Guidelines for personal exposure monitoring of chemicals: Part IV

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Abstract: This Document, “Guidelines for personal exposure monitoring of chemicals” (“this Guideline”), has been prepared by “The Committee for Personal Exposure Monitoring” (“the Committee”) of the Expert Division of Occupational Hygiene & Ergonomics, Japan Society for Occupational Health. Considering the background of the growing importance of personal exposure monitoring in risk assessment and the need to prepare for the introduction of monitoring using personal samplers from an administrative perspective in recent years, the Committee was organized in November 2012. The Committee has prepared this Guideline as a “practical guideline” for personal exposure monitoring, so as to offer proposals and recommendations to the members of the Japan Society for Occupational Health and to society in general. The scope of this Guideline covers all chemical substances and all related workplaces regarded as targets for general assessment and the management of risk. It thus is not to be considered to comment on legal regulations and methodology. The main text provides the basic methods and concepts of personal exposure monitoring, while 31 “Appendices” are provided in this Guideline throughout the series; technical descriptions, statistical bases, and actual workplace examples are provided in these appendices, to assist better understanding. The personal exposure monitoring described as per this Guideline is equivalent to an “expert-centered basic method to reasonably proceed with the assessment and management of risk at workplaces.” It is considered that practicing and expanding on this method will significantly contribute in reforming the overall framework of occupational hygiene management in Japan.

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Chapter 2: Method for Personal Exposure Monitoring

4. Monitoring and analysis
4-1 Methods for monitoring and analysis

This Guideline does not provide the detailed methods for monitoring (sampling apparatus, tools and techniques) and analysis. Instead, their concepts are outlined in this section.

As personal exposure monitoring involves comparison with the occupational exposure limit, the basic sampling time is eight hours for one-day (eight-hour) monitoring. Since the sampling duration varies significantly from, and is longer than that of Working Environment Measurement, the method in the guidebook for Working Environment Measurement cannot always be directly applied to personal exposure monitoring. Therefore, special attention should be paid. Furthermore, monitoring at the workers’ breathing zone requires portable type samplers that
do not add a burden to the work involved. In actual situations, however, the same type of work is not performed continuously for eight hours, and also time-saved sampling and divided sampling are available. And therefore, the capability of performing continuous monitoring with a single sampler for eight hours is not always a necessary condition for exposure assessment. The manual described below specifies the basic conditions for eight-hour monitoring so as to allow the collection of air containing contaminants with a concentration equal to the occupational exposure limit for four hours (240 minutes) or higher. However, when compared with the short term exposure limit (STEL), the basic sampling duration is 15 minutes. When compared with the ceiling value (C), shorter term sampling is possible. In this case, an optimum sampling condition for the type of monitoring is required to be selected.

Since Japan has no regulations concerning personal exposure monitoring, no official methods or well-documented protocols are available. Europe and the USA, however, do have protocols on sampling and analysis, the details of which are given below. The U.S. NIOSH has published the NIOSH Manual of Analytical Method (hereinafter referred to as NMAM), while OSHA has published the Sampling and Analytical Method (hereinafter referred to as SAM). Each summarizes the sampling and analytical methods for approximately 600 kinds of substances. These two protocols are available free of charge for referencing and downloading through their websites.

The NMAM contains detailed protocols for approximately 600 kinds of substances. Yet it does not list chemicals such as acryl amide, alkyl mercury compound, 3,3′-dichloro-4,4′-diaminodiphenylmethane (MBOCA), and β-propiolactone, for which the control concentrations are specified in Japan. On the other hand, the SAM does cover the sampling method for acryl amide and MBOCA. The basic sampling methods include mainly the filtration method, the solid collecting method, and the liquid collecting method that are used in Japan for Working Environment Measurement. Meanwhile for gaseous substances, passive samplers are widely used due to their portability, their light weight and the fact that they reduce the burden on workers.

In recent times real-time monitors with various integrated sensors (a direct reading instrument) have become commercially available. They are useful as auxiliary instruments. Please refer to Section 4-2 for more information.

