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BSI Standards Publication

Workplace atmospheres — Guidelines for selecting analytical methods for sampling and analysing isocyanates in air

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National foreword

This Published Document is the UK implementation of ISO/TR 17737:2012. It supersedes PD ISO/TR 17737:2007 which is withdrawn.

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A list of organizations represented on this committee can be obtained on request to its secretary.

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TECHNICAL REPORT

ISO/TR 17737

Second edition
2012-09-15

Workplace atmospheres — Guidelines for selecting analytical methods for sampling and analysing isocyanates in air

Atmosphères des lieux de travail — Lignes directrices pour la sélection des méthodes analytiques d'échantillonnage et d'analyse des isocyanates dans l'air

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Foreword

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In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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ISO/TR 17737 was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 2, *Workplace atmospheres*.

This second edition cancels and replaces the first edition (ISO/TR 17737:2007), which has been technically revised.

TECHNICAL REPORT **ISO/TR 17737:2012(E)**

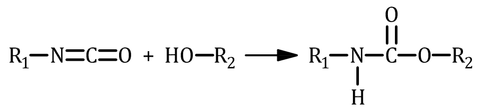
Workplace atmospheres — Guidelines for selecting analytical methods for sampling and analysing isocyanates in air

1 Scope

This Technical Report provides industrial hygienists, employers and workers with a broad overview of isocyanates, their uses in industry, methods of measurement and guidance on choosing the appropriate sampling strategy. While not all issues can be addressed here in detail, this Technical Report discusses areas of concern to alert the industrial hygienist, employer and worker involved with the use of isocyanates to the importance of sampling and the key issues involved in choosing a sampling strategy for their workplace, and directs them to seek further information on the topic(s) of concern.

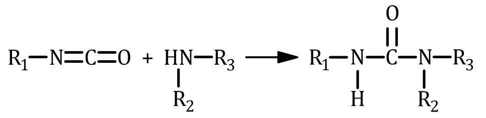
2 Isocyanates

Isocyanates are compounds which contain one or more –N=C=O functional groups attached to an aromatic or an aliphatic molecule. Compounds containing nucleophilic groups with active hydrogen react readily with isocyanates, as in the reaction with primary and secondary amines to form urea compounds and the reaction with alcohols and phenols to form urethane compounds.



$$R_1-N=C=O + HO-R_2 \longrightarrow R_1-\underset{H}{N}-\overset{O}{\overset{\|}{C}}-O-R_2$$

a) Reaction with an alcohol to form a urethane



$$R_1-N=C=O + \underset{R_2}{HN}-R_3 \longrightarrow R_1-\underset{H}{N}-\overset{O}{\overset{\|}{C}}-\underset{R_2}{N}-R_3$$

b) Reaction with an amine to form a urea

$$R_1-N=C=O + H_2O \longrightarrow R_1-NH_2 + CO_2$$

c) Reaction with water to form the corresponding amine

Figure 1 — Reactions of isocyanates

Exposures to isocyanates may result in respiratory disorders and dermal sensitization and are one of the main causes of occupational asthma. As a result, isocyanates are among the compounds with the lowest occupational exposure limits (OELs), the maximum exposure level recommended to avoid unreasonable risk of disease or injury. Their presence in different exposure situations must be monitored.

3 Where are isocyanates found in industry?

Isocyanates with a functionality (number of –N=C=O groups) of two or more are used in the production of polyurethanes (PUR). The most common isocyanates used in the production of flexible and rigid PUR foams are the aromatic methylenediphenyl diisocyanate (MDI) and toluene diisocyanate (TDI). The two major aliphatic isocyanates, which are used predominantly in coatings and elastomers, are hexamethylene diisocyanate (HDI) and isophorone diisocyanate (IPDI).

Within industry, technical grade isocyanate products are mainly used. In most cases, these products consist of different monomeric isomers and oligoisocyanates that have different functionalities, and are often referred to as polyisocyanates of the diisocyanate monomer. The most frequently used TDI products consist of two isomers, 2,4- and 2,6-TDI. Technical MDI products, often referred to as polymeric MDI (pMDI), are mixtures of monomeric MDI isomers and higher molecular mass polyisocyanates. Technical HDI products used in applications such as spray-painting typically contain less than 1 % of the HDI monomer, with the major components HDI isocyanurate and/or HDI biuret and oligomers thereof. Another route to polyisocyanate production is the reaction of di- or polyfunctional alcohols with an excess of isocyanate molecules, which results in prepolymer mixtures of isocyanates. In addition to improved chemical handling properties, prepolymers also reduce the risk of exposure to vapours from the isocyanate by reducing the amount of monomer present in the product.

