakko, 1991; Schapira et al., 1991; Perkins et al., 1993), products of arachidonic acid and lipoxigenase metabolism (Kouzan et al., 1985; Dubois et al., 1989),

proteolytic enzymes (Donaldson et al., 1988b), neuropeptides (Day et al., 1987), immunomodulation factors (Bozelka et al., 1986), chemotactic factors (Hays et al., 1990), and activated oxygen species (Cantin et al., 1988) after exposure to chrysotile asbestos (reviewed in part by Mossman & Begin, 1989). Whether these substances are important causally to the induction of asbestos-associated disease or in mitigating the disease process is unclear. For example, some of these factors, such as platelet-derived growth factor (PDGF), are also induced after exposure to iron spheres (Schapira et al., 1991) and other innocuous particles used as negative controls. However, such particles are not translocated to the interstitium, while chrysotile fibres are readily translocated (Brody & Overby, 1989).

The initial inflammatory response to inhaled asbestos fibres and subsequent development of fibrosis, and also possible neoplasia, is claimed to be mediated by a number of chemical factors, most of which are produced by pulmonary macrophages that have phagocytosed fibres. Lemaire et al. (1986c) examined the production of fibroblast growth factor (FGF) by pulmonary macrophages from rats given a single intratracheal injection of either 5 or 10 mg of Canadian chrysotile. In control rats, pulmonary macrophages secrete FGF while monocytes from peripheral blood secrete fibroblast growth inhibitory factor (FGIF). Subsequent to asbestos treatment, secretion of FGF by pulmonary macrophages was significantly increased and monocyte production of FGIF was reduced. The stimulation of fibroblast proliferation by alveolar macrophages was further examined by co-culturing macrophages from normal rats and rats treated by a single intratracheal injection of 5 mg of Canadian chrysotile with long fibroblasts (Lemaire et al., 1986d). Macrophages from chrysotile-treated animals caused significantly more fibroblast proliferation than controls. Bonner & Brody (1991) demonstrated that, when rats were exposed for only 3 h to chrysotile at a dose level of 10 mg/m³, macrophages lavaged one week later stimulated 2-5 times more production of PDGF than controls. However, exposure to iron (50 mg/m³) caused a similar increase. Cantin et al. (1989) showed that development of asbestosis is associated with increased secretion of plasminogen activator by pulmonary macrophages. In sheep given 100 mg of Canadian chrysotile every 2 weeks by intratracheal injection, some animals developed fibrosis and some did not. Lavaged macrophages from animals developing fibrosis were found to secrete larger amounts of plasminogen activator than those from animals that did not develop fibrosis. Bonner et al. (1993) believe that the combination of retention and translocation, along with release of growth factors and other inflammatory mediators, is responsible for the fibrogenic effects of fibres.

After exposing rats by inhalation to chrysotile or crocidolite asbestos at a dose level of approximately 10 mg/m³ for up to 91 days, Hartmann et al. (1984a,b) found that the expression of the Ia antigen on macrophages lavaged from crocidolite-treated animals was increased 4-fold in male Fischer-344 rats while chrysotile produced no increase over controls. In female ACI rats, crocidolite produced similar

effects but in these animals chrysotile also stimulated an increase in Ia expression at approximately half the level of crocidolite. Significantly greater thymocyte DNA synthesis was induced by supernatants from co-cultures of alveolar macrophages and splenic lymphocytes from asbestos-treated rats than from controls.

An effect on splenocyte mitogenesis by chrysotile treatment was noted by Hannant et al. (1985). In these studies rats were given a 10 mg intraperitoneal injection of Rhodesian chrysotile, quartz or titanium dioxide. After 14 days, splenocytes from animals treated with chrysotile or quartz showed a significant reduction in mitogenic response to phytohaemagglutinin and concanavalin A compared to controls. Titanium dioxide produced no effect. Intraperitoneal injection of chrysotile into mice caused impairment of subsequent production of antibody to the protein antigen.

7. EFFECTS ON HUMANS

Studies reviewed are restricted to those that were considered by the Task Group to be of clear relevance to characterizing the risks associated with exposure to chrysotile. Limitations of particle-to-fibre count conversions on which the exposure estimates in the following studies are based are presented in Chapter 2.

7.1 Occupational exposure

7.1.1 Pneumoconiosis and other non-malignant respiratory effects

The non-malignant lung diseases resulting from exposure to asbestos fibres comprise a somewhat complex mixture of clinical and pathological syndromes not readily definable for epidemiological study. Traditionally, the prime concern has been asbestosis, generally implying a disease associated with diffuse interstitial pulmonary fibrosis accompanied by varying degrees of pleural involvement. More recently, as severe asbestosis has become less frequent clinically, attention has been directed primarily to syndromes reflecting fibrosis of the small and large airways rather than of the lung parenchyma. As a cause of death, the pneumoconioses have never been reliably recorded on death certificates. In investigations of mortality, therefore, all chronic non-malignant respiratory diseases are generally considered as one group. Additionally, mortality studies are generally not sufficient to detect clinically significant morbidity. Equally, in studies of morbidity, the etiological or diagnostic specificity of the usual methods of assessment, i.e. chest radiography, physiological testing and symptom questionnaire, is limited.

Early studies in both the United Kingdom and USA demonstrated an extremely high prevalence of asbestosis among textile workers exposed only to chrysotile at very high dust levels (Dreeson et al., 1938).

Extensive morbidity surveys of chrysotile workers were initiated in the Quebec chrysotile mines and mills in the 1960s (McDonald et al., 1974). These studies included the use by six readers of the then

newly developed UICC/Cincinnati (later ILO) radiographic classification of nearly 7000 films, examinations by questionnaire and lung function tests of over 1000 current employees, and detailed assessments of cumulative dust exposure for each man. In the initial survey, there was a fairly systematic relationship between exposure and these measures of response. The authors concluded that exposure to 70-140 mpcm (2-4 mpcf) for a working life of 50 years was associated with a 1% risk of acquiring clinically significant disease.

Based on additional study of radiological changes in 515 men aged 60-69 years (average 64.6 years) who had been employed for at least 20 years (average 42.3 years) at Thetford Mines, the dustier of the two Quebec mining regions, dose-response relationships for small opacities were essentially linear (Liddell et al., 1982). However, any increase in prevalence in small opacities ($>1/0$ or $>2/1$) above the level of the intercepts (which were high) only became apparent at an accumulated exposure at age 45 of 1200 f/ml-years, equivalent to an

average concentration of about 30 f/ml (Liddell et al., 1982). In contrast to small opacities, pleural thickening was not related to cumulative exposure, although it was more common in men with long service.

Becklake et al. (1979) reported a second study in Quebec of 86 men whose last chest film was taken within 12 months of leaving employment in 1960-1961, and who were examined again in 1972. In 66 men who had been employed for at least two years, there was evidence of an increase in small irregular parenchymal opacities in 8 men (12%) but in none of the 20 men with shorter employment. Increase of pleural thickening was seen in a further 13 (20%) of the 66 men and 4 (20%) of the 20 men.

A dose-related reduction in vital capacity ($p=0.023$) and expiratory volume ($p<0.001$) was observed with increasing cumulative exposure (i.e. ≥ 8 f/ml-years) to chrysotile asbestos in miners and millers (stratified random sample of 111 men) in Zimbabwe, exposed for more than 10 years. The relationship between cumulative exposure and radiographic parenchymal category demonstrated a steep increase with each change in category ($p<0.00001$). Individual estimates of cumulative exposure based on company records of employment history and fibre concentrations (measured and estimated) ranged from 1.1 to 654 fibres/ml-years. Controls were a subset of miners ($n=66$) with no prior respiratory illness, who were lifelong non-smokers with normal chest X-ray and minimal cumulative exposure to chrysotile asbestos (<8 fibres/ml-years) (Cullen et al., 1991).

A number of other studies of radiographic and functional changes have been conducted in occupational populations exposed primarily to chrysotile, in some cases during mining and milling operations (Rubino et al., 1979a; McDermott et al., 1982; Viallat et al., 1983; Cordier et al., 1984; Enarson et al., 1988), asbestos-cement (Weill et al., 1979; Jones et al., 1989) and asbestos textiles (Berry et al., 1979; Becklake et al., 1980). Results were generally comparable to those already described, the presence of small opacities increasing with cumulative exposure (although with some variability in the shape and steepness of these trends) and pleural changes primarily related to time since initial exposure. As demonstrated in several of these studies, e.g., Becklake et al., 1979; Rubino et al., 1979a; Berry et al., 1979; Viallat et al., 1983, and as well recognized clinically, X-ray changes can develop among workers after exposure ceases, in some cases many years later.

Studies that correlate disease prevalence or symptoms with cumulative exposure can underestimate disease risk due to progression of disease after employment ceases. Although workers were exposed to both chrysotile and crocidolite (the latter being approximately 5% of all asbestos used), results for 379 men employed at least 10 years in the Rochdale asbestos textile plant are informative in this regard (Berry et al., 1979). Exposure estimated from work histories ranged from an average of 2.9 to 14.5 f/ml. Overall, small opacities ($>1/0$) were recorded in 88/379 (23%) of chest radiographs, with evidence of a

gradient seriously confounded by date of first employment and transfer of subjects with suspected asbestosis to less dusty conditions. On the basis of data on incidence, the authors drew conclusions on exposure-response between cumulative exposure and prevalence or incidence of crepitations, possible asbestosis and certified asbestosis - all three depending on clinical opinion and judgement. The authors concluded that possible asbestosis occurs in no more than 1% of men after 40 years of exposure to concentrations between 0.3 and 1.1 f/ml.

Mortality studies of Quebec miners and millers by McDonald et al. (1994) have shown exposure-response relationships for pneumoconiosis-related mortality. Crude rates of 0.23 cases per 1000 man-years were observed for those with cumulative exposures less than 3530 mpcm-years (100 mpcf-years) and a rate of 2.7 cases per 1000 man-years was reported for those with more than 10 590 mpcm-years (> 300 mpcf-years). Dement et al. (1994) also reported mortality due to non-malignant respiratory diseases among chrysotile textile workers. An SMR of 1.88 was observed for those with cumulative exposures less than 2.7 f/ml-years and rose rapidly to 12.78 with cumulative exposures greater than 110 f/ml-years. It was noted that cases of pneumoconiosis recorded on death certificates are often verified by pathological diagnosis.

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Chest X-ray changes among textile and friction product workers in China were reported by Huang (1990). A total of 824 workers employed for at least 3 years in a chrysotile products factory from the start-up of the factory in 1958 until 1980, with follow-through to September 1982, were studied. Chest X-ray changes compatible with asbestosis were assessed using the Chinese standard system for interpretation of X-rays. Cases were defined as Grade I asbestosis (approximately equivalent to ILO $\geq 1/1$). Overall, 277 workers were diagnosed with asbestosis during the follow-up period, corresponding to a period prevalence of 31%. Exposure-response analysis, based on gravimetric data converted to fibre counts, predicted a 1% prevalence of Grade I asbestosis at a cumulative exposure of 22 f/ml-years.

7.1.2 Lung cancer and mesothelioma

It has been suggested that in the absence of pulmonary fibrosis, lung cancer cannot be attributed to asbestos exposure regardless of fibre type; however, there is also evidence to the contrary. For example, in a recent case-control study, there was evidence of a statistically significant increase in risk of lung cancer without radiological signs of fibrosis (Wilkinson et al., 1995). The question remains the subject of active controversy (Hughes & Weill, 1991; Henderson et al., 1997).

Results of cohort studies of workers almost exclusively exposed to chrysotile asbestos and considered by the Task Group to be most relevant to this evaluation are summarized in Table 23 and described in section 7.1.2.1. Studies that contribute less to our understanding of the effects of chrysotile, due primarily to concomitant exposure to amphiboles or to limitations of design and reporting, are presented in

section 7.1.2.2. Information most relevant to characterization of risk (i.e. exposure-response assessment) is emphasized.

Assessment of exposure response for mesothelioma is complicated in epidemiological studies by factors such as the rarity of the disease, the lack of mortality rates in the populations used as reference and problems in diagnosis and reporting. In many cases, therefore, cruder indicators of risk have been developed, such as absolute numbers of cases and death and ratios of mesothelioma over lung cancers or total deaths. The mesothelioma/lung cancer ratio in particular is highly variable depending on the industry and the nature and intensity of asbestos exposure, in addition to a number of factors not related to asbestos exposure. Data on mesothelioma occurrence in occupational cohorts should, therefore, be cautiously interpreted.

For the studies reviewed here, the number of mesothelioma deaths is reported, together with the percentage over total deaths (Table 23). It should be noted, however, that additional cases of mesothelioma have been reported in workers from the factories included in the studies reported in Table 23 who were not included in the original cohort studies. However, in the absence of information on the numbers of workers at risk, such reports do not contribute to quantification of risk.

7.1.2.1 Critical occupational cohort studies - chrysotile

a) Mining and milling

Mortality from lung cancer and mesothelioma has been studied extensively in miners and millers of Quebec and in a smaller operation at Balangero in northern Italy.

In 1966, a cohort of some 11 000 men and 440 women, born between 1891 and 1920, who had worked for one month or more in chrysotile production in Asbestos and Thetford Mines and 400 persons employed in a small mixed asbestos products factory in Asbestos, Canada, was identified. The cohort, which has now been followed up to 1988, was selected from a register compiled of all workers, nearly 30 000, ever known to have been employed in the industry. The factory workers were included because there was frequent and often unrecorded movement between the plant and the mine and mill. Apart from a failure to trace 9% of the cohort, most after less than 12 months' employment before 1930, losses have amounted to well under 1%. The intensity of exposure was estimated for each cohort member by year, based on many thousand midget impinger dust particle counts and, more recently, membrane filter fibre counts.

Table 23. Results of cohort studies of chrysotile-exposed workers^a

Study	No. of subjects	All causes		Lung cancer			Mesothelioma	Mean exposure		Slope of dose-respon
		No. of deaths	SMR	No. of deaths	SMR	95% CI ^b	No. of deaths (percentage)	f/ml	f/ml -years	
Mining & Milling										
McDonald et al., 1980 ^{d,e,f}	10 939	3291	1.09	230	1.25	[1.09 - 1.42]	8 (0.24%)	ns	90	0.0006
McDonald et al., 1993 ^{d,e,f}	5335	2800	1.07	315	1.39	[1.24 - 1.55]	25 (0.8%)	ns	90	<i>Arivamani</i>
Nicholson et al.,										

1979 ^d Piolatto et al., 1990	544 1094	178 427	1.11 1.49	28 22	2.52 1.1	[1.68 - 3.65] [0.7 - 1.7]	1 (0.56%) 2 (0.47%)	ns ns	ns ns	0.001 ns
Asbestos-cement Production										
Thomas et al., 1982	1592	351	1.02	30	0.91	[0.61 - 1.30]	2 (0.57%)	<2	ns	ns
Ohlson & Hogstedt, 1985 ^f	1176	220	1.03	9	1.58	0.72 - 3.00	0 (0%)	2	10-20	ns
Gardner et al., 1986	1510	384	0.94	35	0.92	0.64 - 1.27	1 (0.26%)	<1	ns	ns
Hughes et al., 1987 (plant 1) ^f	2565	477	0.91	48 ^k	1.17	[0.86 - 1.54]	2 (0.42%)	11	40	0.0003
Hughes et al., 1987 (plant 2) ^{f,g}	2751	ns	ns	70	1.32	[1.03 - 1.66]	1 (ns)	11	19	0.007
Textile Manufacture										
Dement et al., 1994 ^{h,i}	3022	1258	1.28	126	1.97	[1.64 - 2.35]	2 (0.16%)	5-12	32-105	0.02-0.03
McDonald et al., 1983a ^{f,h}	2543	570	1.27	59 ^k	1.99	[1.52 - 2.57]	1 (0.18%)	ns	ns	0.01
Friction Materials Production										
Newhouse & Sullivan, 1989 ^j	8812	ns	ns	84 ^k	0.93	[0.74 - 1.16]	3 (ns)	2-5	12	0.0006
McDonald et al., 1984 ^f	3641	803	1.09	73 ^k	1.49	[1.17 - 1.87]	0 (0%)	ns	ns	0.0005

Table 23. (continued)

Study	No. of subjects	All causes		Lung cancer			Mesothelioma	Mean exposure		Slope of dose-respon
		No. of deaths	SMR	No. of deaths	SMR	95% CI ^b	No. of deaths (percentage)	f/ml	f/ml -years	
Mixed products										
Szeszenia-Dabrowska et al., 1988	824	285	1.04	24	1.86	[1.19 - 2.77]	0 (0%)	ns	ns	ns
Cheng & Kong, 1992	1172	151	1.16	21	3.15	[1.95 - 4.81]	ns (ns)	ns	ns	ns
Chen et al., 1988	551	156	ns	19 ^k	2.34	[1.41 - 3.67]	1 (0.64%)	ns	ns	ns
Zhu & Wang, 1993	5893	496	ns	18	5.3	[2.67 - 7.1]	ns (ns)	ns	ns	ns

^a ns = not stated

^b values in square brackets were calculated by Task Group

^c Increase in relative lung cancer risk for 1 f/ml-year

^d Partially overlapping studies

^e McDonald et al. (1993) extends the follow-up of McDonald et al. (1980)

^f 20+ years since first employment

^g Only chrysotile-exposed workers; mean exposure refers to both chrysotile and amphibole workers

^h Partially overlapping studies

ⁱ Slopes estimated based on regression of SMRs and risk ratios

^j Only workers employed after 1950; 10+ years since first employment; dose-response from Berry & Newhouse (1983).

^k Respiratory cancers

The most relevant analyses of this cohort are those published by McDonald et al. (1980) and McDonald et al. (1993), and in a preliminary fashion by Liddell (1994). In the first of these reports, where 4463 men had died, the standardized mortality ratio (SMR) for men 20 or more years after first employment, assessed against provincial rates, was 1.09 for all causes and 1.25 for lung cancer. There was no excess mortality for lung cancer in men employed for less than 5 years, but at 5 years and above there were clear excesses. Based on analysis by cumulative exposure up to age 45, there was a linear relationship with lung cancer risk.

