„BABEŞ-BOLYAI" UNIVERSITY CLUJ-NAPOCA

FACULTY OF ENVIRONMENTAL SCIENCE AND ENGINEERING

INTEGRATED EXPOSURE ASSESSMENT MODEL FOR LEAD AND ASSOCIATED RISKS IN CAR BATTERY INDUSTRY

- PhD THESIS -

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Content

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Introduction – the concept of “health and safety at the workplace”

Safety, according to the Romanian Explanatory Dictionary, means being sheltered from danger; protection or defence, whereas **health** stands for the state of an organism, in which each organ functions properly under normal and regulated conditions. By applying these two terms to an operational system, the concept of “**health and safety at the workplace**” was developed.

Creating **a healthy and safe environment** became mandatory with the economical, social and moral development, and the necessity of this became more significant according to the civilization level, the respect of each country for the fundamental human rights.

The International Labour Organisation during the 91st Session of the International Labour Conference in 2003 adopted the global strategy regarding the occupational health and safety with the following motto: “*A decent workplace must be a safe workplace*”. To achieve this goal, the engagement at all levels (international, national, local, but also at the companies’ level) is considered a priority. This engagement regards all social partners in both initializing and sustaining the mechanisms improving the national work health and safety systems. The main pillar of the global strategy is building and maintaining, at the level of each country, a proper national culture regarding the occupational health and safety (US EPA, 1994).

The general objective of work health and safety is eliminating all professional accidents and diseases by implementing the concept of prevention, but also the decrease of the consequences in cases of professional accidents and/or diseases.

1. Documentary study

The first chapter of the PhD thesis is structured in 6 subsections and consists of a documentary study, as well as a revision of the speciality literature regarding the aspects focusing on: sources and intake routes for lead exposure, especially professional exposure, kinetics and absorbtion of lead in the human body, measuring lead concentrations in biological environments and the effects that occupational lead exposure has on the human health.

The presence of lead in the environment is due, mainly, to human activities, mining, smelting, refining and recycling of lead. Unlike other metals, lead has no physiological role in the human organism, so there is no minimal level which can be considered as nontoxic (WHO, 2010). Among adults, the lead exposure takes place mainly in the occupational environment.

Part of the lead found in the human body due to inhalation or ingestion is absorbed and distributed in different parts of the organism, from where it can be eliminated only in certain conditions and in certain quantities. Throughout a lifetime, the lead in the organism (regardless of the intake route) is circulated between the bloodstream and bones and between the blood and soft tissues. These transfers are influenced by the duration and intensity of the exposure, age and various physiological characteristics (US EPA 2006, 2013).

The main lead exposure biomarkers are measuring the total levels of lead in tissues or body fluids such as blood, bone, urine or hair; or by measuring the biological responses to lead exposure. Among these, blood lead level (BLL) is the most frequently used – on a large scale – and considered to be the most trustworthy biomarker intented for general clinical use and monitoring of public health (Sanders et al., 2009).

There is sufficient information to prove that the occupational lead exposure (blood lead levels above 20 μg/dl) affects the nervous, cardiovascular, renal, reproductive and immune systems, and causes hematological effects as well.

2. Framework of the issue and the objectives of the project

Despite the fact that, apparently, many of the aspects linked to the professional exposure to lead in secondary smelters are well known, there are still many unexplored facts revealed by the integrated exposure assessment.

In the context of a continuously developing industry at international level, lead exposure remains a high priority, on the one hand, due to the growing number of exposed people, and on the other hand, due to the necessity of identifying new corelations between exposure and effects. This would give us a better understanding of the processes taking place inside the human body, the consequences on the health status, and at the same time, allowing us the possibility to identify new measurable indicators, useful both in the risk management process, and in the more accurate characterization of human exposure, associate risks and the result quantification by implementing exposure control strategies.

In this context, we formulated the hypothesis stating that employees' exposure at the workplace in an automotive battery plant is associated with important adverse effects, as a multimedia effect and various intake routes. This requires the implemention of new intervention strategies and the introduction of new indicators to evaluate the process of intervention and its progress.

In addition, any proposal regarding the use of new measurable indicators, which can provide the basis for the new intervention programme and initialization of the new reglementations, must rely on solid scientific basis.

In order to respond to these topical scientific requirements, we set up the following major objectives regarding the lead occupational exposure in the automotive battery industry:

- Closer research of specific issues related to the exposure assessment;
- Characterisation of dose-response relationship;
- Identifying new adverse effects, in order to support/highlight existing theories;
- Developing an intervention programme to reduce exposure and implicitly to eliminate associated risks – new approaches in lead exposure control for the employees in the automotive battery industry.

The study model took into consideration large population groups (selected by their activity type) with variable exposure – at group levels, as well as between groups –, with large individual variations (age, seniority at work, different habits - smoking), and different health indicators (effects).

3. Description of the human exposure sources to anorganic lead in the automotive battery manufacturing plant

3.1. Technological flow and the placement of the main exposure sources

The technological process consists of a series of steps taking place in diferent work departments. The main activities include: supplying the raw material, preparation of the lead oxide, alloying of the lead, melting and casting the lead on the grids, obtaining the plates by pasting, producing the carcasses, welding of the plates, battery assembly, adding of the electrolites, forming, labelling, packaging, storage, delivery.

In most departments from the production area lead is the main raw material used, therefore also the main pollutant at the afferent workplaces. Sulphuric acid is used only in workshops profiled on forming of automotive batteries.

3.4. Description of the characteristics of the exposed population group (employees)

The evaluation study focusing on the lead exposure in the automotive battery manufacturing plant lasted 6 years.

Each year, the study included a number of aproximately 250 workers, resulting a total of 1484 examined persons, out of which 1389 work in the production areas of the plant. The great majority of the workers included in the study consisted of men, women representing only 4,51 % of the total number of examined subjects.

Occupational lead exposure is influenced by a series of factors such as the workers' age and sex, being a known fact that youth has a greater susceptibility to lead exposure. Whereas in the case of young employees this high susceptibility may be caused by the metabolic and detoxification particularities of the body, in the case of elderly workers the roll of cumulative exposure is well known (Bardac, 2003). Another category of workers with high risk to illnesses caused by professional lead exposure is represented by women, although their number in the production areas is quite low.

4. Estimation of exposure through ingestion and inhalation using measurments of lead levels at the workplaces

4.1. Characterisation of workplaces air quality through fixed point measurements

The first step in estimating the occupational inorganic lead exposure in the automotive battery manufacturing plant was to determine the hotspots with the highest risks to lead exposure by air quality characterisation via fixed point measurements.

4.1.1. Material and method

In 2009, 39 determinations of inhalable particulates and lead in the air at the workplaces were conducted. The air samples were collected throughout the technological flow near the operator workplace or from areas they are frequently passing by.

Samples were collected from fixed points and the collection time was of 15 minutes (23 samples) and of 8 hours (16 samples), periods for which benchmark values are taken into consideration, defined by the nature of the technological processes taking place in that specific point.

4.1.2. Methodology for inhalable particulates determination in the workplace wir (NIOSH 0500)

The method for inhalable particulates measurement in the workplace atmosphere consists in the suction of a certain air volume through PVC filters and the weighing the pollutants deposited on it.

4.1.3. Methodology for lead determination in the workplace atmosphere (NIOSH 7702)

The amount of lead in the workplace air was measured using a method based on X-ray fluoresence spectrometry with a NITON XL 700 U 3362 series analyzer, implying two types of sources: Cd 109 with serial number 6424LY and Am 241 with serial number 1336CW.

4.1.4. Results and discussions

Figure 9 resumes the mean lead concentrations measured in the air at the workplaces from the two departments, Department I and Department II. As the graphic below confirms, all of the average lead concentrations values in the workplace air – using both the the long-term, and the short-term samples – from both departmens were much higher than the occupational exposure limit (0.05 mg/m^3, respectively 0.10 mg/m^3). The mean lead level in the air in Department I is avowedly higher than the one determined for Department II, both in the case of the short-term samples (0.31 mg/m^3 compared to 0.24 mg/m^3), and the long-term samples (4.98 mg/m^3 compared to 2.4 mg/m^3).

