Relationship between Exposure and Environmental Concentrations in Organic Solvent Workplaces

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Ukai, H., Takada, S., Inui, S. and Ikeda, M. Relationship between Exposure and Environmental Concentrations in Organic Solvent Workplaces. Tohoku J. exp. Med., 1986, 149 (3), 251-260 — The correlation between the exposure concentration (ExpC) of workers and the environmental concentration (EnvC) in their workplaces were examined in 143 printing, painting, gluing, degreasing and other solvent workplaces manned by 535 workers of both sexes. ExpC was measured with carbon felt dosimeters, and EnvC was with grab sampling of air into poly-tetrafluoroethylene bags; both were followed by GC analyses. When ExpC and EnvC were compared on both group and individual basis, the correlation was found to be positive but rather weak, and individual difference in ExpC within the workers of the same workplace was not negligible. Workplaces were classified after regulatory practice into three categories, and attempts were made to find out the conditions so that none among the 174 workers in the 43 Category 1 (i.e., “clean” from regulatory view point) workplaces would be exposed to solvent vapors over the current occupational exposure limit (OEL). Accordingly, it was found that the requirement will be met in case half the OEL is taken as the E value (the EnvC limit set by the regulation). Thus, the same conclusion was reached through the analyses of two separate batches of experiences, i.e., one in the present study and the other in the previous report (Ikeda and Ohtsuki 1985).

Current regulation on occupational hygiene in Japan (Work Safety and Health Law 1972; Work Environment Measurement Law 1975; Guideline for Work Environment Measurement 1976; Labor Standards Bureau 1984) requests that the compliance of the workplace environment should be evaluated on the basis of environmental concentrations as measured following a grid sampling...
strategy. The question invitable then from the viewpoint of occupational health is what is the quantitative relation between the environmental concentration and exposure concentration, as current occupational exposure limit is set based on the latter [i.e., the time-weighted average of the concentration in the breathzone of the individual worker; Japan Association of Industrial Health (1985)].

In a preceding study (Ikeda and Ohtsuki 1985), the relation of exposure concentration with environmental concentration (Labor Standards Bureau 1984) of his/her workplace was investigated based on the experiences with 328 workers in 47 solvent workplaces. The conclusion thus reached was such that, although there exists a general parallelism between the two measurements, it will be necessary to take 1/2 of the current occupational exposure limit (OEL; Japan Association of Industrial Health 1985) as the regulation-defined limit value for environmental concentration (Labor Standard Bureau 1984) in order to rule out the possibility of over-OEL exposure of workers. The conclusion was, however, drawn back by the fact that Measurement B data (or the measures to show possible maximum concentration in breathzone air) were available only in one-third of the workplaces studied; the inavailability might have resulted in the improper categorization of workplace. It was also not possible in the previous study (Ikeda and Ohtsuki 1985) to evaluate the conditions in painting workplaces as only limited number of workplaces were investigated.

The present study, as an extension of the previous one, was initiated in order to re-examine the conclusion with a larger file of data from more precisely defined workplaces, i.e., the workplaces in each of which a complete set of both Measurement A and B were available. Care was taken to obtain enough number of painting workplaces in the study.

**MATERIALS AND METHODS**

Solvent workplaces investigated, 143 in total, were of various types such as for printing (including coating), painting, gluing, degreasing, etc., and manned by 535 workers of both sexes. Survey protocol, chemical analyses and statistical evaluation of the results were as previously described (Ikeda and Ohtsuki 1985) except that spot air samples were collected (following the grid sampling strategy) in poly-fluoroethylene bags and subjected to gas-chromatographic analyses to measure environmental concentrations (EnvC). The solvent concentrations thus measured, 5 or more determinations per unit workplace, were mathematically treated to figure out the geometric mean (EnvC. GM) and the geometric standard deviation (EnvC. GSD) of the EnvC. The two statistical parameters were combined following the equations given in the Notice No. 69 [Labor Standards Bureau 1984; for details of the theory, see the APPENDIX in the previous report (Ikeda and Ohtsuki 1985)], i.e.,

\[
\log E_i = \log \text{EnvC. GM} + 1.645 (\log^2 \text{EnvC. GSD} + 0.084)^{1/2},
\]

and

\[
\log E_n = \log \text{EnvC. GM} + 1.151 (\log^2 \text{EnvC. GSD} + 0.084).
\]