In the second paper (McDonald et al., 1993), mortality up to the end of 1988 of the 5351 men who had survived into 1976 (of whom 16 could not be traced and 2827 had died) was followed. In this survivor population, the SMRs 20 or more years after first employment were 1.07 for all causes and 1.39 for lung cancer. The investigators subdivided the men into 10 groups based on cumulative exposure up to age 55. The highest relative risk (3.04) was in the highest exposure group ($\geq 35\ 000$ mpcm-years; ≥ 1000 mpcf-years), the second highest (1.65) was in the second highest exposure group (14 000 to 35 000 mpcm-years; 400 to 1000 mpcf-years) and the third highest (1.50) was in the third highest exposure group (10 500 to 14 000 mpcm-years; 300 to 400 mpcf-years). In the remaining 7 groups below 10 500 mpcm-years (300 mpcf-years), there was no indication of a trend or pattern of exposure-response with relative risks all being above 1 and averaging 1.27. Similar results were obtained in a heavily exposed subset of the cohort with a long duration of exposure (Nicholson et al., 1979). In the analysis of the large Quebec cohort, the relative increase in risk attributable to chrysotile exposure was lower for ex-smokers than smokers and negligible for smokers of 20 or more cigarettes a day. The authors concluded that the interaction appeared to be less than multiplicative.

The number of deaths attributed to mesothelioma in the Quebec

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cohort has increased with increasing age and time from first employment more rapidly than total mortality (McDonald et al., 1993). At the end of 1988, when some 75% of the cohort had died, and the youngest survivor was aged 73, in a total of 7312 male deaths, there were 33 suspected cases of mesothelioma, 15 coded to ICD 163 and 18 to a variety of other diagnostic codes. After review of all available evidence, including autopsies in 23 and biopsies in 10, the probability of the diagnosis being correct was assessed by the authors as high in 17, moderate in 11, and low in 5. All 33 cases were pleural but in one of low diagnostic probability, the peritoneum was also affected. Of the 33 cases, 20 were miners or millers from Thetford Mines, 8 were miners or millers from Asbestos, and the remaining five cases were observed among men employed in a small asbestos products factory in Asbestos. The median duration of employment was 36 years (range 2.5 to 49 years). There was no case of mesothelioma among the 4371 members of the cohort (40% of 10 925) employed for less than 2 years, eight cases among those 2396 (22% employed for 2-10 years, and 25 mesotheliomas among the other 38% of the cohort (4158 men) with at least 10 years of employment. Crude rates of mesothelioma by

cumulative exposure were calculated. Rates varied from 0.15 cases per 1000 man-years for those with exposures less than 3500 mpcm-years (100 mpcf-years) to 0.97 cases per 1000 man-years for those with exposure of 10 500 mpcm-years (300 mpcf-years) or more.

The most recent account of mortality among the chrysotile miners and millers of Balangero, Italy, was reported by Piolatto et al. (1990) for a cohort comprising 1094 men employed for at least one year between 1946 and 1987, with exposures estimated individually in fibre-years. Of the total, 36 could not be traced and 427 had died. The SMR for all causes based on national rates was 1.49, a high figure largely explained by hepatic cirrhosis and accidents. Numbers of deaths from all cancers (n=86) and lung cancer (n=22) were close to expected (76.2 and 19.9) and there was no evidence that the risk for either of these causes was related to duration of exposure, fibre-years of cumulative exposure, or time since first or last exposure. Little information was provided on the basis for the estimates of cumulative exposure. The first fibre counts were taken in 1969. Earlier exposure levels were estimated by simulating working situations occurring at various periods since 1946 in the plant, and fibre counts were measured by PCOM (Rubino et al., 1979b).

The cohort of chrysotile production workers employed at the Balangero mine and mill, studied by Piolatto et al. (1990), was almost exactly one tenth the size of the Quebec cohort. At the end of 1987, when 427 (45%) of the cohort had died, there were two deaths from pleural mesothelioma, both in men employed for more than 20 years, with cumulative exposure estimated respectively at 100-400 and > 400 f/ml years. One diagnosis was confirmed histopathologically, and one was based on radiological findings and examination of pleural fluid. Fibrous tremolite was not detected in samples of chrysotile from this mine, but another fibrous silicate (balangeroite), the biological effects of which are not known, was identified in low proportions by mass (0.2-0.5%). At a comparable stage in the evolution of the Quebec cohort, mesothelioma accounted for 10 out of 4547 deaths, a lower but not dissimilar proportion.

b) Asbestos-cement production

Numerous studies have been conducted on asbestos-cement workers, but only four, analysing five factories, were of groups exposed almost only to chrysotile. In general, cumulative exposures were low, as were the observed SMRs. In the USA, Hughes et al. (1987) studied two asbestos-cement plants in Louisiana. Observed and expected deaths 20 years from onset of employment were provided according to exposure category. In plant 1, which dealt predominantly with chrysotile, small amounts of amosite were used from the early 1940s until the late 1960s and crocidolite for 10 years beginning in 1962. In plant 2, crocidolite was used continuously in the pipe department located in one building. Chrysotile was only used in the remaining three buildings, and lung cancer and mesothelioma mortality data were supplied for workers (63% of the total) whose only employment assignment was in these buildings. Cohort mortality analyses were

conducted for both plant 1 and plant 2 workers 20 or more years after initial employment. There were 22 respiratory cancer deaths among 996 plant 1 employees with more than 6 months of service, which indicated a small non-significant lung cancer risk. However, a corresponding analysis of 42 lung cancer cases among 1414 plant 2 employees with more than 3 months of service and no assignment in the pipe building indicated a substantial lung cancer risk. Two deaths attributed to mesothelioma were reported among cohort members at plant 1 (mean exposure of 40 f/ml-years), while 1 death from mesothelioma was reported among workers at plant 2 (mean exposure of 19 f/ml-years).

Among 1176 Swedish asbestos-cement workers who were estimated to have used >99% chrysotile (Ohlson & Hogstedt, 1985), 11 cases of lung cancer were observed compared to 9 expected (9 observed versus 5.7 expected for those with a 20-year latency). This non-significant increase occurred in a plant with relatively low exposures. In a 10% sample of the work force, all employed for more than 10 years, overall cumulative exposure was 18 f/ml-years. Among the entire cohort, no deaths from mesothelioma were observed. In a study conducted in the United Kingdom (Gardner et al., 1986), the lack of lung cancer increase (35 observed versus 38 expected) can be explained by low

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cumulative exposures. Since 1970, mean levels were under 1 f/ml throughout the factory and most were under 0.5 f/ml. Higher concentrations of unknown magnitude would have existed prior to 1968. The possibility of low level smoking in the workforce compared to the general population masking lung cancer risks from chrysotile is considered unlikely by the authors. One death from mesothelioma (0.26% of total deaths) was reported among cohort members in this study. A study by Thomas et al. (1982) also did not indicate an excess lung cancer risk (30 observed versus 33.0 expected). Two deaths from mesothelioma (0.57% of all deaths) occurred in this cohort. As with the studies of Ohlson & Hogstedt (1985) and Gardner et al. (1986), the exposures in this plant were very low, the vast majority from 1972 to plant closure being consistently below 1 f/ml.

It must be noted, however, that in most of the cohort studies of asbestos-cement workers, there was no attempt to evaluate the most important confounder of lung cancer, i.e. smoking, or, alternatively, smoking rates were examined only for small subcohorts shortly before the end of follow-up.

(c) Textile manufacture

The health of employees has been studied in any detail in only three asbestos textile plants. These comprise a factory at Rochdale, England, originally studied by Doll (1955) and more recently by Peto et al. (1985), another located in Mannheim, Pennsylvania, USA, studied by McDonald et al. (1983b) and a plant in Charleston, South Carolina, USA. Only the study in South Carolina is considered primarily relevant for assessment of the health effects of chrysotile. Although the SMRs for lung cancer in these plants were broadly equivalent, the rates of mesothelioma varied considerably, which may reflect the greater proportions of amphiboles in the Mannheim and Rochdale cohorts.

The textile workers in the South Carolina plant have been studied in two separate but overlapping cohorts (Dement et al., 1983b; McDonald et al., 1983a; Brown et al., 1994; Dement et al., 1994). The only amphibole used in this plant was approximately one tonne of imported crocidolite from the early 1950s until 1972, plus a very small quantity of amosite for experimental purposes briefly in the late 1950s. The crocidolite yarn was processed at a single location only, so Charleston can be considered an almost pure chrysotile operation. Exposure levels for workers at this plant were estimated by Dement et al. (1983a) using nearly 6000 exposure measurements covering the period 1930-1975 and taking into account changes in plant processes and engineering controls (Table 7). The conversion of past exposures measured in mpcm (mpcf) to f/ml was based on both paired sample data (100 pairs) and concurrent samples (986 samples) by these two methods collected in plant operations during 1968-1971.

The most recent update of the Charleston study by Dement et al. (1994) demonstrated an overall lung cancer SMR of 1.97 (126 observed) and an overall SMR for non-malignant respiratory diseases (ICD 470-478 and 494-519) of 3.11 (69 observed). The data for white males, for which data were more complete, demonstrated an overall lung cancer SMR of 2.34 for those achieving at least 15 years of latency. The risk of lung cancer was found to increase rapidly in relation to cumulative exposure. Data for the entire cohort demonstrated an increase in the lung cancer risk of 2-3% for each fibre/ml-years of cumulative chrysotile exposure. Two mesotheliomas were observed among this cohort and an additional mesothelioma was identified among plant workers, occurred after the study follow-up period. Analyses of an overlapping cohort from the same factory (McDonald et al., 1983a) provided similar results.

It can be seen in Table 23 that the regression line slopes for relative risks of lung cancer in relation to accumulated exposure in the Charleston plant are all some 30 times steeper than those observed in chrysotile mining and cement product manufacture.

(d) Friction materials manufacture

There have been only two cohort studies in which the risks of lung cancer in the manufacture of asbestos friction materials have been examined. One of these was among employees of a plant in Stratford, Connecticut, USA, which used only chrysotile (McDonald et al., 1984). The other was in a large plant in the United Kingdom where, apart from two periods before 1944 when crocidolite was needed for one particular contract, only chrysotile was used (Berry & Newhouse, 1983; Newhouse & Sullivan, 1989).

In the United Kingdom plant, there were no excesses in deaths due to all causes or to lung cancer (Newhouse & Sullivan, 1989). Berry & Newhouse (1983) carried out case-control studies on deaths from lung cancer and gastrointestinal cancer using a detailed assessment based on the work history for each subject and estimated levels of chrysotile exposure. The first fibre counts were taken in 1968.

Earlier work practices were simulated using original machinery and appropriate basic materials to estimate historical fibre counts. Fibre counts (both personal and static sampling) were measured by PCOM (Skidmore & Dufficy, 1983) (Table 10). There was no evidence of any exposure-response relationship for either cancer site. For lung cancer, an estimated relative risk of 1.06 for a cumulative exposure of 100 f/ml-years was associated with a 95% confidence interval of 0.6 to 2.0. A total of 13 deaths from mesothelioma (0.54% of all deaths)

was observed among this cohort.

The study in Stratford, Connecticut, was complicated by the fact that the high SMR for lung cancer, based on state death rates, was largely explained by mortality among men employed in the plant for less than one year. The exposure-response relationship for lung cancer was described; however, there was in fact no significant relationship between risk and cumulative exposure. No mesotheliomas were observed among the cohort members in this study.

(e) Mixed products manufacture

In a study of 824 workers employed during 1946-1973 in a factory producing various chrysotile products in Lodz, Poland, and followed-up until 1985, there was a significant increase in lung cancer mortality, based on 24 observed and 12.9 expected deaths (SMR 1.86, 95% CI 1.19-2.77). When workers were grouped according to cumulative asbestos dust exposure, the SMR of lung cancer was 1.55 in the group with exposure to up to 50 mg/m³-years and 3.11 in the group with higher exposure (Szeszenia-Dabrowska et al., 1988). No mesotheliomas were observed among the cohort members in this study.

In a cohort of 1172 workers in Tianjin, China, exposed to chrysotile in the manufacture of asbestos textiles, friction materials and asbestos-cement for at least one year, and followed from January 1972 to December 1987, Cheng & Kong (1992) reported increased risk of mortality from lung cancer (21 observed/6.67 expected; SMR= 3.15; p<0.05) and "other" non-malignant respiratory disease (29 observed/11.78 expected; SMR= 2.46; p<0.05). The comparison was made with the general population of Tianjin. Based upon employment history and monitoring data collected between 1964 and 1975, estimates of qualitative and quantitative (i.e. low, middle or high; cumulative exposures of <400, 400-800 or ≥800 mg/m³-years) exposure to "asbestos dust" were derived for each worker. The Task Group noted that these exposures were extremely high. Analysis of the relative risk of lung cancer according to level, duration or latency since first exposure indicated significant excess risk of mortality at all levels of cumulative exposure (SMRs ranged from 2.71 to 4.85; p <0.01), with "middle" or "high" levels of exposure (p <0.01), with duration of exposure ≥ 15 years (SMRs ranged from 3.02 to 6.67; p <0.01), and with ≥ 20 years latency (SMRs ranged from 2.97 to 3.11; p <0.05). Information on the distribution of workers across industries or movement of workers from one industry to another was not reported.

Chen et al. (1988) reported mortality for 1551 workers in Shanghai, China, producing asbestos textiles, rubber, brake linings, seal material and thermal insulation products between 1958 and 1985. Compared to the population of Shanghai, lung cancer was increased (SMR = 2.28, 14 observed for males; SMR = 2.17, 5 observed for females).

Zhu & Wang (1993) reported significantly increased relative risk (RR= 5.3; 95% CI= 2.6-7.1) and attributable risk (AR= 63.6%; p<0.01) of mortality due to lung cancer between 1972 and 1991 in a cohort of 5893 asbestos workers from eight factories in China (45 974 person-years for men and 39 445 person-years for women) exposed to chrysotile compared to a control group of unexposed workers (number not reported; 122 021 person-years). Quantitative data concerning the level of exposure to chrysotile (or other compounds) were not presented.

(f) Gas mask manufacture

In a study of a group of women who assembled civilian masks using only chrysotile and a group of women who assembled military masks where crocidolite was used, Acheson et al. (1982) reported one death from mesothelioma among 177 deaths in the former group (0.6%) compared with 5 deaths from mesothelioma among 219 deaths (2.3%) in the latter. The experience of the chrysotile group was thus comparable with frequencies observed both in chrysotile mining and milling and in the manufacture of chrysotile-containing products. The authors noted that the case of mesothelioma occurred in a woman who had transferred to the factory that manufactured crocidolite gas masks.

7.1.2.2 Comparisons of lung cancer exposure-response - critical studies

The slopes of the relationship between cumulative exposure to chrysotile and the relative risk of lung cancer are summarized in Table 23 for those studies that reported this information. These studies all expressed this relationship using the following linear relative risk (RR) model:

$$RR = 1 + B \times E$$

where B is the slope and E is the cumulative exposure to chrysotile asbestos expressed in f/ml-years.

The slopes from the studies of the mining and milling industries (0.0006 to 0.0017), the latter having been estimated on a subset of the cohort on which the former was based, and the friction production industries (0.0005 to 0.0006) are reasonably similar. Hughes et al. (1987) in a study of cement workers (section 7.1.2.1b) reported a similar slope (0.0003) in one plant (plant 1) that only used

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chrysotile, and a nearly 20-fold higher slope (0.007) among workers only exposed to chrysotile in another plant (plant 2).

The slopes of 0.01 and 0.03 reported for the two studies of the chrysotile-exposed textile workers conducted on overlapping populations, as well as the slope of 0.007 from one of the two plants (plant 2) of cement workers in the study of Hughes et al. (1987), were an order of magnitude greater than those reported for the other cohorts. It should be noted that the two textile cohorts were identified from the same textile facility, but were based on different cohort definitions. Hence, it is not surprising that the slopes from these two studies were similar. The slopes in the studies of chrysotile-exposed textile workers are also remarkably similar to those reported in other studies of textile workers with mixed fibre exposures (Peto, 1980; McDonald et al., 1983b; Peto et al., 1985). This similarity in findings provides some support for the validity of the slopes reported in the chrysotile-exposed textile cohorts.

The reason for the much higher slopes observed in studies of textile workers is unknown, although several possible explanations have been suggested. The first is that these differences might be attributed to errors in the classification of exposures in these studies. Particular concern has been raised about errors in the exposure assessment related to conversions from mpcm (mpcf) to fibres/ml that were performed, particularly in the mining and milling studies (Peto, 1989). Sebastien et al. (1989) conducted a lung burden study specifically designed to examine whether the differences in lung cancer slopes observed in the Charleston chrysotile textile cohort and the Quebec mining industries could be explained by differences in errors in exposure estimates. Lung fibre concentrations were measured in: (a) 32 paired subjects that were matched on duration of exposure and time since last exposure; and (b) 136 subjects stratified on the same time variables. Both analyses indicated that the Quebec/Charleston ratios of chrysotile fibres in the lungs were even higher than the corresponding ratios of estimated exposures. This finding was interpreted by the author as being clearly inconsistent with the hypothesis that exposure misclassification could explain the large discrepancy in the lung exposure-response relationships observed in the two cohorts.

Sebastien et al. (1989) offered a second possible explanation for the differences, which was that observations in the Charleston textile cohort may have been confounded by exposure to mineral oils. Dement et al. (Dement, 1991; Dement et al., 1994) have conducted two nested case-control studies designed to evaluate the potential for confounding by exposure to mineral oils in the Charleston textile cohort. Cases and controls were assigned to a qualitative mineral exposure category as well as asbestos exposure. The relationship between chrysotile exposure and lung cancer risk was observed to be virtually unaffected by control for exposure to mineral oils in these analyses. The authors concluded that confounding by machining fluids was unlikely. It should also be noted that studies of other cohorts of workers exposed to machining fluids (including mineral oils) have failed to detect an increase in lung cancer risk (Tolbert et al., 1992).

