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EXPOSURE OF LEAD ENTERING HUMAN BODY THROUGH INHALATION

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SUMMARY

The annual human exposure of lead was estimated due to inhalation and ingestion intake estimates. The inhalation part of the lead intake was based upon the activity patterns of people in the Oslo area, and estimates of indoor/outdoor concentrations of lead. The annual exposure to blood was estimated for different groups of the population living and working inside and outside the city centre.

The human exposure of lead through ingestion was estimated for the average population based upon data on dietary concentrations and intake rates.

The results show that for people living and working in the city centre, where lead due to emissions from traffic give high concentrations of lead in air (1-4 $\mu g/m^3$), the inhalation might represent a significant pathway of lead entering the human body (up to ~ 30%). Outside the city the inhalation part is down to ~ 10%. These data were compared to an agricultural area in the vicinity of coal fired power plants in Poland. Here the inhalation part of the total lead intake only represents ~ 2%. Future work will be concentrated at better estimates for micro environment concentrations (indoor/outdoor), and transfer of pollutants in the different compartments.

TABLE OF CONTENTS

THE EXPOSURE OF LEAD ENTERING HUMAN BODY THROUGH INHALATION

1 INTRODUCTION

The exposure of lead in the human body might be of concern to health effects when the total intake exceeds certain limits. The relative importance of inhaled lead varies considerably from one location to another. This study was undertaken to demonstrate this fact.

When considering uptake through inhalation, it has been shown that smaller aerosols are preferentially deposited deeper in the pulmonary region of the lung, whereas larger particles tend to be deposited along the respiratory tract.

Lead may cause both acute and chronic effects, mainly in the haematopoietic, nervous, gastro-intestinal and renal systems. Initial indicator changes occur at levels of 10-60 μg/dl of lead in blood. Blood is not the ultimate receptor organ in the body, but most reports of biological effects have been correlated with lead concentrations in blood.

The exposure of lead through inhalation has been estimated using data on indoor and outdoor concentrations, indoor-outdoor relationships of respirable particles and human activity patterns. The estimated total intake of lead by the human respiratory tract was compared both to total intake from food and to the FAO/WHO permissible values.

2 DATA BASE

2.1 Area of study

The city of Oslo is situated in a basin, at the end of the Oslo fjord. Within a radius of 6-12 km from the city center, the area is shielded by hills of heights 200-500 m a.s.l. The valleys with outlets into the Oslo basin are short (15-20 km). The climate in Oslo is more continental than maritime. The total population in the study area is about 450 000.

The most important sources of lead are assumed to be: traffic, oil combustion for heating, industry and refuse incineration. The traffic load in Oslo is about 211300 car-km/hour. In this area, fuel oil accounts for approximately 60 per cent of energy consumption for heating.

The human exposure of lead through inhalation in Oslo has been compared to the exposure of lead in an area influenced by other types of sources. Estimates for the TUR area in Poland, dominated by coal fired power plants and smelters, are presented in Appendix A.

2.2 Measurements and sampling sites

Exposure estimates were based upon lead concentrations measured at six stations. Locations and descriptions of the sampling sites are given in Table 1. (1).

Table 1: Location and description of sampling sites.

Location	Description of location	Population density 100 persons/ km^2 *1	Workplace density 100 work-place/km^2 *2	Traffic density 10 car-km/ km^2•hour
Heim-dalsgt.	Industrial/ offices	100	45	291
Mari-boes gt.	Light indu-stry/resi-dental	139	36	190
Stor-torget	Commercial/ offices	91	77	421
Økern	Industrial	30	84	196
Malmøya	Residental	5	1	144
Huseby	Residental/ schools	21	2	92

*1 data from 31.12.1976
*2 data during 1974-1978.

3 METHODOLOGY

3.1 The compartment model

A simple quasi-stationary compartment model for Pb transfer from air to man was used (2). For each of the transfer routes a single pathway was calculated. This concept treats each possible pathway as a series of compartments and equilibria are assumed to exist between successive compartments, except between the next-to-last compartment and man. The last step in this pathway usually depends upon dietary intake.