Under circumstances in which the risk of explosion is high (circumstances not limited to personal exposure monitoring), pumps shall be explosion proof. Passive samplers may be widely used as explosion proofing is not required.

4-2 Instantaneous measurement method and its utilization

The instantaneous measurement method refers to a simplified measuring of the airborne concentration of target substances on the spot. Compared to the solid collecting method or the direct collecting method, both of which require laboratory analysis after sampling, the instantaneous measurement method is characterized by its capacity to obtain results within a short span of time. Thus, monitoring of target substances on the spot while observing the work, is an effective means for exposure estimation as mentioned in the previous section. However, it is necessary to apply this method with consideration of its accuracy and application limit.

A typical example of the instantaneous measurement method for chemical substances is the gas detector tube method. As this method is also used in Japan for Working Environment Measurement, it constitutes a major portion of the instantaneous measurement method. One of the problems regarding the use of gas detector tubes is their low measurement accuracy. JIS K 0804 specifies that the required accuracy be of the indicated value +/− 25% for 1/3 or more of the scale range, and of the indicated value +/− 35% for 1/3 or less of the scale range. Moreover, since it is necessary to observe the change in color by the chemical reactions of filled substances in a detector tube, identification of colors is often difficult on the boundary, due to differences in interpretation between observers. This creates an additional error factor. Indicated values may also be affected by co-existing airborne contaminants.

The instantaneous measurement method also involves the use of real-time monitors (also known as direct reading instruments). These instruments, such as “gas detector,” directly and numerically show the concentration. The advantages these real-time monitors have over gas detector tubes include high sensitivity, quick response, as well as a short measuring time. Certain types of these instruments come equipped with an integrated data logger (electronic recording equipment). This allows for the continuous recording of temporal changes in the monitored concentration for later analysis and ensures that they are highly effective for identification of exposure peak timing and exposure causes, as well as in consideration of the control measures required.

When measuring chemical substances, gas detectors with various types of sensors such as the contact combustion type (inflammable gas), or the constant-potential electrolysis type (for use with toxic gases such as carbon monoxide, hydrogen sulfide, etc.) are available. As for the measurement of particles, laser light scattering type relative concentration meters can be used. Real-time monitors for volatile organic compounds (VOC) (also called VOC monitors) using special sensors such as photo ionization detectors (PID) are used to measure various types of VOC and also hydrocarbons. These monitors are
effective not only for spot monitoring during work and safety walkthroughs, but especially for detection of gas in a space where the source of the generation of toxic substances and their diffusion have not been identified.

One of the most important protocols when using real-time monitors is the proper calibration. The use of a standard gas for the monitoring-target substance for calibration allows reliable measured values. Other noteworthy items may include the following: changes in indications due to deterioration of sensors; the failure to separate and quantify mixtures; and the effects of co-existing contaminants. These items should be well considered when using the real-time monitors for exposure quantification.

In the case of VOC measuring instruments that use PID sensors, etc., the sensitivity varies to a great extent depending on the substance. Multiplication of readings by a correction factor for calibration gas would, in this case, provide accurate measured values. In the presence of co-existing contaminants, it may be possible to estimate the ratio of the co-existing contaminants in advance to estimate the approximate level of exposure.

In this Guideline, the instantaneous measurement method is positioned as “basic characterization” before measurement. If, however, real-time monitors are used and the results are continuously recorded by the data logger, accuracy and details of the measured data can be equivalent to, and in some cases better than those achieved by personal samplers. Thus, in such a case, this measurement may be treated as “formal.”

One thing in common with all the instantaneous measurement methods is the necessity of clarifying the purpose of instantaneous measurement. That is, whether the target of measurement is short term high exposure or average exposure in the course of steady work. When using this method, the measurement is generally conducted within a short period of time when the exposure concentration significantly changes, and the results obtained differ substantially depending on the timing of the measurement. Therefore, options in this case include multiple measurements as needed for improved accuracy, or for verification of the temporal change in exposure. In addition to the above, results of the observation during measurement are also considered to better estimate the exposure concentration from the overall viewpoint.

