

A PROCEDURE FOR QUANTITATIVE DESCRIPTION OF FIBROSITY IN AMPHIBOLE MINERALS

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Amphiboles: Asbestos vs. Non-Asbestos

- **Asbestos**
 - High aspect ratios
 - Long, thin ,flexible fibres

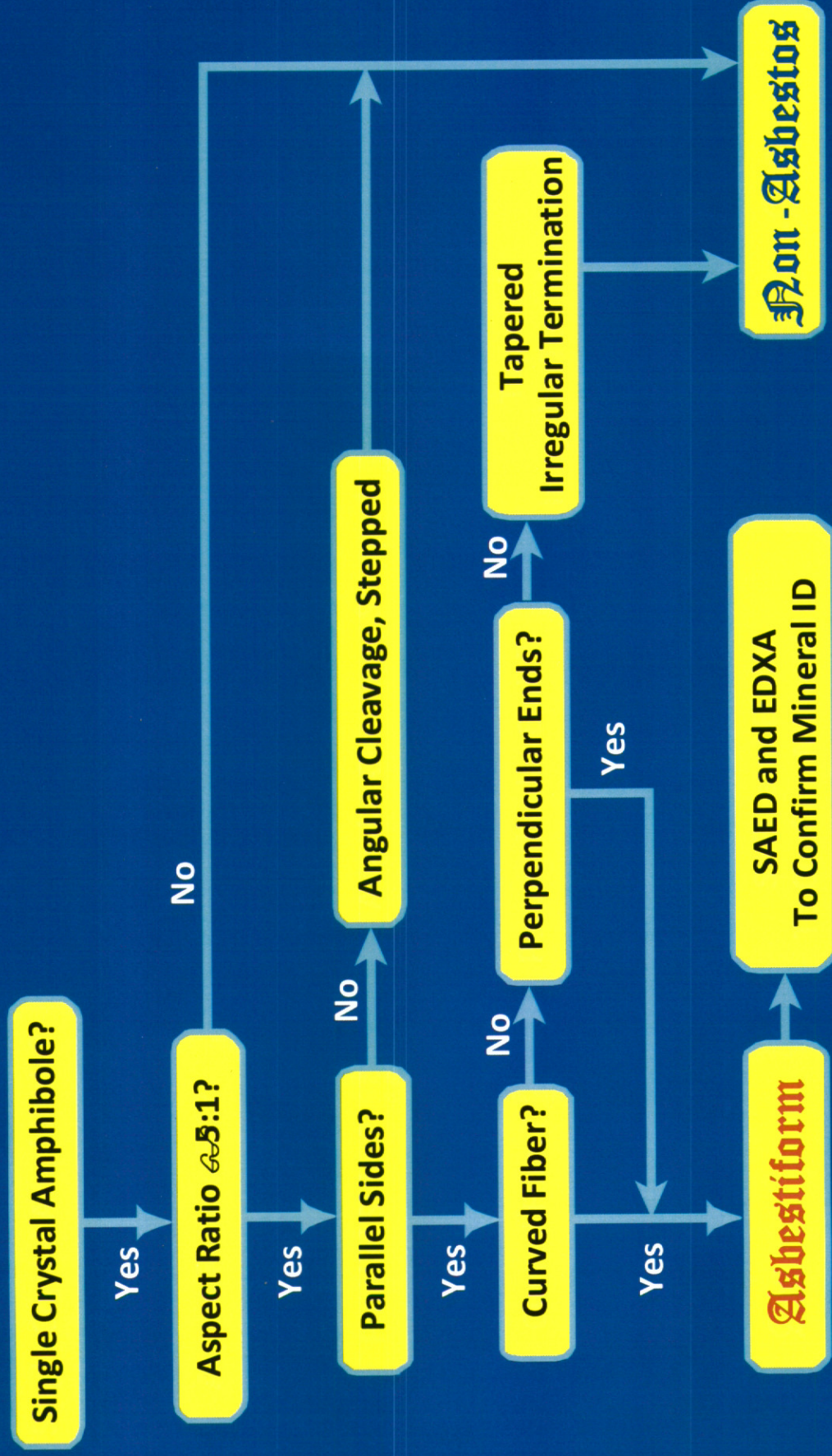


- **Non-Asbestos**
 - Low aspect ratios
 - Short, brittle fibres

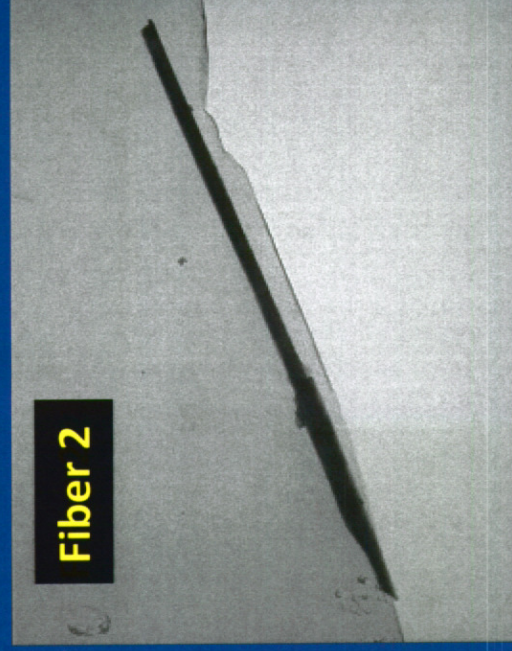
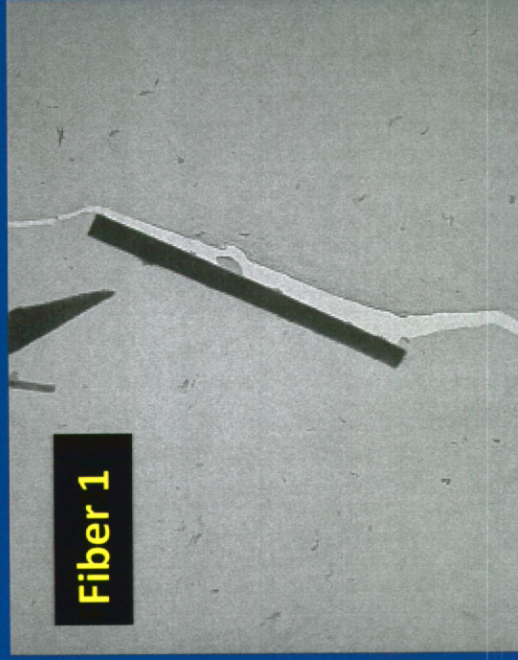


Using the TEM, is it possible to classify an individual amphibole fiber as either asbestos or non-asbestos?

The "Southdown" Protocol



The “Southdown Protocol” classifies only fiber 1 as asbestos. Fibers 2, 3 and 4 are considered to have no health significance



Quantification of Fibrosity in Amphiboles

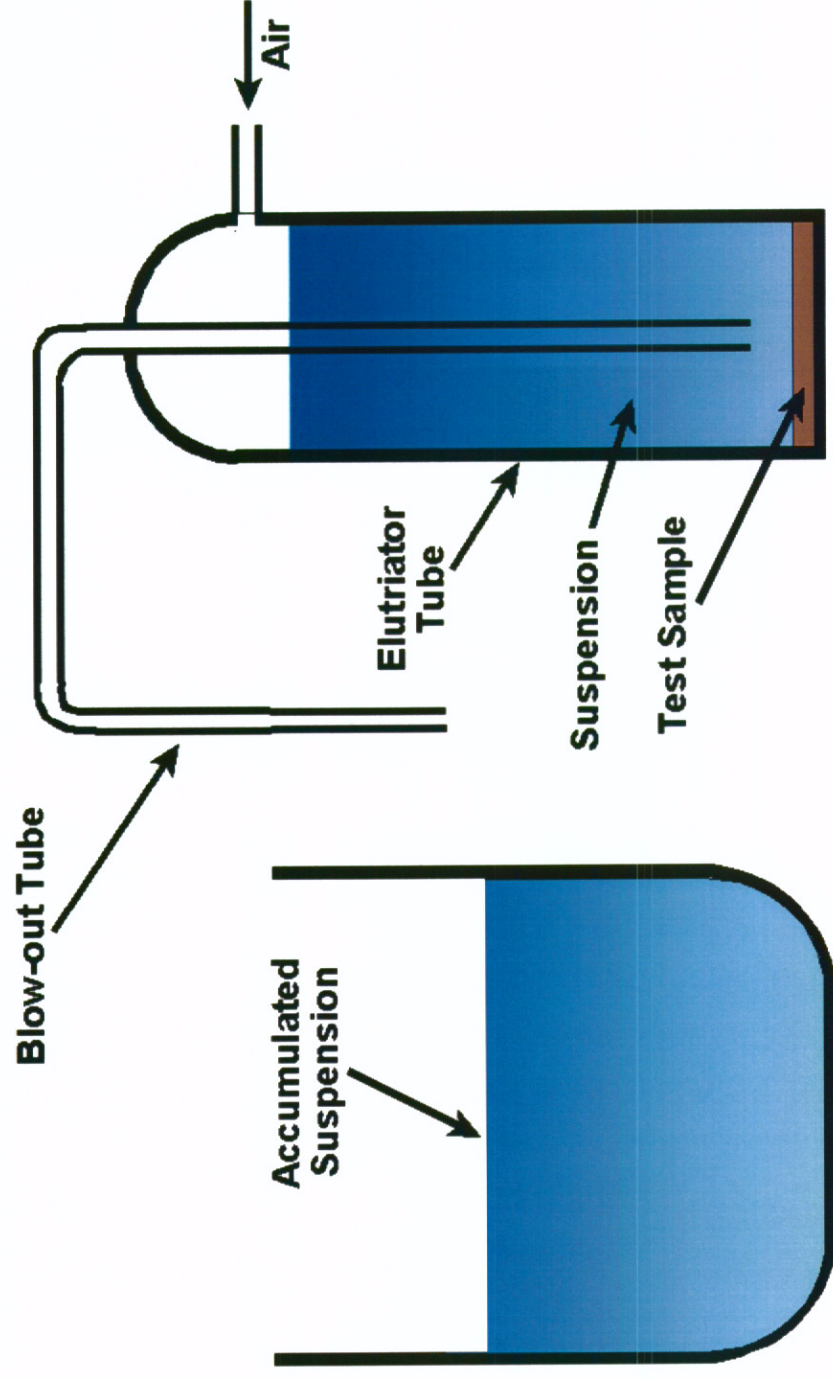
- Clearly, there are differences in fibrosity in amphibole minerals that are currently incompletely understood:
 - Are asbestiform and non-asbestiform amphiboles two completely different species, with some mineral deposits containing mixtures of the two?
 - Or:
 - Do asbestiform and non-asbestiform amphiboles exhibit a continuum of morphology, as suggested by the US Geological Survey?

A Formal and Objective Protocol

- This protocol formalizes in an objective manner the discrimination between non-asbestiform amphiboles and amphibole fibres that can be considered to be asbestos
- The basis of the protocol is to determine the number and mass of respirable amphibole fibres longer than 5 μm that fall outside of the envelope exhibited by non-asbestiform amphiboles
- The protocol does not rely on application of arbitrary or controversial criteria to assess the morphology of individual fibres

Principle of the Discrimination Protocol

- The amphibole is ground in a mortar and pestle
- The respirable fraction is separated by water elutriation using the fractional extraction method
- TEM specimens are prepared from the respirable fraction
- The dimensions of approximately 200 amphibole fibres longer than 5 μm are measured by TEM at a magnification of approximately 10,000
- The aspect ratio distribution is compared quantitatively with the aspect ratio distribution of known non-asbestiform amphiboles



Apparatus for Fractional Extraction Procedure

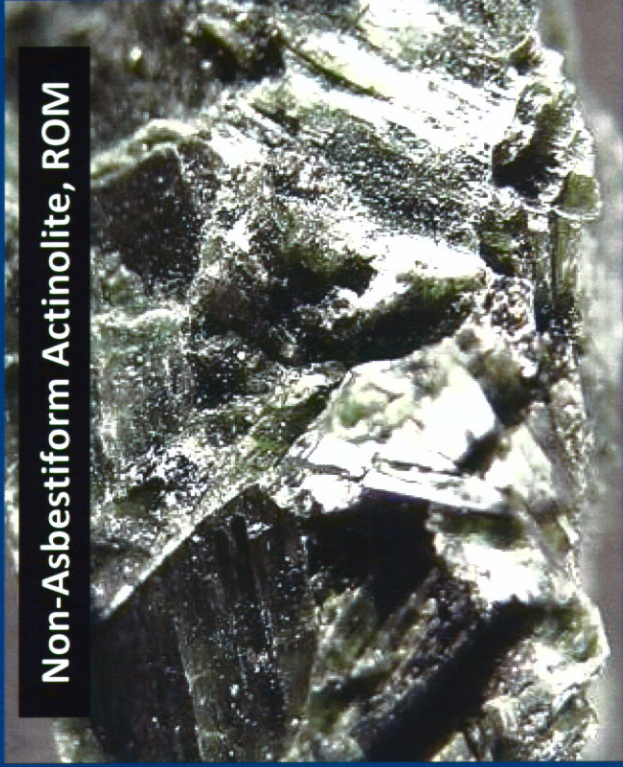
Characterization of the Aspect Ratio Distribution of Respirable Non-Asbestiform Amphibole Fibres Longer than 5 μm

- Four obviously non-asbestiform amphibole samples were selected, and single crystals showing no signs of asbestiform appearance were hand-picked for analysis
- The samples consisted of two sources of actinolite, one of riebeckite, and one of grunerite
- The results are used to determine the maximum range of aspect ratio, as a function of fibre length, exhibited by non-asbestiform amphiboles

