Approaches to exposure assessment

SoBRA Summer 2013 workshop
Risks to human health from asbestos in soil

Possible Approaches

Key Question

- How much asbestos will get airborne?
  - Source – dispersed asbestos fibres in soil or C&D material and/or discrete fragments of ACM
  - Receptor – people
  - Pathways generating airborne fibres:
    - Wind erosion of ground surface
    - Mechanical disturbance of ground

Possible Approaches

- Purely qualitative approach
- Adopt existing dust models
- Adopt empirical data relationships
- Adopt laboratory methods
  - Lab-based empirical relationships
  - Laboratory testing of field samples
- Adopt site-specific field testing (activity-based sampling)

Qualitative Scoring

Qualitative Estimates

- Rank situation according to airborne fibre generation potential
- E.g.:
  - HSG227
  - HSG264
  - DETS
  - RIVM
  - IAQM

Qualitative exposure estimates

- Hazard posed by asbestos is severe
- Risk posed by asbestos can be very high, and can be relatively low, circumstance depending
- Risk = severity x likelihood

Probability (Likelihood)		Consequence			
		Severe	Medium	Mild	Minor
	High likelihood	Very high risk	High risk	Moderate risk	Low risk
	Likely	High risk	Moderate risk	Moderate/low risk	Low risk
	Low likelihood	Moderate risk	Moderate/low risk	Low risk	Very low risk
	Unlikely	Moderate/low risk	Low risk	Very low risk	Very low risk

NHBC, EA, CIEH R&D 66:2008

Table 7 Descriptors for "Significance of Risk"

	Likelihood of Consequence Occurring	Very Likely / Certain	Likely	Unlikely	Very Unlikely	Extremely Unlikely	No Pollutant Linkage
Potential Consequence	Severe	Very High	Very High	High	Medium	Low	None#
	Moderate	High	High	Medium	Low	Very Low	
	Mild	Medium	Medium	Low	Very Low	Trivial	
	Negligible	Low	Very Low	Very Low	Trivial	Trivial	

NIGLQ, 2011

Table 6 Descriptors for "Likelihood of Consequence Occurring"^

Likelihood Descriptor	Probability of Occurrence*
Very Likely / Certain	More than 95%
Likely	45 to 95%
Unlikely	5 to 44%
Very Unlikely	Less than 5%
Extremely Unlikely	Much less than 1%
No pollutant Linkage	Zero

1 in 10,000 is 0.01%; 1 in 100, 000 is 0.001%

Qualitative Estimates

- HSE HSG227 and HSG264 assessment algorithms
- Material assessment – ease of fibre release
- Priority assessment – likelihood of ACM disturbance
- Numerical scoring system (1-3) to assess potential for fibre release
- Not designed to calculate absolute differences in hazard (fibre potency and fibre release).
- Fibre release potential parameters:
  - Product type
  - Extent of deterioration/damage
  - Surface treatment
  - Asbestos type

Qualitative Estimates

- Priority algorithm – key factors
  - Maintenance activity
  - Occupant activity

    } Degree of disturbance
  - Likelihood of disturbance — Location, accessibility, extent of ACM
  - Human exposure potential — Number of people, frequency of exposure
- Scored 0-3

Qualitative Estimates

- RIVM
- Qualitative estimates of air concentrations based on soil content and activity
- Based on empirical measurements

Asbestos Soil Concentration (mg/kg)	No activity	Activity	No activity	Activity
	Bound	Bound	Unbound	Unbound
<5	-	-	-	-
5-100 (0.01%)	-	-	(-)	(+/-,+)
100-1,000	-	(+/-)	(+/-)	(+,++)
>1,000 (0.1%)	(+/-)	(+,++)	(+,++)	++

Qualitative Estimates

Asbestos Soil Concentration (mg/kg)	No activity	Activity	No activity	Activity
	Bound	Bound	Unbound	Unbound
<5	-	-	-	-
5-100 (0.01%)	-	-	(-)	(+/-,+)
100-1,000	-	(+/-)	(+/-)	(+,++)
>1,000 (0.1%)	(+/-)	(+,++)	(+,++)	++

- No activity – no mechanical soil disturbance
- Activity – mechanical disturbance – sampling, digging, sifting, remediation works
- - no fibre release above background
- +/- fibres below 1000 f/m^3 (0.001 f/ml)
- + fibres 100-100,000 f/m^3 (0.001-0.1 f/ml)
- ++ fibres above 100,000 f/m^3 (0.1 f/ml)

Qualitative Estimates

- IAQM
- Activity specific stepped approach to assessing and mitigating dust emissions from construction sites
- STEP 1 – screen requirement for more detailed assessment based on distance to receptor
- STEP 2 – assess risk of dust effects using scale and nature of works (i.e. dust emission potential) and proximity of sensitive receptors
- STEP 3 – Determine site-specific mitigation for each activity
- STEP 4 – Assess significance of dust effects – professional judgement based on Steps 2 and 3

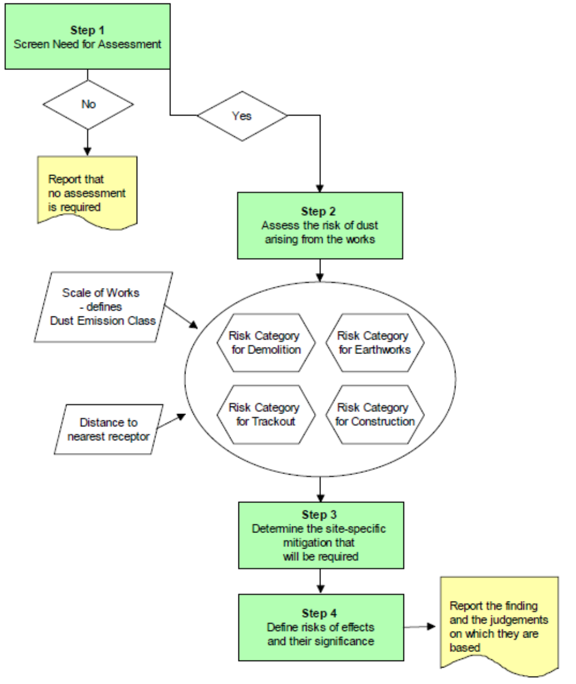


Figure 1: Steps to Perform a Dust Assessment

Qualitative Estimates

Table 4: Risk Category from Trackout

Distance to Nearest Receptor (m)[a]		Dust Emission Class		
Dust Soiling and PM_{10}	Ecological	Large	Medium	Small
<20	-	High Risk Site	Medium Risk Site	Medium Risk Site
20 - 50	<20	Medium Risk Site	Medium Risk Site	Low Risk Site
50 - 100	20 - 100	Low Risk Site	Low Risk Site	Negligible

[a] For trackout the distance is from the roads used by construction traffic.

Table 8: Significance of Effects for Each Activity with No Mitigation

Sensitivity of Surrounding Area	Risk of Site Giving Rise to Dust Effects		
	High	Medium	Low
Very High	Substantial adverse	Moderate adverse	Moderate adverse
High	Moderate adverse	Moderate adverse	Slight adverse
Medium	Moderate adverse	Slight adverse	Negligible
Low	Slight Adverse	Negligible	Negligible

- From IAQM Guidance on the assessment of the impacts of construction on air quality and the determination of their significance, January 2012

Qualitative Estimates

Is it possible to equate a qualitative scoring system to quantitative exposure estimates?

Can a qualitative approach be sufficiently calibrated / adequately balanced?

Dust Models

Can we treat asbestos just like dust?