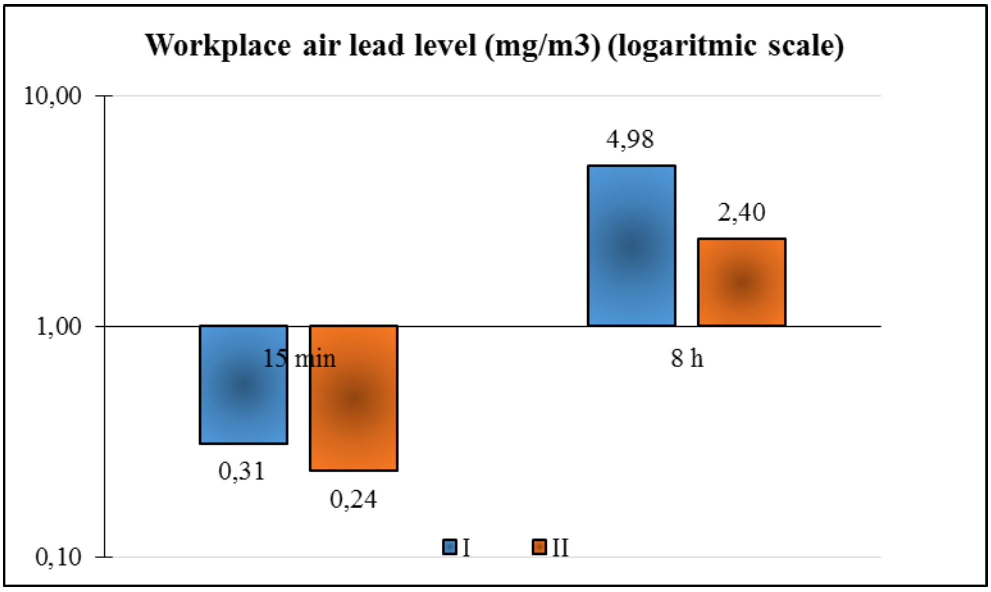


Figure 9. *Mean lead concentrations measured in the atmosphere at the workplaces from Department I and Department II (2009)*

For almost all evaluated workplaces, the average concentration of lead was higher than the occupational exposure limit (0.1 mg/m^3).

The fixed point measurements are intended to provide general information on air quality (presence of occupational hazards). These values don't reflect the actual workers' exposure, because fixed point sampling is performed in a fixed area, adjacent to the source of pollution, without recording the eventual variations of the employees' positions.

4.2. Estimation of lead exposure through inhalation by personal monitoring of workers

4.2.1. Materials and method

In 2010, 12 measurments regarding the lead levels in the workplaces air were performed by personal monitoring. This method presumes that the worker will wear an assembly consisting of a sampling pump and an MCE filter used for metal determinations.

4.2.2. Results and discussions

The data from figure 13 shows that 4 workplaces where lead measurements were taken ranked with exceeding value limits of professional exposure.

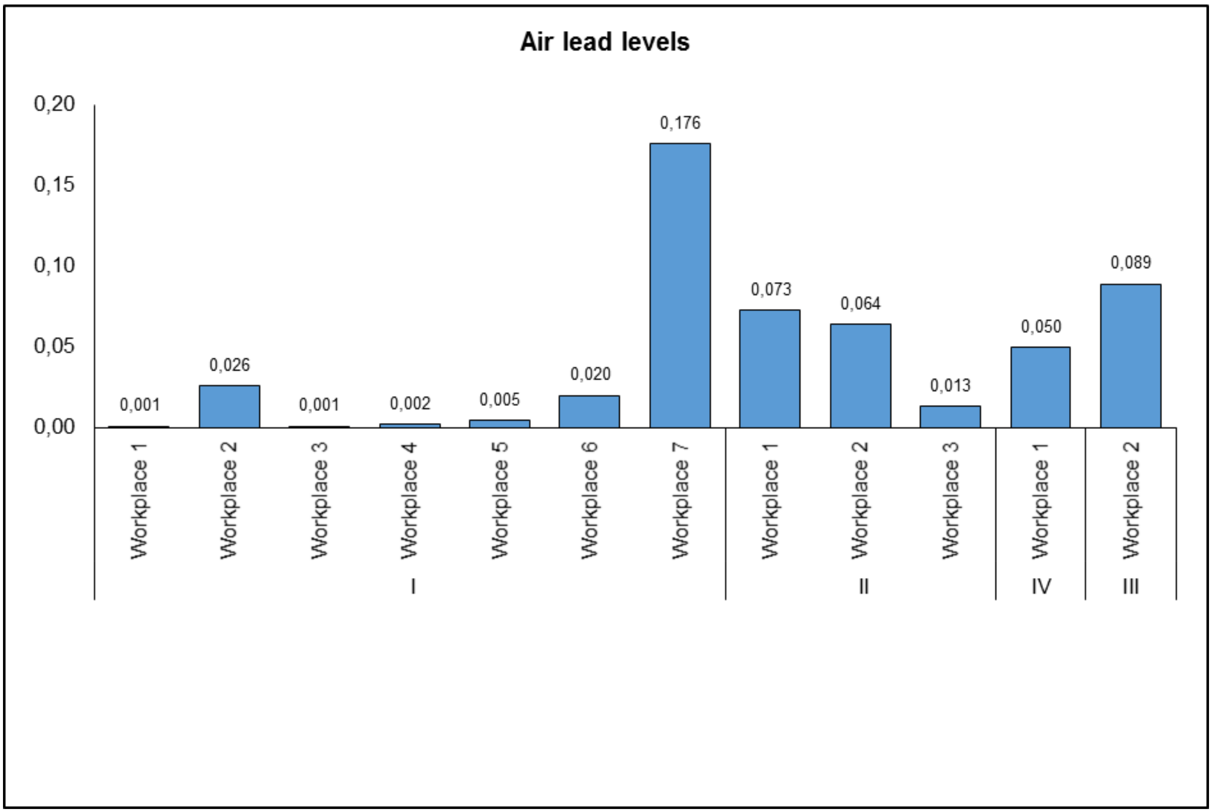


Figure 13. *Lead concentrations found in the workplace air by workers personal monitoring*

Air lead concentrations measured by workers personal monitoring are clearly lower than those sampled in a fixed point, due to the fact that while the first one describes the real exposure of the worker thoughout a shift, the latest describes air quality in the given area where the sampling equipment was placed.

4.3. Estimating the level of exposure due to ingestion – hand-to-mouth mechanism

The main intake routes of lead in industrial conditions are through inhalation and ingestion. Dirty hands of the workers represent one of the most important sources of lead exposure, especially in poor hygienic conditions at the workplace.

4.3.1. Materials and method

The estimation of the exposure through ingestion due to hand-to-mouth mechanism was achieved by analysing 30 samples collected from the hands of the workers from different production departments of the automotive battery manufacturing plant. The 30 samples collected describe 15 workplaces, as they were gathered from two operators from the same workstation, but from different shifts.

4.3.2. Methodology for lead concentrations determination on the workers' hands (US EPA, 2009)

The method principle is using dust wipes for wiping the area meant to be tested, which are analysed through X-ray fluoresence spectrometry.

4.3.3. Results and Discussions

Lead concentrations found on the worker's hands ranged depending on the job tasks, between the minimal value of 45.4 μg/sample and the maximal value of 2,643.2 μg/sample.

It was observed that the contamination level varied on the operator's hands at the same workstation but in different shifts. In most cases, lead levels measured during the first shift were categorically higher than those sampled during the second shift.

Worker's hand lead levels seem to have a wide range. This heterogenity is due to a variety of factors such as compliance with work health and safety standards, personal hygiene at the workplace and wearing of the personal protection equipment.

4.4. Lead levels from the surfaces in locker rooms and lunchrooms

An important aspect in assessing of the occupational inorganic lead exposure in the automotive battery manufacturing plant is the contamination level in the locker rooms and in the lunchrooms.