Non-Asbestiform Actinolite, Brazil



Non-Asbestiform Actinolite, ROM

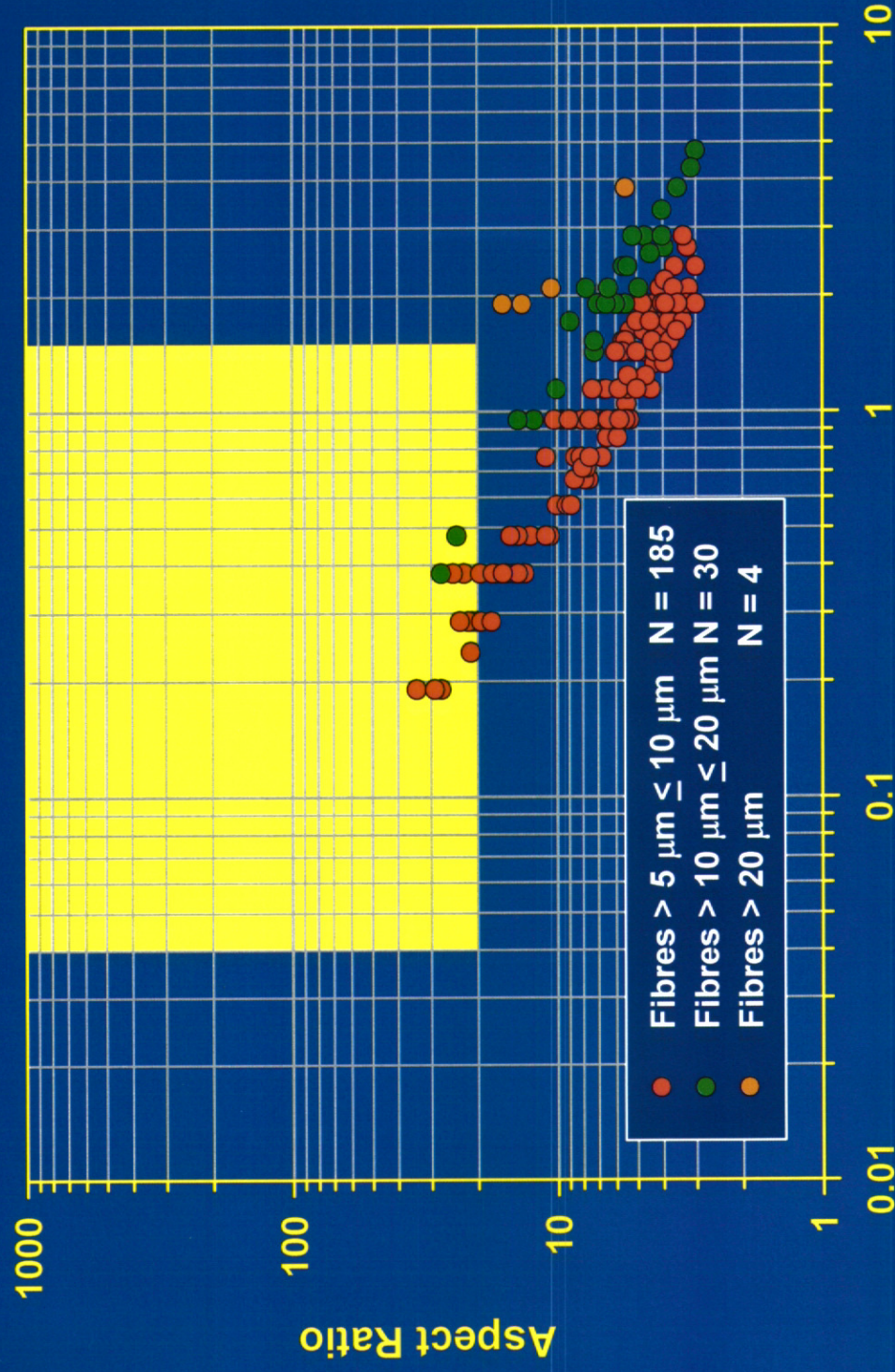


Riebeckite, St. Peter's Dome, Colorado

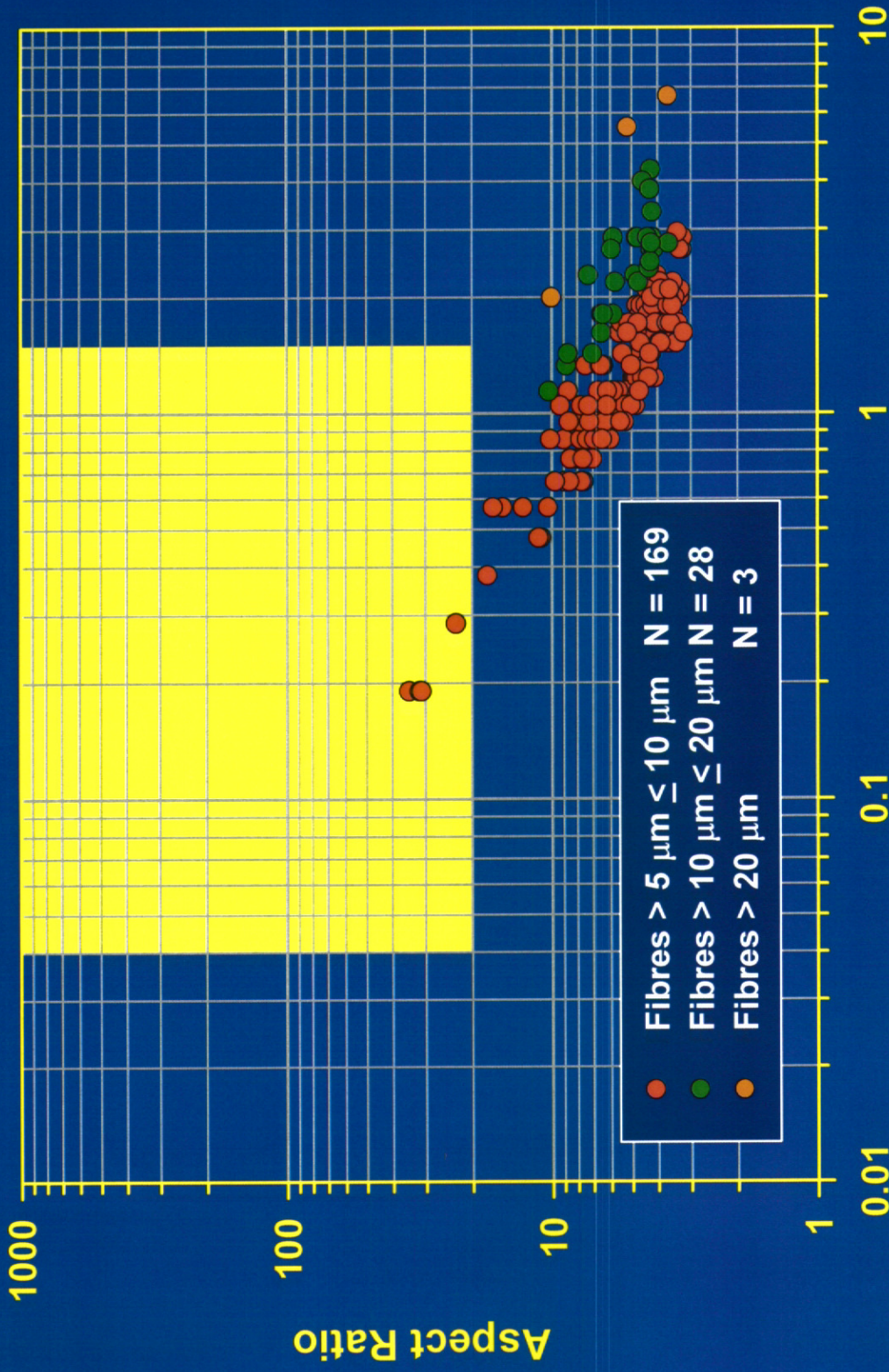


Non-Asbestiform Grunerite, Labrador



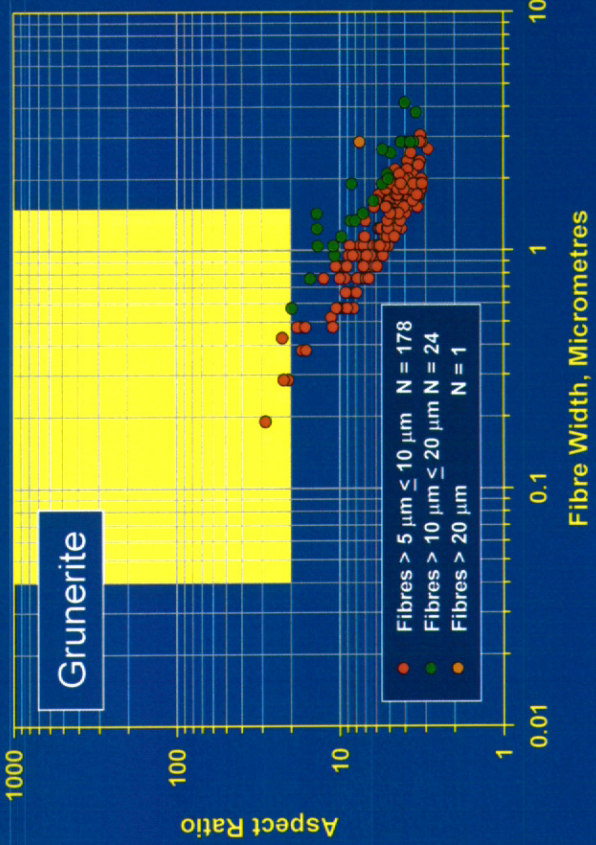
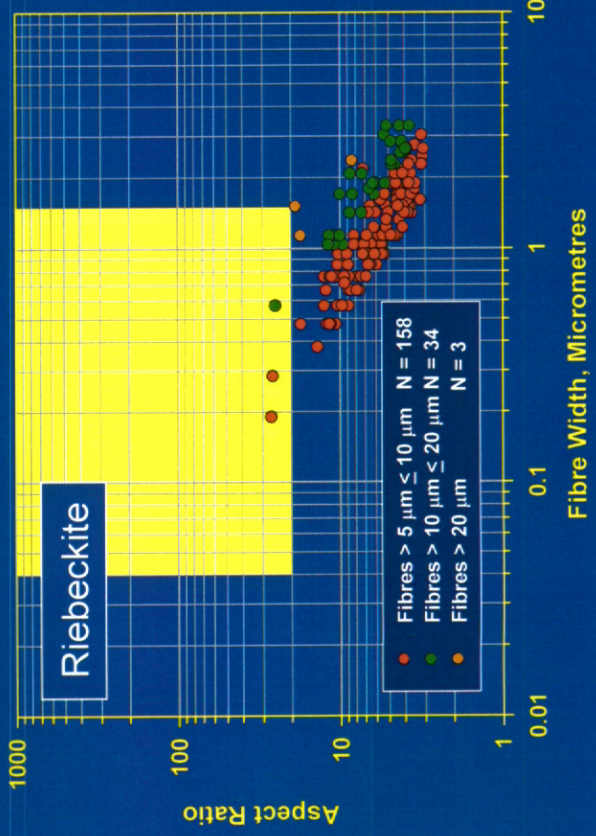
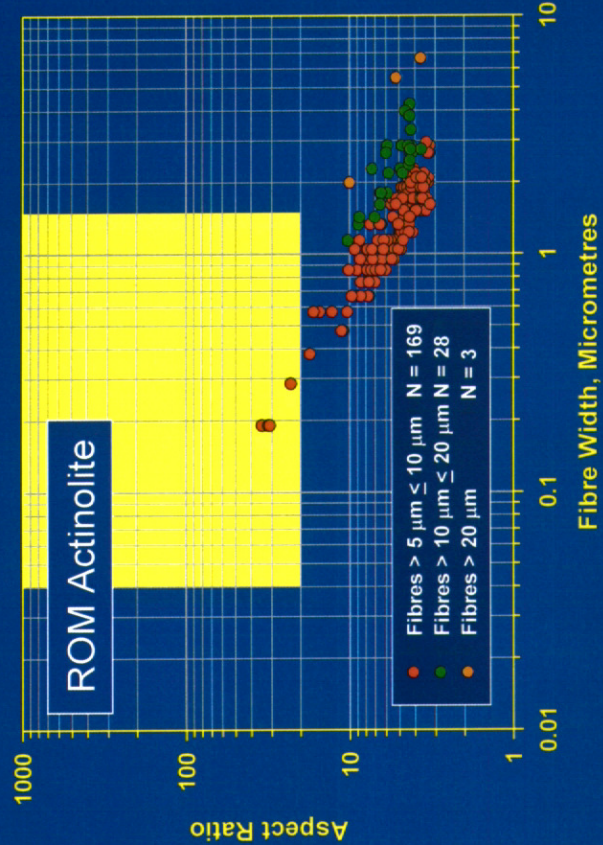
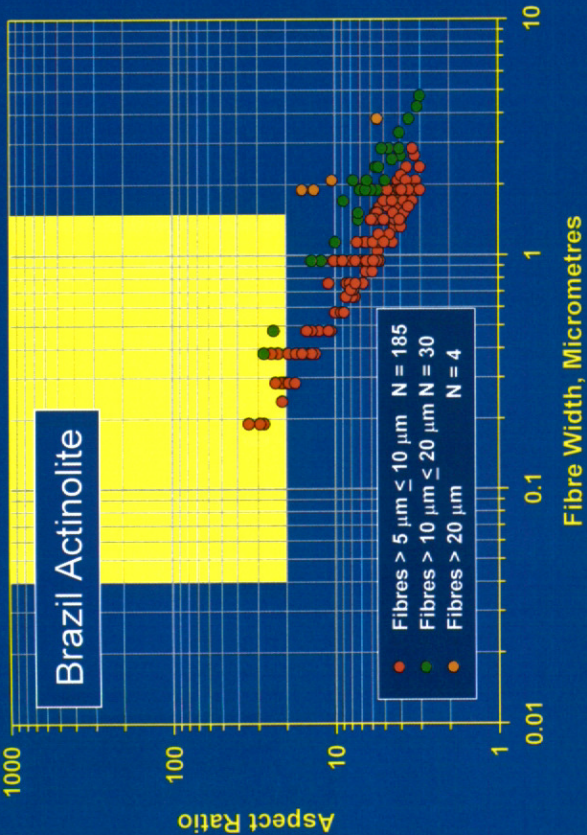