Depending on whether \( E_i \) is less than \( E \) (the limit value set by regulation), \( E_n \) is less than \( E \) or \( E_n \) is greater than \( E \), the environment in the workplace is classified into Category 1, 2 or 3, or in other words, “clean”, “intermediary”, or “dirty” (Labor Standard Bureau 1984).
<table>
<thead>
<tr>
<th>Solvent workplace</th>
<th>Number of workplaces by category(^a)</th>
<th></th>
<th></th>
<th>Total</th>
<th>Number of workers</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>Total</td>
<td>Total</td>
<td>ExpC &gt; OEL</td>
<td></td>
</tr>
<tr>
<td>Printing</td>
<td>10 (19.2)</td>
<td>15 (28.8)</td>
<td>27 (51.9)</td>
<td>52</td>
<td>169</td>
<td>40 (23.7)</td>
<td></td>
</tr>
<tr>
<td>Painting</td>
<td>13 (81.3)</td>
<td>1 (6.3)</td>
<td>2 (12.5)</td>
<td>16</td>
<td>69</td>
<td>3 (4.7)</td>
<td></td>
</tr>
<tr>
<td>Gluing</td>
<td>9 (19.6)</td>
<td>13 (28.3)</td>
<td>24 (52.2)</td>
<td>46</td>
<td>212</td>
<td>41 (19.3)</td>
<td></td>
</tr>
<tr>
<td>Degreasing</td>
<td>10 (40.0)</td>
<td>6 (24.0)</td>
<td>9 (36.0)</td>
<td>25</td>
<td>66</td>
<td>21 (31.8)</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1 (25.0)</td>
<td>0 (0.0)</td>
<td>3 (75.0)</td>
<td>4</td>
<td>19</td>
<td>8 (53.3)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>43 (30.1)</td>
<td>35 (24.5)</td>
<td>65 (45.5)</td>
<td>143</td>
<td>535</td>
<td>113 (21.1)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Categorization after Notice No. 69 from Labor Standards Bureau (1984) with E/OEL = 1.00. The figures are the numbers of the workplaces in the categories followed by the percentages in parentheses.

\(^b\) Coating workplaces were included.

ExpC: Exposure concentration of individual worker.

OEL: Occupational exposure limit as cited from Japan Association of Industrial Health (1985). The additiveness formula (Elkins 1962) was taken into account when combined exposure took place. The figures under the inequality indicate the numbers (followed by the percentage in parentheses) of workers whose exposure concentrations were higher than the OEL.
<table>
<thead>
<tr>
<th>Solvent workplaces</th>
<th>Correlation between EnvC. GM &amp; ExpC. GM</th>
<th>E&lt;sub&gt;i &lt;/sub&gt; &amp; ExpC. GU&lt;sub&gt;95 &lt;/sub&gt;</th>
<th>EnvC. GM &amp; ExpC</th>
<th>E&lt;sub&gt;i &lt;/sub&gt; &amp; ExpC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Printing&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.558 (25)**</td>
<td>0.442 (25)*</td>
<td>0.384 (169)**</td>
<td>0.345 (126)**</td>
</tr>
<tr>
<td>Painting</td>
<td>0.810 (11)**</td>
<td>0.760 (11)**</td>
<td>0.495 (69)**</td>
<td>0.526 (58)**</td>
</tr>
<tr>
<td>Gluing</td>
<td>0.751 (24)**</td>
<td>0.595 (24)**</td>
<td>0.603 (212)**</td>
<td>0.617 (172)**</td>
</tr>
<tr>
<td>Degreasing</td>
<td>0.760 (8)*</td>
<td>0.332 (8)</td>
<td>0.317 (66)**</td>
<td>0.183 (39)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0.379 (3)</td>
<td>0.062 (3)</td>
<td>0.163 (19)</td>
<td>0.166 (16)</td>
</tr>
<tr>
<td>Total</td>
<td>0.668 (71)**</td>
<td>0.424 (71)**</td>
<td>0.429 (535)**</td>
<td>0.416 (411)**</td>
</tr>
</tbody>
</table>

The figures in the table are correlation coefficients followed by numbers of cases in parentheses. Asterisks show statistical significance (* p<0.05; ** p<0.01).

EnvC.GM: Geometric mean of environmental concentrations measured in a given unit workplace;
Exp.C.GM: Geometric mean of exposure concentrations of workers (n≥4) in the same unit workplace.
E<sub>i </sub>: A comprehensive indicator of environmental concentrations, integrating geometric mean and geometric standard deviation. For mathematical definition, see MATERIALS AND METHODS.
Exp.C.GU95: The 95% (one-tail) upper limit of the Exp. C of the workers (n≥4) in the same unit workplace with an assumption of log-normal distribution.