Examples of workplaces in which isocyanates are intentionally used as part of an industrial process, and of other workplaces in which isocyanates could be unintentionally produced during a process or activity are shown in Table 1. Some of the processes employ “cold” handling in which no external heat is required to complete the work. Other processes are termed “hot” handling and require either outside heat to accomplish the work, or produce heat as part of the process or activity.

Table 1 — Examples of activities/industries where isocyanates are used and/or generated

Activity/industry	“Cold” handling	“Hot” handling
Automotive industry, ships, aircraft and trains	Painting, filling, sealing, windscreen assembly, bonding, manufacturing of composites, roofliner pressing, acoustic panel processing, truck bed lining	Cutting, welding, grinding, windscreen removal, removal of underseal
Building	Sealing, bonding, painting, caulking, floor and wall coverings, insulation and roofing	Handling of mineral wool, mat welding, copper pipe welding, paint removal, pipe insulation
Clothing and leisure industry	Manufacture of PUR-textile, shoes, sports grounds and equipment	Flame lamination
Electrical and electronics	Packaging, gluing, casting	Soldering circuit boards, connecting optical fibres and varnished wires, cable insulation, heating Bakelite™ [a]
Paint industry	Manufacturing, automotive and industrial painting	Removal of paints and varnishes with heat
Foundry	Manufacturing of cold-box cores	Manufacturing with hot-box technique, casting cores and shell sand
Graphic trades	Manufacturing of printing inks, lamination	Curing, lamination
Foodstuffs	Food packaging	Repair of conveyors, heat sealing of packaging materials
Plastics industry	Manufacture of foam, automotive fittings	Hot wire cutting
Tunnelling and mining	Sealing, rock consolidation	Self-ignition may occur
Wood and furniture	Manufacture of composite wood panels, use of adhesives, varnishing, upholstery padding, painting	Pressing, cutting and routing, removal of paints and varnishes with hot air gun
Engineering	Gluing, manufacture of elastomers, painting, insulation, fixatives	Repairs and removal of polyurethane materials with heat

[a] Bakelite is the trade name of a product available commercially.

Table 1 *(continued)*

Activity/industry	"Cold" handling	"Hot" handling
White goods industry	Manufacture of refrigerators and freezers (PUR insulation), painting	Mineral wool insulation – Quality assurance (QA) checks, repairs
Medical care	Bandaging, casting, filling, equipment	
Fire extinguishing		Mineral wool, polyurethane in furniture and interior fittings

[a] Bakelite is the trade name of a product available commercially.

4 Airborne isocyanates

Airborne isocyanates in workplace atmospheres can occur both in the gas and particle phase. The distribution depends on the physical properties of the isocyanate and on the nature of the work tasks that introduce isocyanates into the air. Monomeric TDI and HDI have vapour pressures (at room temperature) that are sufficient to contribute to air levels of gas-phase isocyanates above the OELs; whereas MDI, adducts of HDI, and prepolymers have vapour pressures that are much lower and, consequently, the gas phase levels will be lower than the OELs (at room temperature). If aerosolization occurs, the air concentrations can be higher than the OEL even if the vapour pressures are low. Airborne particles containing isocyanates can also contain polyols and other ingredients of the formulation that can react with the isocyanates (reacting aerosol).

Polyurethanes start to thermally degrade at temperatures above 150 °C to 200 °C, possibly resulting in the emission of monomeric diisocyanates, monoisocyanates, aminoisocyanates, and amines both in gas and particle phases. Like polyurethanes, urea based resins can also release isocyanates when heated and material safety data sheets may not contain sufficient information regarding compounds that can be formed during thermal decomposition.