Finally, it has been suggested that the higher lung cancer risk observed among textile workers might be explained by differences in fibre size distributions (Dement, 1991; McDonald et al., 1993; Dement et al., 1994). Textile operations have been shown to produce fibres that are longer in length than in mining and other operations using chrysotile asbestos (Dement & Wallingford, 1990). The study of Sebastien et al. (1989) also examined the hypothesis that differences in fibre size distribution could explain the discrepancy in lung cancer exposure-response relationships between the Quebec mining and Charleston textile cohorts. Although the authors concluded that differences in fibre size distributions were an unlikely explanation, it was noted that there was a slightly higher percentage of long chrysotile fibres (> 20.5 µm) in the lungs of workers from the Charleston textile facility than in the Quebec miners.

7.1.2.3 Other relevant studies

(a) Mining and milling

Kogan (1982) reported on the morbidity and mortality of chrysotile miners and millers in the former USSR. Dust exposure levels were reported to be extremely high in the 1950s (over 100 mg/m³) and were substantially reduced to 3 to 6 mg/m³ in the 1960s and 1970s. The occurrence of asbestosis was substantially reduced by 1979; SMRs of lung cancer in male miners based on reference rates from a neighbouring city were 3.9 during 1948 to 1967 and 2.9 during 1968-1979. In male millers the corresponding values were 4.3 and 5.8. Corresponding figures for women were: miners, 3.9 and 9.4; millers, 2.9 and 9.7 (observed deaths not reported).

Zou et al. (1990) conducted a retrospective cohort mortality study of 1227 men employed at a chrysotile mine in Laiyuen, Hebei province of China, prior to 1972. Mortality in this cohort was compared with that from 2754 local residents of Laiyuen who had never been exposed to asbestos. Based on follow-up of this cohort from 1972 to 1981, 67 deaths were identified (of which 6 were from lung cancer and 3 from mesothelioma) in the asbestos cohort and 247 deaths in the referent population. The lung cancer rate in the exposed cohort was

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reported to be significantly greater ($p < 0.001$) than the rate in the referent group. The interpretation of this study is limited by the poor description of the methodology used for standardization and statistical testing.

Cullen & Baloyi (1991) reviewed the X-rays, demographic data, and medical and occupational histories for 51 workers with asbestos-related diseases that had been submitted for compensation to a medical board in Zimbabwe since its independence in 1980. One pathologically confirmed case of mesothelioma and one case that radiologically resembled mesothelioma were identified. These cases were associated with occupational exposures to chrysotile asbestos in the Zimbabwe mines and/or mills.

(b) Asbestos-cement production

In other studies of asbestos-cement workers, there has been greater exposure to commercial amphiboles. A study by Neuberger & Kundi (1990, 1993) showed an increased lung cancer risk (SMR = 1.72), which became a small, non-significant one (SMR = 1.04) after adjustment for individual smoking histories. Two studies, (Finkelstein., 1984; Magnani et al., 1987) showed high lung cancer risks (SMRs = 4.8 and 2.68, respectively), suggesting very heavy exposures. All other asbestos-cement worker studies (Clemmensen & Hjalgrim-Jenson, 1981; Alies-Patin & Valleron., 1985; Raffn et al., 1989; Albin et al., 1990) showed positive results, with SMRs up to 1.8; however, smoking was not controlled for in these studies.

(c) Mixed products manufacture

In several reported studies, workers have been exposed to unspecified forms of asbestos in production of either unspecified or mixed products (see, for example, Berry et al., 1985; Enterline et al., 1987).

Epidemiological data for asbestos-exposed workers in Germany who died between 1977 and 1988 were reported in a proportional mortality study by Rösler et al. (1993), although diagnostic criteria were not clearly specified nor was it possible to clearly separate exposure to chrysotile alone from that to mixed fibre types. Among those exposed mainly to chrysotile (464 deaths), the lung cancer proportional mortality ratio (PMR) was 1.54 (95% CI = 1.16-2.01); 24 deaths (5.2%) were due to pleural mesothelioma and 5 (1.1%) to peritoneal mesothelioma. Mortality for those exposed to both chrysotile and crocidolite (115 deaths) was similar, and there was a higher proportion of deaths (3.5%) due to peritoneal mesothelioma. The PMR for pleural mesothelioma was highest in textile manufacture, followed by insulation, paper, cement and polymers, and was lowest in friction product manufacture. Peritoneal mesotheliomas were reported in textile, insulation and cement manufacture.

A series of 843 mesothelioma cases identified during 1960 to 1990 in the state of Saxony-Anholt, which was formerly part of the German Democratic Republic, was reported by Sturm et al. (1994). According to the authors, asbestos products were primarily made from chrysotile asbestos from the Ural mountains of Russia. Only small amounts of chrysotile from Canada and even smaller quantities of amphiboles from Mozambique or Italy were used in manufacturing. The authors indicated that, out of 812 cases with complete data, 67 were exposed only to chrysotile, 331 were exposed to chrysotile and possibly amphiboles, 279 were exposed to both chrysotile and amphiboles, and 135 were exposed only to amphiboles.

(d) Application and use of products

Cohort studies of populations of workers using only or predominantly chrysotile-containing products in applications such as construction have not been identified. Some relevant information is available, however, from population-based analyses of primarily mesothelioma in application workers exposed generally to mixed fibre types.

Although the odds ratio for lung cancer associated with exposure to "asbestos" has been estimated in many case-control studies, the studies have not been in general able to distinguish between chrysotile and amphibole exposure, and are therefore less informative for the present evaluation (see, for example, Kjuus et al., 1986). In a multisite case-control study from Montreal, Canada, however, exposures to chrysotile and to amphiboles were separated, although exposure to amphiboles was not controlled for in the analysis on exposure to chrysotile (Siemiatycki, 1991). In this study, the occupational history of male cases (aged 35-70) of cancer at 20 sites and of 533 population controls was evaluated by a team of industrial hygienists and chemists to assess exposure to 293 agents. Overall, the lifetime prevalence of exposure to chrysotile was 17%, and that of exposure to amphiboles, 6%. The main occupations involving exposure to chrysotile that were considered were motor vehicle mechanics, welders and flame cutters, and stationary engineers. When lung cancer cases (N=857) were compared with cases of all other types of cancers, the odds ratio (OR) of any exposure to chrysotile was 1.2 (90% CI=1.0-1.5; 175 exposed cases), and that of 10 or more years of exposure with at least 5 years of latency ("substantial exposure") was 1.9 (90% CI 1.1-3.2; 30 exposed cases). Corresponding ORs of exposure to amphiboles were 1.0 and 0.9. The OR of exposure to chrysotile was higher for oat cell carcinoma than for other types of lung cancer.

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Twelve cases of mesothelioma were included in this study. The OR of any exposure to chrysotile was 4.4 (90% CI=1.6-11.9; 5 exposed cases) and that of substantial exposure was 14.6 (90% CI=3.5-60.5; 2 cases). Corresponding ORs of exposure to amphiboles were 7.2 (90% CI=2.6-19.9; 4 cases) and 51.6 (90% CI=12.3-99.9; 2 cases).

Based on analyses of mortality of workers with mixed exposures to chrysotile and amphiboles in the United Kingdom, by far the greatest proportion of mesotheliomas occurs in users of asbestos-containing products, rather than those involved in their production. In the United Kingdom, all death certificates that mention mesothelioma have been recorded since 1968, and 57 000 workers subject to the 1969 Asbestos Regulation or the 1984 Asbestos (Licensing) Regulations have been followed-up. Analyses of these data have led to the following conclusions:

1. Asbestos exposure caused approximately equal numbers of excess deaths from lung cancer (749 observed, 549 expected) and mesotheliomas (183 deaths) within the occupations covered by the 1969 and 1984 regulations (OPCS/HSE, 1995).
2. Only a few (5%) of British mesothelioma deaths were among workers in regulated occupations (Peto et al., 1995). The majority of deaths occurred in unregulated occupations in which asbestos-containing products are used, particularly in the construction industry. The risk was particularly high among electricians, plumbers and carpenters as well as among building workers.

Extensive case-control studies of 668 cases of mesothelioma as ascertained through pathologists were conducted by McDonald & McDonald (1980) throughout Canada (1960-1975) and the USA (in 1972). Relative risks were as follows: insulation work, 46.0; asbestos production and manufacture, 6.1; heating trades (other than insulation), 4.4. Four subjects were men who had been employed in Quebec chrysotile mines and three were children of employees; no other subjects had lived in the mining area. In some 12 listed occupations, there was no excess of cases over controls, e.g., garage work, carpentry, building maintenance.

Begin et al. (1992) analysed 120 successful claims for pleural mesothelioma submitted to the Quebec Workman's Compensation Board during 1967-1990. Of these, 49 cases occurred among workers in the mining and milling industry, 50 in the manufacturing and industrial application sector and 21 in other types of industry. The miners and millers were thought to be primarily exposed to chrysotile, while the rest were believed to be exposed to mixtures of amphiboles and chrysotile. The numbers of cases ascertained by Begin et al. via the compensation system were consistent with the numbers of incident mesotheliomas observed in miners and millers but grossly underestimated the recorded frequency of mesothelioma in the other industrial sectors (McDonald & McDonald, 1993).

In other large population-based case-control studies of mesothelioma (see, for example, Bignon & Brochard, 1995), it was not possible to separate the effect of chrysotile from that of amphiboles.

Attempts have been made by three groups of investigators to assess the contribution of chrysotile to mesothelioma risk by considering the duration of its use compared with other fibres. These analyses were based, in part, on models for the risk of mesothelioma associated with exposure to various forms of asbestos, which have been widely used by regulatory agencies in the USA, such as the Consumer Product Safety Commission (1987), the Environmental Protection Agency (1986) and the Occupational Safety and Health Administration (1986). Formulae for these models are similar (see, for example, the HEI report) and will not be described here in detail. The analyses include studies of insulation workers (Nicholson & Landrigan, 1994) and railroad machinists in the USA (Mancuso, 1988), and cement workers in

Denmark (Raffn et al., 1989). Although the authors of these studies suggest the occurrence of mesothelioma prior to the widespread introduction of amphiboles into industries, there is unresolved controversy about the reliability of the data on which these conclusions are based.

Motor mechanics who repair asbestos-containing brakes and clutches can be exposed to chrysotile, as this is by far the predominant fibre used in this application. Exposures can occur during removal of wear debris from brake and clutch assemblies and during grinding of new linings (Rohl et al., 1976; Rodelsperger et al., 1986). Cases of mesothelioma have been reported among brake mechanics (Langer & McCaughey, 1982; Woiwitz & Rodelsperger, 1991; Woiwitz & Rodelsperger, 1992).

In two case-control studies of mesotheliomas, there was no excess risk among garage workers or mechanics (Teta et al., 1983; Woiwitz & Rodelsperger, 1994). In the latter study, there were two control groups; one was based on hospital cases undergoing lung resection, in most instances because of lung cancer, and the other was from the general population. The authors noted that confounding due to asbestos exposure in other occupations limited their ability to detect mesothelioma risks among car mechanics.

The proportional mortality for mesothelioma among British motor

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mechanics was reported to be lower than the national average (PMR = 0.40) (OPCS/HSE, 1995). The extent to which all motor mechanics were exposed to friction products was not defined.

7.1.3 Other malignant diseases

Results of cohort studies of workers almost exclusively exposed to chrysotile asbestos and considered by the Task Group to be most relevant to this evaluation are summarised in Table 23 and described in section 7.1.3.1. Studies that contribute less to our understanding of the effects of chrysotile, due primarily to concomitant exposure to amphiboles or to limitations of design and reporting, are presented in section 7.1.3.2.

7.1.3.1 Critical occupational cohort studies involving chrysotile

There has been considerable unresolved controversy regarding the possible carcinogenic effect of asbestos on the larynx, kidney and gastrointestinal tract. Moreover, there is little evidence that permits an assessment of chrysotile, in particular, as a risk factor for these cancers. In four of the cohorts exposed almost exclusively to chrysotile, data were presented on SMRs for laryngeal cancer (Hughes et al., 1987; Piolatto et al., 1990; McDonald et al., 1993; Dement et al., 1994). Non-significant excesses were observed in some of the studies. It is not possible to draw conclusions about the association with laryngeal cancer because the data are too sparse and because confounding may play an important role in creating associations. Where examined, laryngeal cancer was strongly associated

with cigarette smoking (McDonald et al., 1993) and alcohol consumption (Piolatto et al., 1990).

Owing to the rarity of kidney cancer, cohort studies have limited statistical power to detect even moderate increases of kidney cancer. There was no overall excess of kidney cancer in the cohort of miners and millers followed by McDonald et al. (1993), although some increases occurred in subgroups stratified by mine and exposure; however, the number of cases precludes meaningful interpretation. In the study in asbestos-cement production workers, in which the SMR for kidney cancer in plant 1 (chrysotile) was 2.25, based on only four cases, the SMR for lung cancer was 1.17 (Hughes et al., 1987). No other data on kidney cancer risks were presented for the other cohorts of chrysotile workers.

In predominantly "chrysotile"-exposed cohorts, there is no consistent evidence of excess mortality from stomach or colorectal cancer. In the analysis of mortality in the Quebec cohort up to 1989 (McDonald et al., 1993), the SMR for gastric cancer was elevated in the highest exposure category (SMR = 1.39); the corresponding SMR for lung cancer was 1.85. Overall, there was no systematic relationship with exposure.

7.1.3.2 Other relevant studies

Most case-control studies have investigated the association between exposure to unspecified or several forms of "asbestos" and various cancers (see, for example, Bravo et al., 1988; Parnes, 1990; Jakobsson et al., 1994). In the multisite case-control study conducted in Montreal (see section 7.1.2.3d), 177 cases of kidney cancer were included (Siemiatycki, 1991). The OR of any exposure to chrysotile was 1.2 (90% CI=0.9-1.7; 31 exposed cases), and that of substantial exposure was 1.8 (90% CI=0.9-3.7; 6 cases). Corresponding ORs of exposure to amphiboles were 0.7 (8 cases) and 0.8 (1 case).

In this study, a total of 251 stomach, 497 colon and 257 rectal cancer cases were included (Siemiatycki, 1991). The ORs for any and substantial exposure to chrysotile were 1.3 and 0.7 for stomach cancer, 1.0 and 1.6 (90% CI=1.0-2.5) for colon cancer, and 0.7 and 0.5 for rectal cancer. Exposure to amphiboles was not associated with a significant increase in risk of any of these cancers.

7.2 Non-occupational exposure

Data available on incidence or mortality in populations exposed in the vicinity of sources of chrysotile since Environmental Health Criteria 53 was published have not been identified. In studies reviewed at that time, increases in lung cancer were not observed in four limited ecological epidemiological studies of populations in the vicinity of natural or anthropogenic sources of chrysotile (including the chrysotile mines and mills in Quebec) (IPCS, 1986).

Data available on incidence or mortality in household contacts of asbestos workers were reviewed in Environmental Health Criteria 53. In several case-control studies reviewed therein, there were more mesothelioma cases with household exposure than in controls, after exclusion of occupation. However for most of these investigations, it is not possible to distinguish the form of asbestos to which household contacts were exposed on the basis of information included in the published reports.

Available data on effects of exposure to chrysotile asbestos (specifically) in the general environment are restricted to those in populations exposed to relatively high concentrations of chrysotile asbestos in drinking-water, particularly from serpentine deposits or asbestos-cement pipe. These include ecological studies of populations

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in Connecticut, Florida, California, Utah and Quebec, and a case-control study in Puget Sound, Washington, USA, reviewed in Environmental Health Criteria 53. On the basis of these studies, it was concluded that there was little convincing evidence of an association between asbestos in public water supplies and cancer induction. More recent identified studies do not contribute additionally to our understanding of health risks associated with exposure to chrysotile in drinking-water.

8. ENVIRONMENTAL FATE AND EFFECTS ON BIOTA

8.1 Environmental transport and distribution

Soils developed on chrysotile-bearing serpentinitic rocks exist in some areas of the world. Brooks (1987) and Roberts & Proctor (1993) have shown that this rock type forms very poor soils and gives rise to unique plant communities. Natural distribution of chrysotile has only become an issue in the last 25 years or so.

Because of their small size, chrysotile fibres may be transported from their place of origin by wind and water. Wind is the primary medium of transport, and, in areas where chrysotile is abundant, large concentrations have been observed in rain and snow run-off (Hallenbeck et al., 1977; Hesse et al., 1977; Bacon et al., 1986). There is contradictory evidence concerning an increase in global concentrations. Cossette et al. (1986) suggested that the global distribution, estimated by chrysotile content in ice core deposits, has been relatively constant. This is in contrast to findings by Bowes et al. (1977), which suggested increases in asbestos deposits in the Greenland ice core samples from the mid-1750s to the present. The mobility of fibres from sites of asbestos-bearing strata is often due to sparse vegetation cover because of adverse physical and chemical conditions not conducive to plant growth.

The management of sediments deposited during flooding by streams draining asbestos-bearing materials appears to be one of the great concerns in relation to environmental exposure. The large water supply system in the California aqueduct is contaminated by run-off containing chrysotile (Hayward, 1984; Jones & McGuire, 1987).

8.1.1 Chrysotile fibres in water

Lake and stream data have been reviewed by Schreier (1989), and chrysotile concentrations are highly variable, depending on proximity to source areas and river flow regime. Concentrations of 1×10^6 to 1×10^8 f/litre are typical in most rivers draining serpentinitic rocks but concentrations of up to 1×10^{13} f/litre have been reported by Schreier (1987) in a stream draining asbestos-bearing bedrock. There are significant seasonal fluctuations in concentrations in most streams and the fibres may remain in suspension for long periods of time.

Chrysotile is very stable in alkaline water but magnesium leaching occurs from the fibre structure under acidic conditions. Many rivers have acidic conditions and chrysotile's surface charge changes from positive in alkaline conditions to negative under acidic conditions (due to the loss of Mg^{2+} from surface brucite layers). In addition, suspended chrysotile fibres may adsorb organic materials, which eventually cover the entire fibre surface (Bales & Morgan, 1985).

8.1.2 Chrysotile fibres in soils

In the absence of organic material, which when present forms organic acids, chrysotile fibres are fairly resistant to alteration. However, in acid soil environments magnesium and trace metals are released and their concentrations locally increased, whereupon they are selectively taken up by plants or soil biota, e.g., by earthworms (Schreier & Timmenga, 1986). Fibres exposed to surface processes will be affected by acid rain and are likely to be transformed. Most attention has been given to the release of trace metals under acidic weathering conditions (Schreier et al., 1987a; Gasser et al., 1995). However, most studies have focussed primarily on the non-fibrous serpentine minerals. While there is evidence of deficiencies and adverse effects on plants and biota, little research has been conducted on the fibre constituents.