3.2 The micro environment concept

The "Micro environments" are defined from human activity patterns, and/or as areas of expected different pollution exposure (estimated from air quality models) (3). An example of activity pattern classification is given in Table 2 (5).

The exposure is estimated from the joint occurrence of two events: 1) concentration of the pollutants estimated for the different compartments in specified "micro environments".
2) the probability for people being present in the different micro environments.

Table 2: Main activity classification.

Classification I	Classification II	Classification III
1. Home	Housework	Food preparation, setting of table, serving. House cleaning, dish washing, Washing and ironing, mending of clothes, heating, wood chopping.
	Work with children	Childcare and help to children. Help with school work. Other work with children.
	Personal care/sleep	Bedrest in connection to illness. Personal hygiene and dressing. Night sleep. Other rest or sleep.
	Meals	Meals. Other refreshments.
	Education	Full-time instruction. Part-time instruction. Hovework and study in connection to instruction.
	Leisure	Socializing. Rádio and television. Reading.
2. Store/restaurant	Purchase of good and services	Purchase of grocery goods. Purchase of clothes, shoes. Purchase of durable goods. Medical treatment. Visit to public offices and institutions.
	Entertainment	Restaurant or cafe visit. Sports events (spectator). Cinema Theatre, concert, opera. Museum, art exhibition. Other entertainment. Other leisure.
3. Work	Income producing work	Ordinary work in main occupation. Overtime in main occupation. Work in secondary occupation. Meals at the work place.
4. Other	Other	Other, unspecified
5. Sidewalk	Sidewalk	Sidewalk
6. Park, open area	Sport and outdoor recreation	Competitive sport. Skiing Swimming. Walking, hiking in the woods. Boat trips, other trips
	Socializing	Play with children. Holidays.
7. Work	Producing work. Maintenance	(for working outside). Care of garden, lot, and animals. Construction, larger remodelling. Painting. Maintenance and repari of dwelling and household equipment.
8. Transit	Journey to work Travel in connection with household work and family care.	Journey to work. Travel in connection with o household work and family care.
	Travel in connection to leisure time activities.	Travel in connection to leisure time activities.
	Work	(for high exposure work persons)

4 INDOOR AND OUTDOOR ACTIVITY PATTERNS OF PEOPLE

The average personal exposure to air pollution (E_p) can be estimated from a simple model of the form:

$$E_p = (\sum_i c_i \cdot t_i)/\sum_i t_i \qquad (1)$$

where t_i is the time spent in activity i, and c_i is the air pollution concentration associated with that activity. If the air pollution concentraction associated with each activity was known, the exposure of any individual could be estimated directly, when the activity pattern was known. A main task is therefore to estimate as well as possible the air pollution concentrations for each activity ("micro environment").

The total amount of time spent indoors and outdoors at home, at work, and in other activities[9], together with the time spent in transit is summarized in Table 3. The activity patterns are as given in Table 2.

The presented data, were taken from the time budget survey in Oslo (4,5,6).

Table 3: Indoor and outdoor activity patterns of people living in Oslo (hours).

Activity	Population groups					
	Employed persons		Unemployed partner of household	School student	Retired persons	All persons
	In factory	at office				
INDOOR						
1. Home	14.8	14.8	21.5	20.8	20.7	18.1
2. Store/ restaurant	0.3	0.3	0.5	0.7	0.4	0.4
3. Work	5.3	5.3	0.5	0.3	0.6	3.1
4. Other	0.1	0.1	0.2	0.1	0.1	0.1
OUTDOOR						
5. Sidewalk	1.1	1.1	0.2	0.2	0.6	0.6
6. Park, open area	0.6	0.6	0.4	0.7	0.4	0.4
7. Work	0.6	0.6	0.2	0.2	0.6	0.4
8 Transit	1.2	1.2	0.6	1.0	0.6	0.9

5 INDOOR - OUTDOOR CONCENTRATIONS

The average indoor concentration of air pollution can be estimated on the basis of outside concentrations, using a simple mass balance model by Calder (7) and Alzona (8). In this model four processes are defined which determine indoor pollution mass:

(1) Penetration of outside air into the building through windows, doors, ventilators, cracks etc. The influx of pollutants is defined by the product of the volume air flow rate, the outside concentration and the fraction not removed by "filtration" as it enters.

