Supplemental material

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Supplementary Table 1: Enterprise specific cohort characteristics

Location	Years of operation	Number of workers with at least one job in location*	Total employment years	Proportion of employment-years professionally exposed
Factory 0	1896-1956	141	331	97%
Factory 1	1924-1955	281	799	98%
Factory 2	1930-1980	1,960	15,084	93%
Factory 3	1936-1977	1,936	16,031	94%
Factory 4	1956-2010	5,650	45,517	94%
Factory 5	1955-1997	4,230	33,731	92%
Factory 6	1969-present	10,196	83,275	91%
Central Lab	1926-present	695	5,727	97%
Mine	1896 to present	25,173	305,431	83%
External Rail	1970-present	1,202	9,428	98%
Total			**515,355**	**88%**

* note that eligible cohort members had to work for at least one year in an eligible enterprise of JSC Uralasbest between 1975-2010, explaining the decline in workers from recent factory 6 to the first factory (factory 0), and they could have worked in multiple locations over time.

Supplementary Table 2: Key cohort characteristics and their exposure (based on geometric mean monthly concentration per sampling point)

		Median cumulative dust exposure (mg/m³-years)	Median cumulative fibre exposure (fibre/cm³-years)	Median average dust intensity (mg/m³)	Median average fibre intensity (fibre/cm³)
Gender					
Men		26.3 (0.01-1454.6)	18.3 (0.01-438)	2.6 (0.4-97.7)	1.8 (0.4-31.3)
Women		39.1 (0.01-1184.4)	31 (0.01-399.8)	3.5 (0.1-100)	2.9 (0.1-43.2)
Birth year category					
<1930		74.9 (0.05-1454.6)	40.6 (0.01-399.8)	3.7 (1-100)	1.7 (0.6-43.2)
1930-39		77.4 (0.04-1019.4)	48.6 (0.03-438)	3.6 (0.7-100)	2.1 (0.6-32.3)
1940-49		44.1 (0.02-648.5)	32.7 (0.01-193.2)	3 (0.5-24.9)	2 (0.4-8.8)
1950-59		23.6 (0.01-368.8)	17 (0.01-172.1)	2.7 (0.2-23.6)	1.9 (0.3-9.5)
1960-69		15.3 (0.01-364)	11.5 (0.01-161.7)	2.4 (0.1-24.1)	1.8 (0.1-9.1)
1970 on		13.4 (0.01-163.3)	8.1 (0.01-100.7)	2.4 (0.1-19)	1.8 (0.1-7)
Year of first job period					
1930-1955		102 (0.1-1454.6)	52.5 (0.01-438)	4.4 (1.3-100)	1.7 (1.0-43.2)
1955-64		76.8 (0.07-846.8)	47.5 (0.04-296.8)	3.6 (0.7-54.2)	2 (0.6-16.1)
1965-74		40 (0.01-366.2)	30.3 (0.01-193.2)	2.9 (0.5-20.9)	2 (0.4-8.1)
1975-84		19.6 (0.01-368.8)	14.2 (0.01-161.7)	2.7 (0.1-23.6)	1.9 (0.2-9.5)
1985-94		13.8 (0.01-344.2)	10.5 (0.01-130.6)	2.5 (0.1-24.1)	1.9 (0.2-9.1)
1995 on		10.6 (0.02-139.6)	7.8 (0.02-83.8)	2.3 (0.1-13.5)	1.5 (0.1-6)
Work Location					
Factories	Total	39.7 (0.03-1055.8)	34.8 (0.03-438)	3.8 (0.1-100)	3.5 (0.1-43.2)
	Men	36.7 (0.04-1055.8)	31.7 (0.05-438)	3.9 (0.5-92.6)	3.6 (0.4-21.5)
	Women	41.3 (0.03-1011.2)	36.5 (0.03-346.4)	3.8 (0.1-100)	3.5 (0.1-43.2)
Mine/ External Rail	Total	22.9 (0.01-1114.2)	14.7 (0.01-95.3)	2.4 (0.4-47.6)	1.6 (0.4-2.4)
	Men	21.9 (0.01-1114.2)	14.3 (0.01-95.3)	2.3 (0.4-47.6)	1.6 (0.4-2.4)
	Women	29.3 (0.02-767.6)	17.7 (0.01-91)	2.7 (0.5-47.5)	1.7 (0.4-2.4)
Both	Total	32.6 (0.01-1454.6)	24.2 (0.01-399.8)	3.4 (0.1-100)	2.5 (0.2-38.4)
	Men	29.3 (0.01-1454.6)	21.4 (0.03-302.4)	3.2 (0.4-97.7)	2.3 (0.5-31.3)
	Women	40.4 (0.01-1184.4)	31.8 (0.01-399.8)	3.7 (0.1-100)	3 (0.2-38.4)
Total		**30.2 (0.01-1454.6)**	**22.1 (0.01-438)**	**2.9 (0.1-100)**	**1.9 (0.1-43.2)**

Supplementary table 3: Correlation matrix of a) cumulative exposure and b) exposure intensity

a) Cumulative exposure			
N= 35,837	Cumulative dust (AM)	Cumulative fibre (AM)	Cumulative dust (GM)
Cumulative dust (AM)	1		
Cumulative fibre (AM)	0.77	1	
Cumulative dust (GM)	0.99	0.74	1
Cumulative fibre (GM)	0.76	1.00	0.74
b) Exposure Intensity			
	Dust exposure intensity (AM)	Fibre exposure intensity (AM)	Dust exposure intensity (GM)
Dust exposure intensity (AM)	1		
Fibre exposure intensity (AM)	0.70	1	
Dust exposure intensity (GM)	0.97	0.65	1
Fibre exposure intensity (GM)	0.68	0.98	0.68