- Particle sizes:
  - Dust PM10 (<10µm diameter)
  - Dust PM2.5 (<2.5µm diameter)
  - Typical soil descriptors (BS5930)

Soil type	Particle size
Coarse sand	600-2000µm diameter
Medium sand	200-600µm diameter
Fine sand	60-200µm diameter
Coarse silt	20-60µm diameter
Medium silt	6-20µm diameter
Fine silt	2-6µm diameter
Clay	<2µm diameter

- Coarse silt barely visible to naked eye (i.e. particles >60µm diameter)

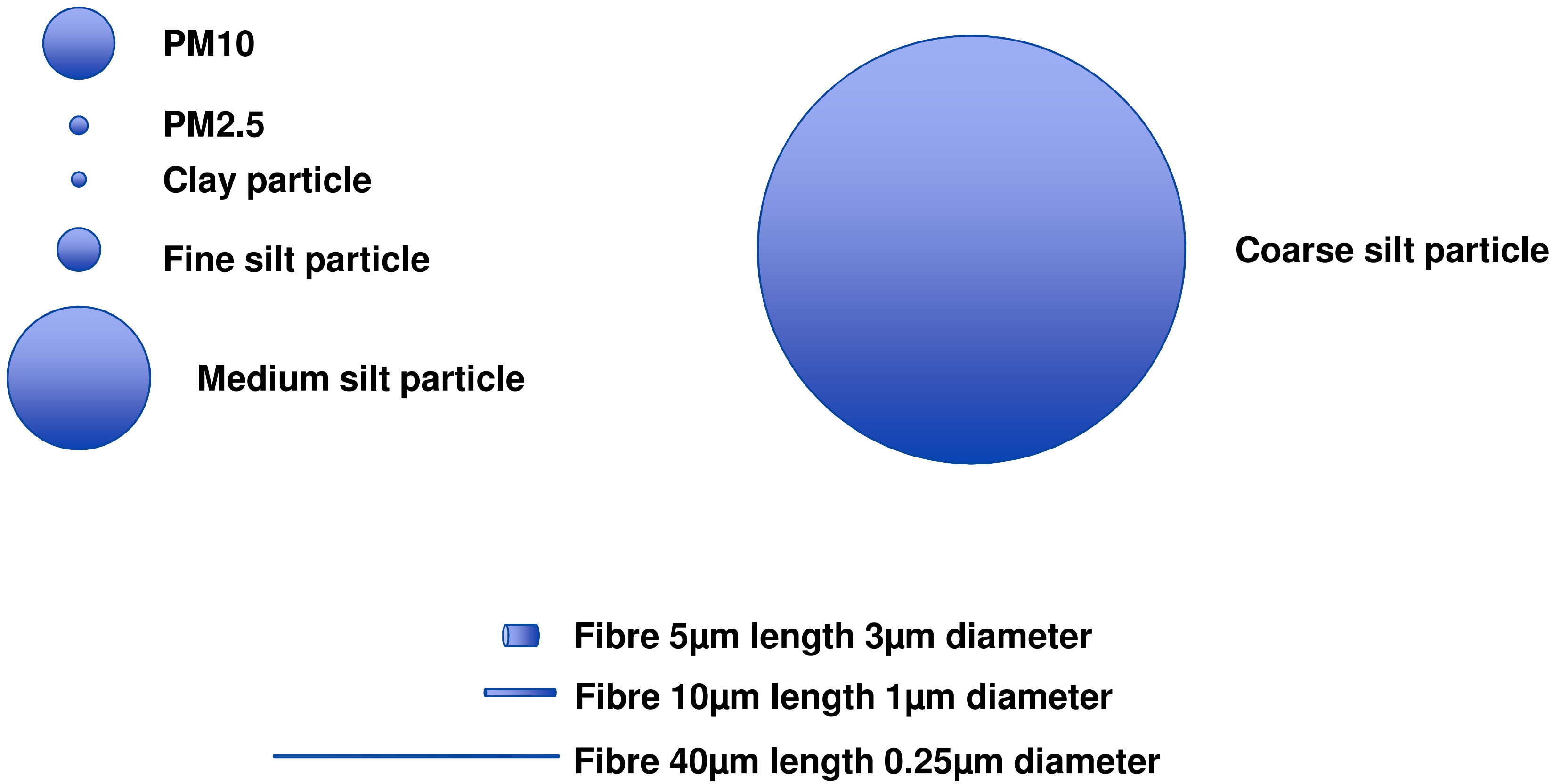
Can we treat asbestos just like dust?

- HPA Compendium of Chemical Hazards:
  - Chrysotile fibres naturally occur in lengths < 5µm
  - Amosite fibres typically 5-10µm in length
  - Crocidolite fibres bundles can disperse into smaller fibres (5-10µm in length) but typically not as small as chrysotile
- Focus on thoracic fibres >5µm length, <3µm diameter, aspect ratio 3:1. Long, thin fibres pose greatest risk
- Fibres in soil won't conform to this narrow range

Can we treat asbestos just like dust?

- Current asbestos fibres size range of concern:

  >5µm length, <3µm diameter



Can we treat asbestos just like dust?

- Range of fibres possible in soil? Not tested?
- Any known studies?

Can we treat asbestos just like dust?

- Particle density:
  - Sand ~ 2.6 g/cm^3
  - Silt and clay ~ 2.8 $g.cm^3$
- Fibre density:
  - Asbestos ~ 1.6 g/cm^3

- Asbestos fibres
  - lighter(?)
  - greater aerodynamic resistance(?)
  - potential to be entrained in air more easily (i.e. lower threshold frictional velocity(?)
  - carried greater distances in air(?)
  - **Use correction factor for dust estimates?**

Dust models

- Previously proposed generic dust levels (PM10):
  - Simmonds et al (1995) – 10,000 µg/m^3 for man-made disturbance
  - Oatway & Mobbs (2003) – 500 µg/m^3 for residential and school land use and 10,000 µg/m^3 for agricultural use
  - Oomen & Lijzen (2004) – data ranging from 12.6-157 µg/m^3 for residential, commercial and school land uses – recommendations for 60 µg/m^3 for homes and 100 µg/m^3 for school classrooms and other very crowded places
  - Van den Berg (1994) – 53 µg/m^3 for indoor air; 70 µg/m^3 for outdoor air
  - Paustenbach (1997) – indoor dust 50 µg/m^3
  - CLEA (2009) – indoor dust 50 µg/m^3

Dust models

- Key factors for dust generation (from Cowherd et al 1985):
  - Surface material texture (dry particle size distribution)
  - Surface material moisture
  - Non-erodible elements
  - Crust formation
  - Frequency of mechanical disturbance
  - Wind speed

Dust models

- Estimating ambient dust concentrations (PM10):
  - CLEA model adopts Cowherd et al (US EPA) 1985

Equation 9.2

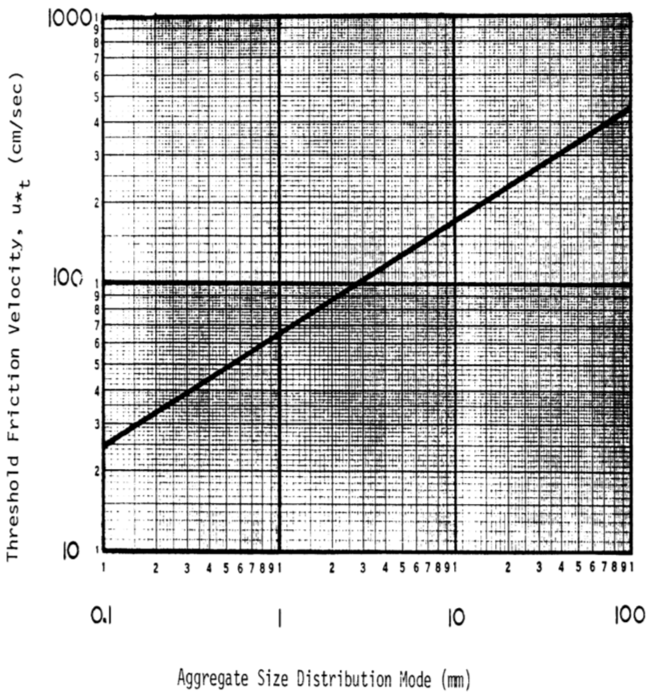
$$J_w = 0.036\,(1-V)\,(\frac{u}{u_t})^3\ F(x) \quad \times \quad \frac{1}{3600} hr\, s^{-1}$$

Where: J_w is the PM_{10} emission flux, g m^{-2} s^{-1}
V is the fraction of outdoor surface cover (equals zero for bare soil), dimensionless [0.5 to 0.8]
u is the mean annual wind speed at height of 10 m, m s^{-1} [5]
u_t is the threshold value of wind speed at height of 10 m, m s^{-1} [7.2]
$F(x)$ is an empirical function of x , dimensionless [1.22]