(2) The volume air flow into the building is balanced by an equal volume air flow out of the building which purges some of the indoor pollution. This outward flux is defined by the product of the volume flow and the indoor concentration.

(3) Pollution is removed or decays inside by physical and chemical reactions such as settling, oxidation, absorption, filtering, etc. This removal is assumed to be a constant times the mass of interior pollutant.

(4) Pollution is generated inside by combustion, condensation, abrasion and resuspension.

These prosesses are all defined in terms of mean values for the entire building. The conservation of mass equation can then be written as:

$$(dQ/dt) = (1-F)qC_o - qC_i - kQ + S \qquad [2]$$

where:

Q = mass of interior contaminant (μg)
F = fraction of pollutant filtered in the entering air
q = volume of air flow into and out of the building (m^3/h)
V = interior volume of the building
t = time (h)

k = rate of decay, settling and removal (1/h)
a = ventilation rate = q/V (1/h) (air changes per hour)
S = interior generation rate ($\mu g/m^3$)
C_o = ambient outside concentration ($\mu g/m^3$)
C_i = ambient inside concentration ($\mu g/m^3$)

Dividing Equation [2] by V gives:

$$(dC_i/dt) = (1-F)qC_o - aC_i - kC_i + S/V \quad [3]$$

Integrating over the sampling period t_s gives a relationship between average indoor and outdoor concentrations:

$$[C_i(t_s) - C_i(o)]/t_s = a(1-F)\bar{C}_o - (a+k)\bar{C}_i + \bar{S}/V \quad [4]$$

where

$$\bar{C}_i = \frac{1}{t_s}\int_o^{t_s} C_i \, dt,$$ is the average indoor concentration.

$\bar{C}_o$ and $\bar{S}$ is the average outdoor concentration and the average emission rate respectively.

For fine particles Equation [4] can be reduced to:

$$\bar{C}_i = (1-F)\bar{C}_o + \bar{S}/q \quad [5]$$

The infiltration rate (1-F) is a function of direct filtration (B_1) and air conditioning (B_2) (9):

$$(1-F) = B_1 + B_2(A) \quad [6]$$

Concerning indoor emission sources:

$$\frac{\bar{S}}{q} = B_3(N_{cig}) + B_4(A \cdot N_{cig}) + B_5(A) + B_6 \quad [7]$$

where N_{cig} is the estimated number of cigarettes smoked per day and the Bs are empirical constants. For respirable particulates:

B_3 = the direct impact of smoking (the average indoor respirable particulate concentrations increase by 0.88 $\mu g/m^3$ for every cigarette smoked in the house)

B_4 = the effect of air conditioning (usually increasing due to recirculation of air)

B_6 = the influence of indoor sources other than smoking (vacuum cleaning, dusting, etc.) in homes without air conditioning

B_5 = reduction of indoor concentrations in homes with air conditioning (or forced ventilation)

The empirical constants have been determined from multiple regression analysis of measured indoor concentrations in a variety of different houses (9). The results presented in this study apply to non smokers (B_3=B_4=0). Estimated exposure of lead to non smokers living in homes with smokers show results not much different from those presented below.

The indoor production rate of lead is assumed to be proportional to the indoor production rate of TSP. The ratio is taken as the ratio of outdoor TSP to lead concentrations at a station not influenced by traffic (Malmøya). The empirical constants selected for this work was based upon literature data (8,9), verified by point measurements in the Oslo area (1). The values are presented in Table 4.

Considerable work still remains to establish these empirical values for the different type of homes in the Oslo area. The indoor production rate of lead will also be a function of the use of oil heaters, open fire places, electric machinery etc..

Table 4: Empirical constants for estimating indoor TSP and lead concentrations in the Oslo area.