5 Alternatives for sampling

5.1 General

Great care must be taken to ensure that representative samples are collected. The analyst and/or industrial hygienist must consider the physical state of the isocyanate(s) likely to be present in the atmosphere being sampled. For example, the isocyanate(s) may be present as a vapour and/or aerosol, or the isocyanate may be coated on another medium, e.g. wood dust. All of the above must be considered when selecting a method for monitoring workplace exposures.

The mechanisms for sampling compounds in the gas and particle phase differ. Gas phase isocyanates are sometimes sampled by molecular diffusion as discussed in 5.6 and Clause 6. Air which may contain isocyanate aerosols, particles coated with isocyanates, and/or isocyanate vapors is often sampled using reagent-coated filters (or other coated substrates) either alone or in combination with impingers containing reactive reagents.

5.2 Impregnated filters

Filter sampling with a filter impregnated with a derivatizing reagent is commonly used for the collection of isocyanates. Both gas and particle-borne isocyanates can be efficiently collected. However, in some circumstances when collecting particles, incomplete derivatization with the reagent may occur due to the presence of other reactive species in the particle. In these instances, field extraction immediately after sampling improves the derivatization and minimizes problems with interfering reactions. If the physicochemical composition of the air being sampled is unknown, samples should be collected using an impinger containing a derivatizing agent with filter backup (5.3). Reagent-impregnated filters are recommended for gas-phase isocyanates.

5.3 Impinger (and filter)

Sampling with a typical industrial hygiene midget impinger containing a derivatizing agent followed by a reagent-coated filter [except for di-*n*-butylamine (DBA)] in series enables the collection of gas- and particle-phase isocyanates. Isocyanate-containing particles < 2 µm are poorly collected by impingers; however, they are efficiently collected by the filter. (Examples of particles < 2 µm are condensation aerosol formed from cooling of isocyanate vapour, combustion/thermal degradation aerosol and, to some degree, paint-spray.)

In situations where the physicochemical nature of the atmosphere is unknown, use of the impinger–filter combination is the most appropriate approach to ensure that the widest range of isocyanate species is efficiently collected and derivatized. If the nature of the aerosol is known and a negligible fraction of particles < 2 µm are present, sampling can be performed (simplified) without a filter in series. Collected particles are dissolved and derivatized.

Impinger sampling is cumbersome and there is a risk of breakage and spillage. In addition, impinger solvents are often volatile (such as toluene), limiting sampling time and generating solvent vapour in the vicinity of sampler. Impinger/filter is the recommended sampler when sampling a reacting aerosol.

5.4 Sorbent tubes

Historically, a small glass cylindrical tube packed with an inert support, e.g. glass powder, glass wool, or an adsorbent material that has been impregnated with a derivatizing agent, is used. This technique is primarily for vapour-phase isocyanates. Impregnated sorbent tubes require a reagent-coated filter at the front or at the back for collection of both gas and particle-borne isocyanates. For efficient derivatization, the tube needs to be extracted immediately after sampling.

5.5 Denuder filter

A denuder sampler consists of a cylindrical tube, and as air flows through the tube, the gaseous molecules diffuse from the air stream to the walls, where they either are adsorbed or react with a reagent coating. The majority of the particulate phase in the air stream passes through the denuder unaffected and is collected on a reagent-coated filter. If the tube is coated with a suitable derivatizing reagent and subsequently analysed, the sampler can be used to separate vapour and particle phase species; however, the limitations previously explained under impregnated filters (5.2) in the presence of reacting aerosols also apply to this technique.

5.6 Diffusive sampling

A reagent-impregnated filter or other absorbing material is placed behind a membrane or diffuser. Gas-phase isocyanates diffuse at a certain rate towards the reagent. The simple design makes it desirable for personal sampling, but diffusive samplers are suitable for monitoring isocyanate vapours only. Some diffusive sampling badges enable measurement in the field immediately after sampling. Other diffusive samplers require laboratory analysis analogous to filter and impinger samples.

6 Direct reading instruments

Several direct reading paper tape instruments are available where air is sampled continuously on a reagent-impregnated paper tape. The developed colour is optically read or stored in memory for future retrieval. Instantaneous and long-term exposure profiles can be derived using paper tape instruments; however, measurement uncertainty may be large. Generally, direct reading instruments are calibrated for the monomer and are only suitable for quantifying isocyanates in the vapour phase but they are not specific and will not differentiate the monomers if a mixture is present. The range of these instruments may vary and require a separate calibration for each isocyanate; however, all have adequate sensitivity, i.e. to measure below the OEL, and are convenient to use.