The instantaneous measurement method would, if properly utilized, prove to be an important tool for personal exposure monitoring. Hence it is expected that substantial exposure may be assessed in many cases without performing regular monitoring, if the results of instantaneous measurement are combined with other workplace environment information (this is especially true in the case of sufficiently less exposure). Research laboratories in universities and enterprises in particular are characterized by their irregular and intermittent use of a variety of chemical substances. In their case, flexible application of the instantaneous measurement method is believed to be effective. For small and medium-sized workplaces having difficulty with initiating personal exposure monitoring due to limited human resources, the results obtained by instantaneous measurement may be interpreted as screening assessment of exposure. This is much more valuable than simply doing nothing, although detailed assessment should be pursued later as needed in this case.

4-3 Recording and observation during monitoring

Each worker to be monitored is expected to write a short record of his/her behavior during monitoring. Recording sheets for this task, required to be prepared in advance, shall be handed over to the worker at the beginning of monitoring and then collected at the end. The purpose of this record is to identify any unusual work or abnormal phenomena (such as abnormal exposure, leakage, or contamination of samplers) that may have occurred during monitoring. Each worker shall be informed to ensure that they record any occurrence of such events. It is therefore sufficient to only keep recording the overall flow of the work contents; it is not necessary to record other minor events.

Whether or not it is necessary for the monitoring staff to observe the work during monitoring is dependent on the situation. For long term (eight-hour) monitoring, observation during work may be effective to identify the high exposure task, to investigate sources of hazards, and to examine behavioral differences among workers. Generally speaking, continuous observation throughout monitoring is not required. In the case of short term exposure monitoring in which time constraints are small, observation during monitoring is recommended for the purpose of detecting high exposure responsible for acute health effects.

Time study refers to the continuous observation and recording of the behavior of workers during monitoring. Many people are reminded by this phase of personal exposure monitoring in connection with time study. However, although time study takes a large amount of effort, execution of it, throughout eight-hour monitoring for instance, is very much limited. In other words, it is conducted only when specifically needed at the time of exposure monitoring.

At present, it is possible for continuous recordings using real-time monitors with a data logger (PID instrument, particle meter, etc.) instead of time study (please refer to the previous section). Moreover, synchronization of video images recorded during the work with the data is performed to visually grasp changes in exposure associated with changes in work. This assists with the identification of the source of exposure, and it also can be utilized for educational purposes.
5. Assessment and Interpretation of Measured Values

5-1 Interpretation of measured values

It is required that the outliers (high or low values significantly different from other values) be identified. If any outliers are detected, either the behavior record made during exposure monitoring shall be reviewed, or the relevant worker monitored shall be consulted. When the causes of outliers become apparent, the values shall be treated as abnormal and shall not be used for later analysis. The causes of outliers may include, but may not be limited to dropping or contaminating samplers by mistake during monitoring, getting involved in a special task that other workers are not engaged in, performing no work due to sudden change in the schedule. Abnormal values such as these occur from time to time. On the other hand, outliers whose causes cannot be identified shall be treated as data on a temporary basis. In some cases, outliers may be caused by a peculiar behavior or habit of a certain worker. In such a case, the worker may be required to be re-monitored for confirmation. This will depend on the situation.

The results of measurements and analysis may be such that the concentration of a part of the sample set is extremely low, i.e., “below the detection limit,” or “not detected (ND, or zero).” In such a case, if the concentration is treated as zero, calculation based on a log normal distribution \(X_{\text{AM}}\) or \(GSD\) cannot be performed. The following interpretation is a measure of how to deal with such a case. In the case of a solid collecting method for instance, the “detection limit of measured concentration” (the unit of concentration: ppm or mg/m³) depends both on the “detection limit obtained by analysis” (unit of weight: μg, etc.), and the measurement condition (sample volume). If these results indicate “below the detection limit,” this detection limit may be treated as a temporary value to be used for subsequent calculations. In such a case, a value equal to “1/2 of the detection limit” can also be treated as a measured value.