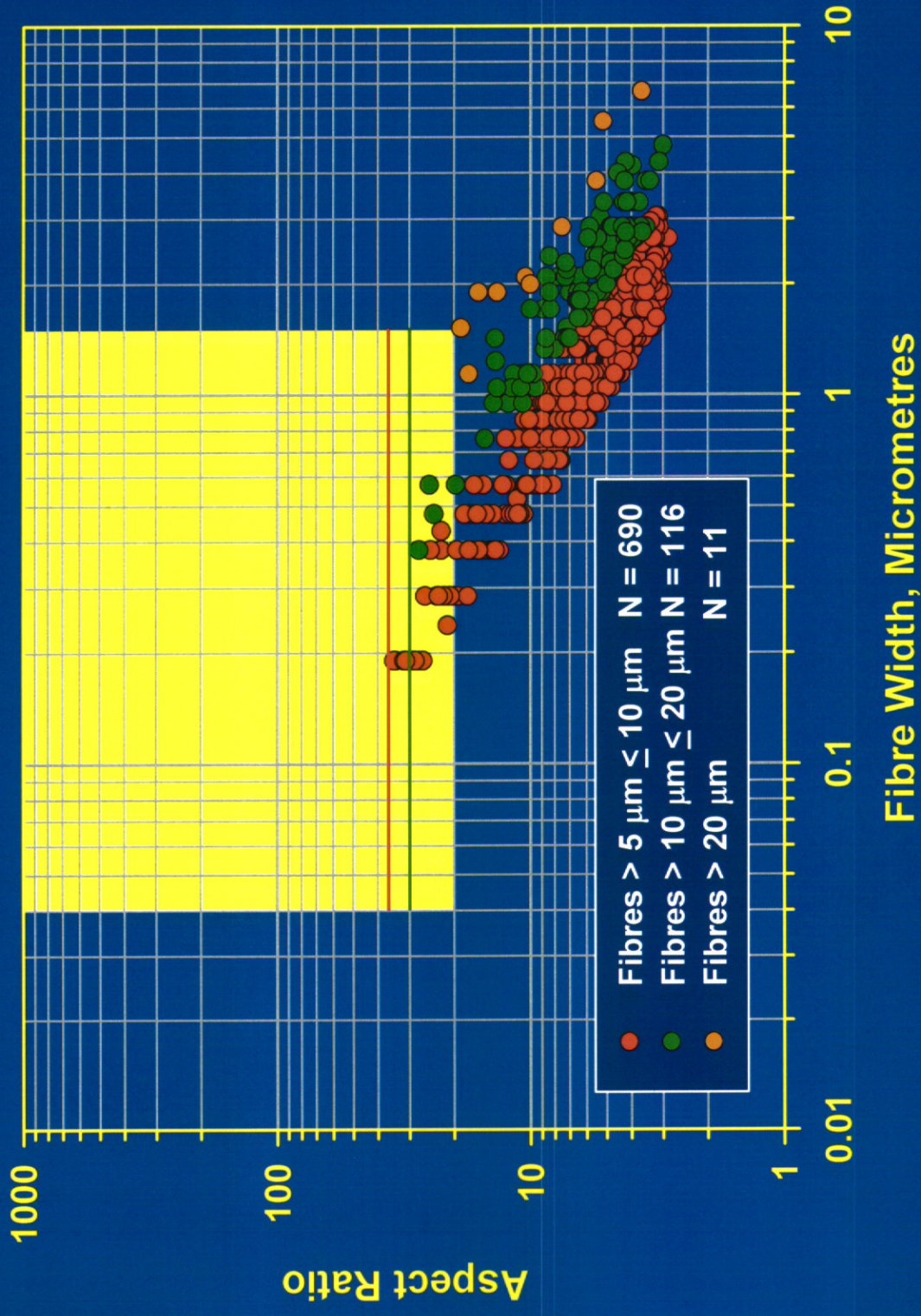
Non-Asbestiform Actinolite (Brazil)



Fibre Width, Micrometres

Non-Asbestiform Actinolite (Royal Ontario Museum #M32007)



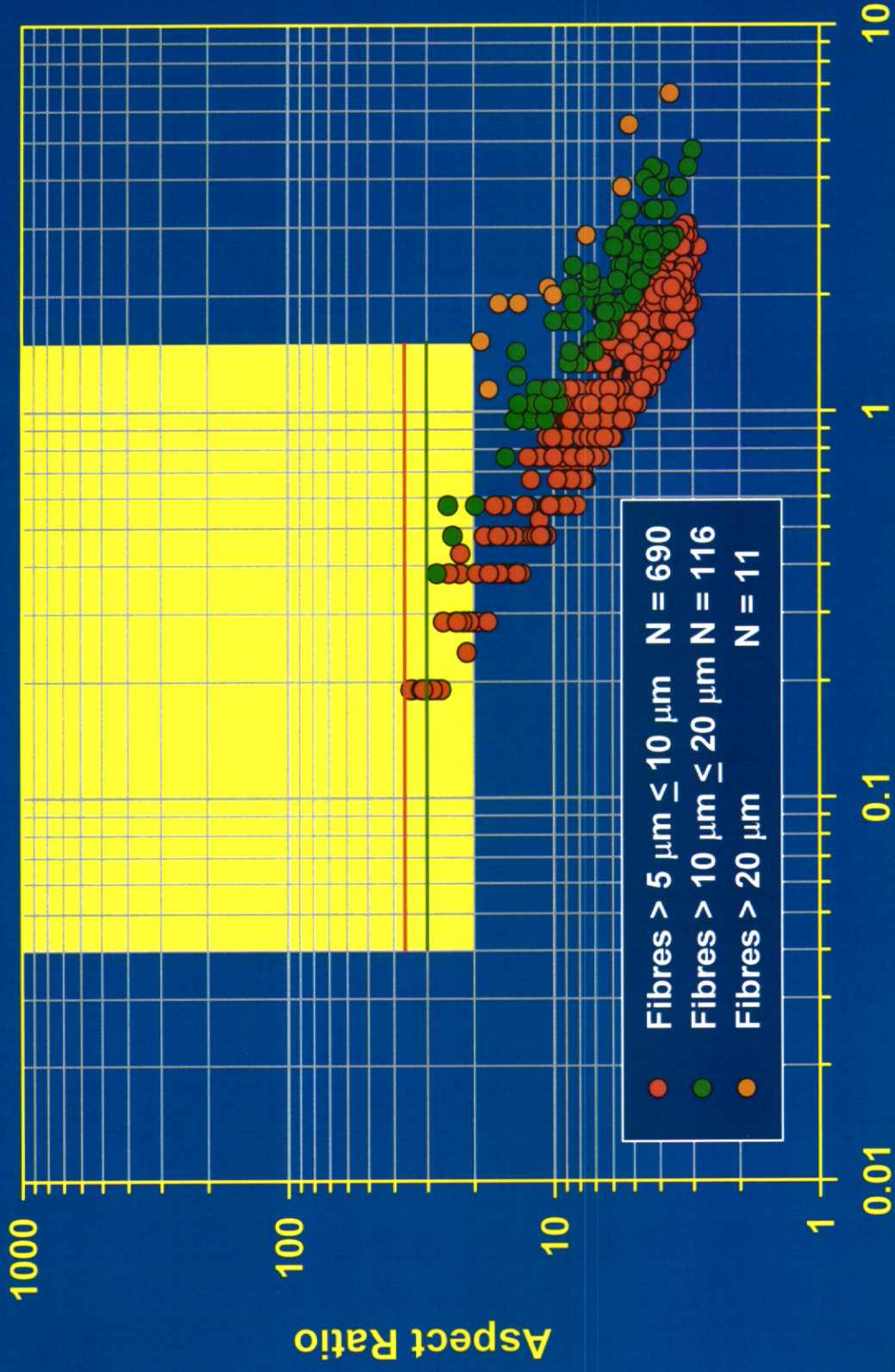


Fibre Width, Micrometres

Composite data for non-asebstiform amphiboles (817 fibres)

Results of Examination of Non-Asbestiform Amphiboles

- For non-asbestiform amphibole fibres longer than 5 μm and thinner than 1.5 μm :
 - Fibres with lengths > 5 μm and \leq 10 μm do not have aspect ratios exceeding 35:1
 - Fibres with lengths > 10 μm and \leq 20 μm do not have aspect ratios exceeding 30:1
 - Fibres with lengths > 20 μm do not have aspect ratios exceeding 20:1



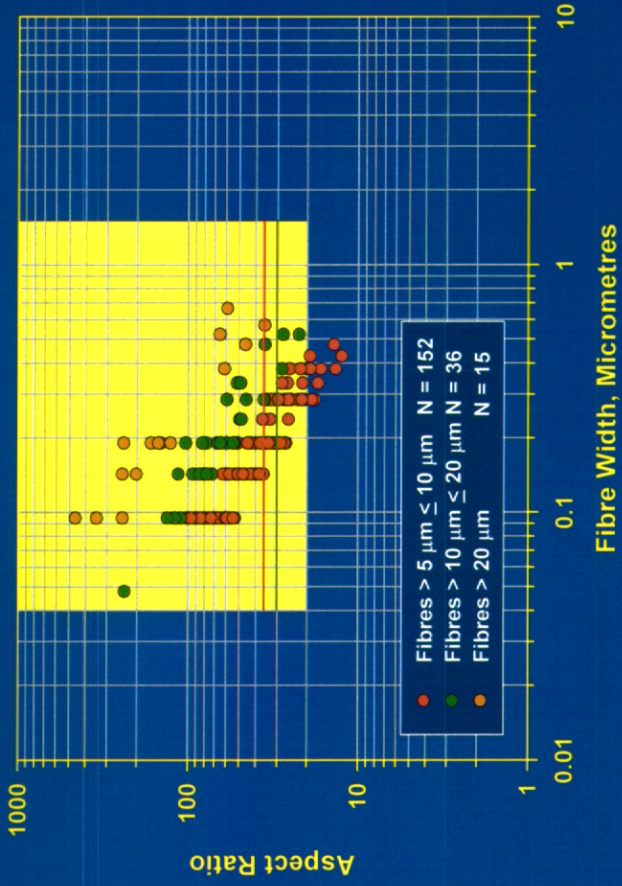
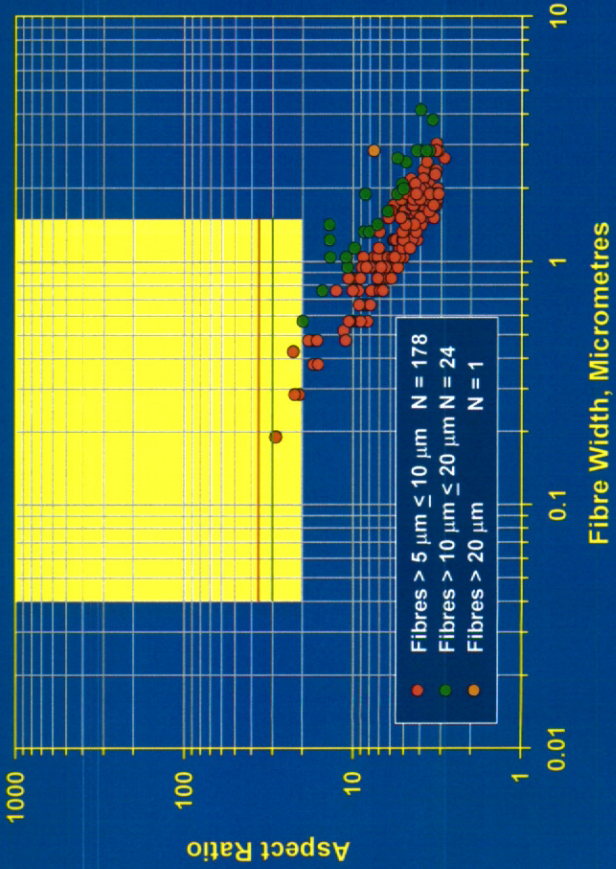
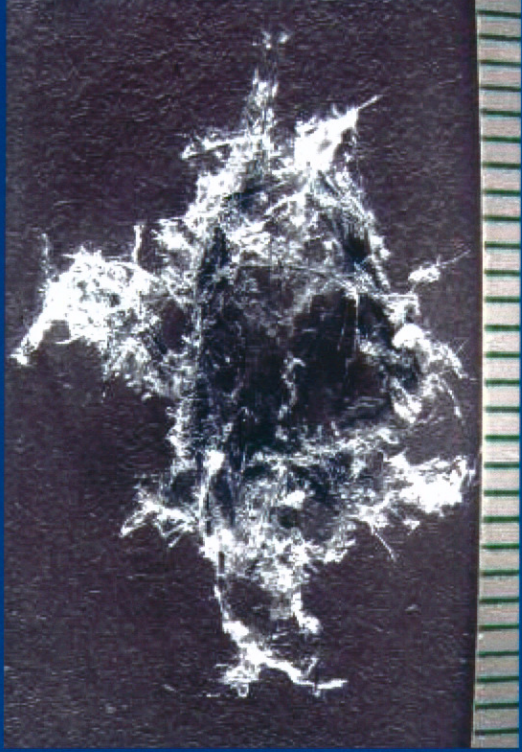
Fibre Width, Micrometres