4.4.1. Materials and method

Each department of the plant is provided with a lunchroom – where workers can serve their daily snacks – and a locker room – where they can change into and out of their working clothes. A series of measurements were conducted to check whether these areas are contaminated with lead.

The locker rooms and the lunchrooms were investigated in two successive days as follows: in the locker rooms sampling was performed from the workers cabinet in three different daytimes: morning, between shifts and evening; in the lunchrooms sampling was performed from the tables in two consecutive times: twice a day (both for the first and the second shift) and after the snack break. For both cabinets and tables, a 30x30 cm square template was used in order to mark the sampling area. Sampling in two successive days was performed in order to evaluate the difference between the efficiency of a regular cleaning procedure and a cleaning procedure that we recommended for this area.

4.4.2. Results and discussions

Lead concentrations in the adjoining workplace areas presented high variations, but overall, both for the locker rooms and the lunchrooms, the average values were higher in the first day compared to the second day. Average values of lead measured from the cabinets in the locker rooms ranged from 0.256 $\mu g/cm^2$ to 0.611 $\mu g/cm^2$ in the first day of the measurements. Regarding the lunchrooms, the highest lead concentration from the tables was at the workplaces where process are generating important amount of dust because of the technological wear (0.79 $\mu g/cm^2$) in the first day of measurements. After the recommended cleaning procedure was applied, the lead concentration in the same place had a more than twice lower value (0.33 $\mu g/cm^2$). Lead concentrations from workers' hands were associated with lead levels from the surfaces in the locker rooms, the last being an important cause for the increased blood lead level, especially in poor personal hygiene or in the case when the workers were smokers.

4.5. Questionnaire-based study of workers exposure level and health status

The occupational lead exposure assessment in the automotive battery factory is highly influenced by the attitude, behaviour and habits of each worker at their workplace. In order to identify these risk factors a questionnaire was applied. This survey meant to evaluate the exposure level and was completed by a number of 188 workers in the production departments.

The survey revealed that the workers from the production departments have cyclical activities and their work requires intense physical effort. Even though personal protective equipment is provided to each of them, only a small number of workers wear them correctly, while the others complain about their inconvinience. The ventilation system in the factory works continuously, yet the employees complain about unventilated spaces, the existence of dust and smokes in the air, as well as about air currents. Although all the conditions are ensured, all employees were properly instructed and are aware of its importance, not all subjects obey the rules of personal hygiene at the workplace. Likewise, even if smoking is prohibited in the area of the plant, a percentage of nearly 4 % of the employees smoke. The most commonly diagnosed disorder is anemia, which may be due to lead poisoning, but may also have a multifactorial causation (for example nutritional deficiencies).

5. Lead exposure assessment through direct indicators

In this study, two lead biomarkers were monitorised: blood lead level (exposure biomarker) and urinary delta-aminolevulinic acid (effect biomarker).

5.1. Measurement of lead in the blood by Graphite Furnace Atomic Absorption Spectroscopy (GF-AAS)

5.1.1. Materials and Method

Over the course of six years blood lead levels measurements were performed for all company employees in the productive departments.

5.1.2. Methodology for blood lead level analysis (CDC, 1994)

The principle of the method relies on measuring the metal ion quantity of the sample through atomic absorbtion spectrometry.

5.1.3. Results and Discussions

The evolution of mean, median and frequency of blood lead levels exceeding the biological limit value for the employees who worked in the production area of the automotive battery plant is relatively similar in the studied time frame.

Exposure time is a very important aspect of the lead exposure analysis and it is quantified by the seniority of the examined plant workers.

Both in case of the exposed workers, but also in case of the employees without direct exposure to lead, the mean values of blood lead levels measured are lower for those with less than a year of working experience in the plant, than for those with greater working experience (Figure 26).

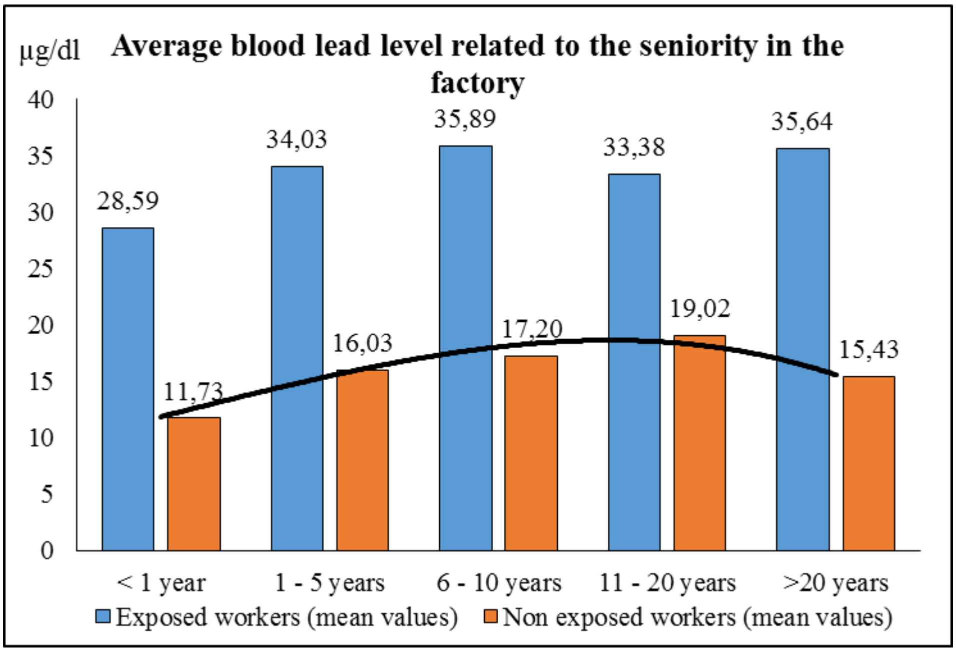


Figure 26. *Average blood lead levels associated with seniority in the factory*

By applying Student's t-test was emphasized the fact that there is statistical significance in the case of each seniority category between the mean blood lead level of workers exposed and those not directly exposed. Regarding the frequences of BLL values exceeding the biological limit, there are significant differences between workers exposed to lead and those without direct contamination among the participants of seniority groups of 1-5 years ($p = 0.001$), 6-10 years ($p = 0.049$), 11 – 20 years ($p = 0.007$) and over 20 years (0.0001).

Another aspect with great relevance of the lead exposure assessment is the exposure frequency. In the case of the automotive battery manufacturing plant employees, this can be evaluated by the number of attendances at the workplaces in the production area. Thereby, the lowest values of blood lead levels throughout the studied years were recorded in the departments without direct exposure to lead (occasional exposure), followed by the production departments.

The exposure intensity, another important factor in the assessment, can be quantified by the workplace air lead levels measured in the automotive battery manufacturing plant.

Depending on the lead concentrations determined in the workplace air, analysing short-term samples (15 minutes), the monitored workers in 2009 were split into 7 categories with exposure levels varying: lower than 0.01 mg/m^3, between 0.01 mg/m^3 and 0.1 mg/m^3, between 0.11 mg/m^3 and 0.2 mg/m^3, between 0.21 mg/m^3 and 0.3 mg/m^3, between 0.31 mg/m^3 and 0.5 mg/m^3, between 0.51 mg/m^3 and 0.8 mg/m^3 and higher than 0.8 mg/m^3. For each group of workers the mean blood lead level and the correlation between blood lead level and air lead concentration were calculated.

The correlation coefficients (R^2 = 0.41, respectively R^2 = 0.34) suggested a weak correlation between average blood lead levels and the workplace air lead level, as well as between the frequencies of blood lead level above 40 µg/dl values and lead concentrations in the air (figure 34).