When using eight-hour occupational exposure limit as a reference value for assessment, each data, from which abnormal values are excluded (total \(n\) data), is first converted to an eight-hour time weighted average. Suppose, for example, work duration is only for seven hours, for which the average exposure concentration for seven-hour monitoring is 10 ppm; the eight-hour value is obtained as follows, with the assumption of the exposure for the remaining one hour to be zero.

\[10 \text{ ppm} \times (7/8) = 8.75 \text{ ppm}\]

Even if the average work hours of a similar exposure group is eight hours or less, the hours for some workers may be extended; thus the overall monitoring may exceed eight hours. In this case, the exposure concentration is “compressed” to eight hours to calculate the eight-hour time weighted average. For instance, if the hours for certain workers are extended to nine hours, and an average concentration for such nine-hour monitoring is 10 ppm, then the eight-hour time weighted average is obtained as follows:

\[10 \text{ ppm} \times (9/8) = 11.25 \text{ ppm}\]

If there is a time period without exposure in the course of eight-hour work, such as noon recess or clerical work in mid-course, such a time period may be ignored regardless of whether samplers are removed or not. Calculation may be performed with the assumption that the sampling continued during this time period, because the subtraction of the time period from the monitoring makes no difference in the result, as explained in detail in the appendix (please refer to Appendix 13).

If the average work hours exceed eight hours (\(T\) hour \(s\); for example: 10 hours), the measured data is converted to a \(T\)-hour time weighted average to be used for calculation of the statistical index. Also, the occupational exposure limit corresponding to \(T\) hours is set for use as a reference value for assessment. This is described in Section 5-4.

5-2 Calculation of statistical indices

Based on the calculated eight-hour time weighted averages (a total of \(n\) data), the following three values are obtained:

1) The arithmetic mean \((AM)\): It is directly calculated from \(n\) data (using the normal method for obtaining an arithmetic mean). In the case of Working Environment Measurement, a geometric mean and a geometric standard deviation are calculated from the obtained data. Then the estimated value of the arithmetic mean is calculated based on these two values. Note that this method is different from the one explained above.

2) The upper 95 percentile of a log normal distribution \((X_{95})\): The calculation method is the same as that for the primary reference value in the Working Environment Measurement.

\[\log (X_{95}) = \log (GM) + 1.645 \times \log (GSD)\]

\(GM\): geometric mean
\(GSD\): geometric standard deviation

3) The geometric standard deviation \((GSD)\).

If the number of samples \((n)\) obtained by measurement is four or less, the method shown in Table 2.7 shall be used for the interpretation. The arithmetic mean is calculated directly from the data when \(n = 2\) to 4, while the measured value is interpreted as the arithmetic mean when \(n = 1\). The 95 percentile of a log normal distribution is set at three times the arithmetic mean. On this ground, when the “GSD” of a log normal distribution is 2 to 3 (the normal range of actual GSD), the ratio \(X_{95}/AM\) is approximately 2.5 to 3.5. As such, the three times value is used as an approximation. Details are provided in the appendix (please refer to Appendix 14).

5-3 Interpretation of short term measured values

Short term measured values may be interpreted in a manner similar to the case of eight-hour (one shift) monitoring. First, abnormal results shall be removed from the
data.

When using the short term exposure limit (TLV-STEL, 15-minute permissible exposure concentration) as a reference value for assessment, with the monitoring duration of 15 minutes or less, each data shall be calculated to their 15-minute time weighted average. On the other hand, when the monitoring duration is in excess of 15 minutes, the measured values shall be used as they are, and without calculation (please refer to Section 3-5).

When using either the ceiling value (TLV-C), or the maximum permissible concentration defined by the Japan Society for Occupational Health as a reference value for assessment, data are used without calculation, regardless of the monitoring duration.

By using the \(n\) data, the \(AM\), the upper 95 percentile of a log normal distribution \(X_{95}\), and \(GSD\) are calculated in the same way for the eight-hour monitoring, and they can be used for assessment.

At the time of performing short term exposure monitoring, and in the case in which the monitoring duration is relatively long (for example one hour or more, which is rare), the short term exposure limit may not be exceeded. However, the eight-hour occupational exposure limit may well be exceeded. And therefore, it is necessary to calculate the measured value to the eight-hour time weighted average as well, and also to perform assessment using the eight-hour time weighted average as a reference value.