Composite data for non-asebstiform amphiboles (817 fibres)

Riebeckite, St. Peter's Dome, Colorado

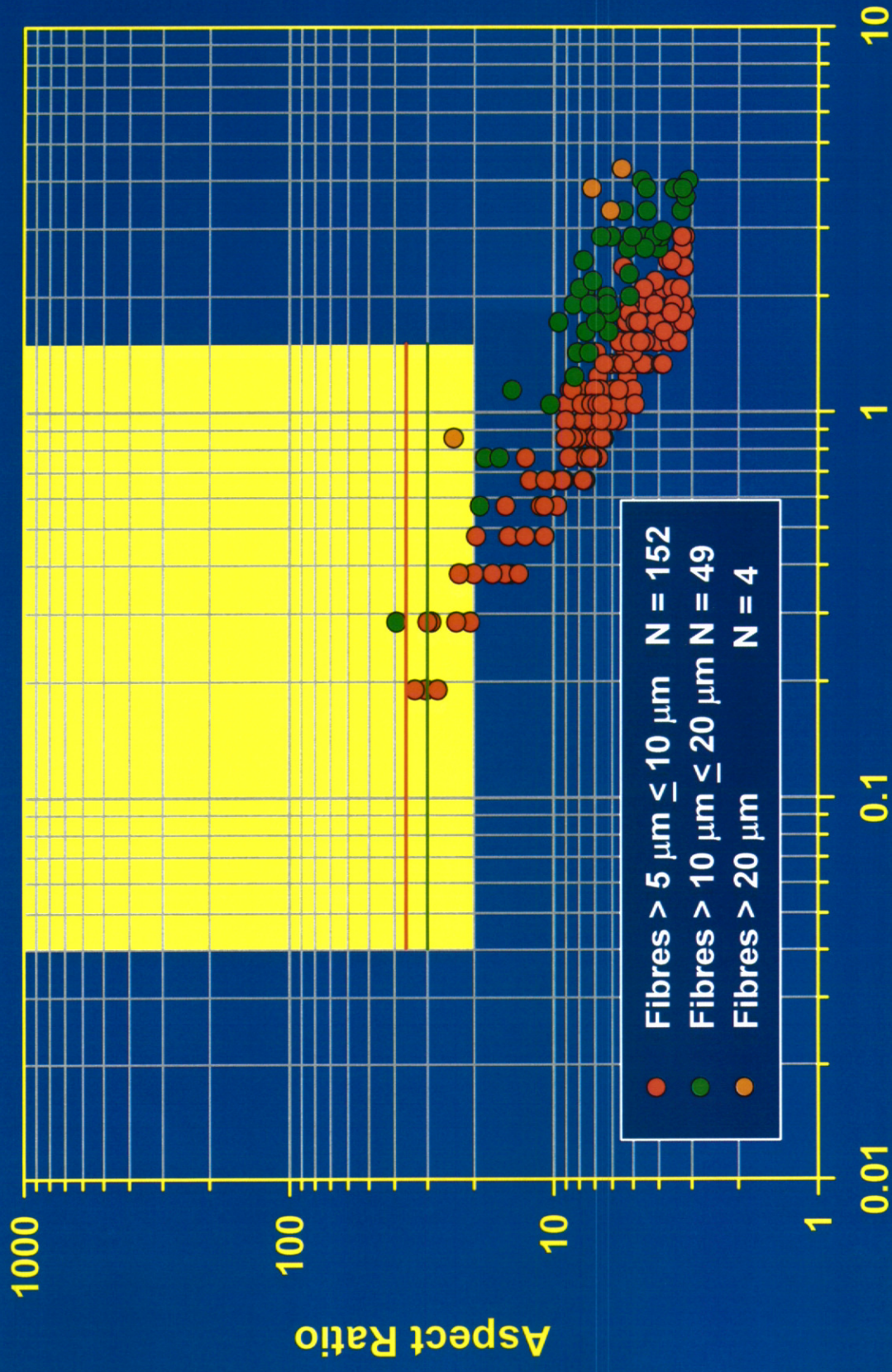


NIST SRM 1866 Crocidolite



Formulation of a Discrimination Rule

- If the plotted distribution does not fall outside of the range for non-asbestiform amphiboles, consider the material to be non-asbestiform
- If the plotted distribution contains fibres in the yellow shaded area that fall outside of the range for non-asbestiform amphiboles, calculate the total numerical and mass concentration of the following fibres:
 - Fibres with lengths $> 5 \mu\text{m}$ and $\leq 10 \mu\text{m}$ with aspect ratios exceeding 35:1
 - Fibres with lengths $> 10 \mu\text{m}$ and $\leq 20 \mu\text{m}$ with aspect ratios exceeding 30:1
 - Fibres with lengths $> 20 \mu\text{m}$ with aspect ratios exceeding 20:1
- Consider the calculated numerical and mass concentration to be “definitive asbestos”



Fibre Width, Micrometres

NIST SRM 1867 Tremolite Asbestos

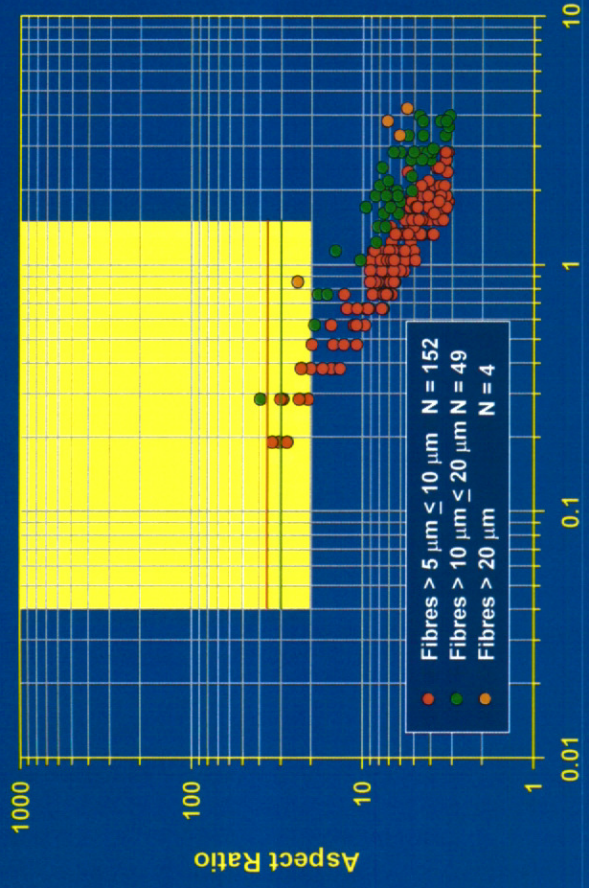
NIST SRM 1867 Tremolite Asbestos



HSE Reference Tremolite Asbestos



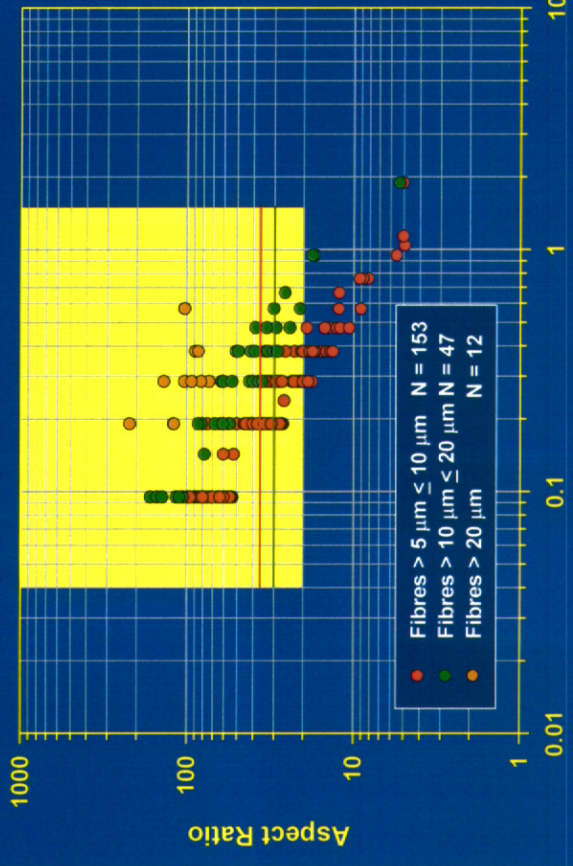
**Two Tremolite Reference Standards.....
Both Described as Asbestos**