  - Most sensitive value is threshold friction velocity
  - Site-specific estimation method provided by Cowherd et al based on empirical (field) data
  - Generic assumption by US EPA and CLEA of 500 µm as modal value for soil particle sizes (medium sand)
  - Cowherd et al report highlights that method provides **order of magnitude** estimates

Dust models

- Cowherd et al threshold velocity sensitivity



Equation 9.3

$$\frac{u_t}{u_*} = \frac{1}{0.4} LN\left(\frac{z_t}{z_0}\right)$$

Where: u_t is the threshold value of wind speed at height of 10 m, m s^{-1}
u_* is the corrected threshold friction velocity at 0 m, m s^{-1} [0.625]
z_t is the height above the ground, cm [1000]
z_0 is the roughness height, cm [10]

Equation 9.4

$$x = 0.886 \frac{u_t}{[u]}$$

Where: *x* is the empirical parameter, dimensionless
u_t is the threshold value of wind speed at 10 m, m s^{-1} [7.2]
[u] is the mean annual wind speed at 10 m, m s^{-1} [5]

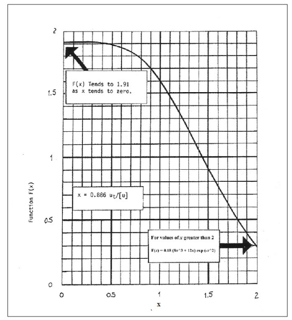


Figure 9.1: Graph of function *F(x)* versus *x* [after Cowherd *et al.*, 1985] used in Equation 9.2, where *x* is calculated from the ratio of the mean annual wind speed (*u*) and the threshold value of wind speed (u_t)

Equation 9.2

$$J_w = 0.036\,(1-V)\left(\frac{u}{u_t}\right)^3 F(x) \quad \times \quad \frac{1}{3600} hr\, s^{-1}$$

Where: J_w is the PM_{10} emission flux, g m^{-2} s^{-1}
V is the fraction of outdoor surface cover (equals zero for bare soil), dimensionless [0.5 to 0.8]
u is the mean annual wind speed at height of 10 m, m s^{-1} [5]
u_t is the threshold value of wind speed at height of 10 m, m s^{-1} [7.2]
F(x) is an empirical function of *x* , dimensionless [1.22]

Dust models

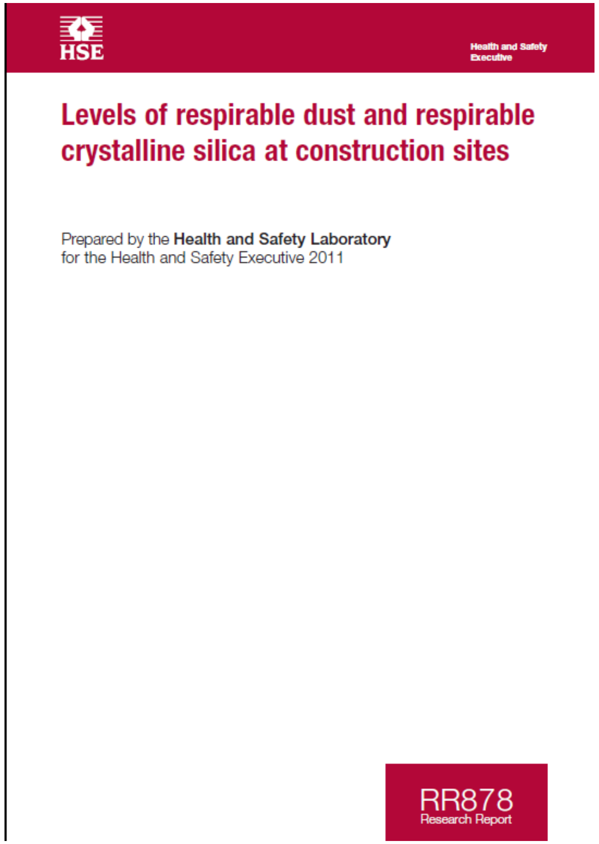
- CLEA ambient dust levels:
  - Default residential assumptions (source area 0.01ha) – 0.4 µg/m^3
  - 0% vegetation cover 1.7 µg/m^3
  - Default commercial assumptions (source area 2ha) – 7-12 µg/m^3
  - 0% surface cover – 34-60 µg/m^3
  - Low, compared to default assumptions for indoor levels (50 µg/m^3 for residential, 100 µg/m^3 for commercial)
  - Estimates are annual average particulate concentrations based on an ‘unlimited reservoir’ of erodible particles (i.e. highly erodible, dry soils)

Dust models

- Occupational dust limits:
  - WEL (inhalable) – 10 mg/m^3
  - WEL (respirable) – 4 mg/m^3
- Defra Air Quality Strategy objective - 50 $\mu g/m^3$
- Construction dust advisory limit - 250 $\mu g/m^3$

Dust models

- HSE study of construction dust
- Small study – 7 sites, 48 samples
- Majority of results < 50 µg/m^3



HSE

Health and Safety Executive

Levels of respirable dust and respirable crystalline silica at construction sites

Prepared by the **Health and Safety Laboratory** for the Health and Safety Executive 2011

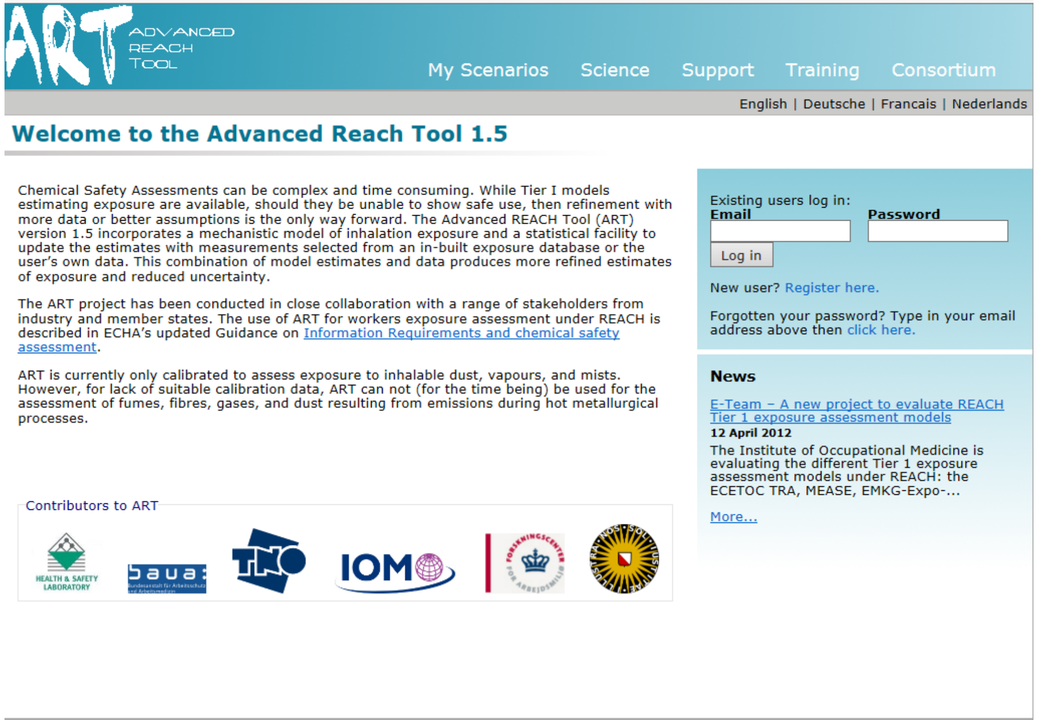
RR878
Research Report

Dust models

- Models for mechanical disturbance:
  - US EPA dust emission factors
  - ECHA guidance on information requirements and chemical safety assessment – REACH - 2012
  - ART model

ART Model

- Bayesian modelling approach to combine mechanistic inhalation exposure estimates with workplace exposure data
- PM 10 estimates
- Contributors:
- HSL
- Baua
- TNO
- IOM
- Arbejdsmiljoforskning
- iras



ART Model

- Key parameters:
  - Dustiness of material (inhalable fraction mg/kg)
  - Moisture content
  - Weight fraction of substance in material
  - Activity class and sub-class
  - Environment