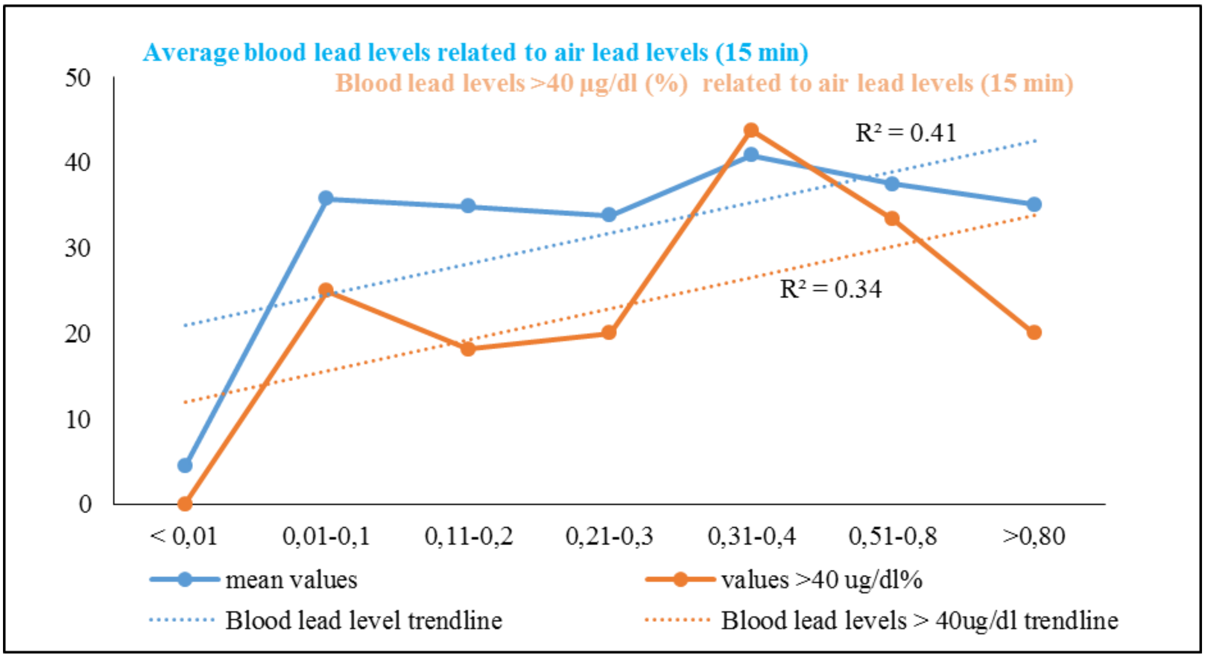


Figure 34. *Correlations between mean blood lead levels and the frequency of values above the biological limit depending on lead levels measured in the workplace air (short-term sampling of 15 min) in 2009*

Both the mean value of blood lead level and the frequency of blood lead concentration values exceeding the biological limit are higher for workplaces were air lead levels was greater than 0.1 mg/m^3.

Inside the automotive battery manufacturing plant smoking is prohibited, however some of the workers stated that they smoked at their workplace. Both for 2009 and 2010 there is a strong association (R^2 = 0.99 in 2009 and R^2 = 0.94 in 2010) between mean blood lead levels and the smoking habit, respectively of smoking at the workplace.

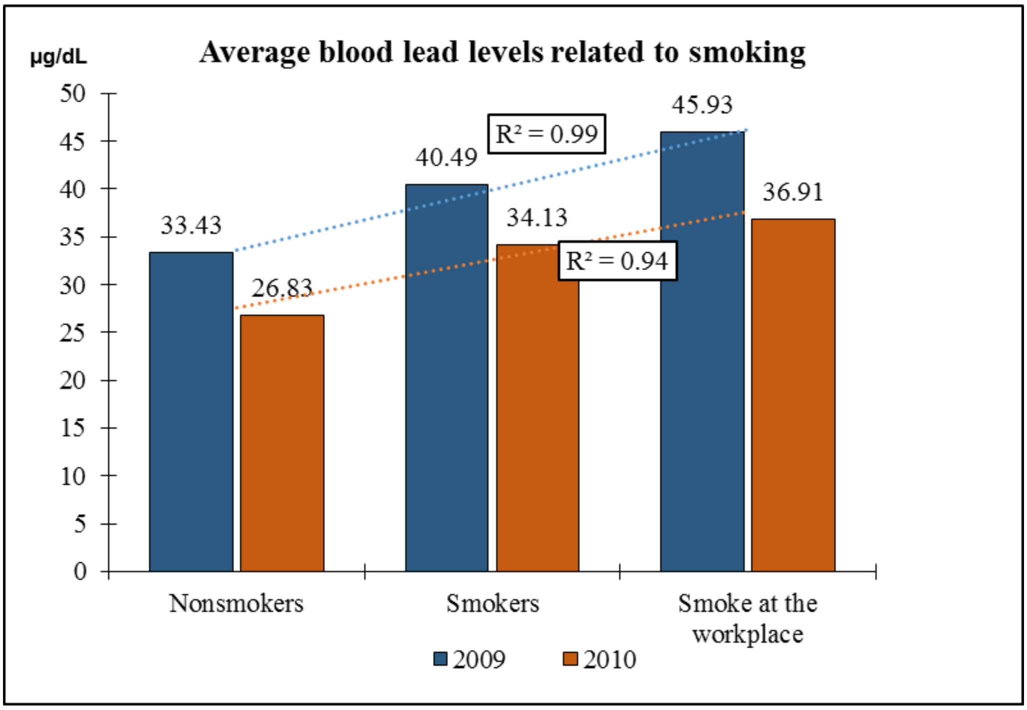


Figure 38. *The relation between average blood lead levels and the smoking habit (2009-2010)*

5.2. Measurement of urinary delta-aminolevulinic acid

Delta-aminolevulinic acid (ΔALA) is an effect biomarker for lead exposure, therefore its determination is crucial in the population study group exposure to lead assessment.

5.2.1. Methodology for measuring delta-aminolevulinic acid in urine samples

The method relies on the condensation reaction of the delta-aminolevulinic acid with acetylacetone. The reaction results in a pyrrole ring with a type CH_2 reactive group. The newly formed pyrrole ring's reaction with para-dimethylaminobenzaldehyde (modified Ehrlich reagent) is accompanied by color change, resulting in a red-colored complex with a maximal absorption at 553 nm.

5.2.2. Results and Discussions

Figure 40 shows the variations of mean, median and frequency of delta-aminolevulinic acid levels exceeding the biological limit (10 mg/l) throughout the three monitored years. There is a clear similarity between the evolutions of the three parameters, characterized by a decrease in values in 2010, but a slight increase in 2011.

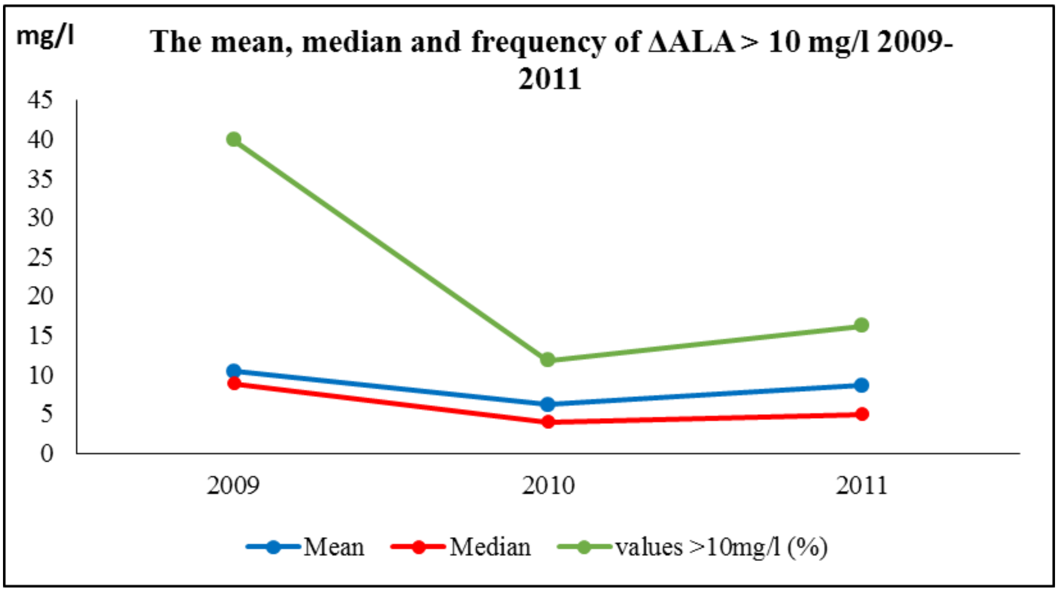


Figure 40. *Mean, median and frequency of delta-aminolevulinic acid levels exceeding the biological limit (2009-2011)*