Parameter	Variable	Unit	Constants in this study	
			TSP	Lead
F	Fraction filtered (B_1, B_2)	none	0.69	0.69
$B_3 = B_4$	sigarettes, air cond.	$\mu g/m^3$	0	0
B_5	air condition, ventilation	"	-2.4	-0.03
B_6	constant (activities)	"	15.	0.13

Ambient outdoor concentrations of total suspended particulate matter (TSP) and lead measured at different sampling points in the Oslo area is given in Table 5. These average concentrations are based upon measurements carried out by different NILU research groups (10,11,12). The indoor concentrations in Table 5 are estimated from equation [5] and [7] with the empirical constants as given in Table 4.

Table 5: Ambient outdoor and indoor concentrations of total suspended particulates (TSP) and lead at different sampling points in the Oslo area.

Sampling location	Concentrations ($\mu g/m^3$)			
	Ambient outdoor		Indoor concentration	
	TSP	Lead	TSP	Lead
Heimdalsgt.	126	1.63	52	0.60
Mariboesgt.	108	2.02	46	0.70
Stortorget	144	1.89	60	0.60
Økern	45	4.44	27	1.50
Malmøya	22	0.19	20	0.16
Huseby	15	0.21	17	0.17

The average indoor to outdoor concentration ratios in Table 5 are in good agreement with measurements when lead is concerned (8). For TSP the indoor concentrations might be slightly over estimated (1).

6 HUMAN EXPOSURE OF LEAD

The annual exposure of lead was estimated based upon annual average concentrations as shown in Table 5, and the activity patterns for different population groups given in Table 2. The estimates were carried out for people living both inside and outside Oslo centrum. The results of these exposure estimates are presented in Table 6.

Table 6: Annual atmospheric exposure of lead ($\mu g \cdot y \cdot m^{-3}$) in the Oslo area.

Group of people	Living outside centrum	Living inside centrum
Employed - factory	0.61[1)]	0.96
Employed - offices	0.36	0.76
Unemployed parter	0.20	0.74
School student	0.22	0.65
Retired person	0.22	0.78
The "average" person in Oslo	0.36	0.83

1) An example estimate of the annual exposure of lead to a person living at Malmøya and working in a factory at Økern is given below:

$$E(Pb)_p = \sum_i t_i \cdot [Pb]_i = \text{(work, factory, Økern)+(home, Malmøya)+(store, restaurant, Stortorget)+(sidewalk, centrum, Stortorget)+(work outside home, Malmøya)+(transit, Økern)+(play, park Malmøya)}$$

$$= (5.3 \cdot 1.5 + 14.9 \cdot 0.16 + 0.3 \cdot 0.6 + 1.1 \cdot 1.89 + 0.6 \cdot 0.16 + 1.2 \cdot 1.5 + 0.6 \cdot 0.16)/24$$

$$= \underline{0.607\ \mu g \cdot y \cdot m^{-3}}$$

Data from Table 6 were used to estimate the human exposure of lead through inhalation. For the inhalation pathway of lead to human body, the main assumptions are the air breathing rate of 8000 $m^3 y^{-1}$, particle retention in the lung of 35 per cent, the

Data from Table 6 were used to estimate the human exposure of lead through inhalation. For the inhalation pathway of lead to human body, the main assumptions are the air breathing rate of 8000 $m^3 y^{-1}$, particle retention in the lung of 35 per cent, the

absorption to blood of 50 per cent and the residence time of lead in blood of 23 days (13). The residence time was derived from the half-time estimate of 16 days (14) and the relationship

$$T_R = (T_{\frac{1}{2}}/\ln 2) \qquad [8]$$

where:

T_R is the residence time, and $T_{\frac{1}{2}}$ the half-time. Human exposure of lead through inhalation are presented in Table 7.

Table 7: Human exposure of lead through inhalation for Oslo area (in μg y dl^{-1} of blood).

Group of people	Living outside centrum	Living inside centrum
Employed - factory	1.02	1.61
Employed - offices	0.61	1.28
Unemployed partner	0.33	1.24
School student	0.37	1.09
Retired person	0.37	1.31
The "average" persons	0.60	1.40

The estimates given in Table 7 were compared to estimates of human exposure of lead through ingestion. Human exposure of lead through ingestion was estimated using data on total intake of lead from food (15,16). It was found that the total intake of lead for inhabitants living in Oslo is equal to ~85 μg Pb/day.