Substance emission potential

Activity emission potential

Localised Controls

Dispersion

Dust models

- US EPA AP42 dust emission factors
  - Unpaved roads
  - Heavy construction operations
  - Aggregate handling and stockpiles
  - Industrial wind erosion

Dust models

- Question – how do we convert dust PM10 estimate to an asbestos fibre concentration?

$$C_{fibre}\ (f/m^3) = C_{dust}\ (mg/m^3) \times C_{soil}\ (wt/wt) \times EF$$

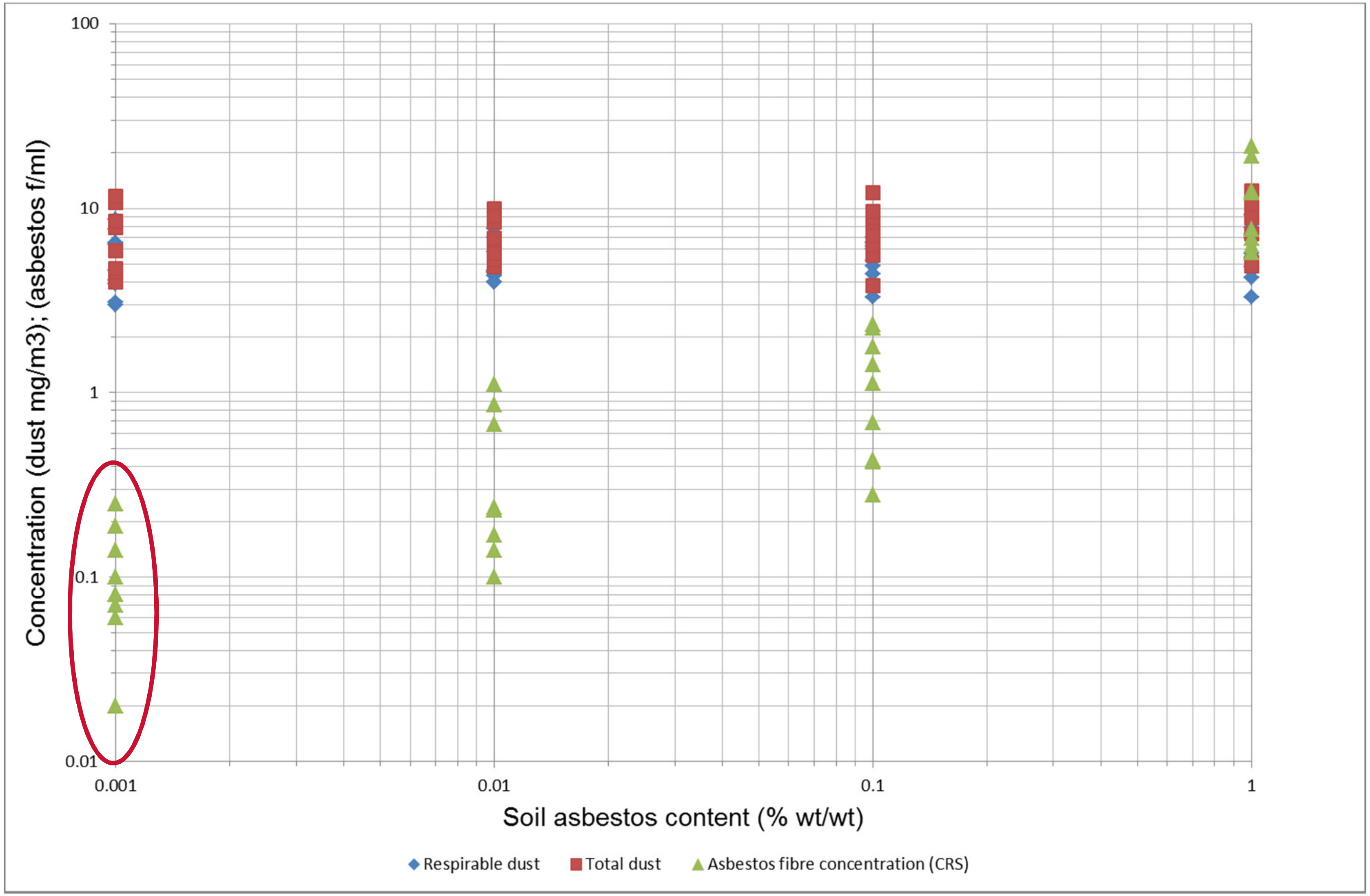
- EF = enrichment factor
- Question – how do we determine the EF? Should it be >1?
- EF needs to convert from wt/wt asbestos in dust to f/vol
- RIVM adopt fibre no./wt. conversion of 2,000-4,000 fibres per ng
- Dutch study into house dust (711701037/2004) assumes asbestos concentration in dust = concentration in soil

Dust models

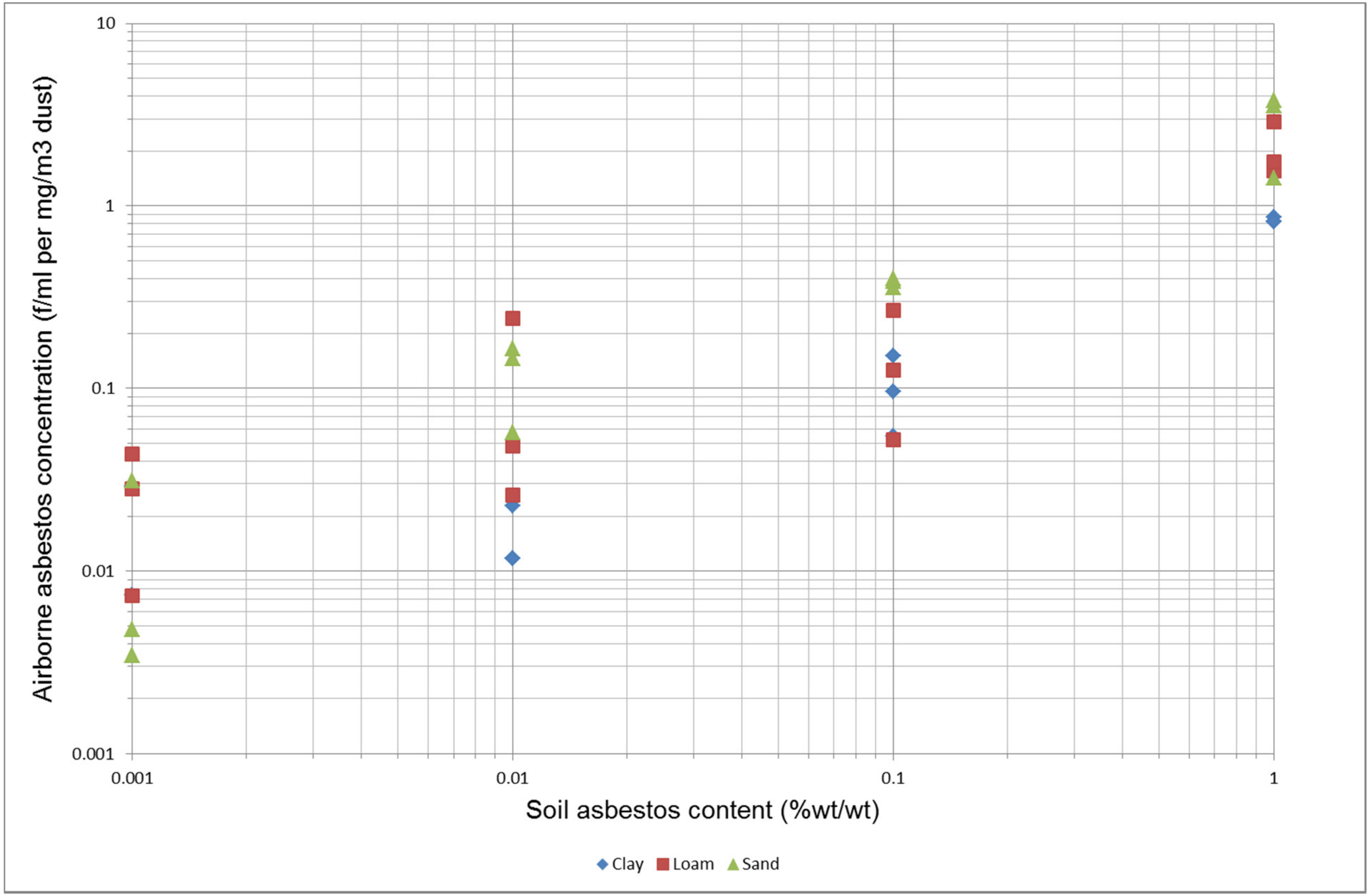
Can we accept lack of validation of dust models for asbestos fibre release?