Fibre Width, Micrometres



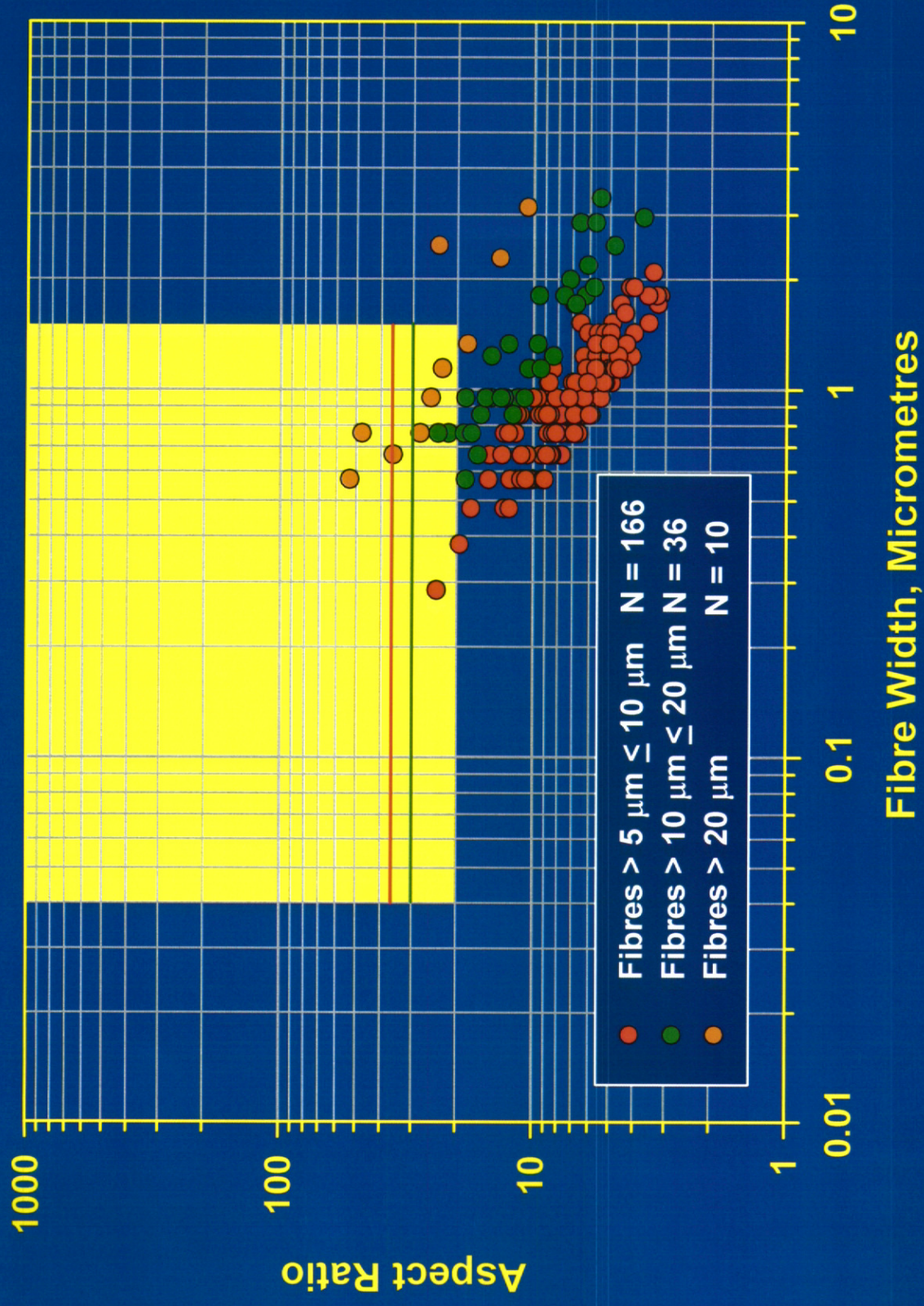
NIST SRM 1867 Tremolite Asbestos



Fibre Width, Micrometres



HSE Reference Tremolite Asbestos

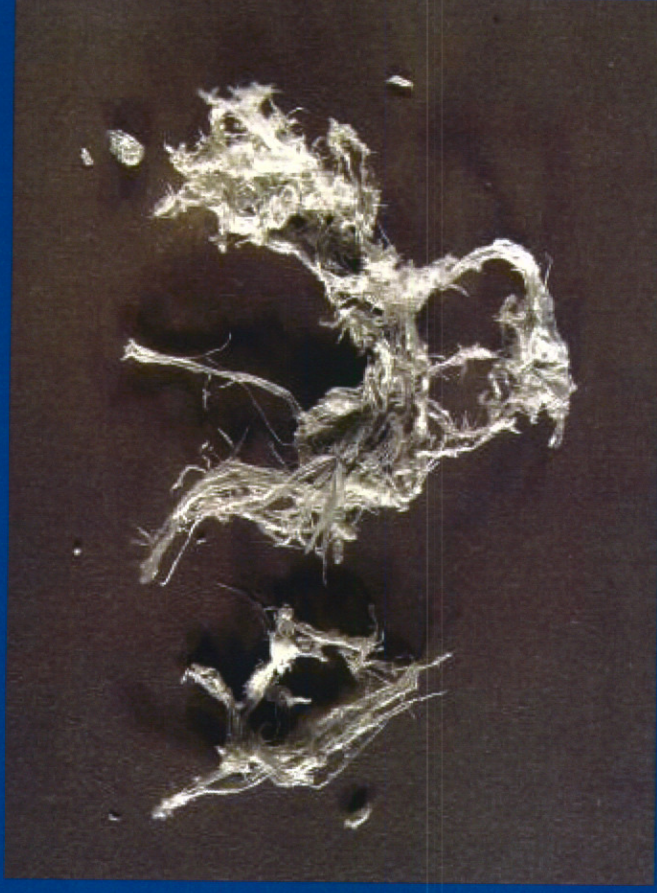


NIST SRM 1867 Actinolite Asbestos

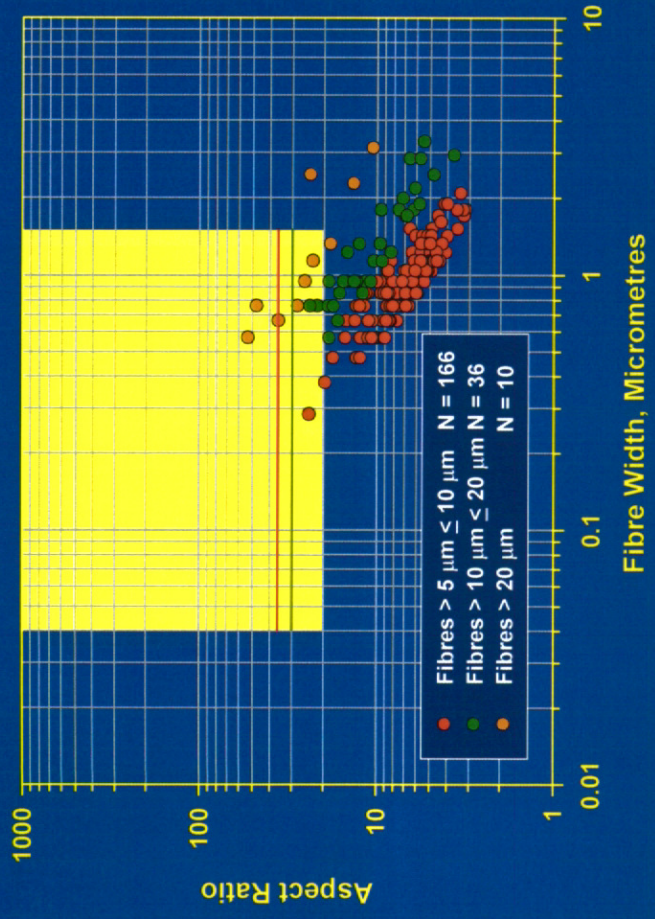
NIST SRM 1867 Actinolite Asbestos



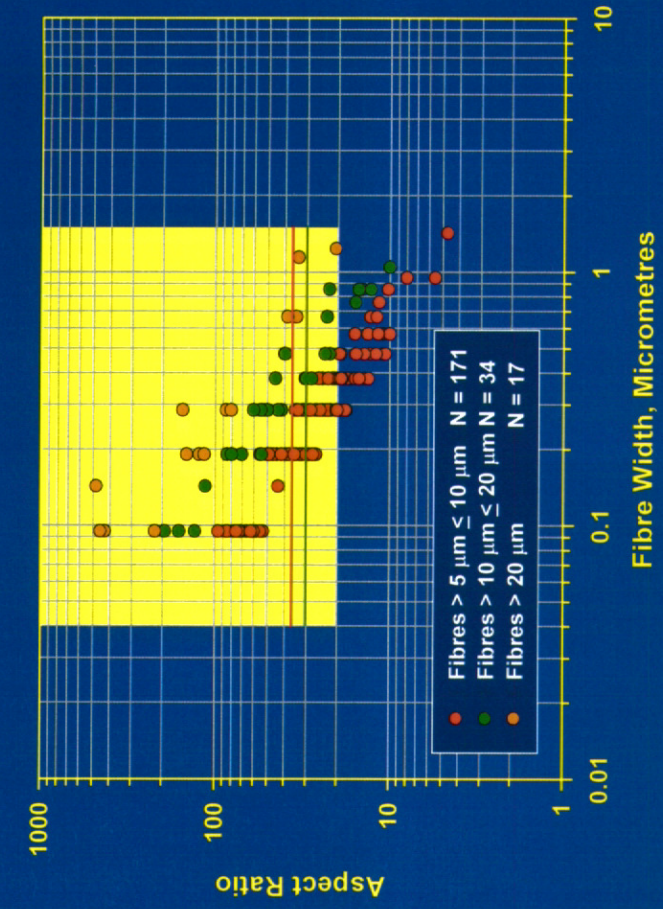
HSE Reference Actinolite Asbestos



**Two Actinolite Reference Standards.....
Both Described as Asbestos**



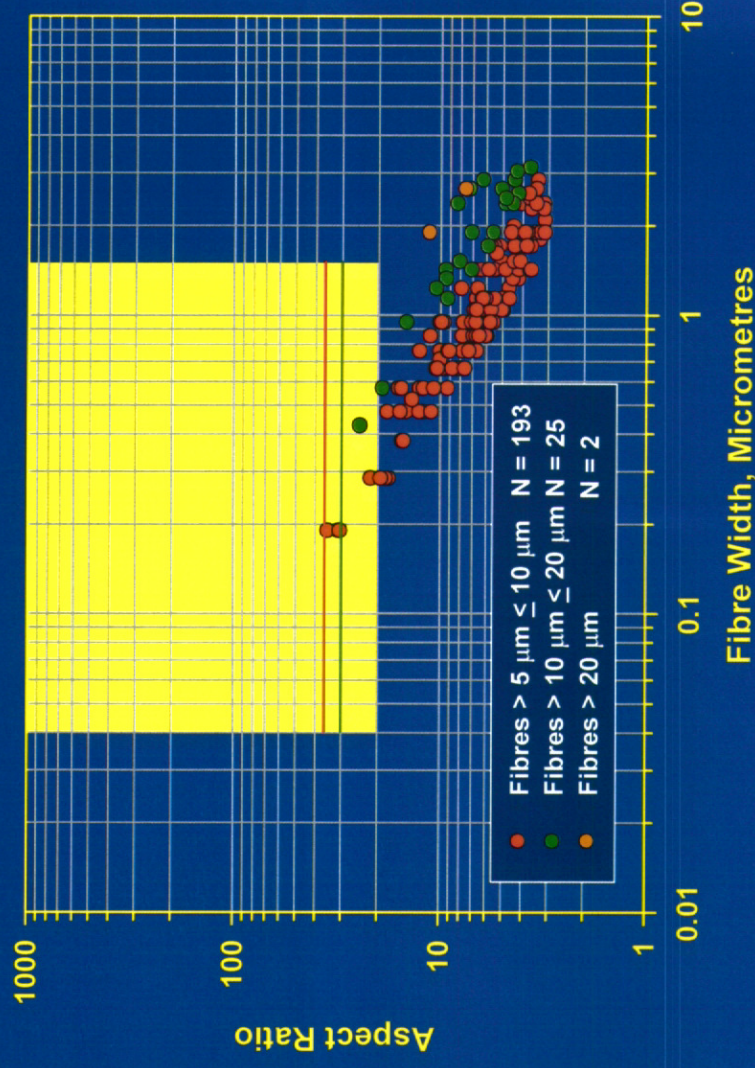
NIST SRM 1867 Actinolite Asbestos



HSE Reference Actinolite Asbestos

Correlation With Health Effects

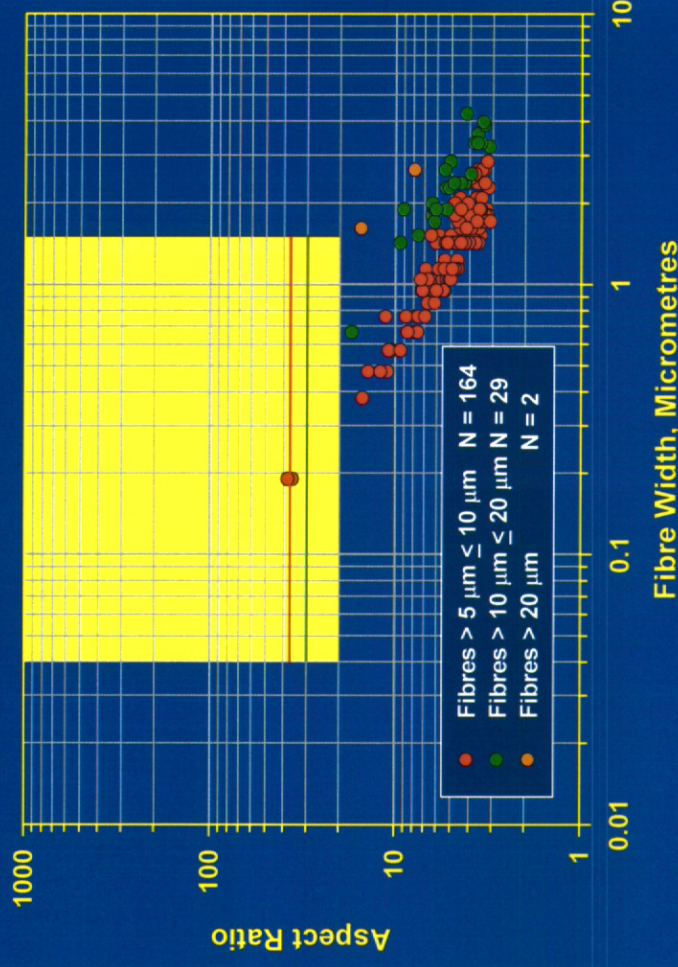
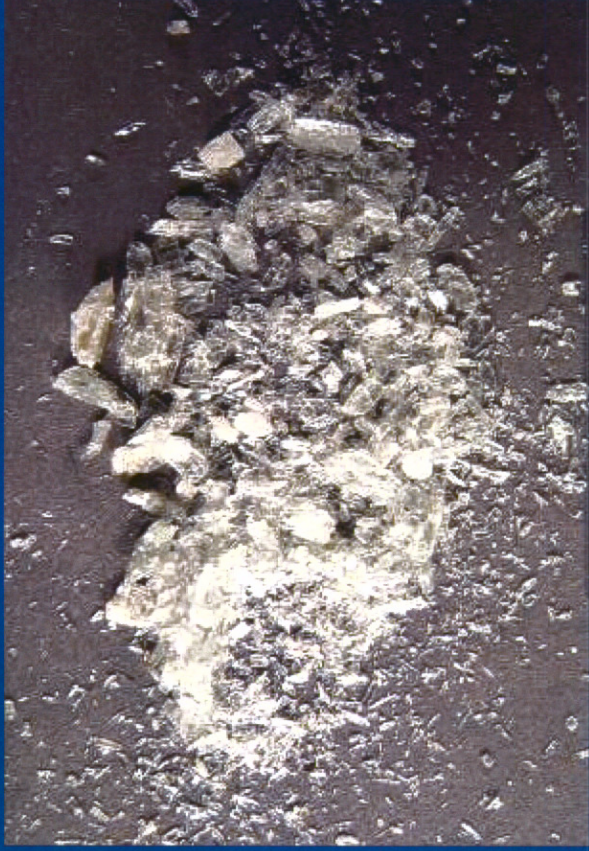
- The protocol has been applied to several tremolite samples for which animal experimental data already exist
- The tremolite samples tested are from the Davis et al. work as follows:
 - Non-asbestiform tremolite from Shinness
 - Non-asbestiform tremolite from Carr Brae, Dornie
 - Tremolite of questionable morphology from Ala di Stura
 - Asbestiform tremolite (Swansea)
 - Asbestiform tremolite from Jamestown, California
 - Tremolite asbestos from Korea



2 tumours were detected in 36 animals

Definitive asbestos – $<0.00031\%$ estimated weight in respirable fraction
 $<2.0 \times 10^7$ fibres/g in respirable fraction

