Arh. hig. rada toksikol., **30** *(1979) suppl. pp. 1091–1097.*

A COST BENEFIT ANALYSIS OF MEDICAL AND OCCUPATIONAL HYGIENE MONITORING TECHNIQUES AVAILABLE FOR THE CONTROL OF THE HEALTH OF THE LEAD WORKER

J. F. TAYLOR and R. I. HIGGINS
Chloride Industrial Batteries Ltd. and Chloride Group Limited, Manchester, United Kingdom

ABSTRACT

During recent years there has been increasing debate on the relative merits, including ethical acceptability, of the biological and environmental tests which are available for the control of the health of the lead worker. A needless and, possibly, counter-productive polarisation of opinion has occurred because of an inadequate appreciation of:

- the purpose of occupational health control programmes in industries and occupations where the occupational health risks are already well understood and operationally controlled
- the reliability of biological and environmental tests as indicators or predictors of the health status of the individual lead worker
- the cost, in terms of time, money, effort and skilled personnel necessary to carry out each type of test to obtain measurements of equal health benefit to the individual worker.

The potential value of haemoglobin, blood lead, zinc protoporphyrin, lead in urine, ALA in urine, coproporphyrin in urine and personal lead in air measurement is discussed on the basis of the above criteria.

The analysis is largely, but not exclusively, based on the authors' experience of the occupational health and welfare needs of workers in the lead acid battery industry and the secondary lead smelter industries.

THE KEY ROLE OF BIOLOGICAL MONITORING

Occupational medicine and occupational hygiene are both concerned with the interaction between the worker and his environment. The common aim of both disciplines is to secure and maintain control over the health and well-being of the worker.

Historically, occupational medicine has approached this objective via monitoring and management of the person; occupational hygiene via monitoring and management of the working environment. As the two disciplines have developed, they have come together and overlapped to a useful and necessary degree in the field of biological monitoring. It is now well recognised by

practitioners of both disciplines that where suitable biological monitoring techniques are available, they have a key role to play in establishing effective control of the worker's health because they have the unique advantage of quantifying the interaction between each worker and his environment. They give direct and valuable information to the occupational physician on the health status of each worker and indicate, unambiguously, to the occupational hygienist the working environments which are having the greatest effect on individual workers. As a result, health and hygiene controls based on biological monitoring offer the worker, on an individual basis, the best guarantee against material impairment of health or well-being due to his working environment.

It is frequently alleged that environmental control strategies based on biological monitoring are unethical because they require that the worker should be first exposed to the health risk before this can be evaluated, and that conversely, control strategies based on monitoring the environment avoid this ethical problem. The validity of this argument relies on the truth of one or both of two assumptions:

(1) Biological monitoring is incapable of measuring the effect of the working environment on the person until an unacceptable level of risk to health has been exceeded.

(2) Monitoring of the environment: (a) requires no exposure of the person to a potential health risk, or (b) allows unacceptable levels of risk to health to be identified much sooner than biological monitoring and for this reason is a more reliable safeguard of each person's health.

Sometimes these assumptions are justified, e.g. sampling of a closed vessel before entry or control of carbon monoxide poisoning on blast furnaces. But frequently they are not. The control of the health of the lead worker is a case where they are not.

In this case assumption 1 is invalid because of the availability of biological tests which allow rising levels of lead absorption to be detected before an unacceptable level of risk to the health of the lead worker is reached. Assumption 2 (a) is invalid because it is the lead in air which arises from the worker's own activities which needs to be measured. Assumption 2 (b) turns out to be invalid because of the large number of lead in air tests that have to be carried out in the breathing zones of most lead workers in order to obtain a usefully accurate estimate of their effective exposure and the associated health risks.

BIOLOGICAL MONITORING TECHNIQUES

The common biological tests available for measuring lead absorption by lead workers (or its metabolic effects) are: blood lead, urinary lead, urinary coproporphyrin, urinary ALA, zinc protoporphyrin (ZPP) and haemoglobin.

It is generally accepted that blood lead concentration is the best measure of risk to health of a normally healthy lead worker. A venous sample has to be taken under medical supervision and the analysis must be carried out by a competent laboratory which specialises in this work. The results will normally be

accurate to ± 15% in the range of interest for the lead worker, i.e. 2.0 – 4.0 micromoles per litre. The cost of a blood lead analysis in the UK is £ 3.00. The total cost of the test depends on the accounting procedure used to apportion overheads but, based on a cost of £ 1.25 for each worker attending the medical department for sampling, a figure of the total cost is about £ 5.00 as shown in Table 1.

Urinary lead correlates fairly well with blood lead ($r \sim 0.7$). It has the advantage that the sampling need not be carried out under medical supervision, but the analysis must still be carried out by a reasonably skilled analyst in a lead free laboratory. It has the disadvantage that the sample is easily contaminated in a lead works. The total cost is about the same as for a blood lead test – i.e. about £4.50.