Exp.C: Exposure concentration of individual worker.
<sup>a</sup> Total cases.
<sup>b</sup> The cases where ≥4 workers served in the same workplace.
<sup>c</sup> Coating workplaces were included.
A carbon felt dosimeter (Hirayama and Ikeda 1979; Ikeda et al. 1984) with K filter TF 1500 (Toyobo Co., Osaka) was equipped by each worker for the determination of time-weighted average concentration of solvent vapor in the breathzone air (exposure concentration or ExpC). When the ExpC values were available from 4 or more workers serving in the same unit workplace, the geometric mean (ExpC.GM), the geometric standard deviation (ExpC.GSD) and the 95% (one-tail) upper limit (ExpC.GU95) of the ExpC were calculated. In practice, such Exp.GM, ExpC.GSD and ExpC.GU95 were available in 71 unit workplaces with 411 workers in total.

Occupational exposure limit (OEL) for each solvent was cited from Japan Association of Industrial Health (1985). In case workroom air was contaminated with more than one solvent vapor and the workers there were exposed to the mixture, the sum by the additivity formula (Elkins 1962),

\[
\sum_{i=1}^{n} \frac{\text{EnvC}_i}{E_i} \text{ for EnvC, and } \sum_{i=1}^{n} \frac{\text{ExpC}_i}{\text{OEL}_i} \text{ for ExpC}
\]

(where i refers to each solvent component)

were employed in the place of EnvC and ExpC for individual solvent to make overall evaluation.

**RESULTS**

**Categorization of workplaces and exposure intensity of workers**

The workplaces were classified by the type of work and also by the category (Table 1). The Category 1 workplaces distributed unevenly among the various types of workplaces (\(p < 0.01\) by chi-square test). Thus, the workroom conditions as evaluated in terms of solvent vapor concentration was generally better in painting rooms as most of them (81.3\%) was classified in Category 1 (or “clean” workplaces), while the reverse appeared to be the case in printing and gluing workplaces (19.2 and 19.6\%, in Category 1, respectively, and 51.9 and 52.2\% in Category 3, respectively). When the ExpC of each of the 535 workers was compared with the OEL, ExpC was larger than OEL in 113 workers. The distribution of over-OEL exposure cases was not uniform among the workers (\(p < 0.01\) by chi-square test), and the over-OEL exposure rate was not low for degreasers whose workplace conditions were evaluated as intermediary (i.e., Category 2). Accordingly, it is plausible that parallelism does not always exist between categorization results of workplaces by means of environmental concentration and exposure intensity of workers serving in the places.

**Correlation between environmental concentration (EnvC) and exposure concentration (ExpC)**

Comparison on group basis was conducted with cases in which 4 or more workers served in the same workplaces and, thus, it was possible to calculate ExpC.GM. As shown in the left half of Table 2, the correlation coefficients between EnvC.GM and ExpC.GM were generally high and statistically significant (\(p < 0.01\) to 0.05) except for the cases of the “miscellaneous” type in which the number of cases studied was very limited. When \(E_i\) (i.e., the environmental
concentration parameter more comprehensive than simple EnvC.GM; for details, see Materials and Methods) were compared with ExpC. GU95 (i.e., a safety-incorporated parameter of exposure), the correlation coefficients tended to be smaller ($p < 0.05$ by paired $t$-test) than the counterpart correlation coefficients between EnvC.GM and ExpC.GM.

Similarly, the exposure concentration indicator of individual worker (ExpC) was compared with the environmental concentration indicators (EnvC. GM, and EI) of his/her workplace to examine correlation on individual basis. The results are summarized in the right half of Table 2. The comparison was made on two levels, namely, one with ExpC of total workers and the other with the cases where 4 or more workers served in the same workplace; the basis of statistical evaluation in the latter was identical with that of the group comparison between EnvC. GM and ExpC. GM, as ExpC. GM was calculated only when ExpC was available for 4 or more workers of the same workplace (see the footnote ExpC. GM under Table 2). The correlation coefficients were rather similar for the total case study and for the $\geq 4$ study, independent of whether ExpC was compared with EnvC. GM or EI ($p > 0.10$ by paired $t$-test for both cases). The coefficients of correlation on individual basis were, however, significantly smaller than the counterpart coefficients on group basis [e.g., $p < 0.05$ by paired $t$-test for the comparison of the coefficients between EnvC. GM and ExpC. GM and those between EnvC. GM and ExpC ($n > 4$)]. When printing workplaces were taken as an example, the correlation coefficient between EnvC. GM and ExpC. GM (i.e., the parameter of comparison on group basis) was 0.558 while the corresponding coefficient between EnvC. GM and ExpC ($n \geq 4$) (i.e., the parameter on individual basis) was 0.345. Although most of the correlation coefficients on individual basis were also highly significant ($p < 0.01$), this was probably attributable to large $n$. Thus, it was apparent that the individual difference within the workers of the same workplace should not be ignored.