Mean levels of delta-aminolevulinic acid do not vary in a very broad range, but they are depending on the workers' seniority in the plant. Both in the case of exposed workers and the ones unexposed directly to lead, ΔALA values increase slightly for the group with 1-5 years seniority compared to the group with under 1 year experience. For the following seniority groups the values decrease, the mean value specific for the >20 years group having similar values with the one from the first category (figure 41)

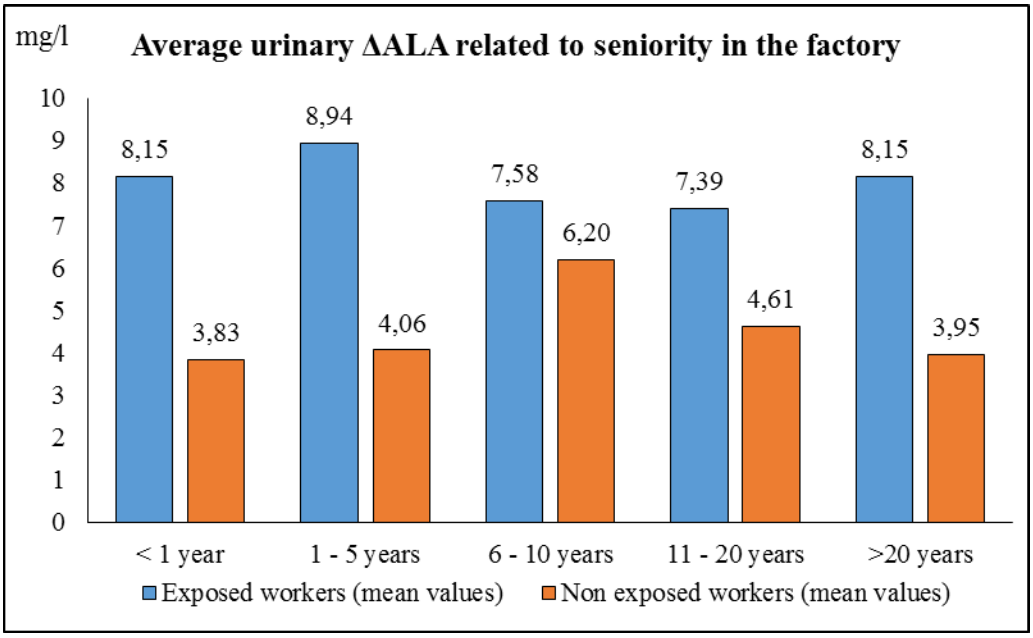


Figure 41. *Mean urinary delta-aminolevulinic acid related to seniority in the plant (2009-2011)*

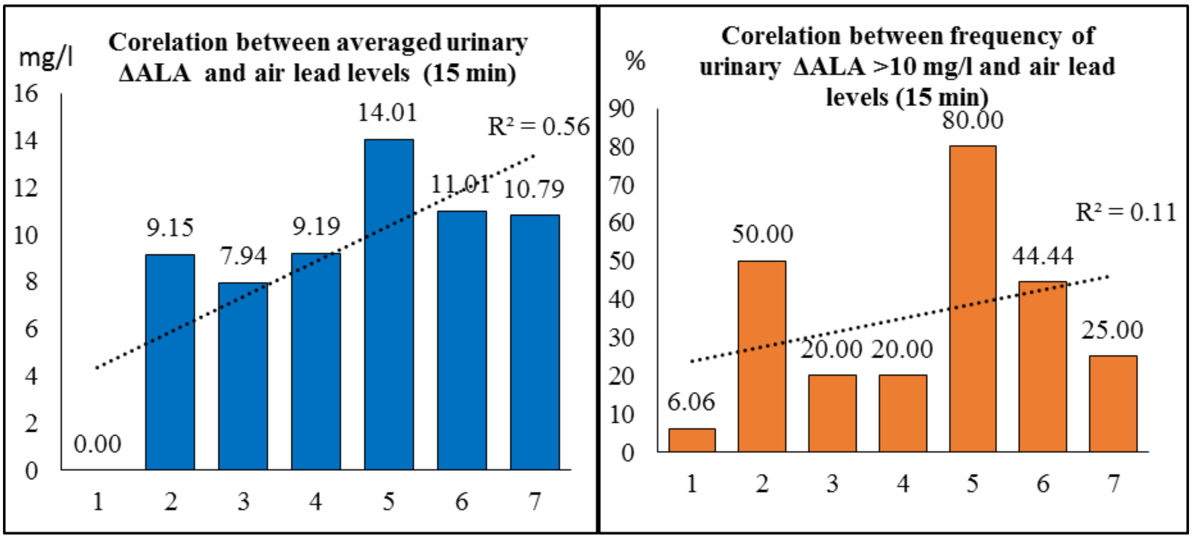
Similar to blood lead level, the delta-aminolevulinic acid is an indicator for human exposure to lead. This way, when ΔALA values exceed the biological limit of 10 mg/l, the possibility to develop a professional disease increases. Association between exposure to lead and the possibilty to develop a professional illness (ΔALA > 10 mg/l) was determinated using risk indicators.

For each seniority category at the workplace, the relative risk (RR) is higher than 1, which means that an association between exposure to lead and the risk to develop a professional illness exists at ΔALA higher than 10 mg/l. Odd ratio (OR) has the same tendencies like the relative risk, whereas the attributable risk shows that workers with under 1 year seniority in the automotive battery manufacturing plant risk to have a level of ΔALA higher than 10 mg/l is 77.42 %, while for the group of above 20 years seniority, this probability is as high as 98.84 % (table 18).

Table 18. *Risk of developing a professional disease depending on the exposure duration*

	< 1 year	**1 - 5 years**	**6 - 10 years**	**11 - 20 years**	**>20 years**
RR	4,43	24,49	5,59	33,15	86,03
OR	5,00	29,42	6,32	38,82	105,04
RA %	77,42	95,92	82,11	96,98	98,84

The correlation index between mean ΔALA values and certain workplace air lead concentrations highlights a strong association (R^2 = 0.56), however between the frequencies of ΔALA > 10 mg/l and airborne lead the association is weak (R^2 = 0.11), as seen in figure 48.



a **b**

Figure 48. *Correlation between the mean urinary ΔALA values and concentration levels of airborne lead at the adjoining workplace (15 min) in 2009 (a) and the correlation between the frequency of ΔALA levels exceeding 10 mg/l and air lead (15 min) (b)*

For 2009 there is a strong association (R^2 = 0.93) between the mean ΔALA values and the smoking habbit and smoking at the workplace. For 2010 this relation is less proeminent (R^2 = 0.19) (figure 51).

