Discussion Paper on Guidelines for Airborne Concentrations of Asbestos Fibres in Ambient Air: Implications for Quantitative Risk Assessment

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Introduction

This paper is an update to that first published in 2017[4]. This updated version includes risk estimates calculated using SoBRA's workbook for the calculation of risk estimates using the linear as well as the non-linear version of the Hodgson & Darnton model as well as updates on the age adjustment calculations.

- Previous published use of the models published by H&D (2000), such as that in CIRIA C733 (2014) have adopted the non-linear version of the H&D model for pleural mesothelioma. Based on the outcomes of a SoBRA asbestos sub-group workshop in April 2019 it was agreed that the linear version of the pleural mesothelioma model is likely to be the more appropriate version for use in estimating risk from low environmental exposures.[5]
- Age adjustment is an important consideration for the use of the H&D models. In this update it is made clearer that the age adjustment factors should be applied to the summed exposure and risk for each 5yr tranche, and the adjusted risk summed for all the relevant 5yr tranches (refer to Annex 2 for details).

This paper has been prepared by a sub-set of the SoBRA asbestos risk assessment working group, to document the results of research and evaluation undertaken over the past year on air quality thresholds for asbestos in ambient air. The scope of this paper includes:

- Presentation of a selection of internationally published air quality guidelines together with the data upon which these are based
- Using the data that underpins some of those air quality guidelines, modelling has been undertaken with two different approaches to demonstrate how the modelling approach adopted alters the air quality guideline. Similarly, the sensitivity to the land use adopted upon the air quality guideline has also been evaluated.
- Information on existing background concentrations to set the calculated air quality guidelines into context
- Implications for current risk assessment approaches adopted in the UK
- Recommendations on next steps for consideration by the asbestos risk assessment working group members.

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[1] AECOM
[2] Arcadis
[3] Wood
[4] Baker, K., Cole, S., Hay, S., Mitcheson, B., Thomas, L., Discussion Paper on Guidelines for Airborne Concentrations of Asbestos Fibres in Ambient Air: Implications for Quantitative Risk Assessment, Society of Brownfield Risk Assessment, December 2017
[5] Reference to the use of the linear model for pleural mesothelioma has been abbreviated in the remainder of this paper as "H&D linear model". Note that this abbreviation encompasses the continued use of the non-linear model variants for peritoneal mesothelioma and lung cancer.

This paper forms one part of SoBRA's efforts to support the wider objectives of the Joint Industry Working Group[6] and support industry in the risk assessment and risk management of asbestos in soil. SoBRA identified in 2013[7] that establishing appropriate air quality values is a key component of the risk-based management process.

Background

Asbestos poses a risk to people when it is airborne, and the fibres inhaled can result in diseases including mesothelioma and lung cancer. In the UK, while there are workplace exposure levels for asbestos fibres in air supporting the assessment and removal of asbestos containing materials in buildings, there is no current consensus on which air quality guidelines should be used to assess potential risks from exposure to asbestos in soils by the general population. This in turn means that there is no UK regulatory or industry-agreed good practice for the assessment of risks from asbestos in soils, which are being - or could be - released to air and subsequently inhaled. The White Paper has been prepared as an evidence base, with the aim of supporting a cross-industry working group in developing good practice for assessment of potential risks from asbestos at sites affected by land contamination.

There are a range of existing air quality guidelines for asbestos fibres, provided both by international bodies (e.g. the World Health Organisation) and national bodies (e.g. Health Council of the Netherlands). There are also different approaches in literature for calculating air quality guidelines for asbestos fibres, dependent on the exposure scenario under consideration. This paper summarises a selection of internationally published air quality guidelines, together with the data upon which these are based, as well as calculating air quality guidelines using two different modelling approaches from literature. The existing air quality guidelines and calculated guidelines have been compared alongside published ambient background airborne concentrations to understand variability in thresholds for asbestos in air and the potential practicalities of those guidelines.

For the purposes of this White Paper, the authors adopted risk of death from cancer[8] of 1 in 100,000 as a risk level to allow true comparison of the different air quality guidelines and calculation methodologies. Appreciating that the UK approach to assessing carcinogens is based on minimal risk rather than a defined risk level, adoption of a 1 in 100,000 risk level was felt to be a reasonable starting point for comparison purposes. While there is ongoing debate regarding non-cancer effects from exposure to asbestos fibres, the authors agreed that the focus of the White Paper should be on cancer effects (mesothelioma and lung cancer) given the weight of evidence from epidemiological studies.

The authors note that for the risk assessment community to be able to draw conclusions as to risks from asbestos in soils, it is also important to reduce the uncertainty and lack of science relating to the relationship between asbestos in soil and asbestos fibres in air. However, this is subject to

[6] Joint Industry Working Group on Asbestos in Soil and Construction & Demolition Materials (www.claire.co.uk/asbestos)
[7] Requirements for further research in to the release of asbestos from soil, SoBRA, October 2013
[8] As noted in Environment Agency (2009) Human Health toxicology assessment of contaminants in soil Science report SC050021/SR2- "…where human data is available, it may be possible to model both risk of cancer (e.g. excess lifetime risk of cancer) and risk of death from cancer. These are sometimes used as though they are synonymous which they are not; their interrelation depends on the survival/fatality rate for malignancy. For example, fatality rates for non-melanoma skin cancer are quite low in western countries (a few percent) while for lung cancer they are high…" The use of risk of death from cancer assesses the whole risk and enables the effect on mortality from the delayed development of cancer later in life to be considered.

further research and will form a separate White Paper. This paper does however provide a preliminary consequence evaluation for one commonly adopted approach for soil risk.

Reporting conventions for asbestos fibres in air do vary and are not necessarily consistent with the definitions used for asbestos content in asbestos in bulk materials or soils[9]. The units used in this paper to compare and contrast guidelines are fibres per metres cubed (f/m^3) and we have chosen where possible to quote values as f/m^3 measured by Transmission Electron Microscopy (TEM). Where source literature quotes concentrations as measured by Phase Contrast Microscopy (PCM) the data have been converted using the adopted convention that TEM = 2 x PCM based on the approaches taken by WHO[10] and RIVM[11]. It is accepted that the conversion between PCM and TEM or SEM is complex and that there is no universally accepted conversion factor. Published values have varied from 1.7 – 4, and up to 30 in one study[12], and ATSDR[13] published a range of 19-76 for "all fibres" and a more restricted range of 1.4-3.2 for respirable fibres. However, an assumption on conversion is necessary to be able to compare and contrast guidelines quoted in the two different methods and is also required when converting PCM-based epidemiological data into TEM-defined guidelines (such as those adopted in the US and The Netherlands). RIVM for example adopts a x2 conversion from PCM to SEM, and WHO also adopts a x2 conversion for the purposes of defining air quality guidelines. It is noted however that ATSDR adopted a 1984 NRC recommendation to use a conversion factor of TEM = 60 x PCM for use in the conversion of historic ambient air measurements. Given this variability in conversion factors we have not converted reported background air concentrations where quoted in this paper. Where source literature quotes values in fibres per millilitre (f/ml) this is stated and the data has been converted using the conversion f/m^3 = f/ml x 1,000,000.

Existing Guidelines

Air quality guidelines protective at population level have been proposed by various organisations[14]; a number of these are summarised in Figure 1 with the raw data provided in Table 1. The organisations were selected based on their influence at an international level (e.g. WHO and USEPA) and the authors' knowledge of research in this field. The list is therefore not exhaustive. Further detail is provided in Annex 1.

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9 In terms of airborne fibres, the critical distinction from a risk perspective is between respirable fibres (those most likely to remain in the lung) and non-respirable fibres (those that are more likely to be expelled from the lung). The current convention in the UK is to define a countable asbestos fibre as one which is longer than 5µm, with an average width less than 3µm and having an aspect ratio greater than 3:1. RIVM (2003) defines respirable fibres as having a diameter smaller than 3µm and a length less than 200µm. The US EPA (2008) recommend a variation to ISO10312:1995 such that fibres are counted based on a length greater than 0.5µm and an aspect ratio of 3:1 or greater using TEM or based on a length greater than 5µm and an aspect ratio of 3:1 or greater for PCM. WHO (1986) recommends a width range of between 0.25µm and 3µm.