8.2 Effects on biota

While the fibre size and geometry appear to be the main issues for human health, the bulk and trace metal chemistry have been identified as factors and agents detrimental to plant growth (Brooks, 1987; Roberts & Proctor, 1993). The chemical impact (little calcium, excess magnesium, chromium, nickel, cobalt) has been studied in many places under the rubric term serpentinitic rock or soil materials, but rarely has chrysotile been identified as the key component mineral.

8.2.1 Impact on plants

The plants most frequently found in serpentinitic environments have been characterized by Brooks (1987) as belonging to insula (neoenidism) and depleted taxa (paleoendism). Almost all plants on chrysotile-enriched soils show stress symptoms, such as reduced growth, lower frequency, low diversity and slight discoloration. Many

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Serpentine-endemic species have been identified, and coniferous trees appear to be more tolerant to such soils than broadleaf species.

There is great internal variability within sites but moisture, magnesium, low calcium:magnesium ratios, excessive nickel and cobalt, and deficiencies in molybdenum, calcium, phosphorus and nitrogen have all been cited as key factors responsible for poor plant growth. Since many of these factors interact, it is impossible to single out any one of them as the prime factor in limiting vegetation growth. Morphological responses to these adverse conditions are: xeromorphic foliage with different coloration; reduction in size leading to shrubby, stunted plagiotropic appearance; and the development of an extensive root system. Chemical responses are exclusion or restriction of some cations, excess metal uptake and metal storage in different compartments of the plants. There is no universal response by plants to these adverse conditions (Brooks, 1987).

Physical stress results because most of the soils on serpentinitic bedrock are shallow and stoney, leading to poor water-holding capacity. All dark coloured serpentinites exhibit elevated diurnal temperature fluctuations. The moisture stress might be responsible for greater root development, and often such soils are prone to instability. No investigation has thus far been made to determine if the physical properties of fibres are relevant to hazards to plant roots and whether these fibres penetrate into the plant cell walls. In addition, no evidence has so far been provided to suggest that roots are injured when expanding into fibre-rich soils.

The chemical stress is either exerted by excessive concentrations of some elements or serious deficiencies of metals or nutrients. Calcium deficiencies have often been cited as one of the key indicators of stress, but excess metals are likely to be more significant. Most chrysotile-rich soils have neutral to alkaline pH, which reduces metal solubility. Metal accumulation by plants is a topic of interest, and Brooks (1987) proposed the term "hyper-accumulators" for plants that grow on asbestos-rich soils and are enriched in nickel to levels far beyond those found in the soil (Wither & Brooks, 1977; Brooks, 1987).

The use of seeds and plants native to serpentinitic sites is desirable for reclaiming chrysotile-contaminated sites. In addition, native plants on serpentinites do not grow vigorously and do not always respond to amendments (Brooks, 1987; Roberts & Proctor, 1993). Tree seedlings invariably have the greatest difficulties surviving the first year after planting. Almost all plants show stress symptoms and fertilizer amendments are necessary to maintain continuous vegetation cover.

8.2.2 Impact on terrestrial life-forms

Few studies have examined the effect of chrysotile on soil animals. There is a general reduction in soil animals in all such soils, which is not surprising given the low organic matter content and adverse plant growing conditions.

Earthworms are known to tolerate and accumulate trace metals but, in the presence of chrysotile fibres, *Lumbricus rebellus* showed reduced survival (Schreier & Timmenga, 1986) after introduction into chrysotile-rich floodplain sediments. Mortality was attributed to the combined effect of exposure to elevated levels of nickel and magnesium (body burdens were 2-10 times higher in exposed animals relative to controls), as well as the abrasive nature of the fibres.

Termites move large quantities of materials from great depths and, in studies of Zimbabwean serpentinites, Wild (1975) and Brooks (1987) showed increases in pH and levels of nickel, calcium and magnesium in the mounds. The increase in pH might be responsible for reducing the metal toxicity, but the termite soldiers, which consume more mineral materials, were found to have higher nickel and chromium accumulation than termites of higher social orders, which consume

different food sources provided to them by the soldiers. The termite mounds were found to be fireproof.

Information on microorganisms is also very limited. There are fewer nitrogen fixers in chrysotile-enriched soils (White, 1967; Proctor & Woodall, 1975) and fewer microorganisms (Ritter-Studnicka, 1970). Fungal populations and heterotrophic bacteria are significantly reduced (Bordeleau et al., 1977). At the same time, populations of facultative heterotrophic and autotrophic bacteria are increased. It is unclear what the causes are for these differences. The lack of organic matter, moisture deficiencies, nutrient imbalances and metal toxicities have all been claimed to be responsible for the lack of soil microorganisms. Trace metals, such as nickel, have been found to inhibit the growth of eubacteria, actinomycetes, cyanobacteria, yeasts, filamentous fungi, protozoa and algae (Babich & Stotzky, 1983). In contrast, Deom (1989) showed that mycorrhizal fungi were not adversely affected and were fully functioning in chrysotile-rich soils in central British Columbia, Canada.

Ingested soil plays a significant part in grazing animals. As shown by Thornton (1981), up to 15% of the dry matter intake in sheep and 10% in grazing cattle can be soil. He also suggested that there is a good relationship between metal levels in the soil and those found in the blood of the grazing animals. This was confirmed in cattle

grazing in fields affected by chrysotile from flooding events (Schreier et al., 1986). Significant increases in nickel and magnesium were observed in the blood of the animals at the time they were grazing on such fields. Unfortunately the animal population was too small and genetically too diverse to be used for a long-term study.

8.2.3 Impact on aquatic biota

The effect of asbestos fibres on aquatic biota has not been investigated in any detail.

Belanger et al. (1986a, 1987) showed that siphoning activity was significantly reduced, and that growth and reproduction were altered in juvenile *Corbicula fluminea* (Asiatic clam) when exposed to chrysotile fibres. Siphoning activity was reduced by about 20% in juvenile clams exposed to 10^2 to 10^8 f/litre for 30 days; shell growth was significantly reduced at concentrations in the range of 10^4 to 10^8 f/litre (Belanger et al., 1986b). Clams were reported by Belanger et al. (1987) to accumulate chrysotile to a greater degree than any previously tested aquatic organism. Whole-body burdens of clams exposed to 10^8 f/litre for 30 days were nearly 10^3 f/mg (dry weight), while field-collected clams, exposed throughout their lifetime (2-3 years) to about 10^9 chrysotile f/litre accumulated as much as 6.5×10^8 f/mg (dry weight). Graney et al. (1983) reported that these clams also accumulated trace metals.

Lauth & Schurr (1983, 1984) suggested that positively charged chrysotile fibres will attach to planktonic cells, inhibiting their swimming capacity and thus removing a potentially important food source from the water column.

Several studies have been conducted on the effect of chrysotile on fish. Behavioural and histopathological aberrations (a few tumour swellings) were reported in larvae of coho salmon (*Oncorhynchus kisutch*) when larvae were reared in chrysotile-rich water at concentrations of 3×10^6 f/litre for up to 86 days (Belanger et al., 1986c). Growth of larvae of juvenile Japanese medaka (*Oryzias latipes*) was significantly reduced at concentrations of 10^6 to 10^8 f/litre in a 13-week exposure study, and 100% mortality occurred at 10^{10} f/litre after 56 days of exposure. Spawning frequency was 33% higher in control populations of medaka compared with those exposed to 10^4 to 10^8 chrysotile f/litre. After exposure for 3 months to 10^8 f/litre, chrysotile was observed to accumulate in the fish tissue at a concentration of nearly 500 f/mg dry weight (Belanger et al., 1990). Mesothelioma has been reported in fish but no reference was made to asbestos exposure (Herman, 1985).

Trace metal uptake in native fish, exposed to very high chrysotile concentrations in a stream, were reported by Schreier et al. (1987b). These fish did not show any evidence of unusual growth but recorded significant levels of nickel in the epiaxial muscle tissue. In contrast, rainbow trout introduced into a serpentinitic lake with chrysotile concentrations of 2 to 100×10^6 f/litre did not show any adverse effect 5 years after introduction (H. Schreier, 1995, personal communication to the IPCS).

Belanger et al. (1987) have suggested that a specific species of clam, *Corbicula*, may be useful as a biomonitor for chrysotile asbestos in public water supplies.

The impact of chrysotile/serpentine presence and degradation on the environment is difficult to gauge. Observed perturbations are many but their long-term impact is virtually unknown.

9. EVALUATION OF HEALTH RISKS OF EXPOSURE TO CHRYSOTILE ASBESTOS

9.1 Introduction

A previous evaluation by an IPCS Task Group (IPCS, 1986) addressed all types of asbestos, including chrysotile. At that time, it was concluded that: "The risk of mesothelioma in chrysotile-exposed workers is less than that in workers exposed to crocidolite or amosite".

In this monograph (EHC 203), the evaluation is focussed, to the extent possible, on data relevant to assessment of the health risks of exposure to chrysotile, although it should be noted that commercial chrysotile may contain a small proportion of amphiboles, some of which may be fibrous. This was considered appropriate in view of the fact that since the publication in 1986 of the Environmental Health Criteria 53, the use of crocidolite and more recently, amosite, has been largely discontinued. Moreover, the pattern of use of chrysotile asbestos in many countries has changed somewhat, with the asbestos-cement industry being by far the largest user worldwide, accounting for some 85% of all use. Although declining in the North American and Western European markets, asbestos-cement product manufacturing continues to grow in areas including South America, South-East Asia, the eastern Mediterranean region and eastern Europe.

Other chrysotile products include friction products, gaskets and asbestos paper. Production of shipboard and building insulation, roofing and, particularly, flooring felts, and other flooring

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Materials, such as vinyl asbestos tiles, has declined considerably, with some of them disappearing from the market place. Friable chrysotile- and/or amphibole-containing materials in building construction have been phased out in many countries. It should be noted, however, that there are large quantities of these materials still in place in buildings, which will continue to give rise to exposure to both chrysotile and the amphiboles during maintenance, removal or demolition. Chrysotile has been used in hundreds (or even thousands) of products that have entered global commerce. These existing products may also give rise to exposure.

This evaluation is based on studies which the Task Group considered contribute to our understanding of the health risks associated with exposure to chrysotile.

Past uncontrolled mixed exposure to chrysotile and amphiboles has caused considerable disease and mortality in Europe and North America. Moreover, historical experience to mixed fibre types in European countries has clearly indicated that a larger proportion of mesotheliomas occurs in the construction trades than in production. Far larger quantities of chrysotile than of other types of asbestos were used in most construction applications. Epidemiological studies that contribute to our understanding of the health effects of chrysotile conducted to date and reviewed in this monograph have been on populations mainly in the mining or manufacturing sectors and not

in construction or other user industries. This should be borne in mind when considering potential risks associated with exposure to chrysotile.

9.2 Exposure

Fibre concentrations reported below are for fibres longer than 5 μm .

9.2.1 Occupational exposure

9.2.1.1 Production

Exposure is dependent upon such factors as the extent of control, the nature of the material being manipulated and work practices. Based on data available to the Task Group, mainly from North America, Europe and Japan, workplace exposure in the early 1930s was very high in most sectors of the industry for which data are available. Levels dropped considerably between the 1930s and the late 1970s and have continued declining substantially to the present day, owing to the introduction of controls. In the mining and milling industries in Quebec, Canada, the average concentration of fibres in air often exceeded 20 fibres/ml (f/ml) in the 1970s and is now less than 1 f/ml. In the production of asbestos-cement, mean concentrations in the 1970s were typically below about 1 f/ml. Mean concentrations of 0.05 to 0.45 f/ml were reported in Japan in 1992. In asbestos textile manufacture, mean concentrations between 2.6 and 12.8 f/ml in the period between 1970 and 1975 and 0.1 to 0.2 f/ml in the period 1984-1986 were reported in Japan. Trends have been similar in the production of friction materials. Based on data available from Japan, mean concentrations of 10 to 35 f/ml were reported in production during 1970 to 1975, while levels in 1984 to 1986 were 0.2 to 5.5 f/ml. In a plant in the United Kingdom at which a large mortality study was conducted, concentrations were above 20 f/ml before 1931 and generally below 1 f/ml during 1970-1979.

Only limited data on concentrations of chrysotile in occupational environments in countries other than the USA, Europe and Japan were available to the Task Group. The data above on historical levels in uncontrolled conditions and additional information on gravimetric concentrations to which workers are exposed in product manufacture in China indicate that concentrations may be very high (up to 100 f/ml) in production facilities without adequate dust control. In a recent survey of chrysotile mills in India, average concentrations of 2 to 13 f/ml were reported.

9.2.1.2 Use

Few data on concentrations of fibres associated with the installation and use of chrysotile-containing products were available to the Task Group, although this is easily the most likely place for workers to be exposed. During maintenance of vehicles, peak concentrations of 16 fibres/ml were reported in the 1970s in the USA. Practically all measured levels after 1987 were less than 0.2 f/ml,

due to introduction of controls. Time-weighted average exposure during passenger vehicle repair reported in the 1980s was less than 0.05 f/ml. However, with no controls, blowing off debris from drums results in short-term high concentrations of dust.

Data on concentrations of airborne fibres associated with manipulation of asbestos-cement products available to the Task Group were sparse. In a South African workshop where asbestos-cement sheets were cut into components for insulation, mean concentrations were 1.9 f/ml for assembling, 5.7 f/ml for sweeping, 8.6 f/ml for drilling and 27 f/ml for sanding. Following clean-up and introduction of controls, levels were 0.5 to 1.7 f/ml.

There is potential for widespread exposure of maintenance personnel to mixed asbestos fibre types due to the large quantities of

friable asbestos materials still in place. In buildings where there are control plans, personal exposure of building maintenance personnel in the USA, expressed as 8-h time-weighted averages, was between 0.002 and 0.02 f/ml. These values are the same order of magnitude as exposures reported during telecommunication switch work (0.009 f/ml) and above-ceiling work (0.037 f/ml), although higher concentrations have been reported in utility space work (0.5 f/ml). Concentrations may be considerably higher where control plans have not been introduced. For example, in one case, short-term episodic concentrations ranged from 1.6 f/ml during sweeping to 15.5 f/ml during cleaning (dusting off) of library books in a building with a very friable chrysotile-containing surface formulation. Most other values, presented as 8-h time-weighted averages, are about two orders of magnitude less.

Although few data on exposures among users of asbestos-containing products in industries such as construction were identified, available data clearly demonstrate the need for appropriate engineering controls and work practices for minimizing exposures to chrysotile both in production and use. It should be noted that construction and demolition operations present special control problems.

9.2.2 General population exposure

Sources of chrysotile in ambient air are both natural and anthropogenic. Most airborne fibres in the general environment are short (< 5 µm).

Few recent data on concentrations of chrysotile in air in the vicinity of point sources have been identified. Concentrations around the Shibani chrysotile mine in Zimbabwe ranged from below the limit of detection of the method (<0.01 f/ml) to 0.02 f/ml (fibres longer than 5 µm).

Based on surveys conducted before 1986, concentrations (fibres > 5 µm in length) in outdoor air measured in five countries (Austria, Canada, Germany, South Africa and USA) ranged between 0.0001 and about 0.01 f/ml, with levels in most samples being less than 0.001 f/ml.

Means or medians were between 0.00005 and 0.02 f/ml, based on more recent determinations in seven countries (Canada, Italy, Japan, Slovak Republic, Switzerland, United Kingdom and USA).

Fibre concentrations in public buildings during normal use where there is no extensive repair or renovation are within the range of those measured in ambient air, even where friable asbestos-containing materials were extensively used. Concentrations (fibres > 5 µm in length) in buildings in Germany and Canada reported before 1986 were generally less than 0.002 f/ml. In more recent surveys in five countries (Belgium, Canada, Slovak Republic, United Kingdom and USA) mean values were between 0.00005 and 0.0045 f/ml. Only 0.67% of chrysotile fibres were longer than 5 µm.

9.3 Health effects

9.3.1 Occupational exposure

Adverse health effects associated with occupational exposure to chrysotile are fibrosis (asbestosis), lung cancer and mesothelioma. These effects have also been observed in animals exposed to chrysotile by inhalation and other routes of administration. Based on available data in miners and millers, there is an interaction between tobacco smoke and chrysotile in the induction of lung cancer which appears to be less than multiplicative. Epidemiological evidence that chrysotile asbestos is associated with an increased risk of cancer at other sites is inconclusive.

Emphasis in this evaluation is on those studies that contribute to our understanding of the health risks associated with exposure to chrysotile, especially those that characterize at least to some extent, the exposure-response relationship. It should be noted, however, that exposure-response relationships have relied upon reconstruction of historical exposures. This is often problematic, due to lack of historical exposure measurements, and changes in measurement methods that have required use of conversion factors which are highly variable. Moreover, there are wide variations in exposure characteristics, including fibre size distributions, which are not well characterized in traditional measures of exposure.

The Task Group noted that there is an exposure-response relationship for all chrysotile-related diseases. Reduction of exposure through introduction of control measures should significantly reduce risks. Construction and demolition operations may present special control problems.

9.3.1.1 Fibrosis

The non-malignant lung diseases associated with exposure to chrysotile comprise a somewhat complex mixture of clinical and pathological syndromes not readily definable for epidemiological study. The prime concern has been asbestosis, generally implying a disease associated with diffuse interstitial pulmonary fibrosis accompanied by varying degrees of pleural involvement.

Studies of workers exposed to chrysotile asbestos in different

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Workers have broadly demonstrated exposure-response relationships for chrysotile-induced asbestosis, in so far as increasing levels of exposure have produced increases in the incidence and severity of disease. However, there are difficulties in defining this relationship, due to factors such as uncertainties in diagnosis, and the possibility of disease progression on cessation of exposure.