The human exposure of lead through ingestion was determined assuming an absorption of lead to blood from the gastro-intestinal tract of 10 per cent and a residence time of lead in blood of 23 days (13). Table 8 presents the human exposure of lead through inhalation and ingestion for the average person living in the Oslo area, (inside and outside centrum). This table also contains the exposure data estimated for an industrialized area of Poland, where a coal fired power plant might be the dominating source. The basis for these estimates is presented in Appendix A.

Table 8: Total exposure of lead (in μg y dl^{-1} of blood).

Area	Exposure group	Exposure (μg•y•dl^{-1} blood) Inhalation	Ingestion	Inhalation as a per cent of total (%)
Oslo	living and working in centrum	1.4	3.7	27.
	living outside working in centrum	0.4	3.7	14.
	living and working outside centrum	0.4	3.7	10.
TUR (Poland)	living in small villages	0.3	16.7	1.8

As can be seen from Table 8 for the Oslo area, where traffic is the most important source of pollutants, human exposure of lead through inhalation represents about 27 per cent of total exposure for people living in centrum and about 10 per cent for people living and working outside centrum. The intake of lead from Norwegian food stuff is relatively small.

The estimated blood lead exposure corresponds well with measured blood lead concentrations in Norway, and in the Oslo area in particular (16,18).

It was also found, that inhalation represented only about 2 per cent of total human exposure for people living in the small villages around the TUR power plant. The main uptake of lead in this area of coal combustion sources is through ingestion. The Polish coal contains rather high concentrations of lead.

The results presented in Table 8 are compared with the levels producing effects of lead in blood. The effects of lead in blood, such as changes in chemical constituent levels, can be associated with 10 to 60 μg of lead in 1 dl of blood (13). More significant harmful effects to the individual may occur at concentrations greater than 60 μg/dl of blood. The total exposure in the Oslo area is thus below any effect level.

7 CONCLUDING REMARKS

From these results the following remarks can be made:

1. In large cities, where traffic is one of the most important sources of atmospheric pollution, the inhalation might represent a significant pathway of lead entering the human body.

2. In the vicinity of coal fired power plants, where the deposition of lead on crops, fruits and vegetable is considerable, and where this is consumed in the area, the dietary intake is much larger than the inhalation intake.

3. Future work will have to be undertaken to verify some of the assumptions made in the estimates:

   - better indoor/outdoor relationships
   - better data on production, consumption and concentrations in diet
   - models for estimating concentrations in the different compartments

4. Some of the above mentioned future work will be carried out as part of the "basic monitoring programme" in the Sarpsborg-Fredrikstad area south east of Oslo.

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APPENDIX A

CALCULATION OF HUMAN EXPOSURE OF LEAD FOR PEOPLE LIVING AROUND A COAL-FIRED POWER PLANT IN POLAND

1 LOCATION AND DESCRIPTION OF SAMPLING SITES

Calculations were made for TUR area with a 200 MW lignite power plant. TUR is located in the south western part of Poland. The site is located close to the border of DDR and Czechoslovakia, in a rather montaineous area. The assumed consumption of coal in TUR power plant is 10^7 tons, and the plant is equipped with electrostatic precipitators on each of 4 units. Average concentration of Pb in lignite burned is 14.8 µg/g.

Calculations were made on the basis of measurements carried out from three stations by research team from Technical University of Wroclaw, Poland (17). Location and description of sampling sites are presented in Table A-1.

Table A-1: Location and description of sampling sites.

Location	Description of location	Distance from TUR power plant km
Ryb (village)	Agriculture-residential	6.0
Opo (village)	Agriculture-residential	6.2
Max (village)	Agriculture-residential	3.5
Zgo (town)	Light industry-residential schools	25.0

Estimations for the location near the power plant, called "Max" in Table A-1 were made using the NILU multiple source dispersion model "Kilder". At this location the maximal concentrations of lead were estimated.

Table A-2: Indoor and outdoor activity patterns of people living in small villages near TUR power plant (in h).