10 WHO (2000) Air quality guidelines for Europe, second edition, WHO Regional Publications, European Series, No. 91, World Health Organization Regional Office for Europe, Copenhagen

11 RIVM (2003) Table 2.1 in Assessment of the risks of soil contamination with asbestos, RIVM report 711701034/2003

12 Boulanger et al (2014) Quantification of short and long asbestos fibers to assess asbestos exposure: a review of fiber size toxicity, Environmental Health, 13:59

13 ATSDR (2001) Toxicological Profile for Asbestos, Agency for Toxic Substances and Disease Registry, September 2001

14 World Health Organisation (WHO), US Environmental Protection Agency (USEPA), Health Effects Institute (HEI), Dutch National Institute for Public Health and the Environment (RIVM), Health Council of the Netherlands (HCN)

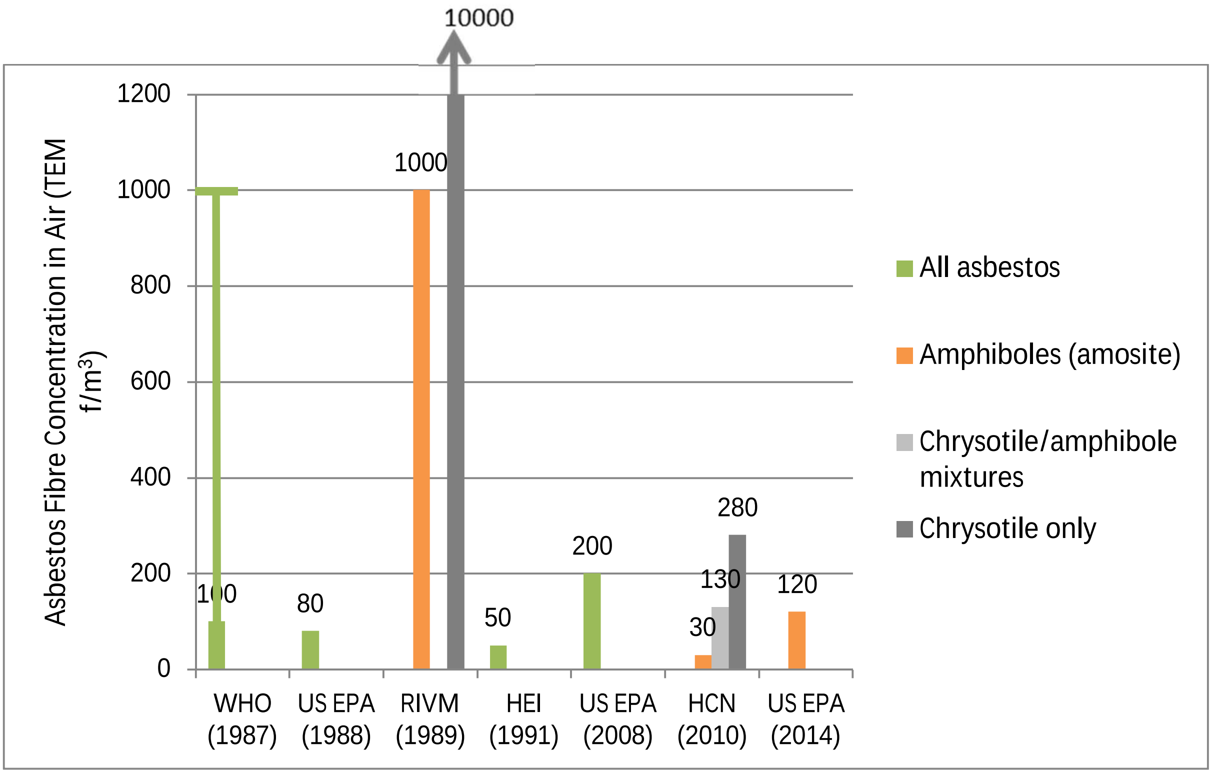

Figure 1 Comparison of Asbestos in Air Quality Guidelines (Selected International and National Organisations)[a]

Table 1 Summary of Asbestos Air Quality Guidelines (Selected International and National Organisations)

Organisation	Air Quality Guideline (f/m^3)[a]			
	All asbestos types/not specified	Amphiboles[15] (amosite)	Chrysotile / amphibole mixtures	Chrysotile only
WHO (1987)	100-1000	-	-	-
US EPA (1988)	80	-	-	-
US EPA (2008)	200	-	-	-
US EPA (2014)	-	120	-	-
HEI (1991)	50		-	-
RIVM (1987)	-	1000	-	10000
HCN (2010)	-	30	130	280

Notes

[a] All published guidelines adjusted by the authors to reflect a 1 in 100,000 risk of death from cancer from developing mesothelioma and lung cancer and quoted in f/m^3 TEM

[15] The use of "amphiboles" is the convention used by RIVM, although the assumption in its use is that the asbestos is amosite

Figure 1 and Table 1 illustrate that RIVM (1989) and the upper guideline from WHO (1987) are considerably higher than the remaining guidelines, which range from 30 to 280 f/m^3 with the lowest value applicable for amphiboles and the highest value applicable for chrysotile.

USEPA Asbestos Working Group

Black (pers comm, 2016) highlighted to the authors that the USEPA criteria in Table 1 are undergoing review within the USEPA Asbestos Working Group[16]. The expectation is that the air quality guidelines for asbestos will be reduced, with the potential for additional non-asbestos fibre types to be included for consideration when evaluating risks from dust and fibres. This information, combined with review of Table 1, indicates a general trend towards lower air quality guidelines for asbestos from those developed in the 1980s.

Modelling Approaches

Two alternative modelling options have been identified as being used by UK practitioners for calculating air quality guidelines for the protection at general population level, using the available epidemiological data and modified according to the exposure scenario under consideration. These modelled approaches are:

- Hodgson and Darnton (2000) algorithms for mesothelioma and lung cancer estimation adopted by the UK HSE (method adopted in CIRIA C733).
- Algorithms for mesothelioma and lung cancer commonly adopted by the US EPA, Berman and Crump, HEI and HCN.

Examples of how these two approaches can be used to calculate air concentrations that represent a given risk to land users in a UK context are provided in Annexes 2 and 3. The modelling outputs are summarised in Table 2. The conceptual exposure models adopted were based on the exposure parameters in the C4SL project (Defra SP1010, 2014) in relation to receptor ages and land-use characterisation. Further details on the exposure assumptions are provided in the model annexes.

[16] The understanding of the authors is that this review is still to be finalised/published.

Modelling Results

The calculations have been completed for residential, commercial, and public open space land uses, with the results summarised in Table 2 below. The risk of death from cancer for this exercise was set at 1 in 100,000. Other risk levels could be adopted, and the air concentrations re-calculated in accordance with the approach outlined in this paper. B&C and HEI calculations remain unchanged from the original version of this paper. The H&D calculations have all be re-done using the new SoBRA calculation spreadsheet.

Table 2 Summary of Calculated Exposure (Air) Concentrations for Residential, Commercial and Public Open Space Scenarios Indicative of risk of death from cancer of 10^{-5}

	Calculated Air Concentration (f/m^3 TEM)														
Land-use	Residential					Commercial					Public Open Space				
Modelling Approach	B&C[a]	B&C[b]	HCN	H&D Non-linear[c]	H&D Linear[c]	B&C[a]	B&C[b]	HCN	H&D Non-linear[c]	H&D Linear[c]	B&C[a]	B&C[b]	HCN	H&D Non-linear[c]	H&D Linear[c]
Chrysotile	2600	-	400	400	3600	24000	-	3640	6400	34000	280000^	-	48000	36000	420000^
Mixed fibres	-	-	80	-	-	-	-	960	-	-	-	-	12800	-	-
Amphiboles (amosite)	14	40	12	5*	48*	200	400	200	80*	560*	1100	2600	1040	420*	4600*

Notes
[a] using Table 7-17 PCME coefficients (Berman & Crump 2003)
[b] using Seidman coefficients in Berman & Crump 2003)
[c] using best estimates from the non-linear and linear models (Hodgson & Darnton 2000). Calculations performed in PCM units (refer to Annex 2) and converted here to TEM using the adopted conversion factor of x2
*Based on H&D estimates for amosite
^ Exceeds the Control Limit of 0.1f/ml but is based on a 2hr exposure duration

The differences in values between chrysotile and amphibole values suggest a potency difference of between approximately 18x and 255x. Further discussion on asbestos fibre potency is provided in Annex 4

Comparison of Model Calculations with Published Air Quality Guidelines

Based on the calculation examples above for residential land-use, Figure 2 compares the existing air quality guidelines (from Table 1) and calculated residential air concentrations in Table 2. This indicates the potential range in values that the UK could adopt, based on an ECLR of 1 in 100,000 for residential land use. The comparison indicates that there is relatively low variation for chrysotile if the value for chrysotile using the Berman and Crump coefficients is excluded. It also indicates that there is relatively low variation for amphiboles, but that the air quality values for amphiboles are typically lower by an order of magnitude or more than for chrysotile. It also shows that UK-based assumptions on early life exposure adjustment and mortality rates using a linear model for pleural risk can result in higher values than those published by the original authors (for example the SoBRA amphibole value of 48f/m^3 by H&D method compared to 12 f/m^3 by HCN method and the HCN published value of 30f/m.