Furthermore, some variations in risk estimates are evident among the available studies. The reason for the variations is not entirely clear, but may relate to uncertainties in exposure estimates, airborne fibre size distributions in the various industry sectors and statistical models. Asbestotic changes are common following prolonged exposures of 5 to 20 f/ml. The risk at lower exposure levels is not known but the Task Group found no reason to doubt that, although there may be subclinical changes induced by chrysotile at levels of occupational exposure under well-controlled conditions, even if fibrotic changes in the lungs occur, they are unlikely to progress to the point of clinical manifestation.

9.3.1.2 Lung cancer

Exposure-response relationships for lung cancer have been estimated for chrysotile mining and milling operations and for production of chrysotile asbestos textiles, asbestos-cement products and asbestos friction products. Risks increased with increasing exposure. The slopes of the linear dose-response relationships (expressed as the increase in the lung cancer relative risk per unit of cumulative exposure (fibre/ml-years)) were all positive (although some not significantly) but varied widely. Textiles produce the highest risk (slopes 0.01 to 0.03). Risks for production of cement products (slopes 0.0003-0.007), friction materials (slopes 0.0005-0.0006) and chrysotile mining (0.0006-0.0017) are lower.

The relative risks of lung cancer in the textile manufacturing sector in relation to estimated cumulative exposure are, therefore, some 10 to 30 times greater than those observed in chrysotile mining. The reasons for this variation in risk are not clear.

9.3.1.3 Mesothelioma

Estimation of the risk of mesothelioma is complicated in epidemiological studies by factors such as the rarity of the disease, the lack of mortality rates in the populations used as reference, and problems in diagnosis and reporting. In many cases, therefore, risks have not been calculated, and cruder indicators have been used, such as absolute numbers of cases and death and ratios of mesothelioma over lung cancers or total deaths.

Based on data reviewed in this monograph, the largest number of mesotheliomas has occurred in the chrysotile mining and milling sector. All of the observed 38 cases were pleural with the exception of one of low diagnostic probability, which was pleuro-peritoneal.

None occurred in workers exposed for less than 2 years. There was a clear dose-response relationship, with crude rates of mesotheliomas (cases/1000 person-years) ranging from 0.15 for those with cumulative exposure less than 3500 mpcm (< 100 mpcf-years) to 0.97 for those with exposures of 10 500 mpcm (300 mpcf-years).

Proportions of deaths attributable to mesotheliomas in cohort studies in the various mining and production sectors range from 0 to 0.8%. Caution should be exercised in interpreting these proportions, as studies do not provide comparable data stratifying deaths by exposure intensity, duration of exposure or time since first exposure.

There is evidence that fibrous tremolite causes mesothelioma in humans. Since commercial chrysotile may contain fibrous tremolite, it has been hypothesized that the latter may contribute to the induction of mesotheliomas in some populations exposed primarily to chrysotile. The extent to which the observed excesses of mesothelioma might be attributed to the fibrous tremolite content has not been resolved.

Epidemiological studies of populations of workers using chrysotile-containing products in applications such as construction have not been identified, although for workers with mixed exposures to chrysotile and the amphiboles, by far the greatest proportion of mesotheliomas occurs in users of asbestos-containing products rather than in those involved in their production.

9.3.2 General environment

Data on incidence or mortality of disease in household contacts of chrysotile workers or in populations exposed to airborne chrysotile in the vicinity of point sources reported since EHC 53 was published in 1986 have not been identified. More recent studies of populations exposed to chrysotile in drinking-water have likewise not been identified.

9.4 Effects on the environment

The impact of chrysotile/serpentine presence and degradation on the environment and lower life forms is difficult to gauge. Observed perturbations are many but their long-term impact is virtually unknown.

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10. CONCLUSIONS AND RECOMMENDATIONS FOR PROTECTION OF HUMAN HEALTH

- a) Exposure to chrysotile asbestos poses increased risks for asbestosis, lung cancer and mesothelioma in a dose-dependent manner. No threshold has been identified for carcinogenic risks.
- b) Where safer substitute materials for chrysotile are available, they should be considered for use.
- c) Some asbestos-containing products pose particular concern and chrysotile use in these circumstances is not recommended. These uses include friable products with high exposure potential. Construction materials are of particular concern for several reasons. The construction industry workforce is large and measures to control asbestos are difficult to institute. In-place building materials may also pose risk to those carrying out alterations, maintenance and demolition. Minerals in place have the potential to deteriorate and create exposures.
- d) Control measures, including engineering controls and work practices, should be used in circumstances where occupational exposure to chrysotile can occur. Data from industries where control technologies have been applied have demonstrated the feasibility of controlling exposure to levels generally below 0.5 fibres/ml. Personal protective equipment can further reduce individual exposure where engineering controls and work practices prove insufficient.
- e) Asbestos exposure and cigarette smoking have been shown to interact to increase greatly the risk of lung cancer. Those who have been exposed to asbestos can substantially reduce their lung cancer risk by avoiding smoking.

11. FURTHER RESEARCH

- (a) Research and guidance are needed concerning the economic and practical feasibility of substitution for chrysotile asbestos, as well as the use of engineering controls and work practices in developing countries for controlling asbestos exposure.
- (b) Further research is needed to understand more fully the molecular and cellular mechanisms by which asbestos causes fibrosis and cancer. The significance of physical and chemical properties (e.g., fibre dimension, surface properties) of fibres and their biopersistence in the lung to their biological and pathogenic effects needs further elucidation. Dose-response information from animal studies for various asbestos fibre types is needed to evaluate the differential risk of exposure to chrysotile and tremolite.
- (c) Epidemiological studies of populations exposed to pure chrysotile (i.e. without appreciable amphiboles) are needed.
- (d) The combined effects of chrysotile and other insoluble respirable particles needs further study.
- (e) More epidemiological data are needed concerning cancer risks for populations exposed to fibre levels below 1 fibre/ml, as well as continued surveillance of asbestos-exposed populations.

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1. RÉSUMÉ

1.1 Identité, propriétés physiques et chimiques, échantillonnage et analyse

Le chrysotile est un silicate de magnésium hydraté de structure fibreuse utilisé dans un grand nombre de produits du commerce. Il est très répandu aujourd'hui dans le commerce mondial. Les propriétés physiques et chimiques de ce minéral varient selon les différents gisements en exploitation. De nombreux minéraux accompagnent la fibre dans le minerai et parmi ceux-ci figurent sans doute certaines variétés d'amphibole fibreuse. On pense que la trémolite est particulièrement importante à cet égard; sa forme et sa concentration varient dans d'importantes proportions.

Du point de vue analytique, la recherche du chrysotile sur les lieux de travail oblige à recourir à la microscopie optique ou électronique. On a utilisé jusqu'ici divers instruments et dispositifs pour surveiller l'environnement en procédant à la recherche et au dosage des poussières et des fibres totales. Aujourd'hui, on utilise couramment la filtration sur membrane et le microscope à contraste de phase pour les mesures sur les lieux de travail (exprimées en nombre de fibres par ml d'air); on utilise aussi la microscopie électronique par transmission. Cette dernière technique est également employée pour l'analyse des prélèvements environnementaux. On a cherché à déterminer la charge tissulaire afin d'obtenir davantage de données sur l'exposition. En fonction du degré de détail que ces études ont permis d'appréhender, on a pu en tirer des conclusions sur les mécanismes et les étiologies en cause.

On utilisait auparavant des techniques gravimétriques, la précipitation thermique ou la collecte sur mini-impacteur pour les contrôles sur les lieux de travail et ces mesures de poussières (et non pas de fibres) sont les seuls indices dont on dispose pour apprécier les relations exposition-réponse. Il y a eu de nombreuses tentatives en vue de convertir ces valeurs en nombres de fibre par volume d'air, mais elles n'ont rencontré qu'un succès très limité. On s'est rendu compte que les facteurs de conversion dépendaient du type d'industrie et même du type d'opération industrielle; les facteurs de conversion universels sont d'une grande variabilité.

1.2 Sources d'exposition professionnelle et environnementale

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On trouve de faibles concentrations de chrysotile dans tout l'environnement de l'écorce terrestre (air, calottes glaciaires et sol). Les phénomènes naturels et les activités humaines contribuent à la production d'aérosols de fibres et à leur dissémination dans l'environnement. Parmi les sources d'origine humaine, on peut citer diverses activités professionnelles génératrices de poussières qui vont de l'extraction et du traitement du minerai jusqu'à la fabrication, aux applications, à l'utilisation et finalement, au rejet sous forme de déchets.

Il y a 25 pays producteurs, parmi lesquels sept gros producteurs. La production mondiale annuelle d'amiante a culminé vers le milieu des années 70 avec plus de 5 millions de tonnes, mais depuis lors elle a reculé à environ 3 millions de tonnes. Plus de 100 pays fabriquent des produits à base de chrysotile et le Japon en est le principal consommateur. Les grands types d'activités qui sont actuellement susceptibles de provoquer une exposition au chrysotile sont a) l'extraction minière et l'élaboration du matériau (broyage, battage, cardage et filage); b) la fabrication de produits à base de chrysotile (matériaux résistants à la friction, tuyaux et plaques ou feuilles de fibro-ciment, joints, papier, textiles); c) le BTP (construction, réparation et démolition); d) le transport et l'élimination. L'industrie du fibro-ciment ou amiante-ciment est de loin le plus gros utilisateur de fibres de chrysotile puisqu'elle consomme environ 85% de la production.

Lors de la fabrication, de la pose et de l'élimination des produits contenant de l'amiante, de même parfois qu'à l'occasion de l'usure normale de ces produits, il y a libération de fibres. La manipulation de produits friables peut également être une source importante de fibres de chrysotile.

1.3 Concentration sur les lieux de travail et dans l'environnement

D'après des données provenant essentiellement d'Amérique du Nord, d'Europe et du Japon, l'exposition était très importante sur les lieux de travail de la plupart des secteurs de production au cours des années 30. Elle a beaucoup reculé à la fin des années 70 pour descendre finalement aux valeurs actuelles. Au Québec, la concentration atmosphérique moyenne en fibres dans les industries d'extraction et de production a souvent dépassé 20 fibres /ml (f/ml) au cours des années 70, alors qu'elle se situe maintenant en général bien au-dessous de 1 f/ml. Vers la même époque, la concentration moyenne dans l'industrie japonaise du fibro-ciment se caractérisait par des valeurs de l'ordre de 2,5 à 9,5 f/ml, valeurs qui sont tombées à 0,05-0,45 en moyenne en 1992. Dans l'industrie des textiles d'amiante au Japon, la concentration moyenne a été de 2,6 à 12,8 f/ml entre 1970 et 1975, pour reculer à 0,1-0,2 f/ml entre 1984 et 1986. On a observé des tendances analogues dans l'industrie des matériaux antifriction: selon les données provenant de ce même pays, la concentration moyenne a été de 10-35 f/ml entre 1970 et 1975, et de 0,2-5,5 f/ml entre 1984 et 1986. Dans une usine du Royaume-Uni où une vaste étude de mortalité a été effectuée, on mesuré des concentrations généralement supérieures à 20 f/ml avant 1931 et des valeurs généralement inférieures à 1 f/ml pendant la période 1970-1979.

On possède peu de données concernant la concentration en fibres sur les lieux où l'on installe et utilise des produits contenant du chrysotile, bien que ce soit là que les travailleurs ont le plus de chances d'être exposés. Dans des ateliers d'entretien de véhicules, on a enregistré dans les années 70 des pics de concentration atteignant 16 f/ml, alors que depuis 1987, on n'a pratiquement plus jamais mesuré

que des valeurs inférieures à 0,2 f/ml. Au cours des années 80, l'exposition moyenne pondérée par rapport au temps lors de la réparation de voitures automobiles a été en général inférieure à 0,05 f/ml. Cependant, faute de contrôle, les débris, en s'envolant des fûts, on fini par donner naissance en peu de temps à de fortes concentrations de poussières.

Le personnel chargé de l'entretien court un risque d'exposition à divers types de fibres d'amiante, du fait de la présence de grandes quantités de matériaux asbestiques friables. Dans les bâtiments où une surveillance a été instituée, comme par exemple aux Etats-Unis, l'exposition du personnel d'entretien, exprimée en moyenne pondérée par rapport au temps sur 8 h, se situe entre 0,002 et 0,02 f/ml. Ces valeurs sont du même ordre de grandeur que celles relevées lors de travaux effectués dans des installations de commutation (0,009 f/ml) ou dans les combles (0,037 f/ml), mais des valeurs plus élevées ont été enregistrées lors de travaux effectués par les services publics (0,5 f/ml). En l'absence de surveillance, la concentration peut être beaucoup plus élevée. Ainsi, dans un cas on a relevé une valeur de 1,6 f/ml lors du balayage d'une pièce et de 15,5 f/ml lors de l'époussetage des livres d'une bibliothèque dans un bâtiment dont les surfaces étaient recouvertes d'un matériau très friable à base de chrysotile. La plupart des autres moyennes pondérées sur 8 h sont d'environ deux ordres de grandeur plus faibles.

Des enquêtes menées avant 1986 ont montré que la teneur en fibres (fibres de plus de 5 µm de longueur) dans l'air extérieur, mesurée en Afrique du Sud, en Allemagne, en Autriche, au Canada et aux Etats-Unis, allait de 0,0001 à 0,001 f/ml environ, la plupart des échantillons contenant moins de 0,01 f/ml. La moyenne ou la médiane s'est située entre 0,00005 et 0,02 f/ml lors de mesures effectuées

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plus récemment au Canada, aux Etats-Unis, en Italie, au Japon, au Royaume-Uni, en Slovaquie et en Suisse.,

Dans les bâtiments publics, même ceux qui contiennent des matériaux friables à base d'amiante, la concentration des fibres reste dans les limites de celles que l'on mesure dans l'air ambiant. En Allemagne et au Canada, la concentration en fibres (fibres de plus de 5 µm de longueur) relevée avant 1986 dans les immeubles, était généralement inférieure à 0,002 f/ml. Lors d'enquêtes menées plus récemment en Belgique, au Canada, aux Etats-Unis, au Royaume-Uni et en Slovaquie, on a obtenu des valeurs moyennes comprises entre 0,00005 et 0,0045 f/ml. Seulement 0,67% des fibres de chrysotile avaient plus de 5 µm de longueur).

1.4 Absorption, élimination, rétention et translocation

Après avoir été inhalées, les fibres de chrysotile vont se déposer selon divers paramètres: diamètre aérodynamique, longueur et morphologie. On considère que la plupart des fibres de chrysotile sont respirables du fait que leur diamètre est inférieur à 3 µm, ce qui correspond à un diamètre aérodynamique de 10 µm environ. Chez le rat

de laboratoire, les fibres de chrysotile se déposent principalement au niveau de la bifurcation des canaux alvéolaires.

Dans le rhinopharynx et la région trachéobronchique, l'élimination des fibres de chrysotile est assurée par l'ascenseur mucociliaire. Au niveau de la bifurcation des canaux alvéolaires, les fibres sont captées par les cellules épithéliales. L'élimination alvéolaire est conditionnée en grande partie par la longueur des fibres. On est largement fondé à penser, d'après les études sur l'animal, que les fibres courtes (moins de 5 µm de longueur) sont plus rapidement éliminées que les fibres longues (plus de 5 µm de longueur). On ne s'explique pas encore totalement pourquoi les fibres de chrysotile sont éliminées plus rapidement que celles d'amphibole. On a avancé l'hypothèse que les fibres courtes de chrysotile sont phagocytées par les macrophages alvéolaires, les fibres longues étant principalement éliminées par rupture, dissolution ou les deux à la fois. On ne sait pas encore très bien dans quelle proportion les fibres de chrysotile subissent une translocation vers le tissu interstitiel, pleural ou d'autres tissus extrathoraciques.

L'analyse des tissus pulmonaires d'ouvriers exposés à du chrysotile montre que dans le cas de la trémolite, une variété d'amphibole communément présente en petite quantité dans le chrysotile du commerce, la rétention est beaucoup plus importante. L'hypothèse d'une élimination plus rapide du chrysotile est corroborée par l'expérimentation animale, qui montre que cette variété d'amiante est plus vite éliminée des poumons que les amphiboles et notamment la crocidolite et l'amosite.

Les données fournies par les études sur l'homme et l'animal sont insuffisantes pour que l'on puisse déterminer si, et selon quelles modalités, les fibres de chrysotile ingérées sont susceptibles de se fixer, de se répartir dans l'organisme et d'être excrétées. Autant qu'on sache, s'il y a pénétration des fibres de chrysotile à travers la paroi intestinale, elle doit être extrêmement limitée. Selon une étude, il y aurait augmentation du nombre de fibres de chrysotile dans les urines des ouvriers professionnellement exposés à cette variété d'amiante.

1.5 Effets sur les animaux et sur les cellules

De nombreuses études au cours desquelles on a fait inhaler pendant de longues périodes divers échantillons de chrysotile à des rats, ont montré que ces fibres avaient des effets fibrogènes et cancérigènes. Il s'agissait notamment de fibrose interstitielle et de cancers du poumon et de la plèvre. Dans la plupart des cas, on a constaté l'existence d'une association entre la fibrose et les tumeurs pulmonaires chez le rat. Des effets fibrogènes et cancérigènes ont été également mis en évidence lors d'études à long terme sur l'animal (principalement des rats) au cours desquelles on a utilisé d'autres modes d'administration (instillation intratrachéenne et injection intrapleurale ou intrapéritonéale).

Au cours de ces expériences d'inhalation, on n'a pas étudié de manière satisfaisante les relations exposition/dose-réponse dans le cas des fibroses, des cancers pulmonaires et des mésothéliomes induits par le chrysotile. Les études effectuées jusqu'ici, qui ont porté dans la plupart des cas sur une seule concentration, mettent en évidence des effets fibrogènes et cancérigènes à des concentrations en fibres aéroportées allant de 100 à quelques milliers de fibres par ml.

Lorsqu'on regroupe les résultats des différentes études, on voit apparaître une relation entre la concentration atmosphérique des fibres et l'incidence du cancer du poumon. Toutefois, ce genre d'analyse n'est peut-être pas valable sur le plan scientifique, car les conditions expérimentales n'étaient pas identiques dans toutes les études.