Group / Location	Employed person: Work inside	Employed person: Work outside	Unemployed partner of household	School student	Preschool person	Retired person	High-exposure working person
INDOOR							
1. Home	12.3	12.3	14.9	17.9	19.1	14.7	12.5
2. Store/ restaurant	1.0	1.0	2.0	0.4	0.5	3.0	1.2
3. Work	8.0	0	2.0	0		1.5	0.5
4. Other	0.2	0.2	0.1	0.2	0.1	0.2	0.8
OUTDOOR							
5. Sidewalk	0.2	0.2	0.6	0.8	0.8	0.5	0.7
6. Park, open area	0.6	0.6	0.5	2.1	3.2	0.5	0.5
7. Work	0.6	8.6	3.2	1.5	0	3.2	0.5
8. Transit	1.1	1.1	0.7	1.1	0.3	0.4	7.3

Differences were found comparing the human activity patterns in small villages and in the city of Zgo, located 20 km from the TUR power plant. Human activity patterns in Zgo are presented in Table A.3.

Table A-3: Indoor and outdoor activity patterns of people living in the city Zgo near TUR power plant (in h).

Location	Employed person		Unemployed partner of household	School student	Preschool person	Retired person	High-Exposure working person
	Work inside	Work outside					
INDOOR							
1. Home	12.4	12.4	17.4	18.3	18.3	16.6	12.5
2. Store/ restaurant	0.8	0.8	3.0	1.2	0.8	2.8	1.2
3. Work	8.0	0	0.1	0	0	2.0	0.5
4. Other	0.3	0.3	0.1	0.2	0.2	0.1	0.8
OUTDOOR							
5. Sidewalk	0.5	0.5	1.7	1.3	1.8	1.8	0.7
6. Park, open area	0.6	0.6	0.6	2.2	0.5	0.5	0.5
7. Work	0.5	8.5	0.5	0.5	0.1	0.1	0.5
8. Transit	0.9	0.9	0.4	0.3	0.1	0.1	7.3

Table A-4: Outdoor and indoor concentrations (μg/m^3).

Location	Particles		Lead	
	Outdoor	Indoor	Outdoor	Indoor
Ryb	860.2	281.6	0.32	0.11
Opo	921.3	300.6	0.34	0.11
Max	1146.0	370.3	0.43	0.14
Zgo	318.5	113.8	0.12	0.04

Table A-5: Yearly atmospheric exposure of lead around the TUR power plant (in µg•y•m^{-3}).

Group of people	Ryb	Opo	Max	Zgo
Employed - work inside	0.12	0.13	0.16	0.04
Employed - work outside	0.19	0.20	0.25	0.07
Unemployed partner	0.14	0.15	0.19	0.05
School student	0.14	0.15	0.19	0.05
Preschool person	0.14	0.15	0.19	0.05
Retired person	0.14	0.15	0.19	0.05
High exposure working person	0.12	0.13	0.16	0.05

Table A-6: Human exposure of lead through inhalation for TUR power plant (in µg•y•dl^{-1} of blood).

Group of pepole	Ryb	Opo	Max	Zgo
Employed - work inside	0.20	0.21	0.26	0.08
Employed - work outside	0.32	0.34	0.42	0.12
Unemployed partner	0.24	0.26	0.32	0.08
School student	0.24	0.26	0.32	0.09
Preschool person	0.24	0.26	0.32	0.09
Retired person	0.24	0.25	0.32	0.08
High exposure working person	0.20	0.22	0.27	0.08

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3 STIKKORD (á maks.20 anslag) Eksponering	Bly	Inne/ute-konsentr.
REFERAT (maks. 300 anslag, 5-10 linjer)		
TITLE		

ABSTRACT (max. 300 characters, 5-10 lines)

The human exposure of lead was estimated from inhalation and ingestion. Indoor/outdoor concentrations, human activity patterns, concentrations in different compartments and the consumption of food made it possible to estimate the inhalation and dietary intake of lead. In cities, where traffic is an important source to lead concentrations, the inhalation part of the total intake might represent a significant pathway of lead entering the human body. For people living and working in Oslo-centrum the inhalation part might be up to 30%.

**Kategorier: Åpen - kan bestilles fra NILU A
Må bestilles gjennom oppdragsgiver B
Kan ikke utleveres C