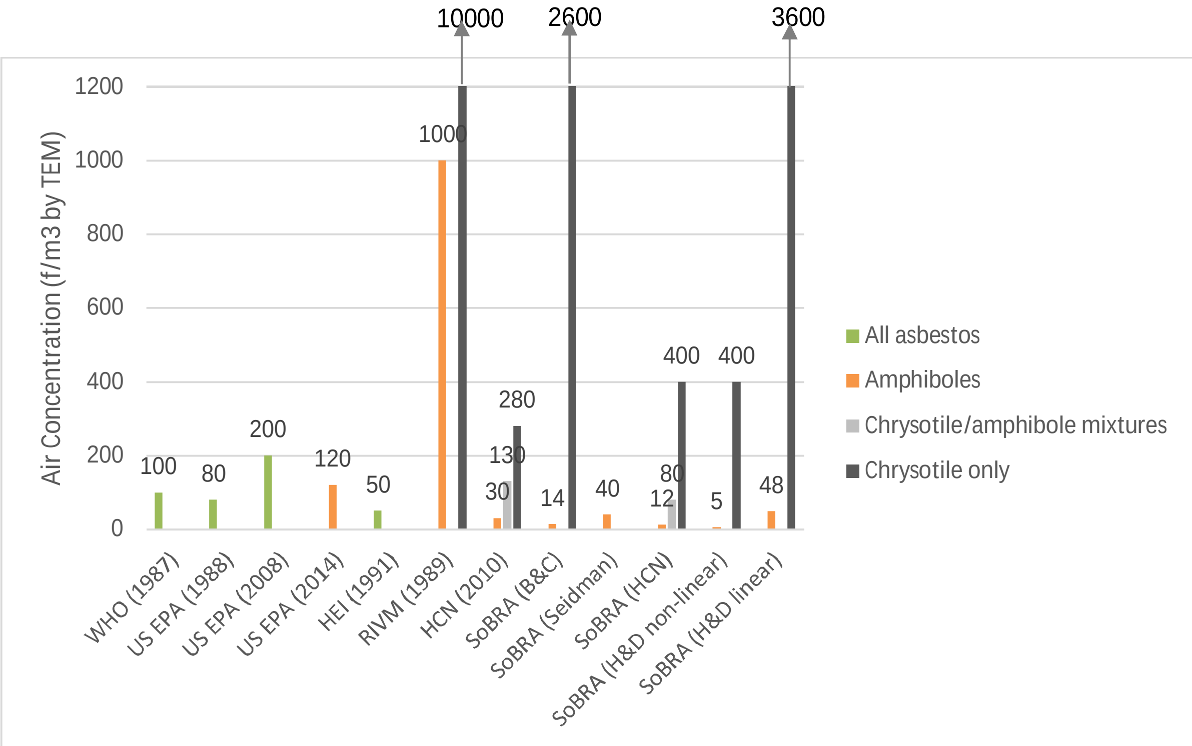

Figure 2 Comparison of Asbestos in Air Quality Guidelines (Selected International and National Organisations)

Model Sensitivity to Air Concentration and Exposure Frequency/Duration

The H&D and HEI models present different exposure/risk relationships and therefore exhibit different sensitivities to changes in air concentration and or frequency and duration of exposure. The H&D relationship includes a power relationship based on cumulative exposure (concentration x duration) although following discussion with the author a linear model for the more dominant pleural mesothelioma risk has been adopted as the preferred approach, whereas the HEI model is a combination of a linear relationship for air concentration and a power relationship for time.

Figures 3 and 4 below provide examples of model sensitivity to changes in air concentration and exposure time based on a single scenario of an adult exposed to amosite.

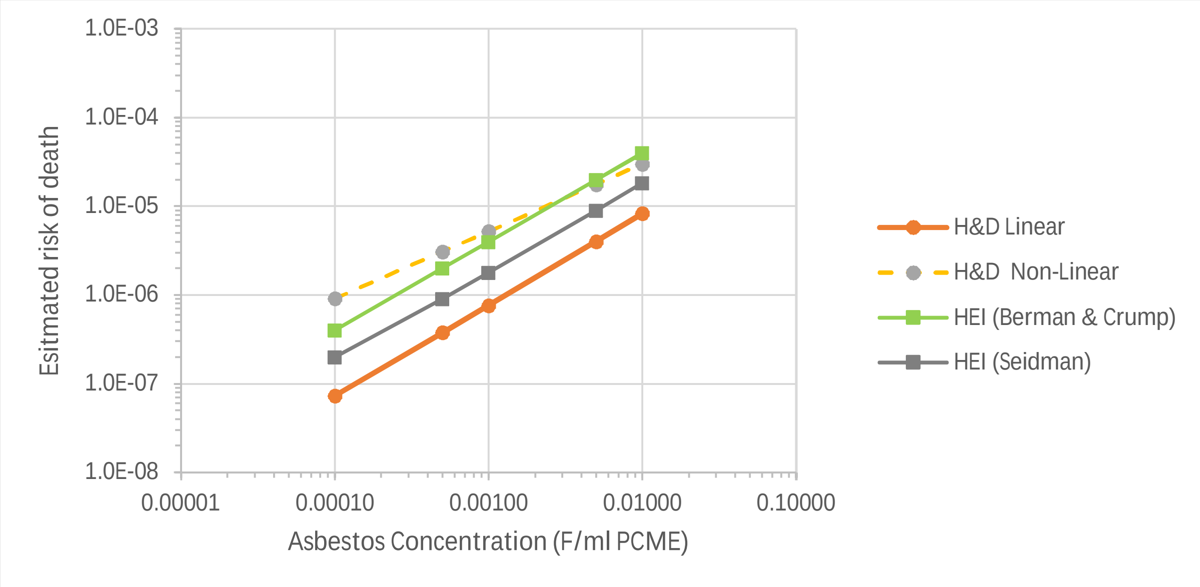

Figure 3 Sensitivity of Risk Models to Changes in Air Concentration

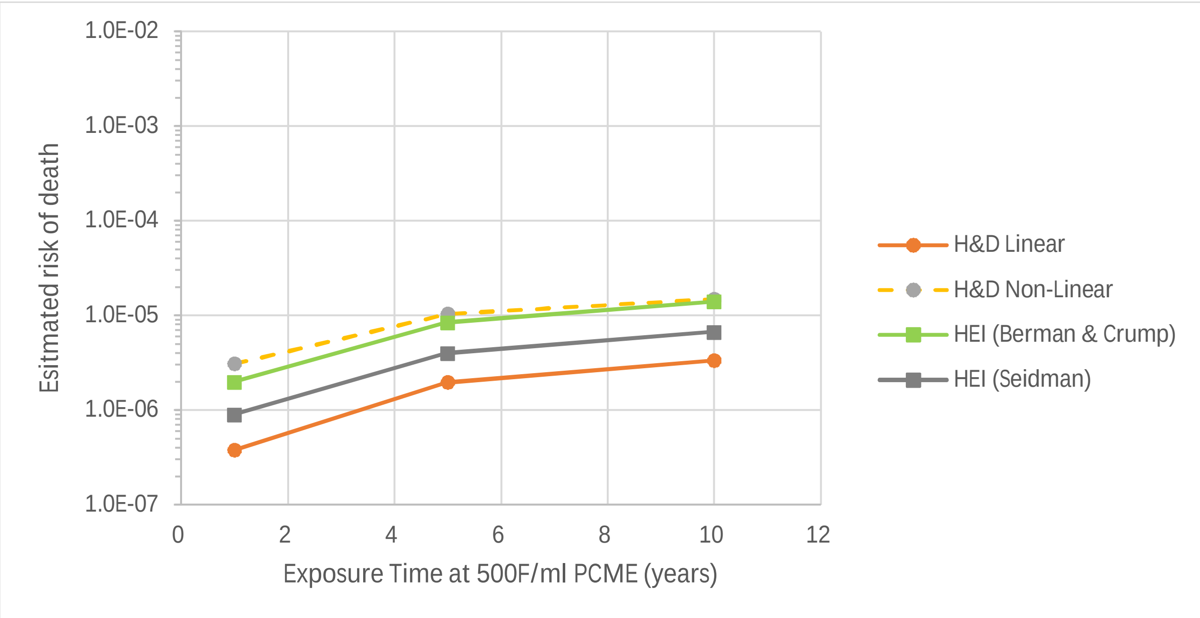

Figure 4 Sensitivity of Risk Models to Changes in Exposure Duration

Principal model assumptions[17] for Figures 3 and 4 above are an adult aged 30 at start of exposure with risk persisting for 80 years.

Figures 3 and 4 show that it is possible to estimate the significance of individual changes to default exposure assumptions; for example, increasing or decreasing the time weighted average exposure

[17] The H&D linear model refers to the use of the linear model for the more dominant pleural mesothelioma risk but the peritoneal and lung cancer risk models remain non-linear in these calculations, The H&D non-linear model uses the non-linear model for pleural, peritoneal and lung cancer risks

concentration or increasing or decreasing the duration of exposure, without needing to undertake detailed modelling. Detailed modelling is likely to be required for changes in multiple parameters.

Background Concentrations
The authors found that research into background concentrations of airborne asbestos fibres in ambient air (indoors and/or outdoors) is limited and is largely restricted to studies undertaken before prohibitions on the importation and use of asbestos containing products came into force. Of the most recent reviews, CIRIA (2014) published a summary of identified studies (Table 6.1 of C733), The Health and Safety Executive (HSE) Working Group on Action to Control Chemicals (WATCH) reviewed background concentrations in 2010, and the HCN also reviewed at background concentrations in 2010.

The conclusion of HCN (based on unpublished reference measurements in uncontaminated urban and non-urban areas by TNO, taken as part of investigations into workplace exposure) was that current background levels in the outdoor atmosphere in the Netherlands are likely to be 10-20 f/m^3 (as measured by TEM). This expected range is narrower although still potentially consistent with the assumption in CIRIA (2014) that outdoor concentrations in rural and urban areas in the UK are likely to be below 100f/m^3 (as measured by PCM).