Les études qui n'utilisaient pas la voie respiratoire (injection intrapleurale ou intrapéritonéale) ont mis en évidence des relations dose-réponse entre la présence de fibres de chrysotile et l'apparition de mésothéliomes. Cependant, il n'est pas certain que les données obtenues soient utilisables pour évaluer le risque encouru par l'homme

en cas d'exposition aux fibres de chrysotile.

La trémolite, qui est un constituant mineur du chrysotile du commerce, s'est également révélée cancérogène et fibrogène chez le rat lors d'une étude comportant une seule inhalation et lors d'une autre étude utilisant la voie intrapéritonéale. On ne dispose pas des données exposition/ dose-réponse qui auraient permis une comparaison directe du pouvoir cancérogène de la trémolite et du chrysotile.

L'aptitude des fibres de chrysotile à provoquer des effets cancérogènes et fibrogènes est fonction de leurs caractéristiques individuelles, notamment les dimensions et la durabilité (c'est-à-dire la biopersistance de la fibre dans les tissus cibles), qui, elle, dépend pour une part des propriétés physico-chimiques de la fibre. L'expérience a amplement montré que les fibres courtes (moins de 5 µm) sont moins actives sur le plan biologique que les longues fibres (plus de 5 µm). Toutefois on ignore encore si les fibres courtes ont la moindre activité biologique. En outre, on ne sait pas combien de temps une fibre doit séjourner dans les poumons pour induire des effets précancéreux, étant donné que l'apparition des cancers liés à l'amiante se produit généralement assez tard dans la vie de l'animal.

Les mécanismes par lesquels le chrysotile et autres matériaux fibreux produisent des effets fibrogènes et cancérogènes ne sont pas totalement élucidés. Dans le cas des effets fibrogènes, il y a peut-être un processus inflammatoire chronique dû à la production de facteurs de croissance (par ex. le TNF-alpha) et d'espèces oxygénées réactives. Dans celui des effets cancérogènes, plusieurs hypothèses ont été avancées. Par exemple: lésion de l'ADN par des espèces oxygénées réactives suscitées par les fibres; lésion directe de l'ADN par suite d'interactions physiques entre les fibres et les cellules cibles; stimulation de la prolifération cellulaire par les fibres; réactions inflammatoires chroniques provoquées par les fibres et

conduisant à la libération prolongée d'enzymes lysosomiales, d'espèces oxygénées réactives, de cytokines et de facteurs de croissance; enfin, action des fibres en tant que co-cancérogènes ou vecteurs de cancérogènes chimiques vers les tissus cibles. En fait, il est probable que tous ces mécanismes interviennent à des degrés divers dans l'activité cancérogène des fibres de chrysotile, car ils ont effectivement été observés *in vitro* dans des systèmes cellulaires humains et mammaliens.

Au total, les données toxicologiques disponibles montrent clairement que les fibres de chrysotile présentent un risque pour l'homme du fait de leur activité fibrogène et cancérogène. Elles ne sont toutefois pas suffisantes pour que l'on puisse en tirer une évaluation quantitative de ce risque. Cela tient au fait que les études utilisant la voie respiratoire n'ont pas fourni de données exposition-réponse suffisantes et aussi aux incertitudes quant à la sensibilité des études sur l'animal pour la prévision du risque chez l'homme.

Plusieurs études de cancérogénicité utilisant la voie buccale ont été consacrées aux fibres de chrysotile. Celles dont on possède les résultats n'ont pas mis en évidence d'effets cancérogènes.

1.6 Effets sur l'homme

Selon de nombreuses études épidémiologiques effectuées sur des travailleurs exposés, l'exposition au chrysotile du commerce accroît le risque de pneumoconiose, de cancer du poumon et de mésothéliome.

Au nombre des affections non malignes attribuables à une exposition au chrysotile, figure tout un ensemble complexe de syndromes cliniques et pathologiques qui ne sont pas suffisamment définis pour que l'on puisse en faire l'étude épidémiologique. On peut citer en premier lieu l'asbestose qui consiste généralement en une fibrose pulmonaire interstitielle diffuse avec une atteinte pleurale plus ou moins importante.

Les études portant sur des travailleurs exposés au chrysotile dans diverses circonstances ont, d'une façon générale, mis en évidence l'existence de relations exposition-réponse et exposition-effet dans le cas de l'asbestose provoquée par le chrysotile, dans la mesure où elles ont permis de constater qu'à un accroissement de l'exposition correspondait une augmentation de l'incidence et de la gravité de la maladie. Il reste toutefois difficile de définir ces relations, en raison de facteurs tels que les incertitudes du diagnostic et la possibilité d'une progression de la maladie après cessation de l'exposition.

En outre, on constate à l'évidence des variations dans l'estimation du risque selon les différentes études. Les raisons de ses variations ne sont pas parfaitement claires, mais il est possible qu'elles tiennent à des incertitudes quant à l'évaluation de l'exposition, à la distribution par taille des fibres atmosphériques

selon les diverses industries et aux modèles statistiques utilisés. Il est fréquent d'observer des effets de type asbestosique après une exposition prolongée à des teneurs en fibres de 5 à 20 f/ml.

Les études consacrées aux travailleurs de l'industrie du fibro-ciment ne font généralement pas état d'un risque relatif élevé de cancer du poumon, ni globalement, ni dans certaines cohortes de

travailleurs. La relation exposition-réponse entre le chrysotile et le cancer du poumon correspond à une corrélation 10 à 30 fois plus forte chez les ouvriers du textile que chez ceux des industries d'extraction et de transformation. Le risque relatif de cancer du poumon dans le cas d'expositions cumulées est donc 10 à 30 fois plus élevé chez les ouvriers du textile que chez les mineurs de chrysotile. Les raisons de ces différences demeurent obscures et plusieurs hypothèses ont été avancées pour tenter de les expliquer, notamment des variations dans la distribution de la taille des fibres.

Les études épidémiologiques qui s'efforcent d'évaluer le risque de mésothéliome se heurtent à des difficultés qui tiennent à la rareté de la maladie, à l'absence de statistiques de mortalité pour les populations utilisées comme référence et à un certain nombre de problèmes de diagnostic et de notification. C'est pourquoi, bien souvent, le risque n'est pas calculé et on se contente d'indicateurs plus grossiers, par exemple le nombre absolu de cas et de décès et le rapport du nombre de mésothéliomes au nombre de cancers du poumon ou au nombre total de décès.

Si l'on se base sur les données examinées dans la présente monographie, c'est dans les industries d'extraction et de transformation du chrysotile que le nombre de mésothéliomes est le plus élevé. Chez la totalité des 38 cas observés, il y avait atteinte pleurale, à l'exception d'un seul, entaché d'incertitude, où l'atteinte était pleuro-péritonéale. Aucun mésothéliome n'a été observé chez les travailleurs exposés moins de 2 ans. On a pu dégager une nette relation dose-réponse, avec des taux bruts de mésothéliomes (nombre de cas pour 1000 années-travailleurs) allant de 0,15 pour ceux dont l'exposition cumulée était inférieure à 3530 millions de particules par m³-années, à 0,97 pour ceux dont l'exposition était supérieure à 10 590 millions de particules par m³-années.

La proportion de décès attribuables à des mésothéliomes que l'on peut tirer des études de cohortes portant sur les industries d'extraction et de transformation varie de 0 à 0,8%. Il convient d'interpréter ces chiffres avec prudence car les études en question ne fournissent pas des données comparables, avec stratification des décès en fonction de l'intensité et de la durée de l'exposition ainsi que du temps écoulé depuis la première exposition.

On possède un certain nombre d'indices qui donnent à penser que les fibres de trémolite sont à l'origine de mésothéliomes chez l'homme. Comme le chrysotile du commerce est susceptible de contenir de la trémolite fibreuse, on suppose que c'est ce minéral qui provoque

l'apparition de mésothéliomes dans certaines populations exposées au chrysotile. On ignore cependant quelle est la relation entre l'excès de mésothéliomes observé et la teneur du chrysotile en trémolite fibreuse.

Les données épidémiologiques ne permettent pas de conclure qu'il y ait une association entre l'exposition au chrysotile et un accroissement du risque de cancers d'autres localisations que la poumon ou la plèvre. Sur ce point, on ne dispose que peu de données au sujet du chrysotile en tant que tel, même si l'on possède quelques indices disparates d'une association entre l'exposition à l'amiante (sous toutes ses formes) et des cancers du larynx, du rein et des voies digestives. Une étude effectuée au Québec sur des mineurs de chrysotile et des ouvriers travaillant à sa transformation, a permis d'observer un excès statistiquement significatif de cancers de l'estomac, mais il est vrai que l'on n'a pas pris en compte la possibilité d'une confusion due au régime alimentaire, aux maladies infectieuses et à d'autres facteurs de risque.

Il faut admettre que, si les études épidémiologiques relatives aux travailleurs exposés au chrysotile se sont cantonnées, pour l'essentiel, aux industries d'extraction et de transformation, il y a lieu de croire, d'après l'histoire naturelle de la maladie et son association à divers types de fibres dans les pays occidentaux, que le risque est probablement plus élevé chez les ouvriers du bâtiment que chez les travailleurs des autres industries.

1.7 Destinée dans l'environnement et effets sur les biotes

Il y a des affleurements de serpentine partout dans le monde. Le travail de l'écorce terrestre provoque l'érosion de ses constituants minéraux et du chrysotile en particulier. Ceux-ci sont transportés à distance et entrent dans le cycle de l'eau, le processus de sédimentation et le profil pédologique. On a trouvé du chrysotile dans l'eau, l'air et dans les constituants de l'écorce terrestre et on en a mesuré la teneur.

Le chrysotile et les autres constituants de la serpentine qui lui sont associés subissent une décomposition chimique en surface. Il s'ensuit une modification profonde du pH du sol et l'apparition de traces métalliques dans l'environnement. Toutes ces transformations exercent des effets mesurables sur la croissance des végétaux et des organismes terricoles (notamment les microbes et les insectes), des poissons et des invertébrés. D'après certaines données, des herbivores comme les ovins et les bovins qui ingèrent des graminées poussant sur des sols où affleure la serpentine présentent des modifications de leurs constantes hémochimiques.

Arivomani

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1.1 Identidad, propiedades físicas y químicas, muestreo y análisis

El crisotilo es un mineral de silicato de magnesio hidratado fibroso que se ha utilizado en numerosos productos comerciales. En la actualidad se usa ampliamente en el comercio mundial. Se ha observado que sus propiedades físicas y químicas como mineral varían entre los depósitos geológicos explotados. Los minerales que acompañan a las fibras en las menas son muchos y entre ellos puede haber algunas variedades de anfíbol fibroso. Se considera que la tremolita es particularmente importante a este respecto; su forma y concentración presentan grandes variaciones.

En el análisis del crisotilo en los lugares de trabajo se requiere ahora el uso de microscopios ópticos y electrónicos. Antes se habían utilizado diversos instrumentos y dispositivos para vigilar la presencia y concentración tanto de polvo total como de fibras en los diversos medios. En la actualidad se suelen utilizar la técnica del filtro de membrana y la microscopía óptica de contraste de fases para la valoración en el lugar de trabajo (expresada como fibras por ml de aire), y también se emplea la microscopía electrónica de transmisión. Para las valoraciones en el medio ambiente se requiere el uso de la microscopía electrónica de transmisión. Se ha recurrido a estudios de concentración en tejidos para mejorar la información relativa a la exposición. En función del grado de atención al detalle en estos estudios se ha llegado a distintas conclusiones acerca de los mecanismos y la etiología.

Antes se utilizaban las técnicas del precipitador gravimétrico y térmico y el sacudidor de muestreo de polvo para la caracterización en el lugar de trabajo, siendo los valores del polvo (no de la fibra) los únicos índices de exposición inicial para calibrar las relaciones exposición/respuesta. Se ha intentado muchas veces convertir estos valores en los correspondientes a fibras por volumen de aire, pero tales conversiones han tenido un éxito muy limitado. Se ha comprobado que los factores de conversión son específicos de cada industria, e incluso de cada operación; en los factores de conversión universal se han registrado grandes variaciones.

1.2 Fuentes de exposición profesional y ambiental

En todo el medio ambiente de la corteza terrestre (aire, agua, casquetes polares y suelo) se encuentran concentraciones bajas de crisotilo. Las actividades tanto naturales como humanas contribuyen a la aerosolización y la distribución de las fibras. Entre las fuentes de origen humano está el polvo procedente de actividades profesionales, que comprenden la recuperación y elaboración de minerales, la fabricación, la aplicación, la utilización y en último término la eliminación.

Hay producción en 25 países y son siete los principales productores. La producción anual de amianto alcanzó un máximo de más de cinco millones de toneladas a mediados de los años setenta, pero luego ha disminuido hasta el nivel actual de unos tres millones de toneladas. Se fabrican productos de crisotilo en más de 100 países, siendo el Japón el principal consumidor. Las principales actividades actuales de las que se deriva una exposición potencial al crisotilo son las siguientes: a) extracción y trituración; b) transformación en productos (materiales de fricción, tuberías y placas de cemento, juntas y cierres, papel y textiles); c) construcción, reparación y demolición; d) transporte y eliminación. La industria del amianto-cemento es con diferencia la principal usuaria de fibras de crisotilo, absorbiendo alrededor del 85% del total.

Se desprenden fibras durante la elaboración, la instalación y la eliminación de productos con amianto, así como por el desgaste de los productos en algunos casos. La manipulación de productos friables puede ser una fuente importante de emisión de crisotilo.

1.3 Niveles de exposición profesional y ambiental

De acuerdo con datos procedentes sobre todo de América del Norte, de Europa y del Japón, la exposición en los lugares de trabajo a comienzos de los años treinta era muy alta en la mayoría de los sectores de la producción. Los niveles descendieron considerablemente a finales de los años setenta y se ha reducido enormemente hasta los valores actuales. En la industria de la extracción y la trituración de Quebec, las concentraciones medias de fibras en el aire superaban a menudo las 20 fibras/ml (f/ml) en los setenta, mientras que ahora suelen estar muy por debajo de 1 f/ml. En la producción de fibrocemento en el Japón, las concentraciones medias habituales eran de 2,5-9,5 f/ml en los setenta, mientras que en 1992 se notificaron unas concentraciones medias de 0,05-0,45 f/ml. En la fabricación de textiles de amianto en el Japón, las concentraciones medias eran de 2,6 a 12,8 f/ml en el período comprendido entre 1970 y 1975, y de 0,1 a 0,2 f/ml en el período comprendido entre 1984 y 1986. Las tendencias han sido análogas en la producción de materiales de fricción: según los datos disponibles del mismo país, en el período comprendido entre 1970 y 1975 se midieron concentraciones medias de 10-35 f/ml, mientras que entre 1984 y 1986 se notificaron mediciones de 0,2-5,5 f/ml. En una instalación del Reino Unido en la que se realizó un estudio amplio de la mortalidad, las concentraciones eran en general superiores a 20 f/ml en el período anterior a 1931 y normalmente inferiores a 1 f/ml durante 1970-79.

Se dispone de pocos datos sobre las concentraciones de fibras asociadas a la instalación y utilización de productos con crisotilo, aunque fácilmente éste es el lugar de trabajo más probable de exposición de los trabajadores. En el mantenimiento de los vehículos se notificaban en los años setenta concentraciones máximas de hasta 16 f/ml, mientras que prácticamente todos los niveles medidos después de 1987 fueron de menos de 0,2 f/ml. Las exposiciones medias

ponderadas por el tiempo durante la reparación de vehículos de pasajeros en los años ochenta eran por lo general inferiores a 0,05 f/ml. Sin embargo, en ausencia de controles la descarga de residuos de los cilindros daba lugar a concentraciones elevadas de polvo de corta duración.

Existe la posibilidad de exposición de personal de mantenimiento a diversos tipos de fibras de amianto debido a la elevada cantidad de amianto friable en su lugar de trabajo. En edificios con planes de control de los Estados Unidos, la exposición del personal de mantenimiento de edificios expresada como promedio ponderado por el tiempo durante ocho horas fue de 0,002 a 0,02 f/ml. Estos valores son del mismo orden de magnitud que las exposiciones normales durante el trabajo de los operadores de telecomunicaciones (0,009 f/ml) y al aire libre (0,037 f/ml), aunque se notificaron concentraciones mayores en lugares de trabajo de espacios cerrados (0,5 f/ml). Las concentraciones pueden ser considerablemente más elevadas cuando no se han introducido planes de control. En un caso se detectaron concentraciones episódicas de corta duración de 1,6 f/ml al barrer y de 15,5 f/ml mientras se limpiaba el polvo de los libros de una biblioteca en un edificio con un tipo de superficie que contenía crisotilo muy friable. La mayoría de los demás promedios ponderados por el tiempo durante ocho horas son alrededor de dos órdenes de magnitud menores.

De acuerdo con los estudios realizados antes de 1986, las concentraciones de fibras (fibras > 5 µ de longitud) en el aire exterior, medidas en Alemania, Austria, el Canadá, los Estados Unidos y Sudáfrica, oscilaban entre 0,0001 y alrededor de 0,01 f/ml, siendo los niveles de la mayoría de las muestras menores de 0,001 f/ml. Las medias o las medianas eran de 0,00005 a 0,02 f/ml, tomando como base determinaciones más recientes en el Canadá, los Estados Unidos, Italia, el Japón, el Reino Unido, la República Eslovaca y Suiza.

Las concentraciones de fibras en edificios públicos, incluso los que tienen materiales con amianto friable, son del orden de las medidas en el aire exterior. Las concentraciones (fibras > 5 µ de longitud) en edificios de Alemania y el Canadá notificadas antes de 1986 eran en general menores de 0,002 f/ml. En estudios más recientes realizados en Bélgica, el Canadá, los Estados Unidos, el Reino Unido y la República Eslovaca se obtuvieron valores medios de 0,00005 a 0,0045 f/ml. Sólo un 0,67% de las fibras de crisotilo eran más largas de 5 µ.

1.4 Absorción, eliminación, retención y desplazamiento

La deposición del crisotilo inhalado depende del diámetro aerodinámico, la longitud y la morfología de la fibra. La mayoría de las fibras de crisotilo transportadas por el viento se consideran respirables debido a que su diámetro es de menos de 3 µ, igual a un diámetro aerodinámico de 10 µ. En ratas de laboratorio, las fibras de crisotilo se depositan principalmente en las bifurcaciones de los conductos alveolares.