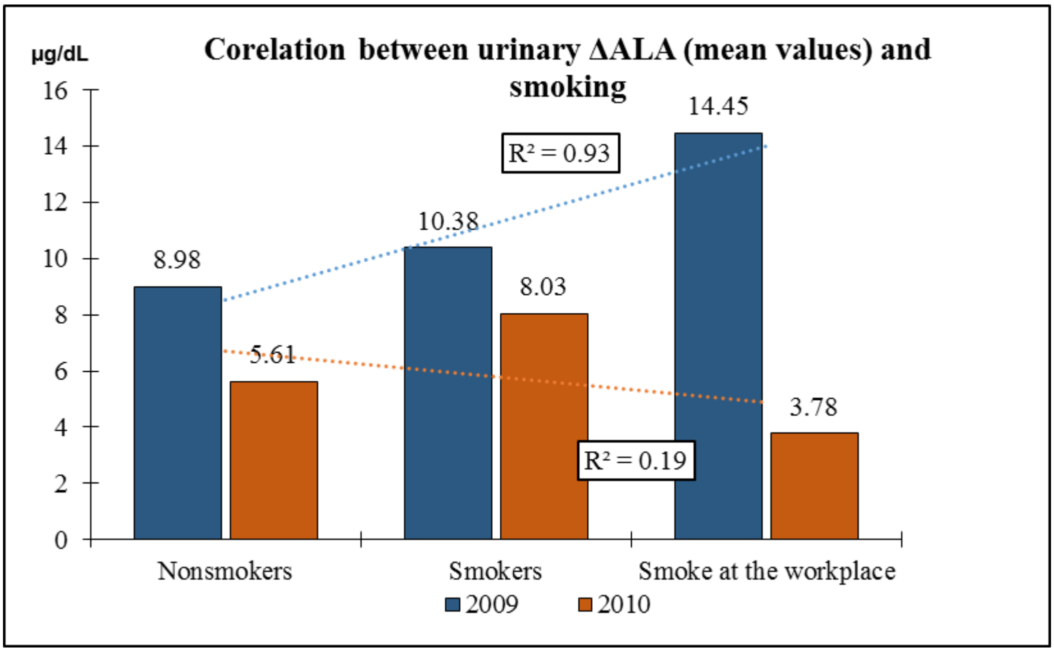


Figure 51. *Correlation between mean urinary ΔALA and smoking at work for 2009-2010*

5.3. The relationship between blood lead levels and delta-aminolevulinic acid

Checking the evolution of the averages of the two biomarkers throughout the 2009-2011, figure 52 demonstrates that the tendency for both parameters is negative for 2009 and 2010 followed by a slight increase, meaning that the evolution of the two biomarkers is identical.

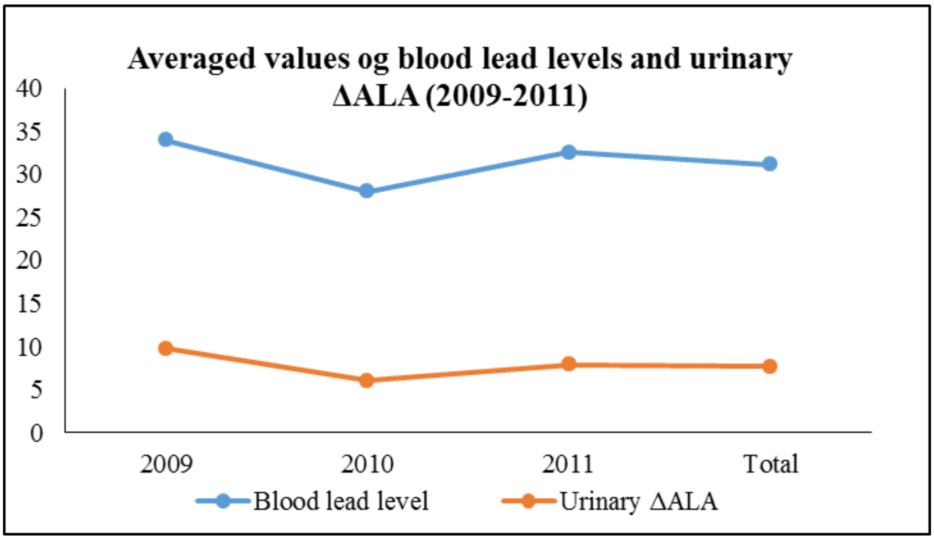


***Figure 52**. Mean blood lead levels and urinary ΔALA in 2009-2011*

Average values of urinary delta-aminolevulinic acid are increasing proportionally with blood lead level values, in each year of the monitored period (figure 53).

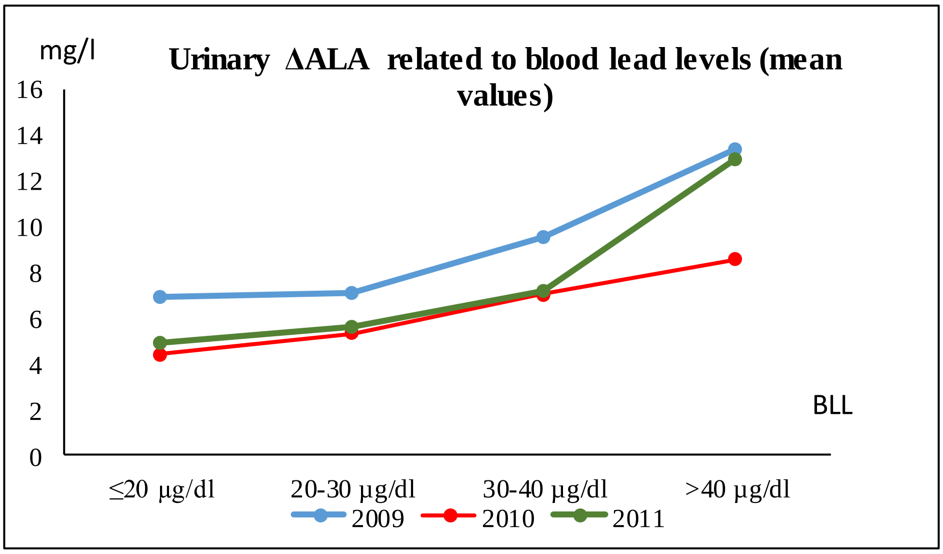


***Figure 53.** Urinary delta-aminolevulinic acid in corelation with blood lead levels in 2009-2011*

6. Effects analysis on the workers' health status in the automotive battery manufacturing plant – hematology tests

6.1. Materials and methods

During 2009-2011 time frame, the lead exposure and its effects on workers' health assessment in the automotive battery manufacturing company, included blood screening (hematological analysis) as well.

The complete blood count contains information regarding:

- The number of red blood cells - erythrocytes;
- The number of white blood cells - leukocytes;
- The total amount of hemoglobin in the blood;
- The hematocrit;
- The average globular hemoglobin;
- The average concentration of hemoglobin;
- Platelets count.

6.2. Analysis methodology

Blood sampling was performed in 2 ml EDTA venoject tubes in accordance with current protocol. The samples were kept in a refrigerator (+ 4 °C) until the following day, when they were analyzed with an automatic electronic measuring instrument (Abacus Plus Hematology Analizer).

Haematological values were interpreted in conformity with the reference values of the laboratory and given in the "Ioana Brudașcă, Anca Cristea - Ghid de laborator, 2005, Editura Medicală Universitară "Iuliu Hațieganu" Laboratory Guide.

6.3. Results and Discussions

For three years (2009, 2010, 2011) both lead exposed and unexposed workers from the automotive battery plant were examined for complete haematological analyses. From a total of 682 examined workers, 495 were monitorized each year during the study period, 140 in two years, while 47 were analysed only once, due to different reasons, mainly regarding the attendance at work.

6.3.1. Haematologic parameters depending on professional lead exposure

The average blood count values and their rate of influenceability by different environments with peculiar exposure levels determined during 2009-2011 are shown in table

22. The calculations were performed separately for workers without direct lead exposure and those exposed to lead at work.