The Institute for Environment and Health published a study of background air concentrations in the UK in 1997. This concluded that outdoor ambient concentrations were generally in the range 1-100 f/m^3, and indoor concentrations were mostly below 200 f/m^3, rising to approximately 500 f/m^3 for buildings containing asbestos in good condition (all values measured by PCM).

WATCH summarised available published information from the UK, Europe and US; the values quoted reasonably consistent with the ranges noted above. Critically the studies did not typically distinguish between asbestos type so detailed comparison with the air guideline values is not possible, however, taking a likely range between 1 and 100 f/m^3, it is evident from Figure 2 that the guidelines for amphiboles (primarily amosite) and the guidelines for mixtures of asbestos types are likely to be within the range of anticipated background concentrations (noting these concentrations are for all asbestos fibres and not specifically for amphiboles). It is likely on the other hand that ambient background concentrations are likely to be lower than the guideline values for chrysotile.

Further information is on published background concentrations are provided in Annex 5.

Implications for QRA
This White Paper highlights that:

- There appears to be good consensus in literature that air quality guidelines for amphibole should be lower than chrysotile, typically by up to two orders of magnitude;
- There is variation but not significant differences (i.e. an order of magnitude of more) in air quality guidelines for general population exposure (assuming sensitive receptor exposure, such as residential land use) when existing air quality guidelines are compared to the guidelines calculated by the authors using different methods[18];
- The existing and calculated air quality guidelines for chrysotile are consistent, or higher, than literature-reported background concentrations of asbestos fibres in air;

[18] With the exception of the calculation undertaken using Berman and Crump co-efficient for chrysotile

- The existing and calculated air quality guidelines for amphiboles are typically lower than literature-reported background concentrations of asbestos fibres in air, however little is known as to the extent to which amphiboles contribute to the reported background values;
- There appears to be a downward trend in air quality guidelines when comparing those derived in the 1980s to those derived in the 2000s;
- The use of the Hodgson & Darnton non-linear model for pleural mesothelioma results in lower air guideline values compared to the use of alternative models (including the H&D linear pleural mesothelioma model);
- The adoption of more recently published air quality guidelines for amphiboles could lead to more stringent assessment and clean-up goals for asbestos at land contamination sites (compared to use of WHO (1987) for example);
- Conversely the adoption of more recently published air quality guidelines for chrysotile could lead to less stringent assessment and clean-up goals for asbestos at land contamination sites
- The adoption of older air quality guidelines should therefore be carefully considered before use in risk-based decision making;
- The adoption of more recently published air quality values for amphiboles likely presents a challenge for existing air sampling and analysis methods and puts into question the practicability of these values – can they be reliably determined?;
- Occupational monitoring/sampling techniques are likely in most cases to be inappropriate for use as a line of evidence in assessments of potential exposure against air quality values such as those referenced in this paper; and
- The use of the HSE clearance indicator level of 0.01 f/ml PCMe (20,000 f/m^3 by TEM) is outside the range of air values for chrysotile quoted in Figure 2 (240-10,000 f/m^3) and significantly outside the range for amphiboles (3-1000 f/m^3).

To illustrate what (if any) implication there may be to the use of one of the most widely adopted guidelines in Europe (Annex 3 of the Dutch Soil Remediation Circular), the graph on which the Dutch guidelines are based is reproduced below with the calculated air values in this paper added.

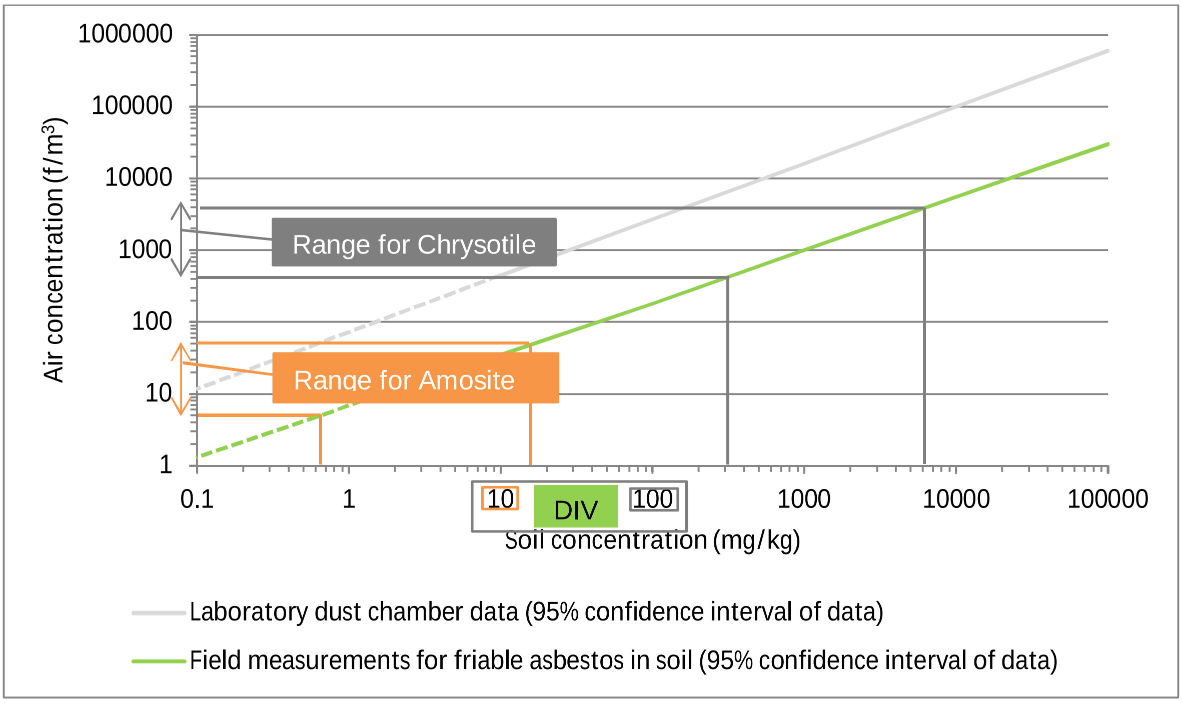

Figure 5 Implication of calculated air values on use of Dutch Guidelines

Figure 5 indicates that the Dutch Intervention Value (DIV) for chrysotile in soil of 100mg/kg (0.01%wt/wt) is likely to remain precautionary (i.e. based on the graphical correlation air concentrations should remain below all calculated air guidelines) unless conditions similar to laboratory conditions prevail. The DIV for amosite of 10mg/kg (0.001%wt/wt) however is unlikely to be similarly precautionary.

In relation to the quantitative risk assessment approach advocated in CIRIA C733 it is evident from the calculations presented in this paper that the Hodgson & Darnton non-linear algorithms for all forms of asbestos-related cancer is likely to produce higher risk estimates than those calculated using alternative risk algorithms such as those advocated by HCN and Berman & Crump. The use of the linear version of the H&D model for pleural mesothelioma in conjunction with the non-linear variants for peritoneal mesothelioma and lung cancer however produces similar to lower risk estimates compared to HCN and B&C.

<u>Recommendations</u>

The authors believe that the information in this White Paper should be used as supporting evidence for the Joint Industry Working Group to formulate a position regarding air quality guidelines for asbestos in the UK. There remain a number of issues that need to be resolved before an air guideline value can be proposed:

1. Should the UK adopt existing air quality guidelines to air assessment of chronic risks from asbestos at land contamination sites? If yes:
    a. Which guidelines could be adopted?
    b. Should a range in guidelines be adopted?
    c. Should the analysis comprise PCM or TEM?
    d. What risk level should be adopted?
    e. Should provision be made for modification to air quality guidelines based on non-residential exposure scenarios?
2. Should the UK adopt a framework for calculating air quality guidelines? If yes:
    a. Which approach should be adopted?
    b. Should the analysis comprise PCM or TEM?
    c. What level of risk should be adopted?
3. Should background concentrations be incorporated into the assessment process in the UK? If yes:
    a. Is more data needed before an approach can be formulated?
    b. Should published background concentrations be used to bench-mark the air quality guidelines?
4. Can we make a clear distinction between the relative risks from chrysotile and amphiboles given the relative abundance of the former compared to the latter, and thereby lead to different risk management approaches?

It is recommended that the linear version of the H&D model for pleural mesothelioma is used to estimate risk and calculate air guideline values in conjunction with the non-linear variants for peritoneal mesothelioma and lung cancer. SoBRA has developed an excel-based tool to implement both the non-linear and linear versions of the H&D model. This model is provided free to use via the SoBRA website.

It is evident from the assessment presented in this paper that there is a clear requirement for further research into background air concentrations in the UK. This is needed to be able to benchmark the practicability of proposed air guidelines. It is also evident that a step change in air monitoring practice is required; with a move away from the use of occupational monitoring techniques that typically report to 10000f/m^3 (0.01f/ml) and use non-fibre-discriminatory PCM analysis to methods capable of measuring down to at least 10f/m^3 using fibre-discriminatory SEM or TEM analysis (as advocated by the authors of CIRIA C733).