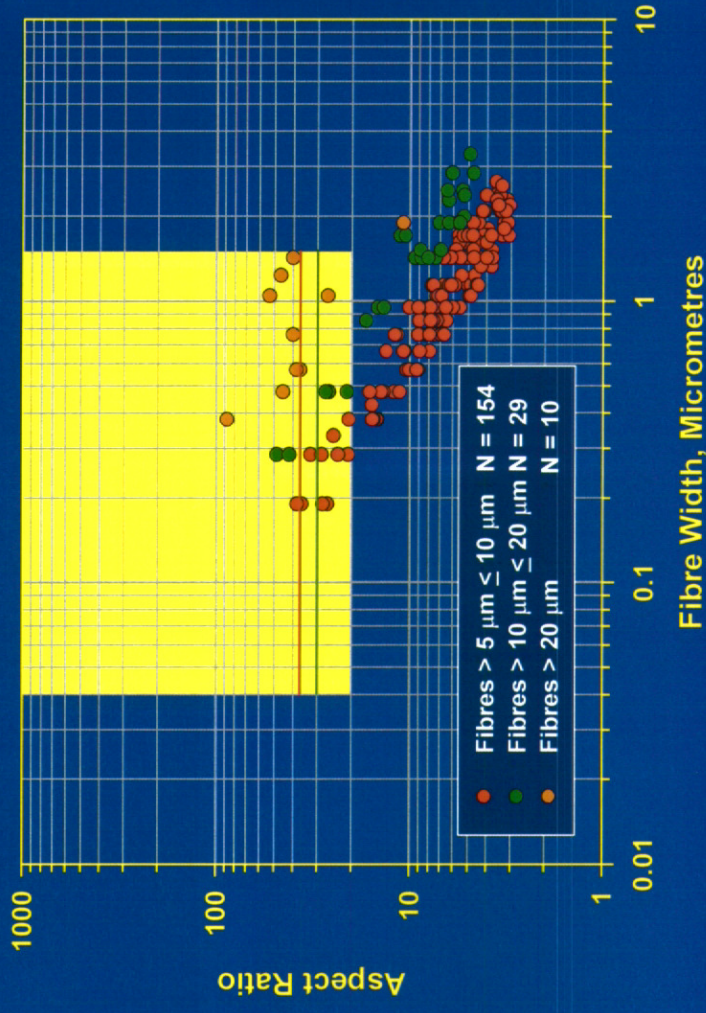
Non-Asbestiform Tremolite from Shinness
(Davis et al. 1991)



4 tumours were detected in 33 Animals

Definitive asbestos – 0.0044% estimated weight in respirable fraction
2.9 x 10⁷ fibres/g in respirable fraction

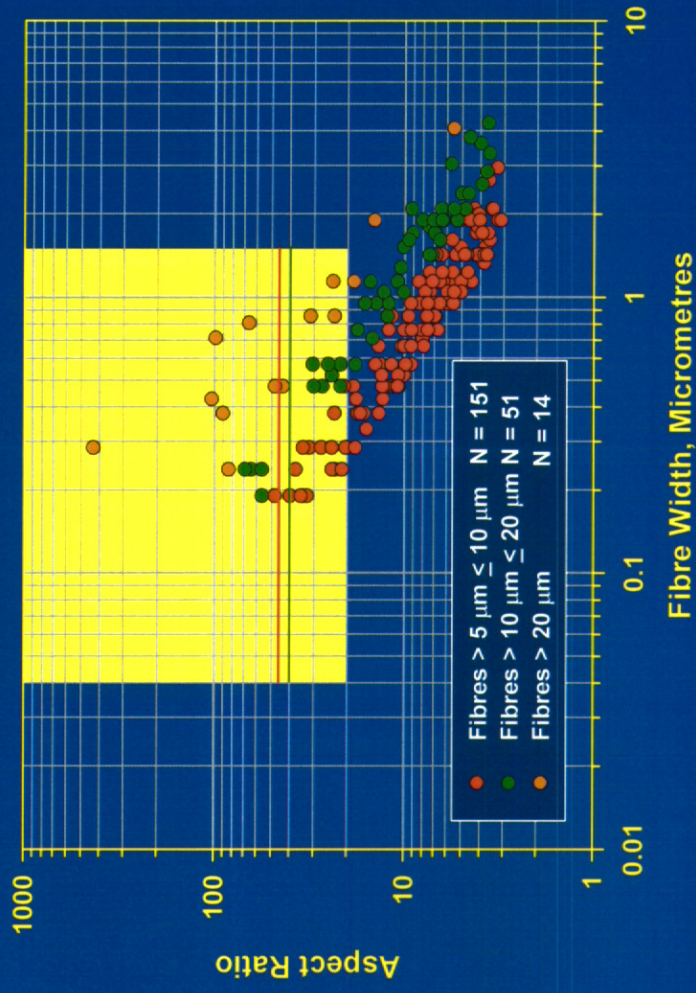
Non-Asbestiform Tremolite from Carr Brae, Dornie
(Davis et al. 1991)



24 tumours were detected in 36 animals

Definitive asbestos – 1.4% estimated weight in respirable fraction
3.3 x 10⁸ fibres/g in respirable fraction

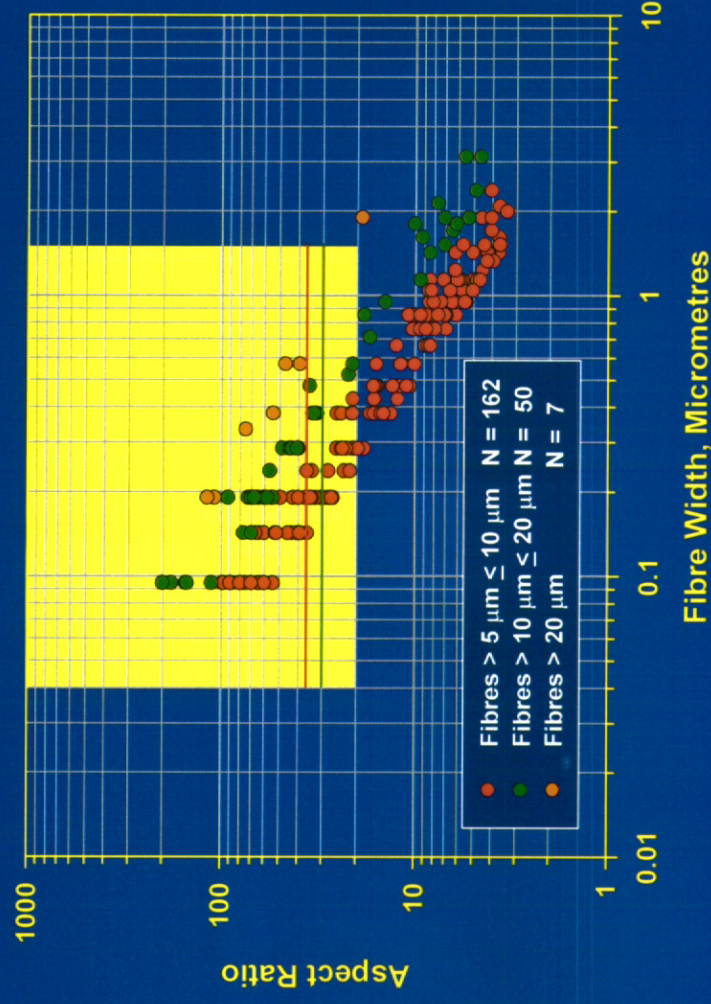
Tremolite of Questionable Morphology from Ala di Stura
(Davis et al. 1991)



35 tumours were detected in 36 animals

Definitive asbestos – 4.1% estimated weight in respirable fraction
9.5 x 10⁸ fibres/g in respirable fraction

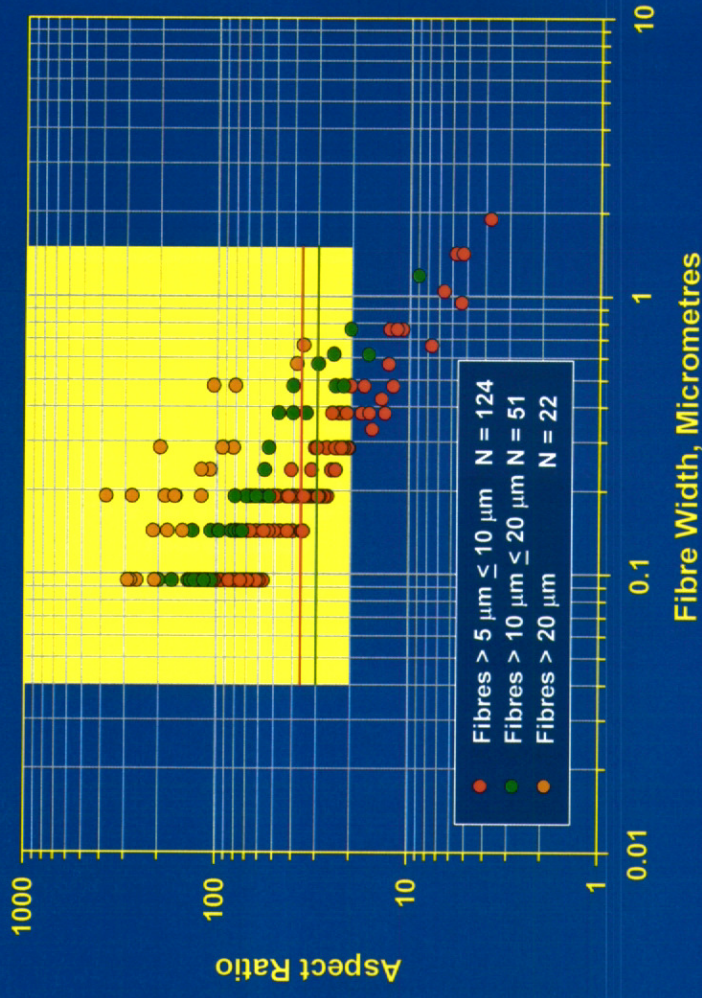
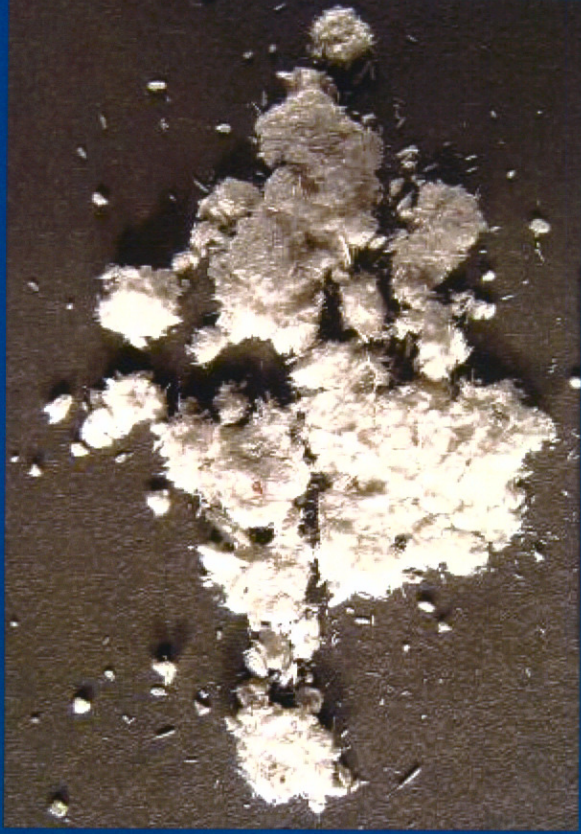
Tremolite from Swansea (Davis et al. 1991)



36 tumours were detected in 36 animals

Definitive asbestos – 1.8% estimated weight in respirable fraction
6.3 x 10⁹ fibres/g in respirable fraction

Tremolite from Jamestown, California (Davis et al. 1991)



32 tumours were detected in 33 Animals

Definitive asbestos – 28.5% estimated weight in respirable fraction
 1.1×10^{11} fibres/g in respirable fraction

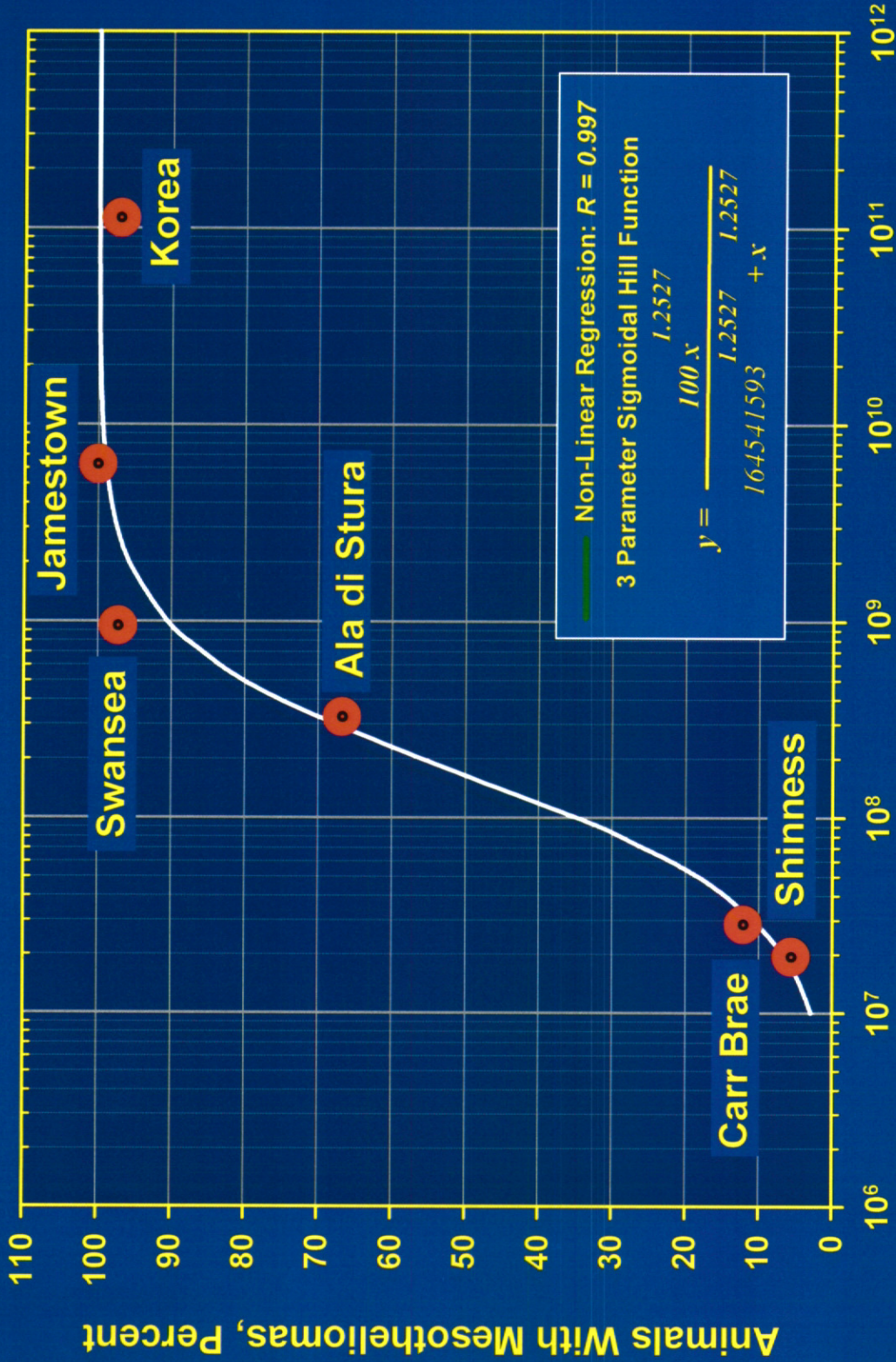
Korean Tremolite (Davis et al. 1991)