Urinary coproporphyrin and ALA correlate less well with blood lead ($r \sim 0.6$), but they have the advantage that the tests are easy to carry out in a lead works and do not require a skilled analyst. The total cost of an ALA determination using a Bio-Rad piggy-back kit is about £ 3.50; that for a coproporphyrin determination is about £ 2.00. Both these tests have considerable merit for screening lead workers for blood lead testing, provided that their specificity has been checked for the population to which they are applied.

The recently introduced ZPP test, although simple to carry out in a lead works and not requiring highly trained personnel, appears to correlate rather poorly with blood lead in the range 1.5 – 3.5 micromoles per litre ($r \sim 0.35$). The total cost of the test is about £ 2.00. Further experience may show that it can play a useful role as a screening test for blood lead determinations.

Haemoglobin correlates too poorly with blood lead ($r \sim 0.15$) to be of any value even as a screening test. The total cost of the determination is about £ 2.00. Nevertheless, it is necessary to carry out this test to make sure that anaemic persons are not being exposed to lead.

CONTROL BASED ON BIOLOGICAL MONITORING

Any measurement, whether it be biological, environmental, or control-plant performance, will not in itself exercise any control of a risk. It merely monitors the success or otherwise of those measures which have been introduced to control a perceived risk.

In well-established lead industries such as battery manufacture and smelting, all the major risks have already been perceived and various steps have already been taken to control them. As a result, adequate control of the lead absorption of the working population has already been secured and the function of monitoring is to help maintain this control.

Many years experience has shown that blood lead measurements are admirably suited for this purpose. For groups of workers engaged on like operations, blood lead values have been found to have a remarkably consistent standard deviation of 0.5 micromoles per litre. Thus, a very simple health and hygiene quality control procedure can be based on group or departmental means

TABLE 1
Cost per test (£)*.

Test	Sampling		Analysis				Total
	Workman[a]	Nurse (hygienist) technician[b]	Nurse (hygienist) technician[b]	Materials	Equipment depreciation[d]	Outside analysis	
Blood lead	1.25	0.50[c]	–	0.20	–	3.00	4.95
Urinary lead	1.25	0.20	–	–	–	3.00	4.45
Urinary coproporphyrin	1.25	0.20	0.55	–	0.05	–	2.05
Urinary ALA	1.25	0.20	0.55	1.25	0.10	–	3.35
ZPP	1.25	0.20	0.30	–	0.25	–	2.00
Haemoglobin	1.25	0.20	0.55	–	0.05	–	2.05
Lead in air	–	2.00[c]	–	–	0.05	2.50	4.55

*While these costs are appropriate for the UK, they are not necessarily applicable elsewhere. They are based on a method suggested by Dr M. K. Williams in "The measurement of lead absorption", a thesis submitted for the degree of Doctor of Medicine in the University of Oxford 1967.
[a]Salary plus 150%
[b]Salary plus 112%
[c]Assumes 1 hour sampling period, 15 tests per day and constant supervision of tests. If full shift samples are taken, this figure must be increased to £ 8.00 and the total cost per test is £ 10.55 for 4 tests per day.
[d]Assuming 3000 tests/year.

and their associated deviations. If the group or departmental means are kept below 3.0 micromoles per litre, individual workers will only rarely exceed 4.0 micromoles per litre. If the mean increases, this indicates a general loss of control in the department. If the standard deviation increases much above 0.5, this suggests that there is a loss of control for some individuals. The individual blood lead values immediately identify the individuals most at risk and hence the work stations, practices or personal hygiene habits which are most in need of attention.

A three monthly frequency of biological monitoring allows a control strategy which gives excellent protection to the worker without being unduly burdensome to operate. Based on the costs in Table 1, it will be seen that on average, this costs about £ 20/year/worker regardless of whether blood leads are measured directly or whether screening tests are used.

ENVIRONMENTAL MONITORING

Three basic types of lead in air testing strategy are available: (a) general workshop atmosphere or "area" sampling, (b) localised or ambient atmosphere sampling and (c) personal "breathing-space" sampling.

The first two types of test are carried out with a static or fixed-position sampler. Personal sampling is carried out by a battery-driven pump which is worn by the worker. The dust sampling head of the apparatus is usually worn in the lapel or collar position where, it is assumed, it takes a sample of air representative of that in the worker's breathing zone. Unfortunately, this assumption is not always true, but provided that this potential source of error is recognized and that the sampling head is suitably located, personal dust sampling

is the best method of measuring the lead in air concentration to which the worker is actually exposed. It is certainly the method currently used by most professional occupational hygienists for this purpose.

Although personal dust sampling apparatus has been available commercially for a little over a decade, it is only during the last five years or so that the technique has come into widespread use throughout the world. As a result, its true potential as an aid to the cost-effective control of industrial exposure to airborne contaminants is only now beginning to come into focus. In the current state of knowledge and experience, the following observations seem pertinent.