<u>Limitations</u>

This white paper has been developed by members of the SoBRA Asbestos-in-soil sub-group acting in a voluntary capacity, and details the views of the individual authors, not those of their employers. It is provided freely on the SoBRA website to help promote discussion on what should constitute good practice in assessing the health risk from asbestos-contaminated soil in the UK. Users of this paper must satisfy themselves that the content is appropriate for the intended use and no guarantee of accuracy or suitability is made.

Feedback

Feedback on this paper is welcomed and should be submitted to SoBRA at info@sobra.org.uk.

January 2021

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Annex 1 – Published Air Quality Guidelines

Organisation/Reference	Air Quality Guideline (f/m^3)	Comments
WHO (2000)	100-1000	Based on toxicological review published in 1987. The review noted that amphiboles were more potent than chrysotile but did not differentiate between asbestos type in the calculations as a precaution. Calculations based on Peto (1984) model for mesothelioma and US EPA (1985) model for lung cancer. Final recommendation that 500f/m^3 (PCM) equated to an approximate risk of mesothelioma of 10^{-5}-10^{-} and 10^{-6}-10^{-5} for lung cancer. A "best" estimate for lifetime exposure to 100f/m^3 (PCM) may be 2x10^{-5}; suggesting an AQG set at 10^{-5} could be 50 f/m^3 (PCM).
US EPA (1988)	80	Inhalation unit risk of 0.23 per f/ml (PCM) based on a 1988 toxicological review available on IRIS. This equates to an air concentration of 40f/ml (PCM) for cancer risk of 10^{-5}. No asbestos type, with calculations based on assumption that airborne fibres are amosite or mixed amosite.
US EPA (2008)	200	This framework document sets out an approach to setting land-use specific air quality guidelines. Based on the IRIS (1988) IUR adjusted for less than lifetime exposure. Value quoted to the left is for baseline residential exposure (30 years exposure from birth) adopting an ELCR of 10^{-5}.
US EPA (2014)	120 RfC 180	Inhalation unit risk of 0.17 per f/ml (PCM) based on the Libby mine cohort only (exposure primarily to tremolite). A reference concentration for non-carcinogenic health effects of 90f/m^3 (PCM) also established based on the risk of pleural thickening.
HEI (1991)	50	The authors concluded that 100f/ml (PCM) equated to a risk of death of 4x10^{-5} for mesothelioma and lung cancer from mixed fibre exposures.
RIVM (1989)	1000 amphiboles 10,000 chrysotile	Based on WHO (1987) toxicological evaluation. Assessment distinguished between amphibole and chrysotile fibres, using an assumption that lung cancer was attributable to chrysotile exposure and mesothelioma only attributable to amphibole exposure. Maximum permissible risk levels were stated for a cancer risk of 10^{-4} and negligible risk levels stated for a cancer risk of 10^{-6} based on the upper values in the fibre concentration ranges for those risk levels. Values quoted to left are the mid-point values for a cancer risk of 10^{-5} to maintain consistency with other values quoted.

Organisation/Reference	Air Quality Guideline (f/m^3)	Comments
HCN (2010)	30 amphiboles 130 mixed fibres 280 chrysotile	Proposed new MPR and NR levels based on a new meta-analysis of the epidemiological data. Values quoted to left are for a mid-point cancer risk of 10^{-5} based on the combination of lung cancer and mesothelioma risk. Risk of mesothelioma differentiated across three categories; no differentiation made for lung cancer risk (i.e. risk the same irrespective of asbestos type)

All AQG are guidelines and are non-statutory. All AQG values quoted as measured by TEM unless stated otherwise. Conversion between PCM and TEM where required based on commonly adopted approximation of TEM = 2x PCM

Annex 2 – Example calculations using Hodgson and Darnton approach

In 2000, Hodgson and Darnton[19] reviewed a number of cohort mortality reports for which quantified data on exposure was available either as an average for the cohort as a whole, or for individual subgroups in order to derive dose response equations for mesothelioma and lung cancer risks from exposure to chrysotile, amosite and crocidolite. At the time of analysis 20 cohorts were available with necessary information published to allow construction of the summary measures of mortality and cohort average cumulative asbestos exposures. In 10 of these cohorts, exposures were to single types of asbestos (3 cohorts with exclusively crocidolite exposures, 2 with amosite and 5 with chrysotile), the remainder involved mixed exposures.

Hodgson and Darnton then derived equations to assess the risk of lung cancer and mesothelioma from cumulative exposure over a five-year period. Hodgson and Darnton fitted both linear and non-linear equations to the risks from mesothelioma and lung cancer. Best fit and reasonable worst case and best-case fits were derived.

Based on discussion with one of the authors of the H&D model (Andrew Darnton), we have chosen the linear model for pleural risk of mesothelioma[20] and non-linear model for the peritoneal risk of mesothelioma and for risks from lung cancer. It is considered that the linear model for pleural risk is more appropriate for use when considering low level environmental exposure (as compared to high level occupational exposure). This is the recommendation of Andrew Darnton based on his re-evaluation of the original H&D paper in light the context of use for low level environmental exposure. Consideration has been given to the risk of death from cancer from both lung cancer risk as well as mesothelioma.

Key uncertainties in the H&D model and differences between the H&D model and others include:

i. The extrapolation of risk to low doses is very sensitive to the model used to fit the data. The use of a linear model for the dominant risk (pleural risk of mesothelioma) is consistent with the linearity assumed in Environment Agency's SR2[21] guidance (e.g. by the use of benchmark doses). The non-linearity of the peritoneal risk of mesothelioma reflects that the incidence of this falls more rapidly than pleural risk of mesothelioma. There is large uncertainty in the calculations below (illustrated by the difference between the non-linear and linear models).

ii. The H&D model coefficients are dependent to some extent on judgements about the interpretation of certain cohorts. Other modellers have made different adjustments

iii. The H&D model was not used for exposures less than 0.002 to 0.005f/ml.year below which risks are described as insignificant for a 5-year tranche in the model. The extrapolations below are all outside this range.

[19] Hodgson, J.T. and Darnton A. (2000). The quantitative risks of mesothelioma and lung cancer in relation to asbestos exposure. Annals of Occ. Hyg., Volume 44, No 8, pages 565-601.
[20] WATCH/2008/7 Annex 1 The risks of mesothelioma and lung cancer in relation to relatively low-level exposures to different forms of asbestos
What statements can reliably be made about risk at different exposure levels?
[21] Environment Agency (2009) Human health toxicological assessment of contaminants in soil, Science Report - Final SC050021/SR2.

iv. The use of age-related exposure tranches and age adjustment factors is used for adjustment for greater sensitivity of children for instance rather than continuous adjustment.

v. The cumulative exposure is based on Phase Contrast Microscopy (PCM) measurements of asbestos in air.

Mechanics of the calculations

Mesothelioma risk

The H&D equations for methothelioma are of the form:

$$P_m = A_{pl}X^r + A_{pr}X^t$$

P_m –mortality from methothelioma as a percentage of expected mortality from all causes

A_{pl} and A_{pr} – constants of proportionality for the pleural and peritoneal elements of the risk

r and t - pleural and peritoneal slopes of the exposure response on a log–log scale

X – cumulative exposure in f/ml.yr based on PCOM fibre measurements and occupational years.

Adjustment for mortality from mesothelioma

To make predictions of mortality from mesothelioma the percentage of mortality (P_m) must be converted back into absolute terms. For exposures starting at age 30 the expected mortality estimate P_M is applied to the total expected mortality from age 40 to age 79 (allowing a 10 yr minimum latency, and truncating risk at age 80). The life table predicts that about 70% of survivors to age 30 will die between the ages of 40 and 80. Absolute risk estimates can therefore be derived from the P_M value for a given exposure by multiplying by a factor of 0.7.

$$O_m = \frac{(A_{pl}X^r + A_{pr}X^t) \times E_{adj}}{100}$$

O_M the observed meso deaths

E_{adj} the expected mortality from all causes adjusted to an age at start of exposure of 30.

Lung cancer risk

The H&D equations for lung cancer are of the form:

$$P_L = A_l X^r$$

P_L – percent excess of expected lung cancer mortality

A_L– constants of proportionality for the lung cancer elements of the risk

r - lung cancer slopes of the exposure response on a log–log scale

X – cumulative exposure in f/ml.yr based on PCOM fibre measurements and occupational years

Adjustment for Predicted excess mortality risk

To make predictions of risk from lung cancer, the percentage excess mortality measure from lung cancer must be adjusted to absolute mortality from lung cancer. The main determinant of the underlying lung cancer risk is smoking, and hence absolute mortality is sensitive to the proportion smokers in the population chosen.

Data for the % mortality from lung cancer and all causes death rate at each age has been considered assuming a starting age of 30 using data from 2016 -2018. Combining data for survival and proportionate mortality from lung cancer we can predict that for 1000 30-year-old men, 36 will die of lung cancer between age 40-79. (For women it is 29). For the population as a whole it is 33. This latter value has been used in the calculations

The excess mortality from lung cancer is given by:

$$Predicted\ excess\ mortality = O_l - E_l = \frac{A_l X^r \ \times E_l}{100}$$

E_L Proportion of the specific population that will die of lung cancer between age 40-79

Additivity across age groups

Mesothelioma

To adjust the risk from other age groups and to account for a potential greater sensitivity of young children from mesothelioma, age adjustment factors are applied.