Empirical Studies

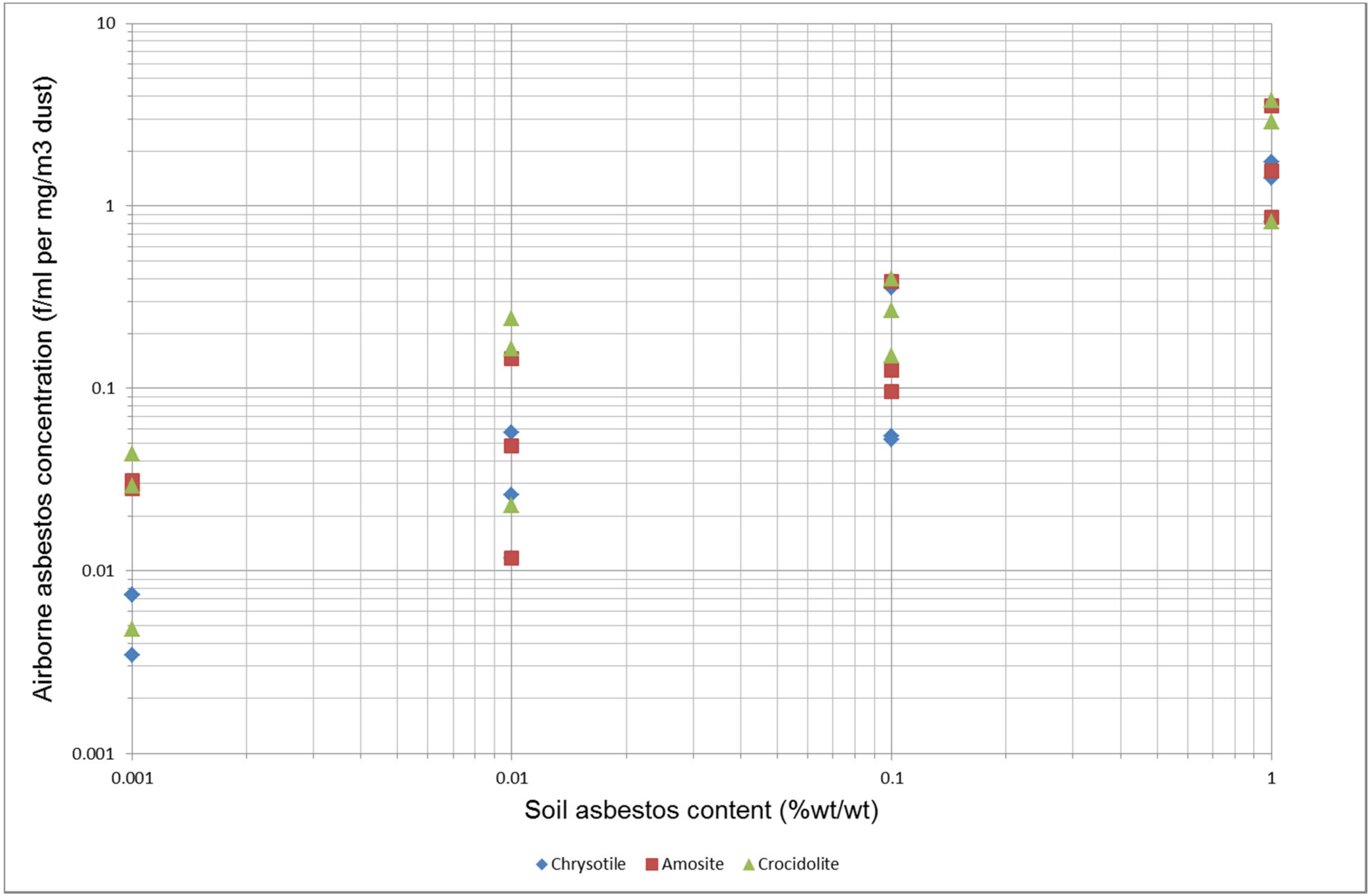
Addison et al 1988



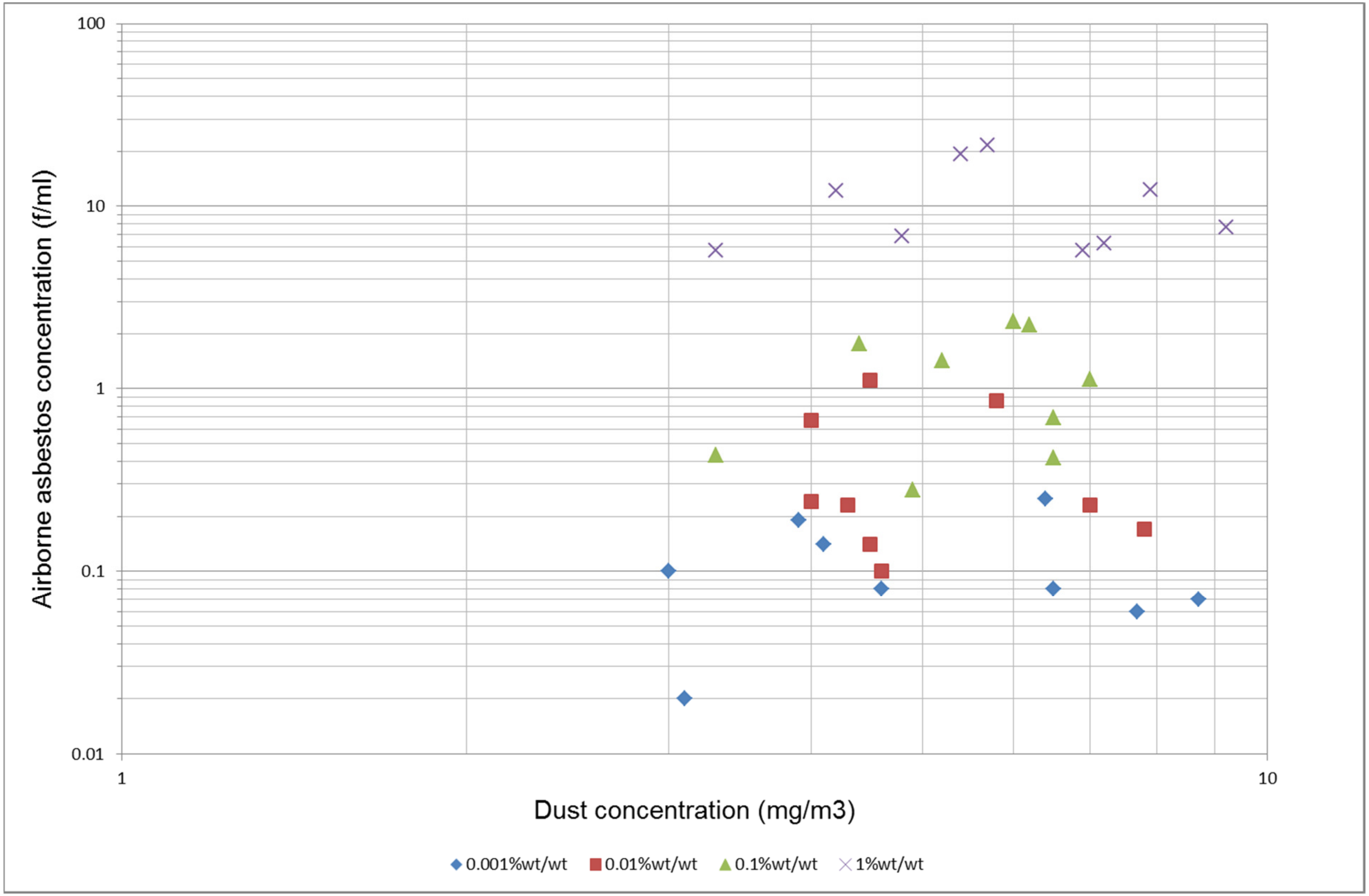
Addison et al 1988



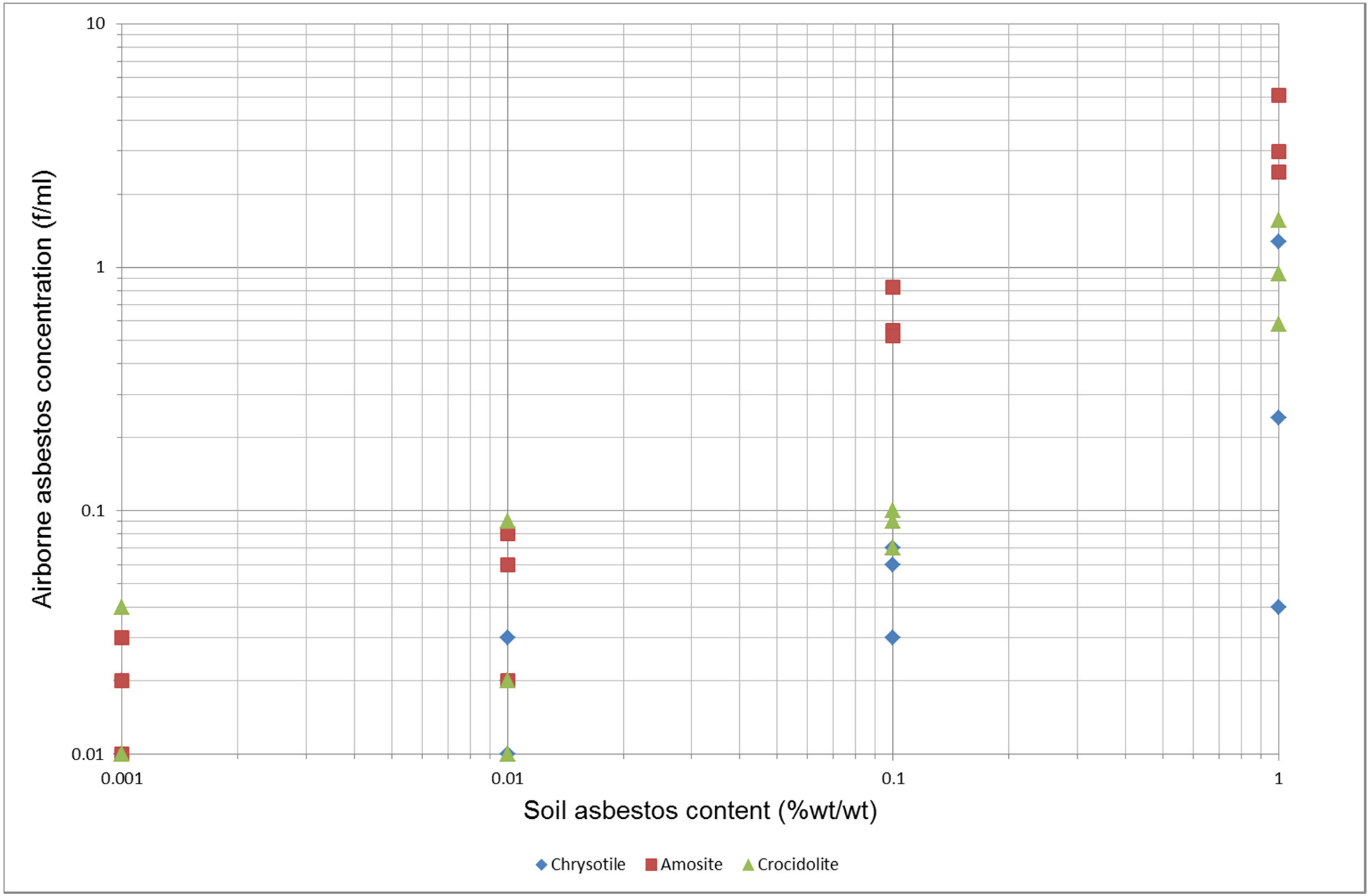
Addison et al 1988