Table 22. *The mean values of hematological parameters and statistical significance related to the exposure (men) 2009-2011*

Hematological parameters	**2009**				**2010**				**2011**			
	No direct exposure	Exposed at the workplace	**t**	**p**	No direct exposure	Exposed at the workplace	**t**	**p**	No direct exposure	Exposed at the workpla ce	**t**	**p**
Leukocytes ($x10^3/mm^3$)	7,56	8,32	**-2,24**	**0,03**	6,64	7,29	**-2,46**	**0,02**	7,40	7,69	-0,98	0,33
Erythrocytes ($x10^6/mm^3$)	5,06	5,12	-1,04	0,31	4,84	4,87	-0,53	0,60	4,92	4,95	-0,36	0,72
Hemoglobin (g/dL)	15,37	15,37	0,01	0,99	15,12	14,74	**2,11**	**0,04**	15,06	14,99	0,38	0,71
Hematocrit (%)	45,23	45,88	-1,49	0,15	46,00	45,43	0,89	0,38	42,85	42,76	0,19	0,85
Platelets ($x10^3/mm^3$)	214,45	232,70	-1,97	0,06	233,55	246,70	-1,62	0,11	241,41	244,60	-0,36	0,72

The most obvious gaps between the two groups of subjects were noticed for the leukocyte count, their mean value was higher in each year for the exposed group compared to the unexposed one. Applying the Student t-test emphasized the fact that during 2009-2010 the differences between the average white blood cell counts of the exposed and unexposed group had statistical significance ($p = 0.03$ in 2009 and $p = 0.02$ in 2010).

For each each, the average number of red blood cells was similar for the exposed group and the unexposed one.

While in 2009 the mean hemoglobin values were the same for the two groups, in 2010 and 2011 these values were significantly lower in the exposed group compared to the unexposed one. Differences between the average hemoglobin values between groups that are subject to direct exposure or not, are statistically relevant only for the workers investigated in 2010 ($p = 0.04$).

The hematocrit follows the same model as hemoglobin, but there is no statistical significance between the mean values of the two groups.

During the three years of haematological investigations, the group consisting of exposed workers showed higher average values of platelets than the unexposed workers, but again with no statistically significant difference.

6.3.2. Corelation of haematologic indicators with blood lead levels

Mean leukocyte values specific to each established blood lead level category indicates higher values of white blood cells for subjects having BLL > 40 μg/dl compared to those with BLL < 20 μg/dl in each of the investigated years.

Table 24. *Leuckocytes number related to blood lead levels in 2009 – 2011*

BLL	**Mean leuckocytes no ($x10^3/mm^3$)**			**Leuckocytes >10 $x10^3/mm^3$ (%)**		
	2009	**2010**	**2011**	**2009**	**2010**	**2011**
≤20 μg/dl	7,26	7,47	7,07	0,00	6,45	3,70
>20-30 μg/dl	8,54	6,92	7,72	19,05	3,80	9,52
>30-40 μg/dl	8,08	7,01	7,80	14,41	5,45	12,90
>40 μg/dl	8,65	7,80	7,67	19,64	6,98	9,38

This was followed by analysing the frequency of white blood cell counts exceeding the normal values for each previously established group depending on their blood lead levels (figure 62). It can be observed that the frequency of abnormal values, leukocytosis, (higher white blood cell count than 10,000/mm3) is net higher for workers with BLL > 40 μg/dl, especially in 2009 and 2010.

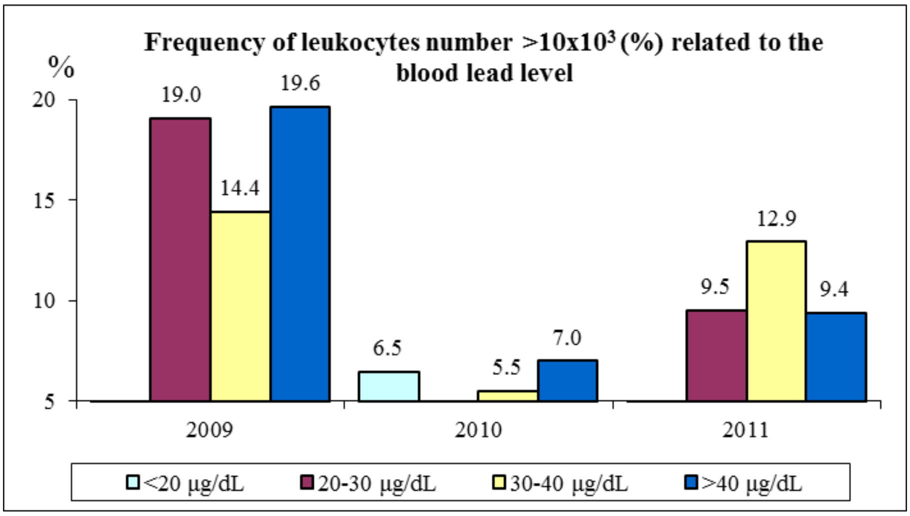


Figure 62. *Frequency of leukocytes number exceeding the normal value (10X103 %) related to the blood lead level*

7. Hazard characterisation in the occupational lead exposure through the calculation of hazard indicators for speciffic effects

The final step in the risk assessment is the risk or hazard characterization. This involves combining exposure information determined during the study with the toxicity international benchmarks well known and documented in legal acts. Concretly, risk and hazard characterization in occupational lead exposure is achieved by calculating hazard indices.

7.1. Hazard characterisation in occupational lead exposure through inhalation

7.1.1. Materials and method

Determining the hazard indices for occupational exposure to inhaled lead was made according the model set by the US Environmental Protection Agency (EPA's Superfund Program, 2009).

The hazard indices were calculated for airbourne lead level values at the workplace determined in 2010, by personal monitoring. These were determined by comparing them to the occupational exposure limit value given by the national legislation, as well as to the exposure frequency and duration specific for each monitored workplace. Calculations were made using Microsoft Office Excel.

7.1.3. Results and discussions

The hazard indices related with the workplace air lead levels presented subunitary values. As a consequence, it can be concluded that it is unlikely that workers from these workplaces to develop adverse health effects due to occupational exposure to inhaled lead.

Table 31. *Hazard indices related to air lead levels (personal monitoring 8 h) 2010*

Departments	**Workplace**	**Exposure concentration (mg/m^3)**	**Occupational exposure limit (HG 1218/2006)**	**HI**
I	Workplace 1	0,000	0,05	**0,005**
	Workplace 2	0,006	0,05	**0,12**
	Workplace 3	0,000	0,05	**0,005**
	Workplace 4	0,000	0,05	**0,01**
	Workplace 5	0,001	0,05	**0,02**
	Workplace 6	0,005	0,05	**0,09**
	Workplace 7	0,040	0,05	**0,80**
II	Workplace 1	0,017	0,05	**0,33**
	Workplace 2	0,015	0,05	**0,29**
	Workplace 3	0,003	0,05	**0,06**
III	Workplace 1	0,011	0,05	**0,23**
IV	Workplace 1	0,020	0,05	**0,41**

7.2. Hazard characterisation in occupational lead exposure by determining of the hazard indexes for the spcific effects

Numerous studies proved that negative effects on human health occure at blood lead levels below 40 μg/dl, therefore we chose to estimate the endpoint-specific hazard indices, depending on target organ toxicity dose values (TTD) due to lead exposure.

7.2.1. Materials and Method

Calculating the hazard indices for specific health effects of lead exposure was achieved by following the model presented by the Agency for Toxic Substances and Disease Registry (Agenția pentru Substanțe Toxice și Registrul Bolilor) (ATSDR, 2001)

7.2.3. Results and discussions

Blood lead level values determined in the trial period were divided in mean values based on the main workplaces in to the automotive battery manufacturing plant. Hazard indices were calculated for these average blood lead levels by taking into consideration the lead effects on health (Target Organ Toxisity Dose – TTD – on the nervous, hematologic, cardiovascular, renal and reproductive systems).

As it can be seen in Table 32, the calculated hazard indices reported to lead exposure effects on the nervous, hematologic and cardiovascular systems may vary from values of only 1.55, up to 4.27, whereas the majority is above 3. No workplace has subunitary hazard index for cardiovascular, neurologic and hematologic effects. Therefore, it can be stated that the majority of automotive battery plant workers has a great risk to develop negative effects on these internal systems due to occupational lead exposure.