The paper tape technology has been adapted in a variety of techniques for a quick “yes/no” answer in many critical situations. Some examples are listed below.

- The **portable active spot colourimetric sampler** is a spot sampling device that can be used for measuring vapour and, qualitatively, condensation aerosol levels of isocyanate compounds such as MDI, TDI, or HDI down to 1×10^{-12} (1 pl/l). In operation, a test card with the reactive paper tape is placed in a holder while a pre-calibrated pump pulls a measured air sample through it (5 min). The intensity of the resulting colour stain is directly proportional to the concentration of isocyanate vapour present. The developed stain is visually matched against a concentration comparator/calculator, providing a readout of volume fraction in pl/l.
- **Diffusive badges** are commercially available for both short- and long-term personal monitoring of some isocyanates. The stain developed on the diffusive badges can be read using visual colour comparators or an optical densitometer for better accuracy and reliability. The considerations mentioned for the paper tape instruments also apply to badges.

Ion mobility spectrometers (IMS) are also used for the online analysis of workplace air; however, they are only suitable for quantifying isocyanates in the vapour phase.

7 Short description of five proposed and/or adopted methods for airborne isocyanates

Summaries of the following proposed and/or adopted isocyanate sampling and analytical methods are shown in Table 2. Methods judged to possess the listed sampling and analytical features are denoted with a “+” symbol and those that do not possess the feature are denoted with a “-” symbol. Methods which could not be clearly judged to possess or to not possess certain features are assigned a “±” symbol.

7.1 DBA method

ISO 17734-1, *Determination of organonitrogen compounds in air using liquid chromatography and mass spectrometry — Part 1: Isocyanates using dibutylamine derivatives*

ISO 17734-2, *Determination of organonitrogen compounds in air using liquid chromatography and mass spectrometry — Part 2: Amines and aminoisocyanates using dibutylamine and ethyl chloroformate derivatives*

The sampler consists of an impinger containing a toluene solution of DBA with a glass-fibre filter placed in series after the impinger. Solvent-free sampling is performed using a sampler consisting of a tube with an inner wall coated with a filter, coupled in series with a filter. The filters are impregnated with equimolar amounts of DBA and acetic acid, which reduces evaporation of the volatile DBA.

7.2 Double-filter method

ISO 17736, *Workplace air — Determination of isocyanates in air using a double-filter sampler and analysis by liquid chromatography*

The sampler is a two-stage filter sampler where the first stage is a polytetrafluoroethylene (PTFE) filter which physically traps airborne particles and is subsequently immersed in MP solution to derivatize (stabilize) any trapped isocyanate species immediately after sampling. The second stage consists of a glass-fibre filter (GFF) impregnated with 9-(methylaminomethyl) anthracene (MAMA) positioned after the PTFE filter, where any isocyanate vapours present in the air sample are instantaneously derivatized. Similar to other filter methods, both gas and particle-borne isocyanates can be efficiently collected; however, because the first stage filter (PTFE) is devoid of any derivatizing reagent (to stabilize the isocyanate) the sampler should not be used where there are possibilities of trapped isocyanate species reacting with other compounds, e.g. sampling reacting aerosols or sampling for prolonged periods.

7.3 MAP method

ISO 17735, *Workplace atmospheres — Determination of total isocyanate groups in air using the 1-(9-anthracenylmethyl) piperazine (MAP) reagent and liquid chromatography*

Depending on the environment to be sampled, the sampler can consist of a MAP-impregnated filter, an impinger containing a solution of MAP in butyl benzoate, or a MAP impinger followed by a MAP-impregnated filter.

7.4 MP method

ISO 16702:—[1], *Workplace air quality — Determination of total organic isocyanate groups in air using 1-(2-methoxyphenyl)piperazine and liquid chromatography*

The sampler consists of an impinger containing a toluene solution of 1-(2-methoxyphenyl)piperazine (MP) with an MP coated filter placed in series after the impinger. Solvent-free sampling is performed with a glass-fibre filter coated with MP.