The accuracy with which the body burden of an atmospheric contaminant can be predicted from an air concentration measurement depends on the biological half-time of the contaminant, the instantaneous variation in air concentration of the contaminant and the sampling period. The longer the sampling period, the better the accuracy of the estimate of mean body burden but the greater will be the variation in instantaneous body burden about this mean. This produces conflicting requirements for the length of sampling period. Short sampling periods increase the uncertainty of the estimate of the mean body burden but decrease the likely variation of instantaneous body burden about this mean. The reverse is true for long sampling periods. In practice, an optimum compromise must be reached. This problem has been studied by Roach[2] who has concluded that the optimum sampling period for most occupational hygiene measurements should be about one tenth of the biological half-time of the contaminant. If the instantaneous variation in airborne contaminants is truly random, the variation in instantaneous body burden will then be about one fifth of the instantaneous variation of airborne concentration. In practice, however, the instantaneous airborne concentration will not vary in a completely random manner. There will be some degree of auto-correlation between sequential samples. Roach[2] has shown that this will increase the variance of the body burden about the mean. It will also shorten the sampling period necessary to estimate the mean to any given level of accuracy. This produces another "swings and roundabouts" situation which has not yet received very much practical attention by occupational hygienists.

The above observations are quite general. When applied to the lead acid battery industry, several interesting facts emerge. The most important is that, since lead has a biological half-time of about six months, estimates of effective lead in air exposure should be based on the average of ten full shift measurements. This is clearly an impracticable strategy to be used for routine monitoring or control.

We have tried, therefore, to base environmental control strategies on results of one-hour personal lead in air tests carried out over what we judged to be periods of "representative" worker activity. Unfortunately our attempts have been frustrated by the high degree of statistical variation in the results which have been found to be log-normally distributed with geometric standard deviations covering the range of 1.5–4.5 and commonly about 2.0. It appears that this finding is by no means unique to the lead industry. What is surprising,

perhaps, is that it should have received so little mention in the published literature.

However, in order to estimate the mean (effective) lead in air concentration with an accuracy of ±25%, ten samples would be required if the geometric standard deviation were 1.5 and no fewer than 38 if it were 2.0. Under reasonably favourable conditions, therefore, the cost of estimating lead in air exposure by environmental monitoring would range from about £ 50 to £ 190 per person per assessment. This contrasts very unfavourably with the much more accurate assessment of effective exposure from a simple blood lead determination which costs only £ 5 per person.

The possibility remains that lead in air tests might still have potential value as screening tests to indicate work situations which are in urgent need of improved environmental control. This seems to be an attractive possibility. In order to investigate its potential two things are necessary: a lead in air "standard" and a prescribed procedure for testing compliance with the "standard".

The "standards" most commonly used by hygienists are the well-known threshold limit values (TLV's). The current ACGIH TLV for lead in air (0.15 mg/m³) is based almost entirely on the work of Williams and co-workers[4]. He used personal dust samples in which the filter was covered and held in place by a plastic cap. Recent work by the present authors in conjunction with Dr E. Bellinger and Mr J. Allen of Manchester University has shown that electrostatic effects from the plastic cap cause wall losses which, on average, amount to 38% of the dust sampled. This means that the TLV derived from Williams' work should be 0.24 mg/m³. Moreover, the TLV derived from Williams' work was designed to keep 97.5% of the population below 80 μg Pb/100 ml blood. If this is adjusted to keep 97.5% of the population below 4.0 micromoles per litre, the corresponding TLV becomes 0.27 mg/m³. The plastic cap on Williams' apparatus was a simple 'push-on' fit onto the sampling head and again recent work has shown that over the full shift tests which he used, it is quite possible that it worked sufficiently loose to cause short circuiting of 10–15% of the sampled air. This would necessitate a further upward adjustment of the TLV to about 0.30 mg/m³.

A retrospective study carried out by the present authors[3] on the results of four years routine air and blood samples taken in the pasting department at Clifton Works has shown that a lead in air TLV of 0.30 mg/m³ would be adequate to keep 97.5% of the population below 4.0 micro-moles per litre.

Thus the best available information on which to base a lead in air "standard" leads to a TLV of 0.30 mg/m³ rather than the extremely doubtful ACGIH figure of 0.15 mg/m³.

The question of compliance testing procedure and the way in which it can be used to 'screen out' those processes, operations and work stations in need of urgent environmental improvement, remains as a project for further study. It would seem, however, that a useful point of departure would be to examine the merits of the compliance testing procedure suggested by Bar-Shalom and co-workers[1].

CONCLUSION

In terms of protection of the health and well-being of the lead worker, the cost-benefit analysis of biological and environmental monitoring techniques and strategies described and discussed in the present paper has demonstrated the clear superiority of strategies based on biological monitoring.

It has also indicated that more work needs to be done to determine the real value and cost-effective applications of lead in air sampling in the overall strategy of health control in a lead works.

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