AM: arithmetic mean; GM: geometric mean

Step 1:

Use the mean monthly dust concentrations by sampling point: flag sampling points that only have one concentration per year or only concentration in one season (i.e. minimum two concentrations per sampling point per year) or are missing concentrations for an entire year

Individual measurements per sampling point in a given month:
$$x_1, x_2, ..., x_n$$

Mean Monthly Dust Concentration per sampling point:
Arithmetic Mean (AM): $MD_{(AM)} = (x_1 + x_2 + ... + x_n)/n$
Geometric Mean (GM): $MD_{(GM)} = \exp((\ln(x_1)+\ln(x_2)+...+\ln(x_n))/n)$

Step 2:

Convert monthly dust concentrations (capped at 100 mg/m³) to estimated monthly fibre concentrations

Monthly Fibre Concentration per sampling point:
$MF_{(AM)Converted}$ = Fibre/Dust-ratio x $MD_{(AM)}$
$MF_{(GM)Converted}$ = Fibre/Dust-ratio x $MD_{(GM)}$

Step 3:

By sampling point, calculate a seasonal and then derive the annual dust and estimated fibre concentrations

Seasonal Dust concentrations per sampling point:
$W_{Dust}=(MD_{Jan}+MD_{Feb}+MD_{Mar}+MD_{Apr}+MD_{May}+MD_{Oct}+MD_{Nov}+MD_{Dec})/8$
$S_{Dust}=(MF_{Jun}+MF_{Jul}+MF_{Aug}+MF_{Sep})/4$
Seasonal fibre concentrations per sampling point:
$W_{Fibre}=(MF_{Jan}+MF_{Feb}+MF_{Mar}+MF_{Apr}+MF_{May}+MF_{Oct}+MF_{Nov}+MF_{Dec})/8$
$S_{Fibre}=(MF_{Jun}+MF_{Jul}+MF_{Aug}+MF_{Sep})/4$

Step 4:

Derive the annual dust and estimated fibre for a Job Group by combining relevant sampling points (1951-2001 data)

Sampling Point Annual Dust Concentration:
$P_nA_{Dust}=(2 \times W_{Dust} + S_{Dust})/3$
Sampling Point Annual Fibre Concentration:
$P_nA_{Fibre}=(2 \times W_{Fibre} + S_{Fibre})/3$

Step 5:   **MODELLING**

Use Step 4 data from 1951/64 to 2001 to model dust and estimated fibre concentrations by Job Group and year separately

Job Group Annual Dust Concentration:
$JobGroupA_{Dust}=(P_1A_{Dust} + P_2A_{Dust} + ... + P_nA_{Dust})/n$
Job Group Annual Fibre Concentration:
$JobGroupA_{Fibre}=(P_1A_{Fibre} + P_2A_{Fibre} + ... + P_nA_{Fibre})/n$

Step 6:

Derive modelled dust concentrations where data were flagged as either not systematically collected, missing or collected using an alternative method

Missing Job Group Annual Dust Concentrations:
Best Linear Unbiased Prediction from Linear Mixed Model (BLUP)

Step 7:

Derive estimated fibre where data were flagged in Step 1 by applying conversion factors to annual modelled dust concentration

Missing Job Group Annual Fibre Concentrations:
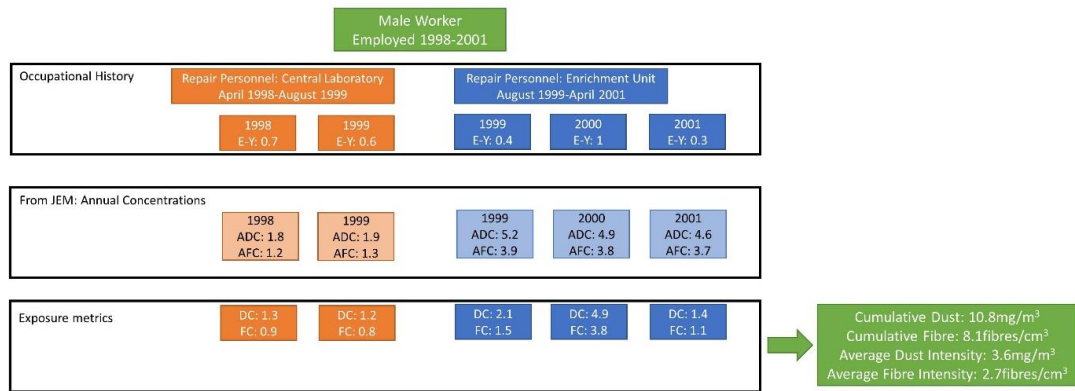Fibre/Dust-ratio x $BLUP_{Dust}$

Step 8:

Match the JEM to the Occupational History Database and assign exposure to individual workers by Job Group in the Mine and/or specific Factory by Year

Individual Annual Dust and Fibre History:
Linking Occupational History to Annual Dust and Fibre Concentration

Supplementary Figure 1: Process of exposure derivation

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E-Y: employment-years; DC: dust concentration; FC: fibre concentration; JEM: job exposure matrices ADC: annual dust concentration; AFC: annual fibre concentration

Supplementary Figure 2: Illustrative example of exposure derivation