Addison et al 1988

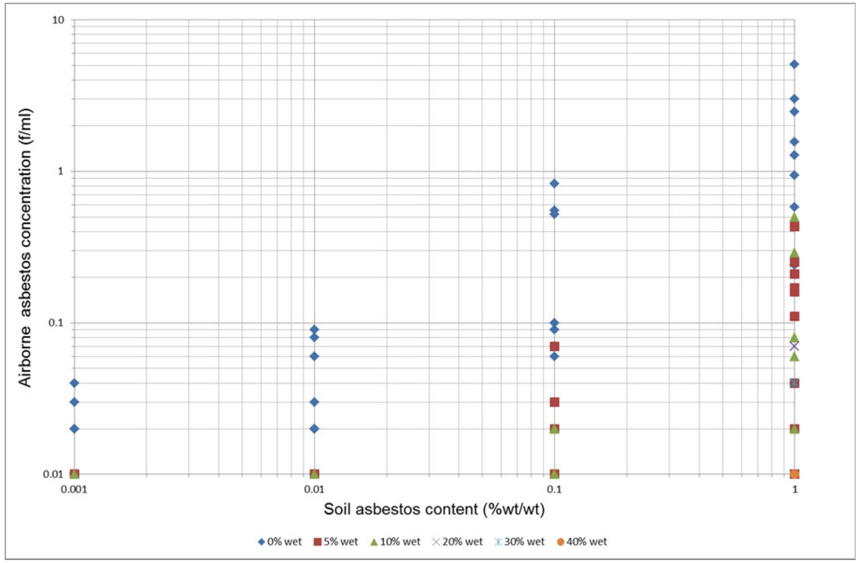


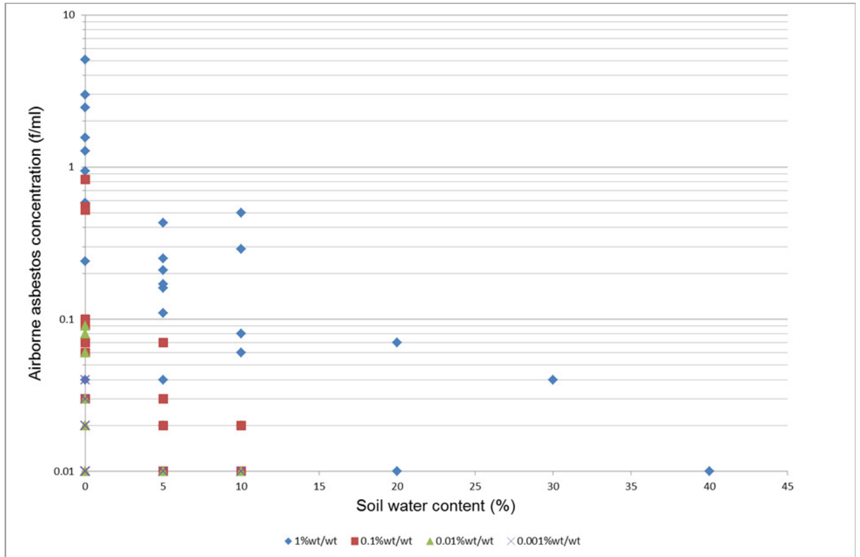
Addison et al 1988

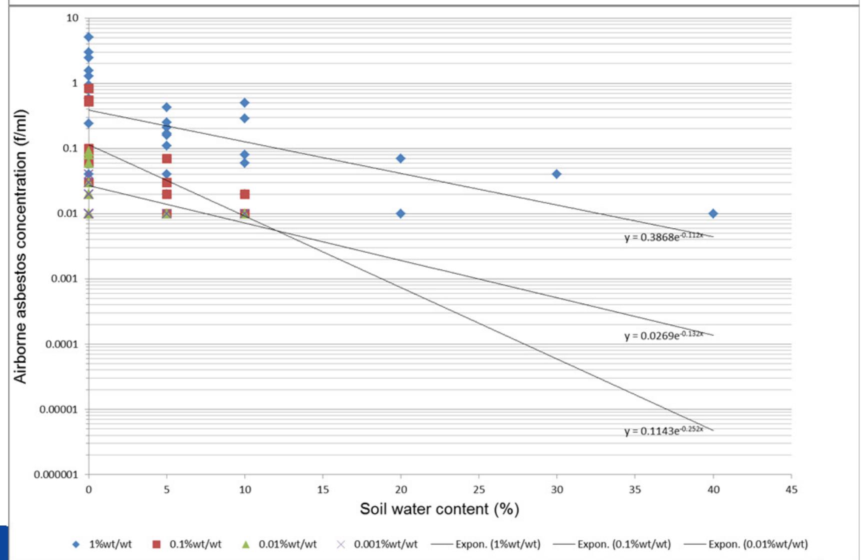


Addison et al 1988

- Effect of soil moisture content:



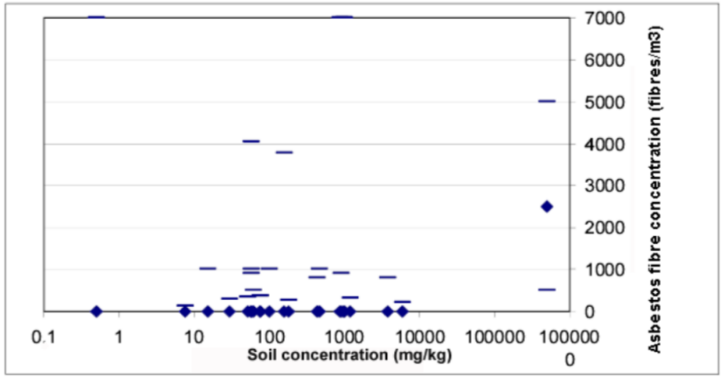


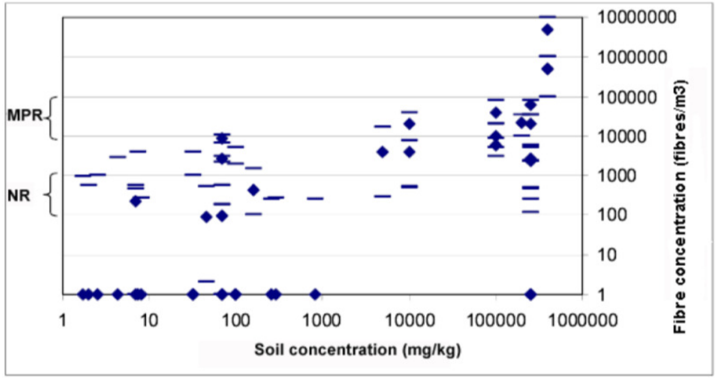


- Authors proposed a min x10 reduction for 5-10% SM

SKB Project (Tromp, 2002)

- 30 research reports since 1987
- 1,000 measurements
- Focus on:
  - 350 field measurements for bound asbestos
  - 200 field measurements for unbound asbestos

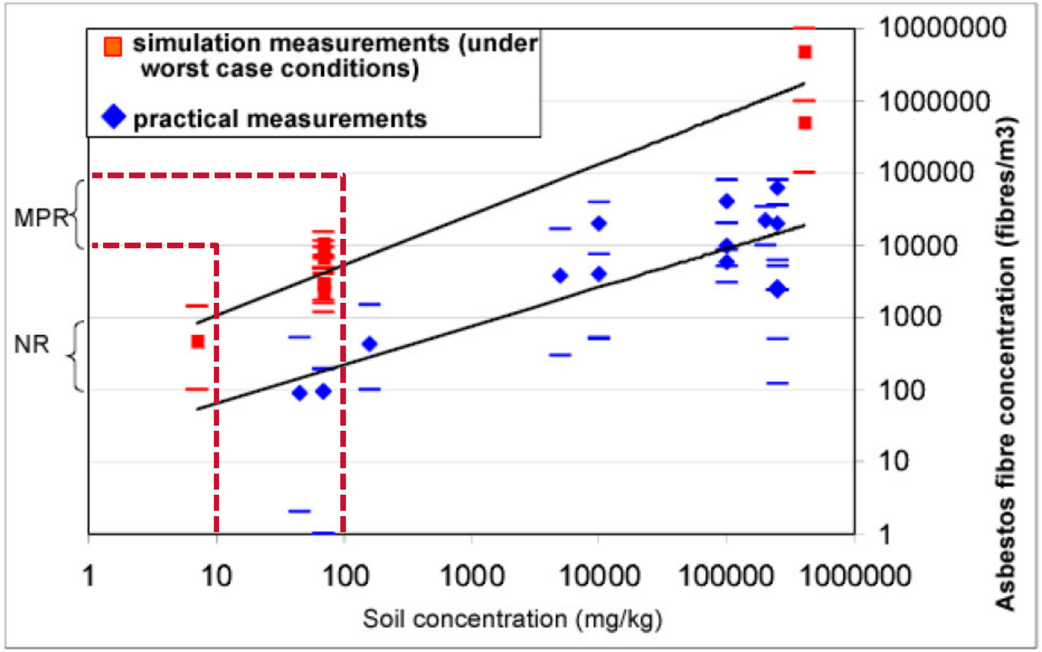




- Figures 2.2 & 2.3 from RIVM report 711701034/2003

SKB Project (Tromp, 2002)

- 85 positive results from unbound asbestos in dry soil
- Practical results order of magnitude lower than lab simulations



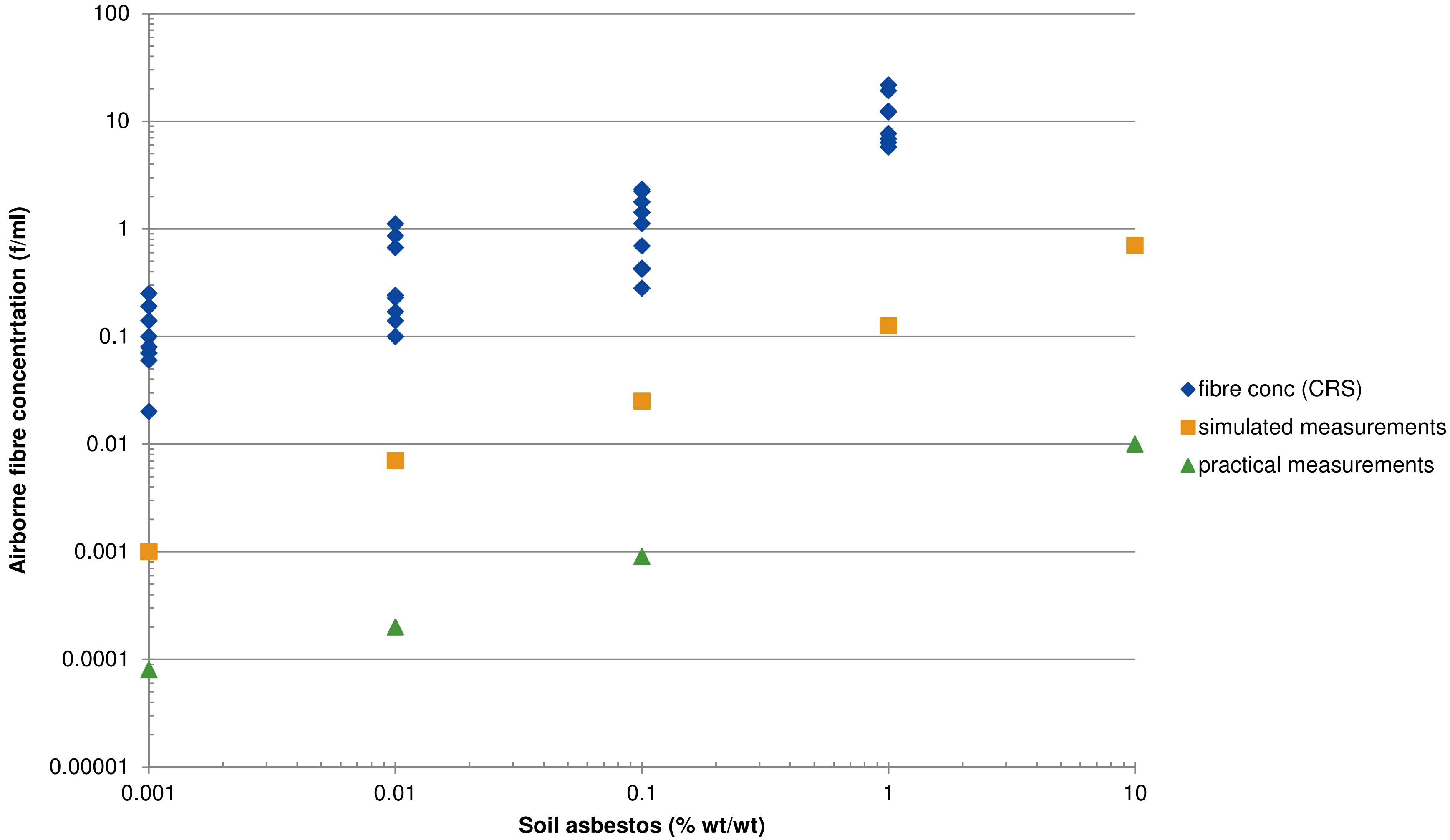
10 f/ml
1 f/ml
0.1 f/ml
0.01 f/ml
0.001 f/ml
0.0001 f/ml
0.00001 f/ml
0.000001 f/ml