En las regiones nasofaríngea y traqueobronquial, las fibras de crisotilo se eliminan por medio de la acción mucociliar. Las células epiteliales absorben las fibras en las bifurcaciones de los conductos alveolares. La longitud de las fibras es un factor determinante importante para la eliminación alveolar de las fibras de crisotilo. Hay pruebas convincentes obtenidas en estudios con animales de que las fibras cortas (de menos de 5 µ de longitud) se eliminan con mayor rapidez que las largas (de más de 5 µ). No se conocen completamente los mecanismos que hacen que las fibras de crisotilo se eliminen de manera relativamente más rápida que las de anfíboles. Se ha planteado la hipótesis de que las fibras cortas de crisotilo pueden eliminarse sobre todo por fagocitosis de los macrófagos alveolares, mientras que las largas lo harían principalmente por rotura y/o disolución. No se conoce del todo en qué medida se desplazan las fibras de crisotilo a los intersticios, al tejido pleural y a otros tejidos extratorácicos.

Los análisis de los pulmones de trabajadores expuestos al crisotilo ponen de manifiesto una retención de tremolita, amianto anfíbol que suele estar asociado con el crisotilo comercial en pequeñas proporciones, mucho mayor que la de crisotilo. La eliminación más rápida de las fibras de crisotilo de los pulmones humanos se ha confirmado en los resultados de estudios con animales, que mostraban que el crisotilo se elimina de los pulmones con mayor rapidez que los anfíboles, incluidas la crocidolita y la amosita.

Los datos obtenidos en estudios con personas y con animales son insuficientes para evaluar la posible absorción, distribución y excreción de fibras de crisotilo a partir de la ingestión. Las pruebas disponibles indican que, en el caso de que se produzca penetración de fibras de crisotilo a través de las paredes del intestino, es extraordinariamente limitada. En un estudio se observó una concentración mayor de fibras de crisotilo en la orina de trabajadores

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expuestos profesionalmente al crisotilo.

1.5 Efectos en animales y en células

En numerosos estudios de inhalación de larga duración se ha comprobado que diversas muestras experimentales de fibras de crisotilo provocan efectos fibrogénicos y carcinogénicos en ratas de laboratorio. Entre esos efectos figuran la fibrosis intersticial y el cáncer de pulmón y de pleura. En la mayoría de los casos parece haber una asociación entre fibrosis y tumores en el pulmón de rata. También se han detectado efectos fibrogénicos y carcinogénicos en estudios de larga duración con animales (principalmente ratas) utilizando otras vías de administración (por ejemplo, instilación intratraqueal e inyección intrapleural o intraperitoneal).

No se han investigado debidamente en estudios de inhalación de larga duración en animales las relaciones exposición/dosis-respuesta para la fibrosis pulmonar, el cáncer de pulmón y el mesotelioma inducidos por el crisotilo. Los estudios de inhalación realizados hasta la fecha, utilizando sobre todo una concentración de exposición

única, muestran respuestas fibrogénicas y carcinogénicas a concentraciones de fibras en el aire que van de 100 a algunos miles de fibras/ml. Al combinar los datos de varios estudios, parece que hay una relación entre las concentraciones de fibras en el aire y la incidencia de cáncer de pulmón. Sin embargo, este tipo de análisis tal vez no sea válido desde el punto de vista científico, debido a que las condiciones experimentales en los estudios disponibles eran distintas.

En los experimentos sin inhalación (estudios de inyección intrapleural e intraperitoneal), se ha demostrado una relación dosis-respuesta para el mesotelioma con las fibras de crisotilo. Sin embargo, es posible que los datos de estos estudios no sean adecuados para evaluar el riesgo humano derivado de la exposición a fibras por inhalación.

El amianto tremolita, mineral que es un componente secundario del crisotilo comercial, también mostró efectos carcinogénicos y fibrogénicos en un experimento de inhalación única y en un estudio de inyección intraperitoneal en ratas. No se dispone de datos sobre la exposición/dosis respuesta para poder establecer una comparación directa de la actividad carcinogénica de la tremolita y el crisotilo.

La capacidad de las fibras para inducir efectos fibrogénicos y carcinogénicos parece depender de sus características individuales, incluidas la dimensión y la durabilidad de las fibras (es decir, la biopersistencia en los tejidos a los que llegan), que están determinadas en parte por las propiedades fisicoquímicas. Está bien documentado en estudios experimentales el hecho de que las fibras cortas (de menos de 5 μ) tienen una actividad biológica menor que las largas (de más de 5 μ). Sin embargo, sigue habiendo dudas acerca de si las fibras cortas tienen una actividad biológica significativa. Además, no se sabe cuánto tiempo tiene que permanecer una fibra en el pulmón para inducir efectos preneoplásicos, puesto que el cáncer relacionado con el amianto suele aparecer en una etapa posterior de la vida del animal.

No se conocen completamente los mecanismos mediante los cuales el crisotilo y otras fibras provocan efectos fibrogénicos y carcinogénicos. Entre los posibles mecanismos de los efectos fibrogénicos de las fibras cabe mencionar el proceso de inflamación crónica debido a la producción de factores del crecimiento (por ejemplo, el TNF-alfa) y especies de oxígeno reactivo. Con respecto a la carcinogenicidad inducida por las fibras, se han propuesto varias hipótesis. Son las siguientes: daños en el ADN provocados por especies de oxígeno reactivo inducido por las fibras; daños directos en el ADN por las interacciones físicas entre las fibras y las células a las que llegan; intensificación de la proliferación celular debida a las fibras; reacciones inflamatorias crónicas provocadas por las fibras, que da lugar a una liberación prolongada de lisozimas, especies reactivas de oxígeno, citoquinas y factores del crecimiento; y actuación de las fibras como agentes cocarcinógenos o portadores de productos químicos carcinógenos hasta los tejidos a los que llegan. Es

probable, sin embargo, que todos estos mecanismos contribuyan a la carcinogenicidad de las fibras de crisotilo, puesto que se han observado tales efectos en diversos sistemas *in vitro* de células humanas y de mamíferos.

En conjunto, los datos toxicológicos disponibles demuestran claramente que las fibras de crisotilo pueden crear peligros fibrogénicos y carcinogénicos para el ser humano. Sin embargo, los datos no son suficientes para obtener estimaciones cuantitativas del riesgo para las personas. Esto se debe a que son insuficientes los precedentes de estudios de inhalación relativos a la exposición-respuesta y a que hay dudas acerca de la sensibilidad de los estudios con animales para predecir el riesgo humano.

Se han realizado pruebas con fibras de crisotilo en varios estudios de carcinogenicidad por vía oral. En los estudios disponibles no se han notificado efectos carcinogénicos.

1.6 Efectos en el ser humano

Las calidades comerciales de crisotilo se han asociado con un

aumento del riesgo de neumoconiosis, cáncer de pulmón y mesotelioma en numerosos estudios epidemiológicos de trabajadores expuestos.

Las enfermedades no malignas asociadas con la exposición al crisotilo forman una mezcla algo compleja de síndromes clínicos y patológicos imposibles de definir para un estudio epidemiológico. La preocupación se ha concentrado primordialmente en la asbestosis, que generalmente consiste en una enfermedad asociada con una fibrosis pulmonar intersticial difusa acompañada de diversos grados de afección pleural.

Los estudios realizados en trabajadores expuestos al crisotilo en distintos sectores han demostrado en general una relación exposición-respuesta o exposición-efecto para la asbestosis inducida por crisotilo, puesto que el aumento de los niveles de exposición ha producido un incremento de la incidencia y la gravedad de la enfermedad. Sin embargo, hay dificultades para definir esta relación, debido a factores como la incertidumbre del diagnóstico y la posibilidad de progresión de la enfermedad después de cesar la exposición.

Por otra parte, entre los estudios disponibles son evidentes algunas variaciones en las estimaciones del riesgo. Los motivos de estas variaciones no son totalmente claros, pero pueden estar relacionados con la incertidumbre en las estimaciones de la exposición, la distribución por tamaños de las fibras del aire en los diversos sectores industriales y los modelos estadísticos. Son habituales los cambios en la asbestosis tras exposiciones prolongadas a concentraciones de 5 a 20 f/ml.

Los riesgos relativos totales de cáncer de pulmón no son por lo general elevados en los estudios realizados con trabajadores de la producción de fibrocemento y en algunas de las cohortes de trabajadores de fábricas de fibrocemento. La relación exposición-respuesta entre el crisotilo y el riesgo de cáncer de pulmón parece ser en los estudios de trabajadores textiles 10-30 veces mayor que en los estudios de trabajadores de las industrias de la extracción y la trituración. No están claros los motivos de esta variación del riesgo, por lo que se han propuesto varias hipótesis, incluidas las variaciones de la distribución de las fibras por tamaños.

La estimación del riesgo de mesotelioma se complica en los estudios epidemiológicos debido a factores como la rareza de la enfermedad, la falta de tasas de mortalidad en las poblaciones utilizadas como referencia y los problemas de diagnóstico y notificación. Por consiguiente, en muchos casos no se han calculado los riesgos y se han utilizado indicadores más aproximativos, como el número absoluto de casos y de muertes y la razón mesotelioma/cáncer de pulmón o número total de muertes.

Tomando como base los datos reseñados en esta monografía, el mayor número de mesoteliomas se ha registrado en el sector de la extracción y la trituración del crisotilo. Los 38 casos fueron pleurales con la excepción de uno de probabilidad baja de diagnóstico, que fue pleuroperitoneal. No se produjo ningún caso en trabajadores expuestos durante menos de dos años. Se observó una relación dosis-respuesta clara, con tasas brutas de mesoteliomas (casos/1000 años-persona) comprendidas entre 0,15 para los casos de una exposición acumulativa a menos de 3530 millones de partículas/m³-año (< 1000 millones de partículas por pie cúbico-año) y 0,97 para los de una exposición a más de 10 590 millones de partículas/m³-año (> 300 millones de partículas/pie cúbico-año).

Las proporciones de muertes atribuibles a mesoteliomas en estudios de cohortes en los diversos sectores de la extracción y la producción oscilan entre el 0% y el 0,8%. Estas proporciones se han de interpretar con cautela, puesto que los estudios no suministran datos comparables con una estratificación de las muertes por intensidades de exposición, duración de ésta o tiempo transcurrido desde la primera.

Hay pruebas de que la tremolita fibrosa provoca la aparición de mesoteliomas en el ser humano. Debido a que el crisotilo comercial puede contener tremolita fibrosa, se ha planteado la hipótesis de que ésta puede contribuir a la inducción de mesoteliomas en algunas poblaciones expuestas primordialmente al crisotilo. No se ha determinado en qué medida podría atribuirse el aumento observado de mesoteliomas al contenido de tremolita fibrosa.

No se han obtenido pruebas epidemiológicas concluyentes de que la exposición al crisotilo esté asociada con un mayor riesgo de tipos de cáncer distintos del de pulmón o el de pleura. Hay información

limitada acerca de este tema para el crisotilo en sí, pero no son convincentes las pruebas aducidas para demostrar una asociación entre la exposición al amianto (todas las formas) y el cáncer de laringe, el de riñón y el gastrointestinal. Se ha observado un aumento significativo de cáncer de estómago en un estudio de mineros y trituradores de crisotilo de Quebec, pero no se ha examinado la posible confusión con la alimentación, con la presencia de infecciones y con otros factores de riesgo.

Hay que reconocer que, aunque los estudios epidemiológicos de trabajadores expuestos al crisotilo se han limitado fundamentalmente a

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la extracción y la trituración, así como al sector de la fabricación, existen pruebas, basadas en la evolución histórica de las enfermedades asociadas con la exposición a mezclas de diversos tipos de fibras en los países occidentales, de que probablemente los riesgos sean mayores entre los trabajadores de la construcción y posiblemente entre los de otras industrias que utilizan el producto.

1.7 Destino en el medio ambiente y efectos en la biota

En todo el mundo hay afloramientos de serpentina. Los componentes minerales, entre ellos el crisotilo, se erosionan como consecuencia de los procesos de la corteza terrestre y se transportan hasta convertirse en un componente del ciclo hídrico, los sedimentos y el perfil del suelo. Se ha medido la presencia y las concentraciones de crisotilo en el agua, el aire y otras unidades de la corteza.

El crisotilo y los minerales de serpentina asociados con él se degradan químicamente en la superficie. Esto da lugar a cambios profundos del pH del suelo e introduce una serie de metales traza en el medio ambiente. Esto ha producido a su vez efectos mensurables en el crecimiento de las plantas, la biota del suelo (incluidos microorganismos e insectos), los peces y los invertebrados. Algunos datos indican que los animales de pastoreo (ovinos y vacunos) sufren cambios de la química sanguínea tras la ingestión de gramíneas que han crecido en afloramientos de serpentina.

See Also:

[Toxicological Abbreviations](#)

ANNEXURE- C**SIXTIETH WORLD HEALTH ASSEMBLY****WHA60.26****Agenda item 12.13****23 May 2007****Workers' health: global plan of action**

The Sixtieth World Health Assembly,

Having considered the draft global plan of action on workers' health;¹

Recalling resolution WHA49.12 which endorsed the global strategy for occupational health for all;

Recalling and recognizing the recommendations of the World Summit on Sustainable Development (Johannesburg, South Africa, 2002) on strengthening WHO action on occupational health and linking it to public health;²

Recalling the Promotional Framework for Occupational Safety and Health Convention, 2006, and the other international instruments in the area of occupational safety and health adopted by the General Conference of the ILO;³

Considering that the health of workers is determined not only by occupational hazards, but also by social and individual factors, and access to health services;

Mindful that interventions exist for primary prevention of occupational hazards and for developing healthy workplaces;

Concerned that there are major gaps between and within countries in the exposure of workers and local communities to occupational hazards and in their access to occupational health services;

Stressing that the health of workers is an essential prerequisite for productivity and economic development,

¹ As contained in document A60/20, Annex.

² Plan of Implementation of the World Summit on Sustainable Development. Document A/Conf.199/20, Annex.

³ International Labour Conference, Ninety-fifth Session, Geneva 2006. Provisional Record 20A.

1. ENDORSES the global plan of action on workers' health 2008–2017;
2. URGES Member States:
 - (1) to devise, in collaboration with workers, employers and their organizations, national policies and plans for implementation of the global plan of action on workers' health as appropriate, and to establish appropriate mechanisms and legal frameworks for their implementation, monitoring and evaluation;
 - (2) to work towards full coverage of all workers, including those in the informal economy, small- and medium-sized enterprises, agriculture, and migrant and contractual workers, with essential interventions and basic occupational health services for primary prevention of occupational and work-related diseases and injuries;
 - (3) to take measures to establish and strengthen core institutional capacities and human resource capabilities for dealing with the special health needs of working populations and to generate evidence on workers' health and translate that evidence into policy and actions;
 - (4) to develop and make available specific guidelines for the establishment of appropriate health services and surveillance mechanisms for human and environmental hazards and diseases introduced into local communities where mining, other industrial and agricultural activities have been set up to meet the associated needs of those communities;
 - (5) to ensure collaboration and concerted action by all national health programmes relevant to workers' health, such as those dealing with prevention of occupational diseases and injuries, communicable and chronic diseases, health promotion, mental health, environmental health, and health systems development;
 - (6) to encourage incorporation of workers' health in national and sectoral policies for sustainable development, poverty reduction, employment, trade, environmental protection, and education;
 - (7) to encourage the development of effective mechanisms for collaboration and cooperation between developed and developing countries at regional, subregional and country levels in implementing the global plan of action on workers' health;
 - (8) to encourage development of comprehensive health and non-health strategies to ensure reintegration of sick and injured workers into the mainstream of society, in coordination with different government and nongovernmental organizations;
3. REQUESTS the Director-General:
 - (1) to promote implementation of the global plan of action on workers' health 2008–2017 at national and international levels with a definite timeline and indicators for the establishment of occupational health services at global level;
 - (2) to strengthen collaboration with ILO and other related international organizations and to stimulate joint regional and country efforts on workers' health;

- (3) to maintain and strengthen the network of WHO collaborating centres for occupational health as an important mechanism for implementation of the global plan of action;
- (4) to report to the Health Assembly through the Executive Board at its 132nd (2013) and its 142nd (2018) sessions on progress made in the implementation of the global plan of action.

ANNEX

GLOBAL PLAN OF ACTION ON WORKERS' HEALTH 2008–2017**INTRODUCTION**

1. Workers represent half the world's population and are the major contributors to economic and social development. Their health is determined not only by workplace hazards but also by social and individual factors and access to health services.
2. Despite the availability of effective interventions to prevent occupational hazards and to protect and promote health at the workplace, large gaps exist between and within countries with regard to the health status of workers and their exposure to occupational risks. Still only a small minority of the global workforce has access to occupational health services.
3. Increasing international movement of jobs, products and technologies can help to spread innovative solutions for prevention of occupational hazards, but can also lead to a shift of that risk to less advantaged groups. The growing informal economy is often associated with hazardous working conditions and involves such vulnerable groups as children, pregnant women, older persons and migrant workers.
4. The present plan of action deals with all aspects of workers' health, including primary prevention of occupational hazards, protection and promotion of health at work, employment conditions, and a better response from health systems to workers' health. It is underpinned by certain common principles. All workers should be able to enjoy the highest attainable standard of physical and mental health and favourable working conditions. The workplace should not be detrimental to health and well-being. Primary prevention of occupational health hazards should be given priority. All components of health systems should be involved in an integrated response to the specific health needs of working populations. The workplace can also serve as a setting for delivery of other essential public-health interventions, and for health promotion. Activities related to workers' health should be planned, implemented and evaluated with a view to reducing inequalities in workers' health within and between countries. Workers and employers and their representatives should also participate in such activities.

ACTIONS

5. The following actions are to be considered and adapted by countries, as appropriate, to their national priorities and specific circumstances in order to achieve the objectives described below.