To assess the contribution from each 5 year period the difference in cumulative exposure risk (P_m) at the end of each 5 year period and the cumulative exposure risk up to the start of that five year is multiplied by the age adjustment factors. The contributions from each 5-year tranche are then summed[22].

$$Mortality\ from\ Mesothelioma = \sum_{tranche\ i=1}^{all\ ages} Age\_Adj_i(Pm_i - Pm_{i-1}) \times \frac{E_{adj}}{100}$$

In deriving age adjustment factors for mesothelioma, the life expectancy must be taken into account. In the calculation carried out in this paper a life expectancy of 80 has been assumed and

[22] Based on personal communication with Andrew Darnton (2019)

the age adjustments are taken from a 2010 HSE/WATCH paper[23], but other adjustments including those for 90 years and for 60years have also been considered.

Lung cancer

Age adjustment has also been applied to the lung cancer risk using a similar approach:

$$Excess\ Mortality\ from\ Lung\ Cancer = \sum_{tranche\ i=1}^{all\ ages} Age_{Adj_i}\,(PL_i - PL_{i-1}) \times \frac{E_L}{100}$$

For lung cancer in Hodgson & Darnton exposures at ages above 45 were not considered. In order to estimate "working lifetime" effects the correction factors need to be extended to older ages. At these older ages it is no longer reasonable to assume that lung cancer risks will be unchanged. Most lung cancer deaths occur at ages 60+ and therefore fall in the 20+ year latency period whether exposure starts at age 20 or 40. At higher ages however a more substantial proportion of lung cancer deaths will occur before the full impact of asbestos exposure on this cause of mortality is expressed. For this reason, the assumption made is that the impact of exposure starting at ages 45, 50, and 55 is 75%, 50% and 25% respectively of that estimated for younger exposure starting ages[24].

Calculation

To determine the concentration in air at which a particular risk occurs the model was set up to calculate the risk from continuous residential and commercial exposure to a given concentration in air in Excel. Solver (equation solution finder within excel) was used to find the concentration equivalent to a risk of 1 in 10^{-5}.

A spreadsheet setting out the basis of calculation is provided to support this paper including details of the input parameters used.

[23] HSE WATCH 2010 Extrapolations of the Hodgson & Darnton (2000) (H&D) model (WATCH/2010/3 – Annex 3)

[24] Personal communication with Andrew Darnton (2019)

Output

<u>Chrysotile concentration in air thresholds using H&D linear model with lifetime of 80 years</u>

		Chrysotile			
		CLEA exposure scenario*			
		Residential		Public Open Space (Parks)	Commercial
	Age	0-6	0-60	0-6	16-60
Linear model for pleural risk of mesothelioma					
Asbestos concentration in air thresholds	F/m3	7300	1800	210000	17000
Risk of death from mesothelioma	risk	9.0E-06	7.0E-06	9.2E-06	5.3E-06
Risk of death from lung cancer	risk	1.1E-06	2.9E-06	1.1E-06	5.2E-06
Overall risk of death from cancer	risk	1.0E-05	1.0E-05	1.0E-05	1.0E-05
Non-Linear model for pleural risk of mesothelioma					
Asbestos concentration in air thresholds	F/m3	600	200	18000	3200
Risk of death from mesothelioma	risk	9.9E-06	9.9E-06	1.0E-05	9.5E-06
Risk of death from lung cancer	risk	4.2E-08	1.7E-07	4.5E-08	5.9E-07
Overall risk of death from cancer	risk	1.0E-05	1.0E-05	1.0E-05	1.0E-05

Notes:
F/m^3 are all Fibres measured by PCM
*denotes the exposure scenario adopted from CLEA, (ref: technical background to the CLEA model, Science Report SC050021/SR3, Environment Agency, 2009). Aspects of the exposure scenario used in the calculations are:
Residential
6 years of exposure to asbestos from ages 0 to 6 for 365 days per year 24hours per day; or
60years of exposure to asbestos from ages 0 to 60 for 365 days per year 24hours per day.
Public Open Space
6years of exposure to asbestos from ages 6months to 6years for 2hours per day for 170 days per.
Commercial
43years of exposure to asbestos from ages 16 to 60years for 9hours per day for 230 days per year

Amosite concentration in air thresholds using H&D linear model with lifetime of 80 years

		Amosite			
		CLEA exposure scenario*			
		Residential		Public Open Space (Parks)	Commercial
	Age	0-6	0-60	0-6	16-60
Linear model for pleural risk of mesothelioma					
Asbestos concentration in air thresholds	F/m3	80	24	2300	280
Risk of death from mesothelioma	risk	9.9E-06	9.4E-06	1.0E-05	8.7E-06
Risk of death from lung cancer	risk	1.7E-07	6.1E-07	1.8E-07	1.4E-06
Overall risk of death from cancer	risk	1.0E-05	1.0E-05	1.0E-05	1.0E-05
Non-Linear model for pleural risk of mesothelioma					
Asbestos concentration in air thresholds	F/m3	7.5	2.5	210	40
Risk of death from mesothelioma	risk	1.0E-05	1.0E-05	1.0E-05	9.9E-06
Risk of death from lung cancer	risk	8.0E-09	3.2E-08	7.9E-09	1.1E-07
Overall risk of death from cancer	risk	1.0E-05	1.0E-05	1.0E-05	1.0E-05

Notes:
F/m^3 are all Fibres measured by PCM
*denotes the exposure scenario adopted from CLEA, (ref: technical background to the CLEA model, Science Report SC050021/SR3, Environment Agency, 2009). Aspects of the exposure scenario used in the calculations are:
Residential
6 years of exposure to asbestos from ages 0 to 6 for 365 days per year 24hours per day; or
60years of exposure to asbestos from ages 0 to 60 for 365 days per year 24hours per day.
Public Open Space
6years of exposure to asbestos from ages 6months to 6years for 2hours per day for 170 days per.
Commercial
43years of exposure to asbestos from ages 16 to 60years for 9hours per day for 230 days per year

Crocidolite concentration in air thresholds using H&D linear model with lifetime of 80 years

		Crocidolite			
		CLEA exposure scenario*			
		Residential		Public Open Space (Parks)	Commercial
	Age	0-6	0-60	0-6	16-60
Linear model for pleural risk of mesothelioma					
Asbestos concentration in air thresholds	F/m3	16	5	450	62
Risk of death from mesothelioma	risk	1.0E-05	1.0E-05	1.0E-05	9.9E-06
Risk of death from lung cancer	risk	2.1E-08	7.9E-08	2.1E-08	2.0E-07
Overall risk of death from cancer	risk	1.0E-05	1.0E-05	1.0E-05	1.0E-05
Non-Linear model for pleural risk of mesothelioma					
Asbestos concentration in air thresholds	F/m3	0.55	0.18	15	3
Risk of death from mesothelioma	risk	1.0E-05	1.0E-05	1.0E-05	1.0E-05
Risk of death from lung cancer	risk	2.7E-10	1.1E-09	2.6E-10	3.9E-09
Overall risk of death from cancer	risk	1.0E-05	1.0E-05	1.0E-05	1.0E-05

Notes:
F/m^3 are all Fibres measured by PCM
*denotes the exposure scenario adopted from CLEA, (ref: technical background to the CLEA model, Science Report SC050021/SR3, Environment Agency, 2009). Aspects of the exposure scenario used in the calculations are:
Residential
6 years of exposure to asbestos from ages 0 to 6 for 365 days per year 24hours per day; or
60years of exposure to asbestos from ages 0 to 60 for 365 days per year 24hours per day.
Public Open Space
6years of exposure to asbestos from ages 6months to 6years for 2hours per day for 170 days per.
Commercial
43years of exposure to asbestos from ages 16 to 60years for 9hours per day for 230 days per year

Variation in Amosite concentration in air thresholds using H&D linear pleural risk model for lifetime persisting for 60 to 90 years

			Amosite			
			CLEA exposure scenario			
			Residential		Public Open Space (Parks)	Commercial
			0-6	0-60	0-6	16-60
WATCH – risk persisting for 80 years	Linear model for pleural risk of mesothelioma	F/m^3	80	24	2300	280
CIRIA – risk persisting for 60 years		F/m^3	190	35	5200	300
WATCH – risk persisting for 90 years		F/m^3	50	15	1400	175

Notes:
F/m^3 are all Fibres measured by PCM
*denotes the exposure scenario adopted from CLEA, (ref: technical background to the CLEA model, Science Report SC050021/SR3, Environment Agency, 2009). Aspects of the exposure scenario used in the calculations are:
Residential
6 years of exposure to asbestos from ages 0 to 6 for 365 days per year 24hours per day; or
60years of exposure to asbestos from ages 0 to 60 for 365 days per year 24hours per day.
Public Open Space
6years of exposure to asbestos from ages 6months to 6years for 2hours per day for 170 days per year for 4hrs per day.
Commercial
43years of exposure to asbestos from ages 16 to 60years for 9hours per day for 230 days per year for 4hrs per day.

Assessment of uncertainty

The choice of model has a significant effect on the predicted risk particularly at low doses and tends to lead to an approximate order of magnitude increase in the concentration of asbestos leading to a 1 in 10^{-5} risk. It is noted that even with the H&D model the fitted non-linear model predicted risks ranging by several orders of magnitude between best and worst estimate.