Estimation of $E$ value that will prevent over-OEL exposure of workers

The various solvent workplaces were classified into three categories as defined by Notice No. 69 from Labor Standard Bureau (1984). Smaller $E$/OEL of 0.75 and 0.50 in addition to that of 1.00 were employed for study purpose. After the classification, ExpC for each worker was compared with the OEL so that the number of workers with exposure higher than the OEL could be confirmed. The results are summarized in Table 3. At all three $E$/OEL levels of 1.00, 0.75 and 0.50, over-OEL exposure cases (i.e., $\text{ExpC} > \text{OEL}$ cases) distributed unevenly among the three categories ($p < 0.01$ by chi-square test); the rate of over-exposure was lower in Category 1 and higher in Category 3. The point is the fact that, at $E$/OEL = 1.00, the over-OEL exposure was observed in 4% of the workers despite that they were in Category 1 (i.e., “clean”) workplaces, indicating the lack of due safety. Among the 174 workers in Category 1 workplaces at $E$/OEL = 1.00, the
<table>
<thead>
<tr>
<th>Solvent workplaces</th>
<th>E/OEL = 1.00</th>
<th>E/OEL = 0.75</th>
<th>E/OEL = 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total&lt;sup&gt;b&lt;/sup&gt;</td>
<td>ExpC &gt; OEL</td>
<td>Total&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Category 1 workplaces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Printing&lt;sup&gt;c&lt;/sup&gt;</td>
<td>26 (15.4)</td>
<td>0 (0.0)</td>
<td>16 (15.4)</td>
</tr>
<tr>
<td>Painting</td>
<td>61 (16.7)</td>
<td>1 (1.6)</td>
<td>55 (16.1)</td>
</tr>
<tr>
<td>Gluing</td>
<td>62 (14.8)</td>
<td>3 (4.8)</td>
<td>34 (13.5)</td>
</tr>
<tr>
<td>Degreasing</td>
<td>21 (14.3)</td>
<td>3 (14.3)</td>
<td>11 (0.0)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>4 (0.0)</td>
<td>0 (0.0)</td>
<td>4 (0.0)</td>
</tr>
<tr>
<td>Total</td>
<td>174 (4.0)</td>
<td>7 (4.0)</td>
<td>120 (3.5)</td>
</tr>
<tr>
<td>Category 2 workplaces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Printing</td>
<td>39 (15.4)</td>
<td>6 (15.4)</td>
<td>44 (15.4)</td>
</tr>
<tr>
<td>Painting</td>
<td>2 (50.0)</td>
<td>1 (50.0)</td>
<td>6 (50.0)</td>
</tr>
<tr>
<td>Gluing</td>
<td>52 (3.8)</td>
<td>2 (3.8)</td>
<td>54 (3.8)</td>
</tr>
<tr>
<td>Degreasing</td>
<td>16 (5.3)</td>
<td>5 (5.3)</td>
<td>16 (5.3)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Total</td>
<td>109 (12.8)</td>
<td>14 (12.8)</td>
<td>120 (9.5)</td>
</tr>
<tr>
<td>Category 3 workplaces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Printing</td>
<td>104 (32.7)</td>
<td>34 (32.7)</td>
<td>109 (33.9)</td>
</tr>
<tr>
<td>Painting</td>
<td>6 (16.7)</td>
<td>1 (16.7)</td>
<td>6 (16.7)</td>
</tr>
<tr>
<td>Gluing</td>
<td>98 (36.7)</td>
<td>36 (36.7)</td>
<td>124 (38.0)</td>
</tr>
<tr>
<td>Degreasing</td>
<td>29 (14.8)</td>
<td>13 (14.8)</td>
<td>39 (16.1)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>15 (53.3)</td>
<td>8 (53.3)</td>
<td>15 (53.3)</td>
</tr>
<tr>
<td>Total</td>
<td>252 (36.5)</td>
<td>92 (36.5)</td>
<td>295 (34.2)</td>
</tr>
<tr>
<td>Grand total</td>
<td>535 (21.1)</td>
<td>113 (21.1)</td>
<td>535 (21.1)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Categorization after Notice No. 69 from Labor Standards Bureau (1984). For theoretical consideration of Category 1 to 3, see Materials and Methods.