Objective 1: to devise and implement policy instruments on workers' health

6. National policy frameworks for workers' health should be formulated taking account of the relevant international labour conventions and should include: enactment of legislation; establishment of mechanisms for intersectoral coordination of activities; funding and resource mobilization for protection and promotion of workers' health; strengthening of the role and capacities of ministries of health; and integration of objectives and actions for workers' health into national health strategies.

7. National action plans on workers' health should be elaborated between relevant ministries, such as health and labour, and other major national stakeholders taking also into consideration the Promotional Framework for Occupational Safety and Health Convention, 2006. Such plans should include: national profiles; priorities for action; objectives and targets; actions; mechanisms for implementation; human and financial resources; monitoring, evaluation and updating; reporting and accountability.
8. National approaches to prevention of occupational diseases and injuries should be developed according to countries' priorities, and in concert with WHO's global campaigns.
9. Measures need to be taken to minimize the gaps between different groups of workers in terms of levels of risk and health status. Particular attention should be paid to high-risk sectors of economic activity, and to the underserved and vulnerable working populations, such as younger and older workers, persons with disabilities and migrant workers, taking account of gender aspects. Specific programmes should be established for the occupational health and safety of health-care workers.
10. WHO will work with Member States to strengthen the capacities of the ministries of health to provide leadership for activities related to workers' health, to formulate and implement policies and action plans, and to stimulate intersectoral collaboration. Its activities will include global campaigns for elimination of asbestos-related diseases – bearing in mind a differentiated approach to regulating its various forms – in line with relevant international legal instruments and the latest evidence for effective interventions, as well as immunization of health-care workers against hepatitis B, and other actions addressing priority work-related health outcomes.

Objective 2: to protect and promote health at the workplace

11. The assessment and management of health risks at the workplace should be improved by: defining essential interventions for prevention and control of mechanical, physical, chemical, biological and psychosocial risks in the working environment. Such measures include also integrated management of chemicals at the workplace, elimination of second-hand tobacco smoke from all indoor workplaces, improved occupational safety, and health-impact assessment of new technologies, work processes and products at the design stage.
12. Protecting health at the workplace also requires enacting regulations and adopting a basic set of occupational health standards to make certain that all workplaces comply with minimum requirements for health and safety protection, ensuring an appropriate level of enforcement, strengthening workplace health inspection, and building up collaboration between the competent regulatory agencies according to specific national circumstances.
13. Capacities should be built for primary prevention of occupational hazards, diseases and injuries, including strengthening of human, methodological and technological resources, training of workers and employers, introduction of healthy work practices and work organization, and of a health-promoting culture at the workplace. Mechanisms need to be established to stimulate the development of healthy workplaces, including consultation with, and participation of workers, and employers.
14. Health promotion and prevention of noncommunicable diseases should be further stimulated in the workplace, in particular by advocating healthy diet and physical activity among workers, and promoting mental and family health at work. Global health threats, such as tuberculosis, HIV/AIDS, malaria and avian influenza, can also be prevented and controlled at the workplace.

15. WHO will work on creating practical tools for assessment and management of occupational risks, recommending minimum requirements for health protection at the workplace, providing guidance on development of healthy workplaces, and on promoting health at the workplace. It will also incorporate workplace actions in international programmes dealing with global health threats.

Objective 3: to improve the performance of and access to occupational health services

16. Coverage and quality of occupational health services should be improved by: integrating their development into national health strategies, health-sector reforms and plans for improving health-systems performance; determining standards for organization and coverage of occupational health services; setting targets for increasing the coverage of the working population with occupational health services; creating mechanisms for pooling resources and for financing the delivery of occupational health services; ensuring sufficient and competent human resources; and establishing quality-assurance systems. Basic occupational health services should be provided for all workers, including those in the informal economy, small enterprises, and agriculture.

17. Core institutional capacities should be built at national and local levels in order to provide technical support for basic occupational health services, in terms of planning, monitoring and quality of service delivery, design of new interventions, dissemination of information, and provision of specialized expertise.

18. Development of human resources for workers' health should be further strengthened by: further postgraduate training in relevant disciplines; building capacity for basic occupational health services; incorporating workers' health in the training of primary health care practitioners and other professionals needed for occupational health services; creating incentives for attracting and retaining human resources for workers' health, and encouraging the establishment of networks of services and professional associations. Attention should be given not only to postgraduate but also to basic training for health professionals in various fields such as promotion of workers' health and the prevention and treatment of workers' health problems. This should be a particular priority in primary health care.

19. WHO will provide guidance to the Member States for the development of basic packages, information products, tools and working methods, and models of good practice for occupational health services. It will also stimulate international efforts for building the necessary human and institutional capacities.

Objective 4: to provide and communicate evidence for action and practice

20. Systems for surveillance of workers' health should be designed with the objective of accurately identifying and controlling occupational hazards. This endeavour includes establishing national information systems, building capability to estimate the occupational burden of diseases and injuries, creating registries of exposure to major risks, occupational accidents and occupational diseases, and improving reporting and early detection of such accidents and diseases.

21. Research on workers' health needs to be further strengthened, in particular by framing special research agendas, giving it priority in national research programmes and grant schemes, and fostering practical and participatory research.

22. Strategies and tools need to be elaborated, with the involvement of all stakeholders, for improving communication and raising awareness about workers' health. They should target workers, employers and their organizations, policy-makers, the general public, and the media. Knowledge of

health practitioners about the link between health and work and the opportunities to solve health problems through workplace interventions should be improved.

23. WHO will define indicators and promote regional and global information platforms for surveillance of workers' health, will determine international exposure and diagnostic criteria for early detection of occupational diseases, and will include occupational causes of diseases in the eleventh revision of the International Statistical Classification of Diseases, and Related Health Problems.

Objective 5: to incorporate workers' health into other policies

24. The capacities of the health sector to promote the inclusion of workers' health in other sectors' policies should be strengthened. Measures to protect workers' health should be incorporated in economic development policies and poverty reduction strategies. The health sector should collaborate with the private sector in order to avoid international transfer of occupational risks and to protect health at the workplace. Similar measures should be incorporated in national plans and programmes for sustainable development.

25. Workers' health should likewise be considered in the context of trade policies when taking measures as specified in resolution WHA59.26 on international trade and health.

26. Employment policies also influence health; assessment of the health impact of employment strategies should therefore be encouraged. Environmental protection should be strengthened in relation to workers' health through, for instance, implementation of the risk-reduction measures foreseen in the Strategic Approach to International Chemicals Management, and consideration of workers' health aspects of multilateral environmental agreements and mitigation strategies, environmental management systems and plans for emergency preparedness and response.

27. Workers' health should be addressed in the sectoral policies for different branches of economic activity, in particular those with the highest health risk.

28. Aspects of workers' health should be taken into account in primary, secondary and higher level education and vocational training.

IMPLEMENTATION

29. Improving the health of workers can be achieved through well-coordinated efforts of society as a whole, under government leadership and with substantial participation of workers and employers. A combination of actions, adapted to national specificities and priorities, is needed to meet the above-mentioned objectives. Actions are designed for implementation at national level, and through intercountry and interregional cooperation.

30. WHO, supported by its network of Collaborating Centres for Occupational Health and in partnership with other intergovernmental and international organizations, will work with the Member States to implement this plan of action by:

- promoting and engaging in partnership and joint action with ILO and other organizations of the United Nations system, organizations of employers, trade unions and other stakeholders in civil society and the private sector in order to strengthen international efforts on workers' health;

- in coherence with the actions undertaken by ILO, setting standards for protection of workers' health, providing guidelines, promoting and monitoring their use, and contributing to the adoption and implementation of international labour conventions;
- articulating policy options for framing national agendas for workers' health based on best practices and evidence;
- providing technical support for tackling the specific health needs of working populations and building core institutional capacities for action on workers' health;
- monitoring and addressing trends in workers' health;
- establishing appropriate scientific and advisory mechanisms to facilitate action on workers' health at global and regional levels.

31. Progress in implementing the plan of action will be reviewed and monitored using a set of national and international indicators of achievement.

Eleventh plenary meeting, 23 May 2007
A60/VR/11

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FOR BRIG. SETHI / MIL 1581

ANNEXURE- D

1/5

No.40018/ 32/99-Ch.I
Government of India
Ministry of Chemicals and Fertilizers
Department of Chemicals and Petrochemicals

Shastri Bhasan, New Delhi
Dated the 2nd November, 2004

To,
Brig. A.K.Sethi,
Advisor,
The Asbestos Cement product Manufacturers' Association
607, Ashok Bhawan,
93, Nehru Place,
New Delhi-19

Subject: Rotterdam Convention – the issue of Chrysotile- Study by NIOH on Health and environmental hazards

Sir,

We had made a request to National Insti. Of Occupational Health, Ahmedabad to consider undertaking a study on the above issue, so that with proper documentation the ongoing proposal to bring the chrysotile form of asbestos under the Convention to restrict its trade/usage could be countered. We have received an offer from NIOH which is enclosed. You are requested to consider possible industry,s part financial contribution for undertaking the study. We shall appreciate your earliest response..

Yours faithfully,

P.S. Singh

(P.S. Singh)

Under Secretary to the Govt. of India
Tel.23070712

Encl: As above.



राष्ट्रीय व्यावसायिक स्वास्थ्य संस्थान

NATIONAL INSTITUTE OF OCCUPATIONAL HEALTH
(WHO Collaborative Centre for Occupational Health & IPCS Participating Institute)
(Indian Council of Medical Research)

P.B. No. 2031, Meghani Nagar, Ahmedabad-380 016, India

Ref No : NIOH/Hyg/Proj/05 / 4928

Date : 3RD March 2005

SPEED POST

P. S. Singh
Under Secretary to the Govt. of India
Ministry of Chemicals and Fertilizers
Department of Chemicals and Petrochemicals
Shastri Bhavan,
New Delhi-110001

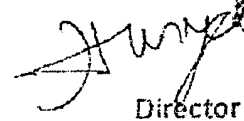
Subject: Implementation of Rotterdam Convention on Prior Informed Consent Procedures – Study of Health Hazards/Environment Hazards resulting from use of Chrysotile variety of Asbestos in the country.

Dear sir,

This has reference to the proposed environmental-epidemiological study in relation to the above-mentioned subject. In this connection I am sending you the project proposal along with the estimated cost. It is also to be noted that the budget has been prepared as per the Indian Council of Medical Research guidelines.

Thanking you,

Yours faithfully,


Director

Encl. As above

3/5

Environmental cum Epidemiological survey of Chrysotile Asbestos based Industries**Status of the project:** New**Duration of the project:** 2 years from date of commencement**Background:**

A request from Department of Chemicals and Petrochemicals, Ministry of Chemicals and Fertilizers, Govt. of India was received regarding a survey in relation to the hazards resulting from use of Chrysotile variety of asbestos in the country. Consequently in consultation of the scientists of National Institute of Occupational Health and the concerned Under Secretary to the Govt. of India, Ministry of Chemicals and Fertilizers it was decided that an environmental cum epidemiological study would be carried out in the following industries (organized sectors):

- Asbestos cement industry manufacturing asbestos cement sheets
- Asbestos cement industry manufacturing asbestos cement pipes
- Asbestos industry manufacturing asbestos containing friction materials
- Asbestos textile industry

Methodology:

An environmental as well as epidemiological study will be carried out involving the workers of the representative organizations of the aforesaid industries.

Environmental Study:

Fiber concentrations in the workplaces will be evaluated by membrane filter method using phase contrast optical microscopy as per ILO and AIA guidelines.

Epidemiological Study:**Study settings:**

This study will be undertaken in different representative industries of the above said sectors.

Sample size:

A total of 800 workers (representing every sector of activity) will be included in this study as the study subjects.

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Study parameters:

Every individual worker will be interviewed with a pre designed questionnaire to collect information in relation to personal, occupational and morbidity details of the workers.

Lung function test will be carried out in all workers

All the study subjects will be evaluated by radiological examination as per ILO guidelines

Statistical analysis:

Collected data will be analyzed by using Epi Info 6 and SPSS 6.1 4 software.

Budget (Rupees):

Manpower involvement	1191000
Costs towards environmental and medical examination (25% overhead)	500000
TADA	500000
Contingency	300000
Intellectual fees	1191000
Total project cost	3682000

Detailed breakup of manpower, costs towards environmental and medical examination:

A. Manpower:

Designation	No. of posts	Rate/day/person	Days involved	Total amount
Senior scientist	2	1300	90	234000
Scientist	2	900	90	162000
Assistants	8	500	90	270000
Project staff	2	10000/month/person	2 years	480000
Others	2	250	90	45000
Total				1191000

8/5-

B. Costs towards environmental and medical examination:

Parameters	No. of subjects	Rate/subject	Total
Environmental assessment			200000
Lung function test	800	100	80000
Radiological Examination	800	150	120000
25% overhead			100000
Total			500000

No.40018/ 9/2005-Ch.1
Government of India
Ministry of Chemicals and Fertilizers
Department of Chemicals and Petrochemicals

Shastri Bhawan, New Delhi
Dated the 24th June, 2005.

To
Brig. A.K.Sothi,
Advisor,
The Asbestos Cement product Manufacturers' Association
Nehru Place,
New Delhi 110019.

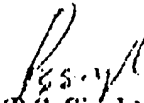
Subject: Rotterdam Convention -- the issue of Chrysotile- Study by NIOH on Health and environmental hazards

Sir

The proposal of the study to be undertaken by NIOH was discussed in a meeting held on 16th June, 2005. NIOH has now reworked out and submitted a fresh proposal covering all the parameters including those raised by your Association. A copy of the proposal received from NIOH is enclosed.

2. It will be noticed that as per the fresh proposal received the cost of the study will be Rs.59.66 lakhs. Your Association had earlier agreed to part fund the study and contrib. Ute Rs. 10 lakhs for same. As the cost of study has gone up you are requested to consider enhancing your contribution, if possible. We will appreciate your earliest response so that we could initiate further action on undertaking the study.

Yours faithfully,


(P.S. Singh)

Under Secretary to the Govt. of India
Tel.23070712



NATIONAL INSTITUTE OF OCCUPATIONAL HEALTH

(WHO Collaborative Centre for Occupational Health & ICMR Participating Institute)

(Indian Council of Medical Research)

P.B. No. 2031, Meghani Nagar, Ahmedabad-380 016, India

Ref No. NIOH/Hyg/Proj/05 / 1125

Date : 27th June 2005

P. S. Singh
Under Secretary to the Govt. of India
Ministry of Chemicals and Fertilizers
Department of Chemicals and Petrochemicals
Sanskri Bhavan,
New Delhi 110001

By SPCET/2005

Subject: Implementation of Rotterdam Convention on Prior Informed Consent Procedures - Study of Health Hazards/Environment Hazards resulting from use of Chrysotile variety of Asbestos in the country.

Dear sir,

This has a reference of your letter No.40018/9/2005-CI:1 dated 15th June 2005 regarding above mentioned subject. Please find enclosed herewith a copy of the revised proposal for undertaking the study on "An Environmental cum Epidemiological survey in and around Chrysotile Asbestos based Industries" as requested by you.

Thanking you,

Yours faithfully,

Encl. As above

An Environmental cum Epidemiological survey in and around Chrysotile Asbestos based Industries

Status of the project: New

Duration of the project: 4 years from date of commencement

Epidemiological Study:**Study settings:**

This study will be undertaken in different representative industries of the above said sectors. Representative samples of population residing in the vicinity of these industries will be included in this study

Sample size:

A total of 1500 subjects will be included in this study as the study subject:

Study parameters:

Every individual subject will be interviewed with a pre-designed questionnaire to collect information in relation to personal, occupational and morbidity details of the workers.

Lung function test will be carried out in all subjects

All the study subjects will be evaluated by radiological examination as per ILO guidelines.

Statistical analysis:

Collected data will be analyzed by using Epi Info 6 and SPSS 6.1.4 software.

Budget (Rupees):

Manpower involvement	1833000
Costs towards environmental and medical examination (25% overhead)	1000000
TA/DA	1000000
Contingency	300000
Intellectual fees	1833000
Total project cost	5966000



No.40018/ 9 / 2005-Ch.I
Dated the 16th June , 2005

1589
भारत सरकार
GOVERNMENT OF INDIA
रसायन और उर्वरक मंत्रालय
MINISTRY OF CHEMICALS & FERTILIZERS
रसायन और पेट्रोरसायन विभाग
DEPARTMENT OF CHEMICALS & PETROCHEMICALS
शास्त्री भवन, डॉ. राजेन्द्र प्रसाद रोड़,
SHASTRI BHAVAN, DR. RAJENDERA PRASAD ROAD,
नई दिल्ली-११० ००१
NEW DELHI-110 001

To,
Director
National Institute of Occupational Health
P.B. No.2031, Meghani Nagar,
Ahmedabad-380 016

(Kind Attn: Dr. Asim Saha)

Subject: Implementation of Rotterdam Convention on Prior Informed Consent Procedures – Study NIOH of Health Hazards /Environment Hazards resulting from use of Chrysotile variety of Asbestos in the country

Sir,

Various issues pertaining to the above mentioned study were considered in a meeting held in this Department today. The following decisions were taken -

- (i) NIOH will prepare a revised proposal for undertaking a study with the following scope
 - (a) Organized sector covering the four segments of the industry i.e. Asbestos cement industry manufacturing asbestos cement sheets; Asbestos cement industry manufacturing asbestos cement pipes; Asbestos industry manufacturing asbestos containing friction materials; and Asbestos textile industry.
 - (b) People residing in the vicinity of the industry as at (a) above.
 - (c) The unorganized sector / small scale industries
 - (d) End users.
- (ii) The study will commence covering (a) & (b) of (i) above. This will be followed by (c) & (d) as above.
- (iii) While initiating the study at (a) & (b) above NIOH will first cover the industry segments in the following sequence.
 - (A) Roofing sheets and friction material sector in the first instance.
 - (B) AC Pipes and Textile Sector in the second instance.
- (iv) NIOH will submit a revised proposal for undertaking study within a period of three days after the scope of the study is intimated to them.

Yours faithfully,

(P.S. Singh)

Under Secretary to the Govt. of India
Tel.23070712Fax-23073050
e-mail :usc.cpc@sb.nic.in

Copy to: 1.. Brig. A.K.Sethi,
Advisor, The Asbestos Cement product Manufacturers' Association, New Delhi.

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2016

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