Using a linear model means the risk from lung cancer particularly for chrysotile become more similar to the risks from mesothelioma and hence both must be considered.

Assessment of the variability based on changes to the life expectancy has the greatest effect on scenarios with exposure mainly at a young age where the variation is a factor of 3.7-3.8 between assuming a 60- and 90-year lifetime. For exposure to adults in a commercial setting the variation falls to less than double between assuming a 60- and 90-year life.

Consideration may thus need to be given to using longer assumed lifetimes where exposure by children is significant particularly if expected lifetimes increase

Annex 3 – Example calculations using HEI approach

Introduction

The approach described below employs the equations described by the Health Effects Institute in 1991 (HEI, 1991). The approach models the asbestos related cancer risk as roughly proportional to the asbestos exposure level. Mesothelioma and lung cancer risk are modelled separately using the exposure-response relationships. The HEI provided equations were also presented in earlier publications including the US. Environmental Protection Agency in 1986 (USEPA, 1986).

Exposure-Response Data

A large volume of exposure-response data is available from workplace cohort studies. Based on such studies, coefficients have been provided to best fit model predictions to the observed exposure-response relationship. In recent years, a number of re-analyses and meta-analyses of workplace cohort studies have been published with the aim of refining predicted exposure-response relationship. This approach has adopted coefficients provide by Berman and Crump (Berman & Crump, 2003).

Exposure-response data from workplace cohort studies relates to occupational exposure. This means that when calculation predicted incidence rates from other exposure scenarios, such as residential exposure, a factoring of exposure concentrations is required to a workplace equivalent exposure. This approach assumes a typical working week relating to 1909 hours per year (230 days per year at 8.3 hours per day).

Predicted Risk of Mesothelioma

Predicted mortality risk from mesothelioma due to asbestos exposure is modelled by the following equation:

$I_M = 0$ for $(t_1)<10$

$I_M = K_M f (t_1-10)^n$ for $10<(t_1)<10+d$

$I_M = K_M f \{(t_1-10)^n-(t_2-10)^n\}$ for $(t_1)>10$

Where:

I_M = predicted mortality incidence from mesothelioma

K_M = risk per unit of exposure 1/(fibres/ml x time^n)

f = average fibre concentration during equivalent workplace exposure (f/ml)

t_1 = time since first exposure (years)

t_2 = time since exposure has ceased (years)

n = time dependency parameter

d = duration, (t_1)-(t_2).

The equation includes an allowance for a 10-year latency of disease after first exposure.

The increase in mesothelioma incidence caused by the exposure period is proportional to the exposure level multiplied by duration and to a power of time since it occurred. Taking an exponent, n, of 3 is generally considered to provide a ‘best fit’ (USEPA, 1986) and has been adopted in more recent meta-analysis (RIVM, 2010, Berman & Crump, 2003).

The lifetime cumulative risk to an individual posed by asbestos exposure is calculated as the sum of yearly risks over a lifetime. However, this will result in a significant overestimate, since it is necessary to take account of the lifetime risk of mesothelioma-related mortality and mortality from other causes. Life tables are used to calculate the population incidence rate once the cumulative survival rate of the non-exposed population has been taken into account. Life tables provided by the UK National Office of Statistics have been used, with cumulative survival rates for females from England and Wales adopted.

Predicted Risk of Lung Cancer

Predicted mortality risk from lung cancer due to asbestos exposure is modelled by the following equation:

$$I_L = K_L\ f\ d\ I_u$$

Where:

I_L = predicted increase in mortality from incidence of lung cancer

K_L = risk per fibre-year per ml 1/(fibre-year/ml)

f = average fibre concentration during equivalent workplace exposure (f/ml)

d = duration of exposure (years)

I_u = mortality incidence from lung cancer in non-exposed population

Incidence of lung cancer in a non-exposed population is relatively high compared to incidence of mesothelioma so the predicted risk is calculated as in increase upon residual background risk. Background risk of lung cancer is dependent upon smoking habits with incidence being more common in smokers. This higher background risk for smokers leads to a higher increase in risk for smokers than non-smokers. The non-smoker has been considered in calculations. Smoking has been considered as a lifestyle choice so has not been accounted for.

The value for cumulative risk of lung cancer in the non-exposed population (background risk) is taken from a study by Peto et al. (Peto et al., 2000). This value is calculated from a prospective study of mortality in one million Americans during the 1980s. The predicted observed lung cancer rates were shown to agree with data from a British study conducted between 1951 and 1990.

Selection of Model Coefficients

The nature of the fibre exposure in terms of fibre size varies between workplace studies, and exposure to asbestos is often to mixed asbestos forms. Consequently, individual workplace exposure studies provide widely varying interpretations of the risks present. Key meta-analyses combining a number of workplace study cohorts have been undertaken by RIVM (RIVM, 2010) and by Berman and Crump (Berman & Crump, 2003) which provide suitable coefficients for use in the equations selected.

Coefficients from the Protocol to Assess Asbestos Related Risk (Berman & Crump, 2003) have been selected to model asbestos related disease incidence rates. The selected coefficients are from Table 7-17 which have been optimised for pure fibres types taking into account effects of fibre length, size and measurement techniques. Coefficients for use with both Tunnelling Electron Microscopy (TEM) and PCME data are presented using factors derived to account for the analytical differences. The use of these parameters for Phase Contrast Microscopy Equivalent (PCME) data is discussed in the WATCH paper published by the HSE (HSE, 2007).

Although TEM provides the preferred method of analysis for concentrations of asbestos fibres in air or in dust, this technique cannot currently be readily applied to concentrations of asbestos in soil due to the complexities of the matrix and bulk nature of the sample. Therefore, this assessment is based on data from PCM analysis following methodologies based on HSG248.

Output

<u>Asbestos concentration in air thresholds using HEI approach</u>

		CLEA exposure scenario*			
		Residential		Public Open Space (Parks)	Commercial
	Age	0-6	0-60	0-6	16-60
Chrysotile[1]	f/m^3	5600	1300	140000	12000
Chrysotile[2]	f/m^3	900	200	24000	1820
Amosite[3]	f/m^3	50	20	1300	200
Amphibole[1]	f/m^3	20	7	550	100
Amphibole[2]	f/m^3	20	6	520	100
Mixed Fibres[2,4]	f/m^3	120	40	6400	480

Notes: *denotes the exposure scenario adopted from CLEA, reference ####. Residential exposure assumes 24hrs per day, 365 per year. Commercial exposure assumes 230 days per year for 8.3hrs per day. POSpark run assuming 2hrs per day, 170 days per year.

		CLEA exposure scenario*			
		Residential		Public Open Space (Parks)	Commercial
	Age	0-6	0-60	0-6	16-60

- Concentrations in f/m3 PCME and at a risk of 1 in 100,000
- Cumulative risk of lung cancer (non-exposed population) assumed as 0.44% (non-smokers)
- Population mortality rates based on England and Wales life tables from Office for National Statistics

1. Run using coefficients for PCME from Berman & Crump 2003, Table 7-17
2. Run using coefficients from B&C (2008) reproduced and used in HCN 2010
3. Run using coefficients from Seidman 1984
4. HCN mixed fibres comprises chrysotile and amphibole (up to 20%)

Annex 4 - Fibre potency

One of the reasons for the differences in risk estimates from different epidemiological evaluations is the difference in approach taken to accounting for fibre potency. This typically takes two forms; the asbestos fibre type, and the fibre size (often described in terms of length and width).

Hodgson & Darnton (2000) suggested a potency difference based on asbestos type of 1:100:500 for mesothelioma for chrysotile:amosite:crocidolite. This however is only relevant to the range of occupational exposures measured in the occupational cohorts. The ratio is more like 1:10:100 at lower environmental exposure levels.

RIVM (2003) evaluated potency based on fibre asbestos type and fibre dimension as follows:

Chrysotile	Fibre length >5um	1
Amphiboles	Fibre length >5um	10
Chrysotile	Fibre length <5um	0.1
Amphiboles	Fibre length <5um	1

The Health Council of the Netherlands in 2010 re-evaluated the epidemiological data and provided a revised analysis of potency differences. It concluded on a potency ratio of 1:2:10 for chrysotile:mixed fibres:amphiboles.

ATSDR (2001) concluded that mineral type and fibre size were of prime importance to health risk, and that long fibres were more carcinogenic than short ones.

US EPA (1986) concluded that crocidolite was 2-4 times more potent than chrysotile for mesothelioma but that the difference may be overstated by differences in fibre size distribution in the exposures received by the occupational cohorts.

The World Health Organisation (1987) and US EPA (1986) chose not to distinguish between fibre potency when developing guideline values and unit risks for air concentrations and as a result these values can be taken to be associated with amphibole exposure.

Berman & Crump (2008) looked more closely at accounting for fibre mixtures and fibre size distributions in the historic occupational cohort data. In doing so they produce very different exposure-risk coefficients to those based solely on the reported air concentration. They suggest a potency ratio of at least 1:200 for chrysotile:amphibole mesothelioma risk.