<sup>b</sup> Total number of workers.

<sup>c</sup> Coating workplaces were included.

<sup>d</sup> Uncalculable.
distribution of over-OEL exposure cases appeared to be biased \((p = 0.10\) by chi-square test\) to degreasers (14.3\%) and then to glue workers (4.8\%). The higher risk associated with degreasing work persisted also in “less clean” workplaces of Categories 2 and 3. When smaller E/OEL of 0.75 or 0.50 was employed, the risk of over-OEL exposure tended to be reduced (even though insignificantly; \(p > 0.10\) by chi-square test) in all types of workplaces in every categories, e.g., the rate was 36.5\% at E/OEL = 1.00, 34.2\% at E/OEL = 0.75 and 29.0\% at E/OEL = 0.50 among workers in Category 3 workplaces. The most remarkable was the finding that, at E/OEL = 0.50, there was no over-OEL exposure case among 61 workers in Category 1 workplaces.

In order to find the E/OEL ratio below which no over-OEL exposure would occur among those in Category 1 workplace, the over-OEL exposure cases were identified and the rate of such over-exposed workers over total workers was calculated with decreasing E/OEL ratios. The results of the titration study is depicted in Fig. 1. It is evident that there was a sharp decrease in the over-OEL exposure rate around E/OEL = 0.6 and the rate was zero at E/OEL = 0.55 and less.
When the data (excluding the cases where the rate was zero) were assumed to fit with a quadratic regression curve, the assumption gave the curve as,

\[ y = -4.64x^2 + 13.04x - 4.61 \]

where \( x \) is the ratio of E/OEL and \( y \) is the rate of over-OEL exposed workers divided by total workers (i.e., the over-OEL exposure rate). The curve gave \( x = 0.41 \) when \( y = 0 \).

**DISCUSSION**

Since the issue of Notice No. 69 from the Labor Standard Bureau in 1984, increasing attention has been focussed on the validity of EnvC as a possible indicator of dose of industrial intoxicants to workers. Accordingly, it was stated schematically that the EnvC measurement is primarily for the maintenance of workplaces and only indirectly related to the exposure intensity of workers in the workplace (Konishi 1985). Thus, ExpC determination was recommended even in Category 1 (i.e., “clean”) workplaces to confirm that the intoxicant dose is low enough not to provoke any health problem (Shoji 1985).

Because ExpC and EnvC are theoretically independent of each other (Koizumi et al. 1980; Takada et al. 1983), the relation between ExpC and EnvC can be established only empirically. From this view point, it is worthy to note that the same E/OEL ratio of 0.5 was obtained through the analyses of two separate batches of experiences [i.e., one in the present study and the other in the previous report (Ikeda and Ohtsuki 1985)] in the attempt to find out the conditions so that no over-OEL exposure would occur among the workers in Category 1 workplaces. The procedures to find this ratio was based on the confirmation of ExpC for each of 535 workers in 143 solvent workplaces of different types at various EnvC. Thus, it should be stressed that no safety factor was taken into account in establishing this ratio; otherwise, the ratio could be even lower. Many factors would be involved in making ExpC and EnvC unrelated to each other. For example, Nakaaki and Fukabori (1985) reported that solvent vapor concentrations will increase only in the very vicinity (yet including the breathing zone) of a worker when he manually dilutes paint with thinner. The geographical extent of concentration increase may be so limited that the increase will not be detected by the grid sampling to measure EnvC, yet just wide enough to elevate ExpC. Similar cases were also noted in small-scale industry surveys (Ikeda et al. 1985).

No over-OEL exposure was detected among 26 printers in Category 1 printing rooms (Table 3), although the printing workplaces as a whole were generally not “clean” and individual ExpC often exceeded OEL among a total of 169 printers (Table 1). Such agreement among printers was in accordance with the observation that printing rooms are often air-conditioned with semi-closed (i.e., high return rate) ventilation systems and solvent vapors are rather uniformly distributed in the workplaces. In the cases of painting workplaces, exhaust fans are well
equipped even in small-scale industries (Ikeda et al. 1985) so that most of the
workplaces are classified in Category 1 and the rate of over-OEL exposure is
correspondingly low (Table 1). In contrast, installation of effective local exhaust
system is rather difficult in gluing and degreasing workplaces, especially in the
former (Koizumi et al. 1980), at least partly due to work performance. Namely,
during the manual work of gluing or degreasing, dense solvent vapor will be
generated very close to the nose of the worker. Such topical high concentration
may result in elevation of ExpC, but not necessarily EnvC as already discussed
(Ikeda and Ohtsuki 1985).

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