5-4 Occupational exposure limit (eight hours)

In this Guideline, the major targets of personal exposure monitoring are chemical substances with defined occupational exposure limits.

The maximum permissible concentration defined by the Japan Society for Occupational Health or the TLV-TWA values of the American Conference of Governmental Industrial Hygienists (ACGIH), whichever is lower, is used for occupational exposure limit as a reference value for assessment of exposure limits. This concept is also adopted by the “Investigative Committee for Risk Assessment of Chemical Substances” of the Ministry of Health, Labor, and Welfare.

If the values of the Japan Society for Occupational Health or the ACGIH values are not available, other internationally recognized occupational exposure limits may be used as reference. These include the Workplace Exposure Limits (WEL) used in Britain, Maximale Arbeitsplaz-Konzentration (MAK) in Germany, and the Workplace Environmental Exposure Levels (WEELs; about 120 kinds of substances) of the American Industrial Hygiene Association (AIHA) used in the USA.

Chemical substances without defined occupational exposure limits are out of the scope of measurement. However, if the toxicological data (for example a NOAEL [no observed adverse effect level] obtained by animal experiments, etc. are available, in some cases, it may be possible to estimate the occupational exposure limit on the basis of such data. Since this Guideline will not address this issue any further, appropriate information should be referred to make necessary judgments. This shall be the responsibility of either the employers or the risk assessment supervisors.

For the measurement results of a task whose duration is in excess of eight hours, the eight-hour occupational exposure limit is corrected as explained in the appendix (please refer to Appendix 15).

If there are multiple chemical substances with similar toxicological effects within the organic solvent mixture, it is necessary to compare the combined and converted concentration with the reference value. The method is explained in the appendix (please refer to Appendix 15).

5-5 Occupational exposure limit (short term)

For substances with short term exposure limits (TLV-STEL) of ACGIH, such limits are used as the reference for assessment of short term monitoring results. The TLV-STEL is defined as the “15-minute time weighted average concentration that shall not be exceeded, even if the eight-hour time weighted average exposure concentration is below the TLV-TWA.”

For substances with the ceiling values (TLV-C) of the ACGIH, or the maximum permissible concentration values of the Japan Society for Occupational Health, such values are used as a reference for assessment. If both values are available, the lower value shall be adopted, as in the case of eight-hour values. The TLV-C is defined as the “value that shall not be exceeded at any part of exposure due to work,” while the maximum permissible concentration is defined as the “value below which the concentration shall always be kept,” respectively. However, neither of them shall be treated as “maximum instantaneous values” in the practical sense, as already described in Section 3-5.
Table 2.3.

| Control 1 | Control 2 | Control 3 |
|-----------|-----------|-----------|
| X₉₅ < OEL | AM ≤ OEL ≤ X₉₅ | OEL < AM |

OEL: Occupational Exposure Limit
AM: Arithmetic Mean
X₉₅: Upper 95 percentile of distribution

For substances that have neither the TLV-STEL values nor the ceiling values, a value of three times the eight-hour occupational exposure limit shall, in principle, be used as an STEL equivalent value. This (three times) value is derived from the magnitude of variance in exposure concentration during a single day as it is considered that, by restricting the variance, health effects due to high concentration exposure may be prevented (please refer to Appendix 16).

ACGIH has specified the excursion limits, which are values of three times and five times the TLV-TWA; Thus, the ACGIH has defined the control of exposure by using these values for substances without the TLV-STEL value. This Guideline does not recommend the use of these values. The explanation for this and the additional descriptions of the TLV-STEL value are given in the appendix (please refer to Appendix 17).

5-6 Assessment of results and exposure class

Results are evaluated by comparing the AM and the upper 95 percentile of a log normal distribution (X₉₅) obtained from the monitored data with the Occupational Exposure Limit (OEL). Here, an evaluation of results is conducted by dividing the control class into six classes in total. This is shown in Table 2.3.

The control class is roughly divided into three classes: 1, 2, and 3 (Fig. 2.3). The control class 2 is further divided into two, in which the control class 2B mandates exposure reduction measures (Fig. 2.4). The control class 1 is further divided into three classes, thus distinguishing their “goodness” (Fig. 2.5).