Table 1. Correlation of Protocol With Biological Effects

Tremolite Source	"Definitive Asbestos" in Respirable Fraction †		Number of Animals*	Number of Mesotheliomas*
	Weight %	Fibres/gram		
Shinness, Scotland	<0.00031	<2.0 x 10 ⁷	36	2
Carr Brae, Dornie, Scotland	0.0044	2.9 x 10 ⁷	33	4
Ala di Stura, Italy	1.4	3.3 x 10 ⁸	36	24
Swansea	4.1	9.5 x 10 ⁸	36	35
California, Jamestown	1.8	6.3 x 10 ⁹	36	36
Korea	28.5	1.1 x 10 ¹¹	33	32

† All measurements referred to the weight of the respirable fraction

* Data from Davis, J.M.G., Addison, J, McIntosh, C., Miller, B.G. and Niven, K., 1991



"Definitive Asbestos" Fibres in Respirable Fraction, Fibres/Gram

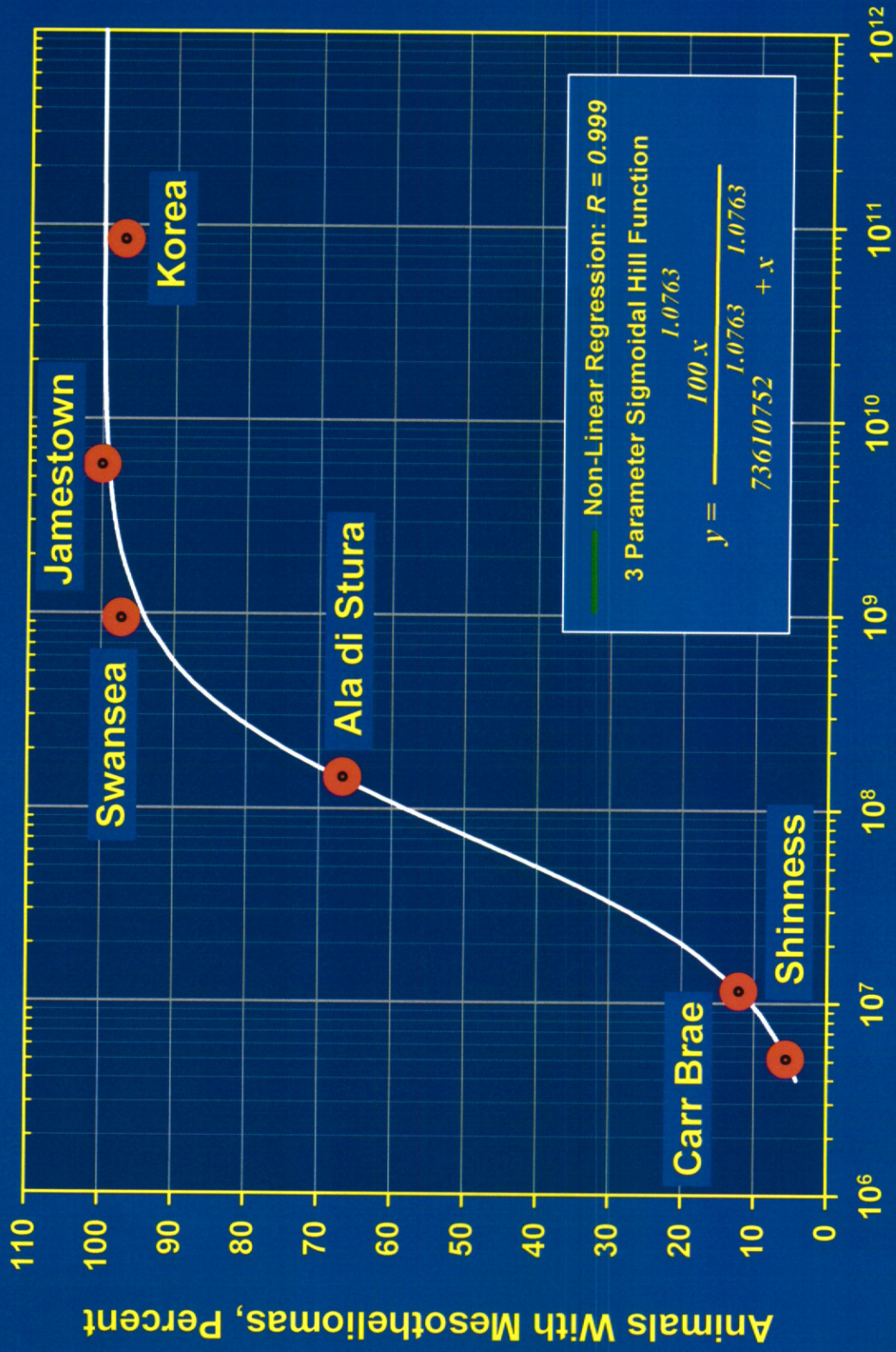
Figure 1. Tumour Incidence vs. Respirable "Definitive Asbestos"

Table 2. Correlation of Protocol With Biological Effects

Tremolite Source	"Definitive Asbestos" in Original Crushed Sample †		Number of Animals*	Number of Mesotheliomas*
	Weight %	Fibres/gram		
Shinness, Scotland	<0.000080	<5.2 x 10 ⁶	36	2
Carr Brae, Dornie, Scotland	0.0018	1.2 x 10 ⁷	33	4
Ala di Stura, Italy	0.64	1.5 x 10 ⁸	36	24
Swansea	4.1	9.5 x 10 ⁸	36	35
California, Jamestown	1.7	5.9 x 10 ⁹	36	36
Korea	21.5	8.5 x 10 ¹⁰	33	32

† All measurements referred to the weight of original crushed sample

* Data from Davis, J.M.G., Addison, J, McIntosh, C., Miller, B.G. and Niven, K., 1991

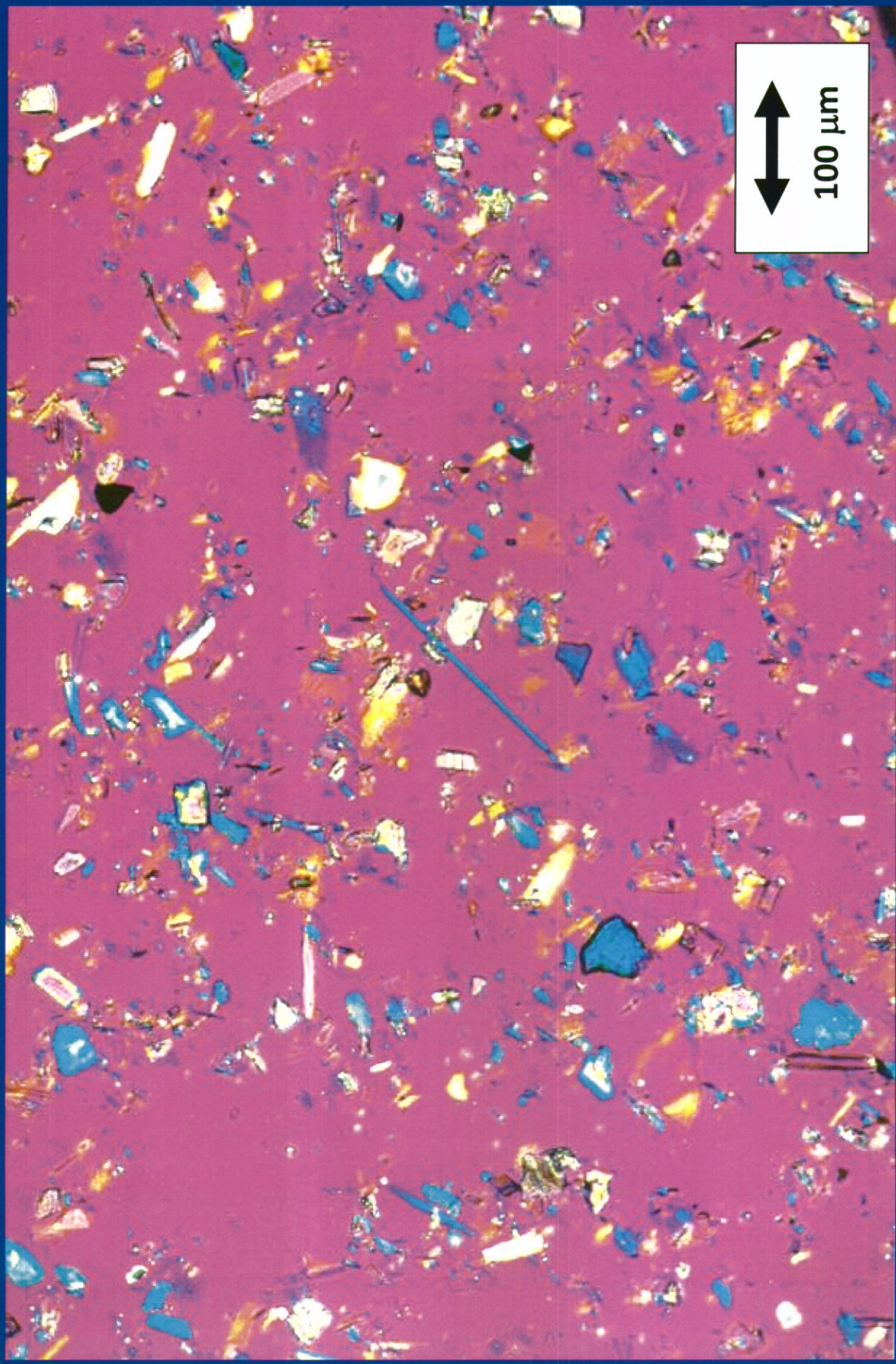


"Definitive Asbestos" Fibres in Crushed Sample, Fibres/Gram

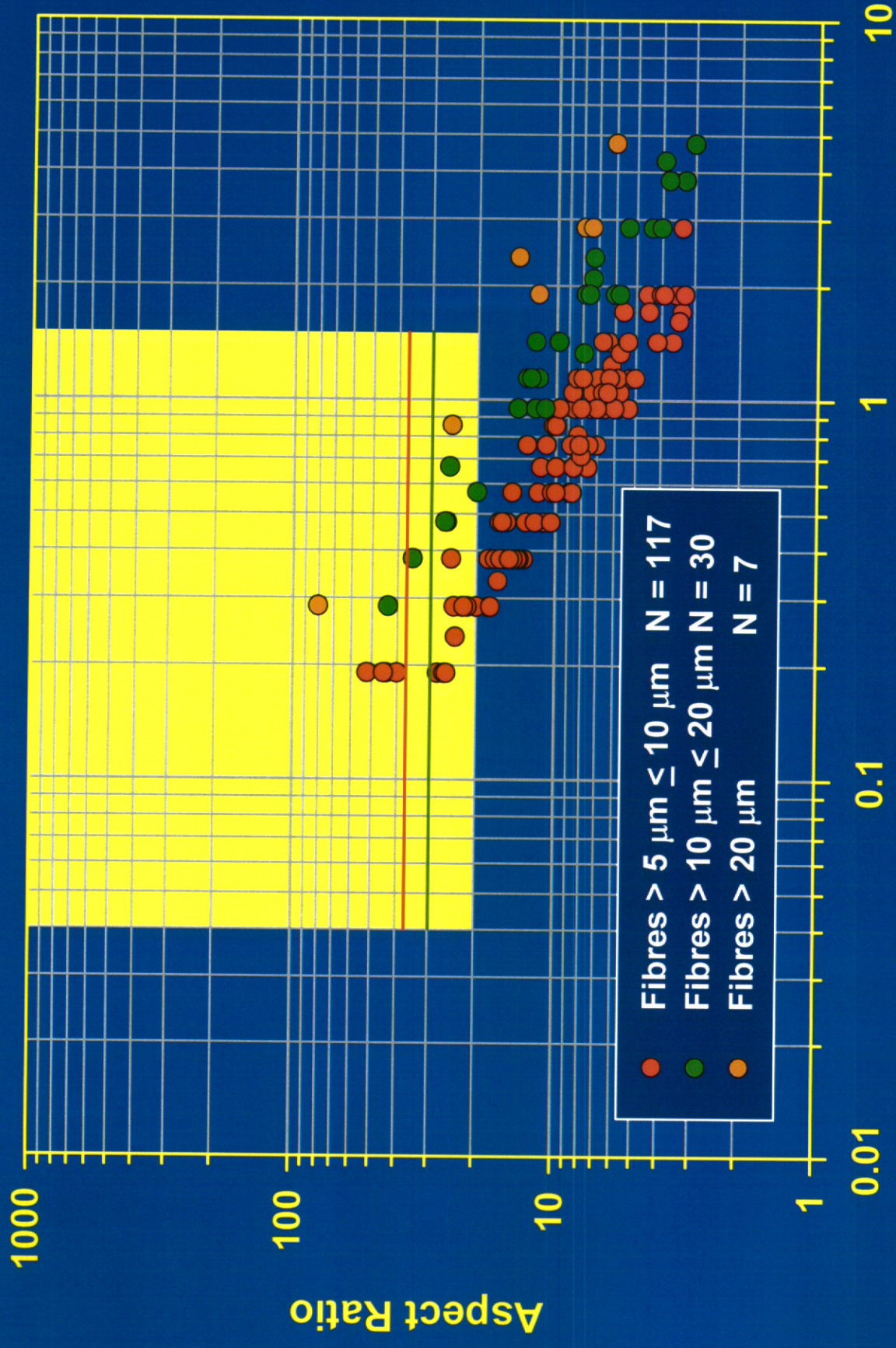
Figure 2. Tumour Incidence vs. "Definitive Asbestos" in Crushed Sample