Although focus can sometimes be on mesothelioma, lung cancer risk can be an important factor at low concentrations. CIRIA (2014) provides a summary of the different potencies for mesothelioma and lung cancer based on the HEI and H&D models:

Mesothelioma	HEI	1:3.2
	H&D	1:100*
Lung cancer	HEI	1:4
	H&D	1:10-50

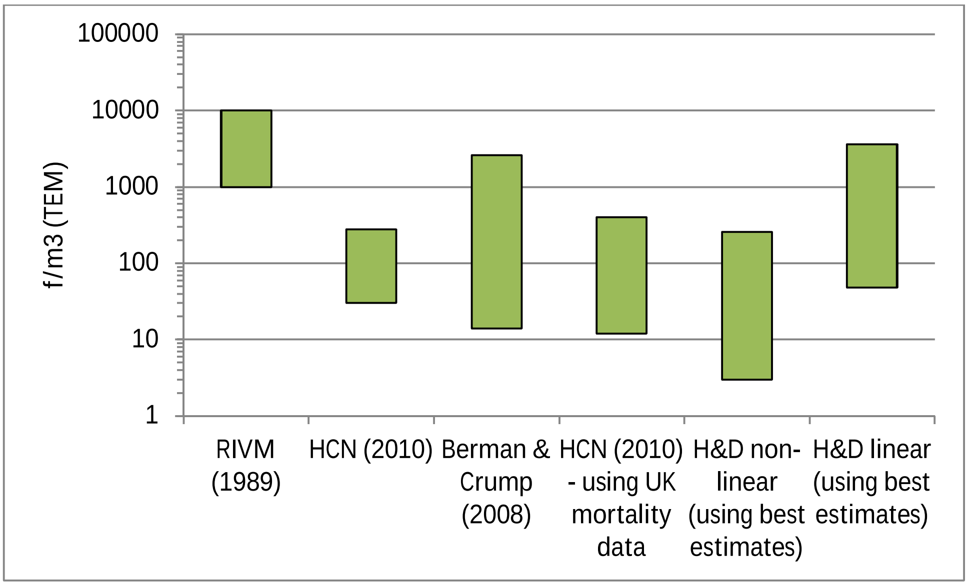
Ratios expressed as chrysotile:amphiboles

The results of SoBRA's modelling using the HEI and H&D models, accounting for the summation of mesothelioma and lung cancer risk suggests the following:

Berman & Crump (2008) analysis taking into account fibre size distribution and fibre mixture of original occupational exposure (adjusted coefficients)	1:185
HCN (use of unadjusted cohort coefficients and UK mortality data)	1:35
Hodgson&Darnton (non-linear) (best estimates)	1:80 (residential scenario)
Hodgson&Darnton (linear) (best estimates)	1:75 (residential scenario)

Potency ratio expressed as chrysotile:amphibole

These different potency ratios have a strong influence on the model outputs, but don't in themselves dictate the values since the ratios are relative. The graph below illustrates the range in ambient air concentrations associated with a risk of 10-5 (the upper value in the range being for chrysotile and the lower value in the range being for amphiboles).



Annex 5 – Background Air Concentrations

Background air concentrations from the UK HSE's Working Group on Action to Control Chemicals (WATCH), outdoor and indoor concentrations reported in CIRIA C733 and information from the Health Council of the Netherlands has been reviewed and is presented in this annex. It should be noted that the authors have not undertaken an exhaustive literature review; there may be additional published data that is not included here.

UK HSE WATCH

The UK HSE's WATCH looked at background air concentrations during its consideration of asbestos between 2007 and 2011. The summary of the information is reproduced below:

WATCH 2010-02-Annex 3 Table 1: Update of publications giving quantitative airborne asbestos fibre measurements in buildings during normal occupation since the HEI-AR review on asbestos in the non-occupational environment (units are in PCM equivalent fibres/m^3).

Study	No of buildings or people and (air samples)	Types of buildings / or person sampled	Arithmetic average indoor in asbestos containing buildings (F/m^3)	Arithmetic average outdoors (F/m^3)	Special observations
HEI – Review (1992) Non litigation data	198 (1377)	All buildings (occupied). Including:	270	~10 rural ~100 urban	Includes some maintenance and custodial work and cable pulling gave highest value. Excluding highest value (sample) average becomes:
		Schools and colleges	510	-	0.00038 (mechanical room)
		Residences	190	-	-
		Public and commercial	200	-	0.00008 (during cable pulling)
HEI Review – Litigation data	171	Schools and colleges	110	50	-
	10	Residences	BLD	-	-

Study	No of buildings or people and (air samples)	Types of buildings / or person sampled	Arithmetic average indoor in asbestos containing buildings (F/m^3)	Arithmetic average outdoors (F/m^3)	Special observations
	50	Public and commercial	60	-	-
Review by MRC Institute for Environmental Health (1997)		Buildings containing asbestos material	~500	0 – ~200	Review and tabulation of previous individual studies carried out no detailed calculation of averages.
Schneider et al. (1996)	5 (40)	School children	44	-	Personal sampling, sample changed once in 24 hours for day and night
	5 (40)	Retired persons	66	-	-
	5 (40)	Office workers	10	-	-
	5(40)	Taxi drivers	105	-	-
Italian Schools Campopiano et al. (2004)	59 (132)	Schools during normal occupation	83% <400 Max 2200 Average ~250	-	Building containing ACMs (vinyl tile and Asbestos cement) Chrysotile only found although AC had amosite
US schools and public buildings with asbestos containing materials. Lee and Van Orden, (2008). 752	752 (3978)	All indoor	120	-	Max for building = 0.004 90% of buildings had no PCME asbestos fibres detected
	752 (1678)	All Outdoor	-	20	-
	371	Schools during normal occupation	100	-	-
	752	All buildings	80	-	-

Study	No of buildings or people and (air samples)	Types of buildings / or person sampled	Arithmetic average indoor in asbestos containing buildings (F/m^3)	Arithmetic average outdoors (F/m^3)	Special observations
Polish city urban air asbestos measurements outside asbestos cement buildings. Krakowiak et al. (2009)	27 (41)	Close to degraded AC buildings	-	1800	SEM study debris on ground limited analytical sensitivity no averages given.
	24 (42)	100-500 m from buildings	-	<1000	-
	11 (17)	Close to buildings with no ACMs		<1000	
UK Schools with CLASP construction. Burdett et al. (2009)	7 (28)	Schools during normal occupation after remediation / sealing gaps	Average <50	Not done	Mainly asbestos insulating boards in columns with metal cladding around it
	1 (8)	Office in normal use sampled during day time for 4 weeks	Average <30	Not done	Mainly asbestos insulating boards in columns

CIRIA C733 Table 6.1 Background asbestos concentrations reported in indoor and outdoor air

Outdoor air [1,2]	
Rural areas (remote from asbestos emission sources)	Below 100 f/m^3 (0.0001 f/ml)
Urban areas	General levels may vary from below 100 to 1000 f/m^3
Near various emission sources the following figures have been measured as yearly averages	• downwind from an asbestos-cement plant 300m: 2200 f/m^3, at 700 m: 800 f/m^3, at 1000 m: 600 f/m^3 • at a street crossing with heavy traffic 900 f/m^3 • on an express-way, up to 3300 f/m^3
Indoor air [1,2]	
In buildings without specific asbestos sources	Concentrations are generally below 1000 f/m^3
In buildings with friable asbestos	Concentrations vary irregularly, usually less than 1000 F/m^3 are found but in some cases exposure reaches 10000 F/m^3 (values measured by PCM)

Notes:

[1] All reported concentrations are based on measurements by electron microscopy methods, except where stated otherwise.

[2] The data represents a range of different sampling and analytical techniques and was collected for a variety of purposes. A direct comparison between different values is not appropriate.

[3] Much of this data relates to measurements collected in the 1980s. The more stringent restrictions and controls implemented in many countries since then mean that current background concentrations would be expected to be lower than those cited.

The information summarised in Table 6.1 is attributed in CIRIA C733 to WHO (2000) Air quality guidelines for Europe. Second edition, European series, No. 91, Regional Office for Europe, World Health Organization, Copenhagen, Denmark (ISBN: 9-28901-358-3), however, the authors of this paper note that this information is not contained in this WHO publication, rather in WHO (1986) International Programme on Chemical Safety, Environmental Health Criteria 53, Asbestos and other natural mineral fibres.

Health Council of the Netherlands

Health Council of the Netherlands (2010) quotes RIVM (1987) Basisdocument Asbest, Rapport nr. 758473006, Sloof, W. and P.J Blokzijl (eds.). RIVM (1987) data summary reproduced in RIVM 758473013 (1989) (English translation). Measurements by Den Boeft and Lanting made between 1978 and 1980:

Summary of Health Council of the Netherlands (2010) based on measurements in 1978 and 1980

Outdoor	
Rural	100-1000 f/m^3
Towns	1000-10,000 f/m^3
Near sources	10,000-100,000 f/m^3
Indoor	
Living area	100-1000 f/m^3
Factories with sprayed asbestos	<1000 – 600,000 f/m^3

Boeft, J. Den and R.W Lanting. Asbest en andere minerale vezels in de buitenlucht Orienterende metingen van concentratieniveaus in Nederland, IMG-TNO rapport G 856