Under the state in the sub-division of control class 2 closest to the control class 3 in the rough classification, nearly half the workers exceed the occupational exposure limit. Since this situation is generally not preferable, reduction measures should be undertaken (please refer to Appendix 18).

In the recent exposure assessment methods used in Europe and the USA (the AIHA method and the EU method), the condition “OEL ≤ X₅₀” is defined as “control measures required” (2, 3). Thus, the control class 2 is further divided into the control classes 2A and 2B on the border of “50% of OEL,” in which the control class 2B essentially requires exposure reduction measures (Fig. 2.4).

In the case that the number of samples is around five, the reliability of results is not so good. As described earlier, depending on the sampling method it may not be
6. Risk Reduction Measures

6-1 Formulation of control measures and order of priority

Risk reduction measures are required as determined by the control class. As a general rule, a risk assessment supervisor is the person to report the results of exposure assessment and monitoring to the manager. The supervisors are also in the position of recommending the design of control measures. On the other hand, the responsibility for formulating and undertaking the control measures following any recommendations lies upon the manager. In addition to simply reporting and recommending, the risk assessment supervisor is also expected to actively assist the manager in the workplace by devising and also by advising upon effective and reasonable control measures to adequately meet the circumstance of the workplace based on his/her expertise and experience. In order that they may be highly practicable, it is important that the control measures advised incorporate the opinions of both the manager and the affected workers. It is also advisable to complete the above process before preparing the final report, thus allowing its results to be included in the report.

The exposure prevention measures shall start with the workplace environment control, followed by work control. In line with the above, health management and dissemination and education shall be implemented as appropriate (Table 2.8). Use of personal protective equipment is the “last resort.” The above order of priority is the basis for occupational hygiene control which does not depend on the assessment or the monitoring method (personal exposure monitoring, area monitoring, etc.) In Japan, this concept has become widely known in recent years. In Europe and the USA, it is prevalent and long established. It is sometimes said that “work control is performed when personal exposure monitoring has been conducted.” Such an idea is far from correct. Even in the case of personal exposure monitoring the order of priority remains unchanged; it is primarily workplace environment control, and then work control (please refer to Appendix 20).

6-2 Relationship with health management

As part of risk reduction measures, health management shall be implemented by an occupational physician as deemed appropriate (Table 2.8).

As the procedure for special medical examination for organic solvents and specially regulated chemical substances is stipulated by laws and regulations, verification of the health status is described here.

Personal exposure monitoring is the most basic and important means of determining the magnitude of health risk. It can be said that performing health management (the verification of health conditions, biological monitor-
ing (if possible), and continuous monitoring) on a similar exposure group (SEG) judged to have high exposure as a result of personal exposure monitoring-based exposure assessment is the reasonable risk-based procedure.

For example, if it is revealed that an SEG has large exposure (control classes 2B or 3) after undergoing the first personal exposure monitoring (eight-hour monitoring), it is recommended that the health conditions of all the workers belonging to the SEG be quickly examined. In this case it is obviously necessary to proceed with permanent risk reduction measures in parallel (according to the prescribed order of priority (Table 2.8)). For an SEG in which the control classes 2B or 3 continue in eight-hour exposure, it is also recommended to periodically verify the condition of health. For these control classes, the exposure reduction measures shall be performed as per the workplace environment control or work control. However, in special circumstances, workers wearing respiratory protective equipment may also be involved in the work. In such a case, the following idea is pursued: since the protection provided by such respiratory protective equipment is never complete, due to effects such as the protection factor of respiratory protective equipment, wearing or not wearing such protective equipment (it is not necessarily worn in time of need), wearing it appropriately, as well as losing the seal during its use, health conditions should be verified for safety.

Meanwhile, from the standpoint of reasonable risk-based judgment, performing active health management for an SEG with low exposure (control classes 1C to 1A) is not particularly meaningful.

Additional explanations concerning personal exposure monitoring and health management are indicated in the appendix (please refer to Appendix 21).

Conflicts of interest: None declared.

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