Table 32. *Hazard indices calculated for mean blood lead levels related to health effects*

Departments	**Workplaces**	**BLL µg/dl (media)**	**HI (neurological, hematological, cardiovascular effects)**	**HI (renal effects)**	**HI (reproductive effects)**
I	Workplace 1	40,01	**4,00**	**1,18**	**1,00**
	Workplace 2	32,35	**3,24**	**0,95**	**0,81**
	Workplace 3	40,18	**4,02**	**1,18**	**1,00**
	Workplace 4	42,74	**4,27**	**1,26**	**1,07**
	Workplace 5	34,58	**3,46**	**1,02**	**0,86**
	Workplace 6	35,04	**3,50**	**1,03**	**0,88**
	Workplace 7	35,15	**3,52**	**1,03**	**0,88**
	Workplace 8	38,69	**3,87**	**1,14**	**0,97**
II	Workplace 1	31,02	**3,10**	**0,91**	**0,78**
	Workplace 2	36,97	**3,70**	**1,09**	**0,92**
	Workplace 3	32,44	**3,24**	**0,95**	**0,81**
III	Workplace 1	29,99	**3,00**	**0,88**	**0,75**
	Workplace 2	15,54	**1,55**	**0,46**	**0,39**
IV	Workplace 1	32,91	**3,29**	**0,97**	**0,82**
V	Workplace 1	15,93	**1,59**	**0,47**	**0,40**

Although a small percentage of the subjects from the unexposed areas did not present hemoglobin levels below the normal limit, IH = 1.59 proves that depending on the blood lead level values effects may appear.

In order to identify the most vulnerable working areas, average hazard indices for each section/industrial subanssambly were calculated. The final classification is seen in table 34, indicating that the most dangerous working area (IH = 1.92) is Department I, followed by Department II (IH = 1.72), Department IV (IH = 1.69), Department III (IH = 1.17) and administrative departments (IH = 0.82).

Table 34. *Average hazard indexes reported to the effects had on the target organs for each department in the plant*

Departments	**Mean HI related to the health effects on the target organ**
I	**1,92**
II	**1,72**
III	**1,17**
IV	**1,69**
V	**0,82**

8. The intervention program to reduce exposure and eliminate associate risks

Risks associated with occupational lead exposure in the automotive battery plant – identified and evaluated in previous chapters – require an intervention program to reduce exposure and eliminate the related risks.

8.1. Proposed control measures

The best way to protect human health against lead intoxication is *prevention of the exposure*, however in certain industries this is not a viable option, therefore designed control measures must focus on the following aspects:

1. Technical control measures
2. Administrative control measures
3. Providing workers with appropriate personal protective equipment (PPE)

Technical control measures refer to the elimination of the lead from the air or creation of a barrier between the worker and the pollutant. In the specific case of the automotive battery manufacturing plant, the following engineering control measures are indicated:

- Introducing of a new ventillation system;
- Substituing the old thechnological equipment with new, automatic and more environmental friendly ones.

Administrative control measures that can be implemented in the automotive battery plant to reduce the lead risks include: measures focusing on work practices, health measures, workers training and periodical monitoring.

The **personal protection equipment** is indispensable at workplaces, where technical and administrative measures can not give a solution to exposure reducement quantified by direct markers (blood lead level) under the limit indicated by the national legislation. The personal protection equipment against lead exposure consists of:

- Proper protective gloves in accordance with EN 374 Standard
- Air-purifying respirator in conformity with EN 143 Standard
- Chemically resistant sealed goggles as indicated in EN 943 Standard
- Overalls/work clothes according to EN 943, which can not be taken outside the unit.

9. Overall Conclusions

Occupational exposure is the main cause underlying the influence/awareness of the population health status in terms of the concept of ensuring Security and safety of citizens.

A large number of workers of an automotive battery manufacturing plant were monitored for a period of 6 years, highlighting the fact that the most exposed employee category to the main pollutant (lead) is represented by the workers in the productive areas. Among these, young, aged above 50 years and women workers seem to be the most vulnerable.

Identification of individual physical risk factors due to the variability in attitudes and behaviors at the workplace is a very important step in the process of occupational exposure assessment and risk reduction associated with it.

Exposure assessment for the monitored workplaces was performed using a complex approach regarding the establishment of individual characteristics in terms of exposure assessment, both by a number of subjective indicators such as interviews and case history (professional/health history), and markers based on observation (investigating in real time each workspace with the specific job descriptions: working equipment, specific tasks performed and determining of the exposure hotspots for each individual).

Objective/measurable markers focused on personal monitoring, assessing the conditions in the areas "outside" of the working zone (locker rooms and break rooms) and measuring lead concentrations on the workers' hands.

The complex analysis of the data indicated the tendencies regarding the possibility to establish certain "cut outs" considering the answer-dose relationship in populational groups occupationally exposed depending on age, seniority and activity type.

With the help of descriptive and analytical statistical tests, associations between exposure (working space/ exposure biomarkers) and effects (effect biomarkers) were established. Blood lead levels and delta-aminolevulinic acid through mean and median values, but also the frequencies of the values exceeding the biological limit increased with the level of seniority (statistically significant differences).

Airbourne lead concentration exceeding the occupational exposure limit value was associated with a higher exposure and effect biomarker at group level, rather than at individual level.

Extremely significant associations were deduced throughout the study: increased exposure to lead - decrease in hemoglobin synthesis - increased number of leukocytes, together with other associations characteristic to lead exposure and which are commonly described in the specialized literature.

By calculating the hazard indexes in relation with lead levels measured in the air at the workplaces, it was demonstrated that it is unlikely for a worker to develop adverse effects on his/her health due to occupational exposure through inhalation, which means that another intake source must exist, which leads to the rise of lead levels in blood.

In the present study, lead concentrations sampled from the workers' hands and in the external areas from their workspace, together with the poor hygienic and sanitary habits lead to the establishment of the main route cause of exposure – digestion.

Classification of the departments taking into consideration the risk level is driven by a combination of factors: outdated technology, large number of workers, workers' age and seniority in the factory.

Exposure control measures must be designed, structured and implemented depending on the specifics of each workstation (technology, ventillation performance, exposure level quantified by lead concentration at the workspace and blood lead levels), but must also take into consideration the individual (age, sex, education level, habits and behaviors at work (smoking and level of compliance with the personal hygiene standards).

In the present study, finding new measurable indicators, which allowed establishing new associations between the exposure and the effects on human health, brought new strong arguments regarding the intervention program and the improvement of the workers' health status in this industry branch.

The determined results must contribute to the improvement of living conditions and increasing progress, to ensure the concept of work safety and health for all employees of automotive battery manufacturing industry.

In the same time, the model applied in the study, but especially its results can be transferred to other types of activities, where exposure levels to lead, or other types of metals, is significant. This is another major requirement the study meets, namely the transferability of the newly determined knowledge and information to other types of activities and other category of metals, with new occupationally exposed populational groups, as well as initializing the use of these newly introduced markers in reglementation and control.

10. Thesis originality and innovative contributions

This paper treats occupational health and safety issues as an active component of the concept of sustainable development, on the one hand, and on the other hand as the organic part of the safety and health of citizens, through a multidisciplinary approach: chemical sampling, analitical chemistry, industrial hygiene, occupational health and bio-toxicology, sociology/psychology, statistics/biostatistics.

From a scientific point of view, the thesis covers two national and international innovative categories:

- The first category includes the introduction of new markers in exposure assessment in the case of automotive battery manufacturing plant employees. These markers are represented by personal monitoring as integrated part of the fixed point monitoring and associations between exposure biomarkers, determinations via complex analytical methods of occupational exposure through dust (at workspaces and ares adjacent to these – locker and break rooms) and lead assimilation by the human body through the hands (determining the lead concentration on the workers' hands);
- The second category consists of scientific aspects regarding the association, relationing between exposure, including exposure biomarkers, and effects, represented by certain effect and biotoxicological biomarkers. To our knowledge, the relationship between exposure and white cell line (WBC) is a new concept studied at national level, and even at international level only few records of it exist.

As another innovative ideea, the thesis identifies measures to correspond the translationality requirements by the scientifically fundamented proposal to introduce new markers in the professional exposure assessment and control for the automotive battery manufacturing industry.

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