- Figure 4.1 from RIVM report 711701034/2003

SKB Project (Tromp, 2002)

- Influence of soil moisture:
  - Exponential relationship
  - Greatest influence in sandy soils (lowest fibre adsorption)
  - Factor of 100 reduction with 5-10% SM

Comparison between Addison et al and Tromp…



N.B. Not corrected for airborne dust levels

Empirical Studies

Can we accept limitations in current studies?

Are empirical relationships adequate for use?

Activity–based sampling

- US EPA 2008 Superfund framework
- Emphasises empirical approach
- Predictive models for airborne asbestos from soil not validated
- Preliminary screening – worst case ABS
  - Indoors – disturbance of house dust
  - Outdoors – highest soil concentrations, dry conditions, ‘aggressive’ raking or other SOP activity
  - If airborne asbestos detected, move to next step…

Activity–based sampling

- US EPA 2008 Superfund framework
- Site-specific ABS
- Requirement for samples to reflect differences in time and space
- Range of disturbance activities
- Requirement for QAPP and SAP
- HASP, PPE and training important
- Determination of pathway specific exposure point concentration
- Adjustment for potential future increase in fibre releasability

Activity–based sampling

- Site-specific ABS scenarios
  - ATV riding
  - Child playing in the dirt
  - Gardening/rototilling
  - Weed whacking/cutting
  - Digging
  - Lawn mowing
  - Walker with stroller
  - Jogging
  - Two bicycles
  - Basketball

Activity–based sampling

- US EPA 2008 Superfund framework
- No current validated technique for modelling or adjusting for releasability
- Actively pursuing development and validation of methods for assessing releasability from solid matrices (inc soil)
  - Field
  - Laboratory

Air monitoring – issues to consider

- Required detection limit
- Sample volume required to meet detection limit
- Sample duration (sampling rate)
- Variations to standard protocols required – is standard protocol sufficient?
- Adverse effect of dust levels
    - Masking of fibres on filter
    - Requirement to reduce sample volume
    - Knock-on effect on detection limit

Activity-based sampling

Is ABS practicable?

In what circumstances?

Background Exposure

Background exposure

- Typical concentrations in the UK?

Study	No of buildings or people and (air samples)	Types of buildings / or person sampled	Arithmetic average indoor in asbestos containing buildings (f/ml)	Arithmetic average outdoors (f/ml)	Special observations
HEI – Review (1992) Non litigation data	198 (1377)	All buildings (occupied). Including:	0.00027 **270 f/m^3**	~0.00001 rural ~0.0001 urban	**10 f/m^3** e maintenance and custodial work and cable pulling gave highest value. Excluding highest value (sample) average becomes:
		Schools and colleges	0.00051	**510 f/m^3**	0.00038 (mechanical room)
		Residences	0.00019	**190 f/m^3**	
		Public and commercial	0.00020	**200 f/m^3**	0.00008 (during cable pulling)
HEI Review – Litigation data	171	Schools and colleges	**110 f/m^3** 0011	0.00005	**50 f/m^3**
	10	Residences	BLD		
	50	Public and commercial	0.00006	**60 f/m^3**	

WATCH paper 2010 02 annex 3

Background exposure

- Typical concentrations in The Netherlands

Table 11. Overview of studies reporting asbestos levels in air.

Source	Location	Concentration asbestos in air^Δ	
Slooff 1989	Outdoor	<0.1-5 ng/m^3 (~10^2-10^4 fibres/m^3)	…nside houses roughly similar to concentration in outdoor air in 1980s.
Slooff 1989	Indoor	<1 – 6000 ng/m^3	Measured in building in which sprayed asbestos layers were present.
Slooff 1989	Indoor	Up to 170 ng/m^3	Caused by chrysotile containing floor covering
Brand 1994	Indoor	Asbestos levels in indoor air usually around 1000 fibre equivalents/m^3	Year average
Besson 1999	Indoor	3×10^3-8×10^4 fibres/m^3	Building with low levels of asbestos pollution; extrapolated from measurement of fibres greater than 3 µm in length.
Mennen 2001	Outdoor	250-580 fibre equivalents/m^3 highest value 10900 fibre equivalents/m^3	… days following the …sion*. Highest asbestos levels found in a few samples in days following the …schede explosion*.
Swartjes 2003	Outdoor	10-100 fibers/m^3	…ference: ATSDR

100-10,000 f/m^3

1000 f/m^3

3,000-80,000 f/m^3

250-580 f/m^3

10-100 f/m^3

RIVM, 2004

Background exposure

- Typical concentrations in the US

Table E-1: Background Levels of Asbestos in Environmental Air Samples in USA (fibers/ml, >5 um)[1]

	Median	Mean*	Range*	
Urban Outdoor Air[2]	0.0003a		ND-0.008	300 f/m^3
Urban Outdoor Air[3]		0.00005a		50 f/m^3
Outdoor Air[4]		0.00039b		
Residences with ACM[5]		0.0001	ND-0.002	
Buildings with ACM[6,7,8]		0.00005	ND-0.00056	50 f/m^3
Buildings without ACM		ND	ND	
Schools[9]		0.00024	ND-0.0023	200 f/m^3
Schools with ACM[10]		0.0002	ND-0.0016	
Public Buildings (no ACM)		0.00099		
Public Buildings (with ACM in good condition)		0.00059		590 f/m^3
Public Buildings (with damaged ACM)		0.00073		730 f/m^3

University of Illinois, 2006

Fibre release in other scenarios

- HPA (2007) report on risk from building fires (inc. data from NY twin towers)
  - Assumption of 2 days exposure at 0.1 f/ml
- HSL (2006) report on fibre release from asbestos cement

Table A2: Summary of all results in HSL database for asbestos cement work.

	Type of sample	No of data /site entries	Mean (f/ml)	SD	Minimum of means	Maximum of means	No of samples	Sum (mean * number)	Weighted mean (f/ml)
All	All	51	0.189	0.757	0	5.45	245	48.184	0.197
	Personal	36			0.0015	0.23	94	7.665	0.082
	Static	8			0	0.4	103	24.486	0.238
	Unspecified	7			0.008	5.45	48	16.033	0.334
Dry	All				0				
	Personal	7	0.124	0.076	0.03	0.23	39	4.450	0.114
	Static								
	Unspecified								
Not Known	All	43	0.203	0.825	0	5.45	198	43.494	0.220
	Personal	28	0.057	0.052	0.0015	0.195	47	2.975	0.063
	Static	8	0.120	0.149	0	0.4	103	24.486	0.238
	Unspecified	7	0.881	2.019	0.008	5.45	48	16.033	0.334
Wet	All								
	Personal	1	0.03		0.03	0.03	8	0.240	0.030
	Static								
	Unspecified								

  - 51 results
  - Range: 0.03 f/ml – 0.334 f/ml weighted mean; maximum of means 5.45 f/ml

Can we understand and work within limitations of current science?

Thank you

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