Conclusions

- The protocol provides an objective method to discriminate quantitatively between non-asbestiform amphibole and amphibole asbestos fibres
- The protocol is generally applicable to situations where amphibole asbestos co-exists with non-asbestiform amphiboles
- The protocol is based on objective and rational criteria
- There is a very strong correlation between the results from this protocol and the observed tumor incidence in the Davis et al. animal studies

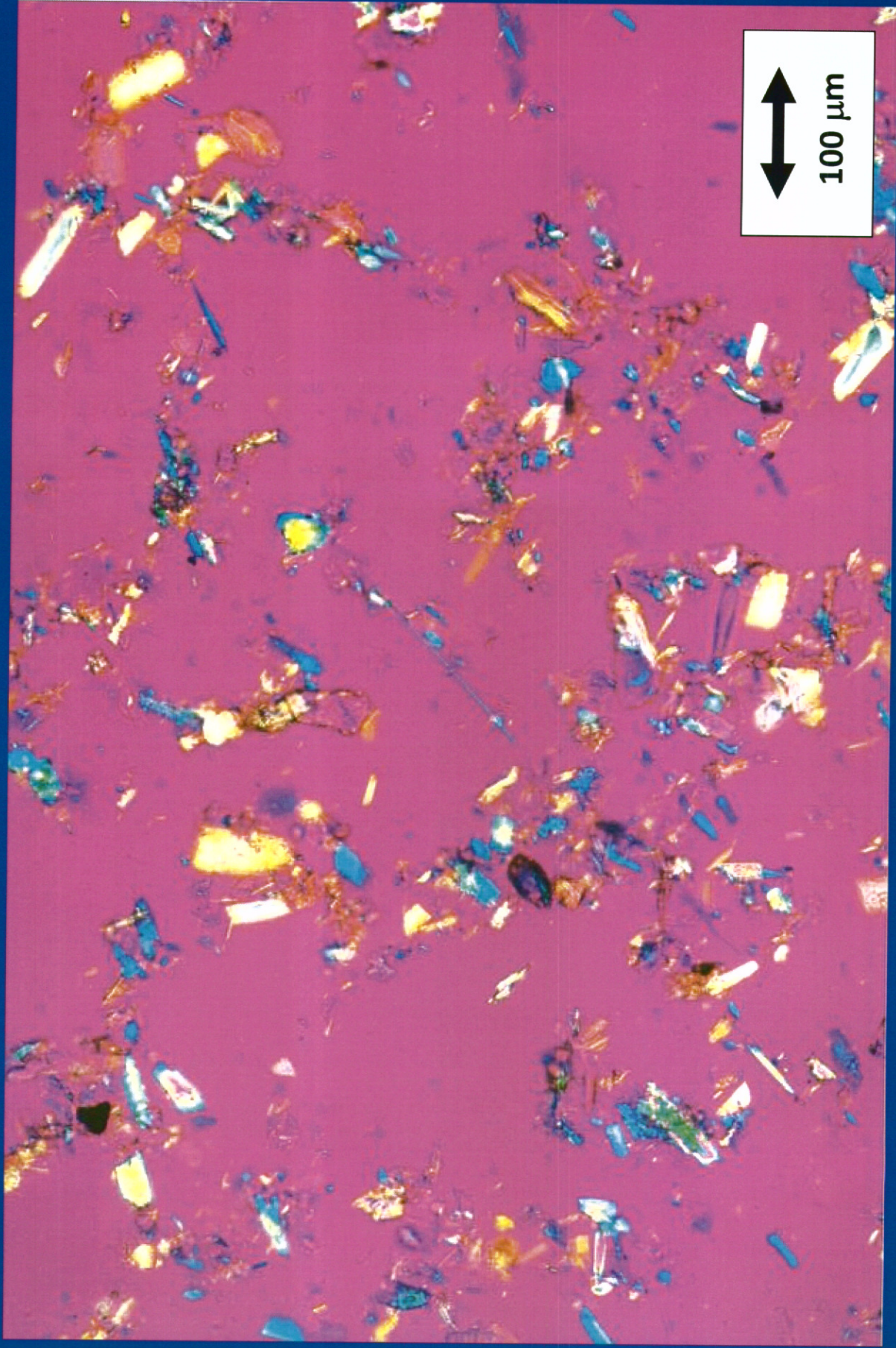


Industrial Talc: PLM micrograph

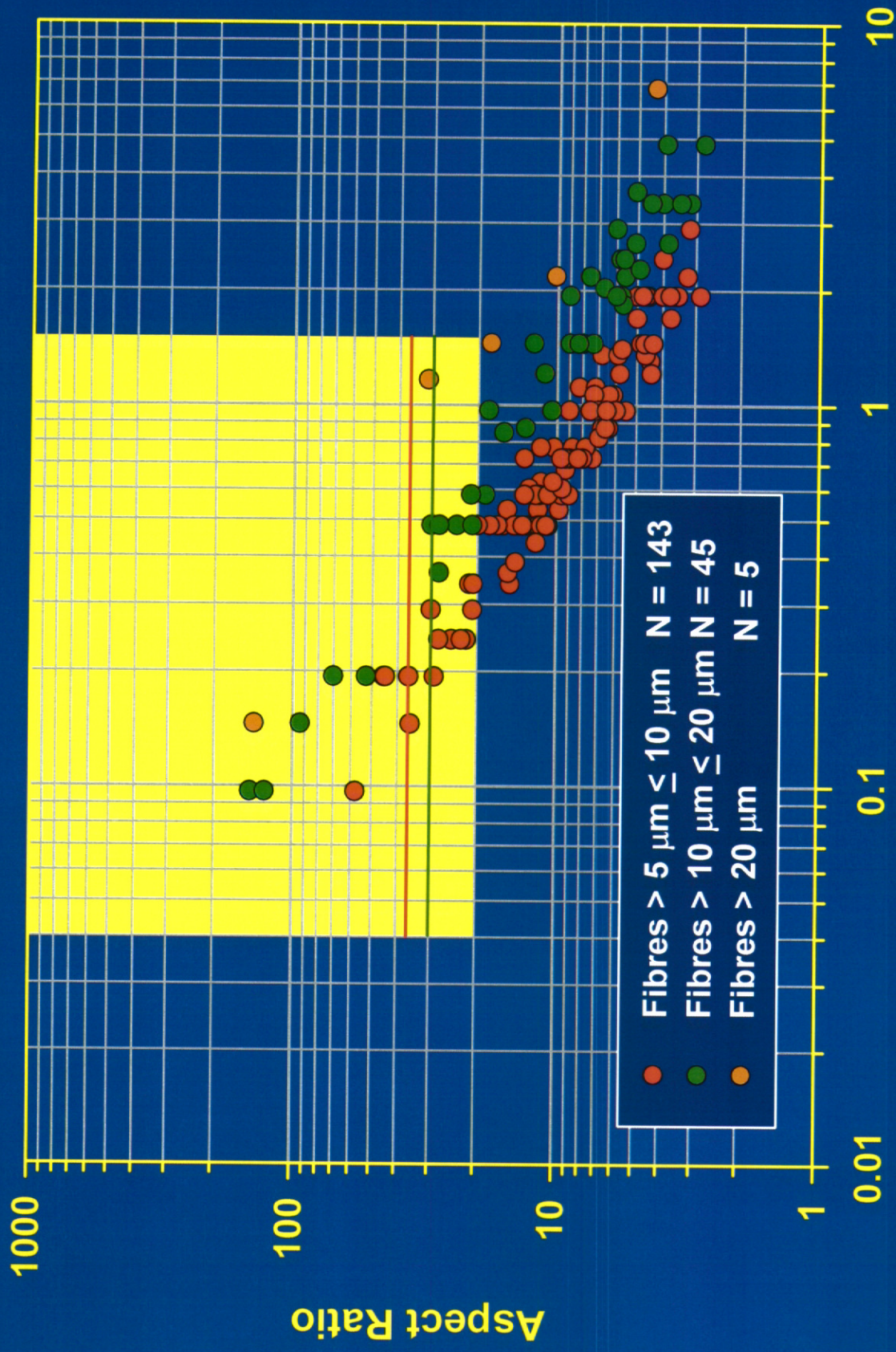


Fibre Width, Micrometres

Tremolite Detected in Industrial Talc Sample



**Industrial Dolomite: PLM Micrograph of residue
after treatment with hydrochloric acid**

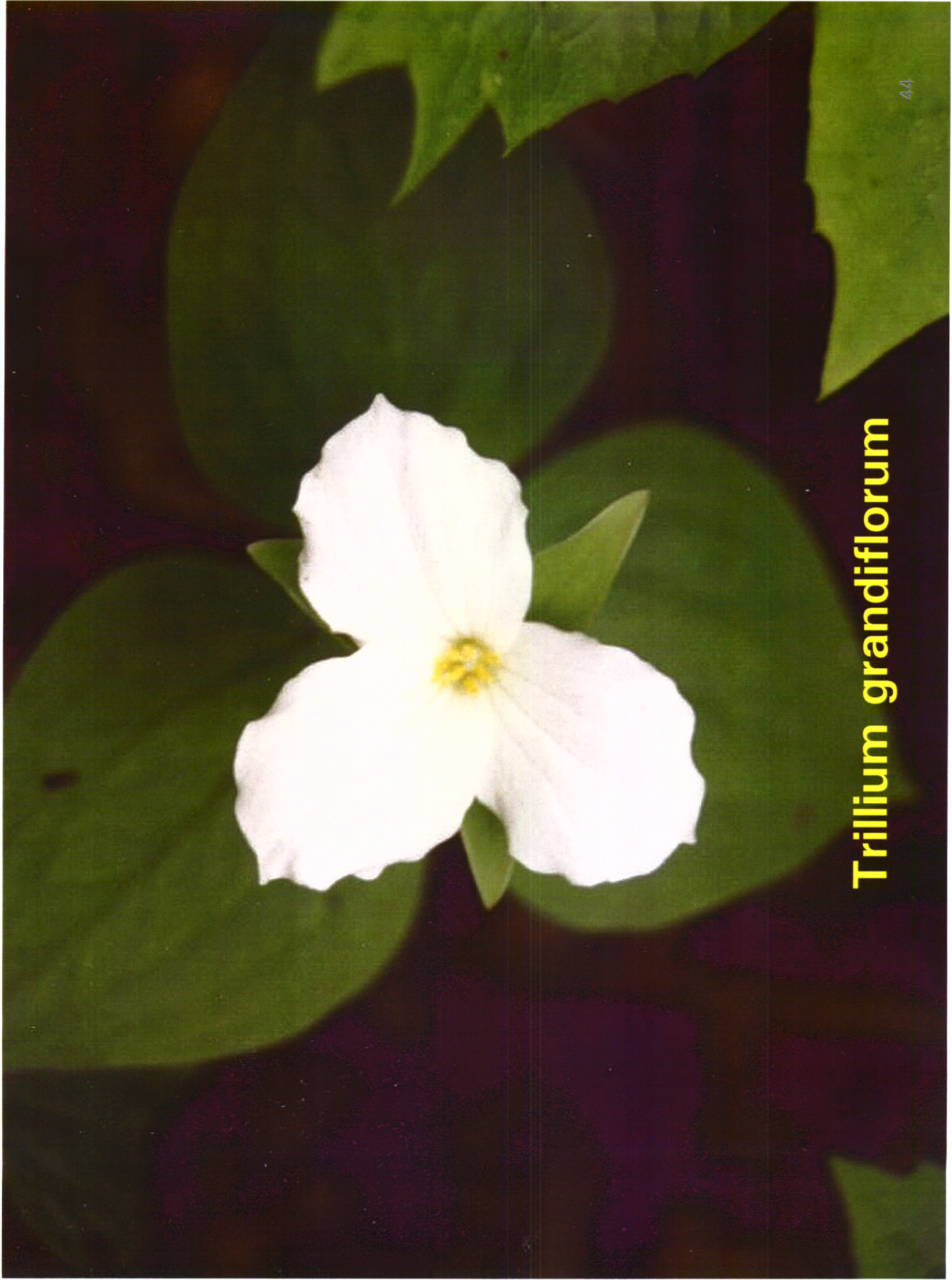


Fibre Width, Micrometres

Tremolite Detected in Industrial Dolomite Sample

Application to Air Sample Analysis

- The numerical concentration of definitive asbestos fibres longer than 5 μm in the respirable size range for tremolite of various morphologies correlates very strongly with the observed tumor incidence in the Davis et al. studies ($R=0.997$)
- There seems little reason why this protocol could not be applied to exclude non-asbestiform amphibole fragments in the analysis of air samples for asbestos for the purpose of risk estimation



Trillium grandiflorum