7.5 PP method

ISO 14382, *Workplace Atmospheres - Determination of toluene diisocyanate vapours using 1-(2-pyridyl) piperazine-coated glass fibre filters and analysis by high performance liquid chromatography with ultraviolet and fluorescence detectors.*

The sampler is a glass fibre filter impregnated with 1-(2-pyridyl)piperazine (PP).

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1) To be published. (Revision of ISO 16702:2001)

Table 2 — Summary of isocyanate sampling/analytical methods

	Method				
	DBA	**Double-filter**	**MAP**	**MP**	**PP**
Sampling:					
Phase separation (vapour/particle)	±	+[a]	–	–	–
Efficient collection (small particle)	+	+[b]	+[b]	+[b]	+[b]
Non-impinger version available [c]	+	+	+	+	+
Maximum sampling time (hours)	0,25 - 8[d]	0,25	10	0,25 - 8[d]	0,25 - 4
Accurate analysis of:					
Unknown species (identification) [e]	+	±	±	±[e]	–
Low-molecular mass species(e.g. methyl NCO) [f]	+	±	±	±	–
Unstable species	+	+[g]	+	+	+
Volatile species	+	+[a]	+	+	+
Large particles	+	+[h]	+	+	+[l]
Amino isocyanates	+	–	–	–	–
Pre-polymers	–	–	–	–	–
NCO group (direct measure)	+[i]	–[e]	+[j]	+[k]	–

[a] Volatile aerosols initially captured on the front filter can be lost to the second filter. Though phase separation is lost, the volatile isocyanate species are detected on the second filter. Similarly, active interferences (e.g. alcohols) may, in isolated instances, react with non-derivatized isocyanates on the first filter, even with short sampling times.

[b] All the methods employ a final filter to reduce impinger losses of smaller particles. The filter must be desorbed in the field.

[c] Filter-based methods are more convenient to use. However, for some low molecular mass isocyanates, impinger methods may be less prone to vapour breakthrough. The double-filter method is already a non-impinger method.

[d] The short time in the range refers to the impinger version of the method. The long time period refers to the filter (no impinger) version. A non-volatile solvent (as in the MAP method) provides for a longer sampling time than impinger methods using volatile solvents.

[e] The MP and MAP methods were designed for NCO functional group concentration measurement. Unknown species can be identified if a MS detector is used during MP analysis. The double-filter method was designed to measure specific isocyanates.

[f] Methyl isocyanate and isocyanic acid can be readily determined by the MP method, providing a backup filter is used.

[g] The double-filter method is designed for short-term sampling with field extraction and would therefore only account for species that are stable over the sampling period.

[h] The filter must be extracted (desorbed) in the field to prevent loss of isocyanate-containing large particles.

[i] The DBA method relies on MS and deuterated internal standards for calibration.

[j] MAP-isocyanate derivatives exhibit a constant UV response for NCO-group measurement. The introduction of a second independent detector can be used to identify isocyanates.

[k] The MP method uses two independent detectors (UV and EC) for identifying isocyanates. In addition, MS detectors can also be used, providing reference materials of the pure derivatives are available.

[l] The PP filter can be extracted in the field if large particles are suspected to be present.

8 Analysis

A number of methods and techniques are available for analysing isocyanates in workplace samples. The majority of these methods including all of the current/proposed International Standards for monitoring isocyanates in the workplace, are based on the derivatization of isocyanates with amine reagents to form stable non-volatile urea derivatives. After sampling and following a number of extraction and/or preconcentration stages, liquid chromatography is used to separate the urea derivatives. Detection is accomplished using ultraviolet, electrochemical, fluorescence or mass spectrometric detectors. Isocyanate-derived peaks are qualitatively identified by their retention times, spectra, and/or detector response ratios and quantitatively determined by their peak areas or peak heights. Quantitation of the isocyanate derivatives can be complicated by the lack of characterized and commercially-available reference standards that have been prepared with the correct reactive reagents.

9 Interferences

Isocyanates are highly reactive. If compounds are present in air that can react with isocyanates, these compounds can compete with the derivatization reagent, causing inaccurate analyses especially at high concentrations. Such compounds are primary and secondary amines, alcohols, water, or other compounds with active hydrogens. Solvent-free sampling may be more affected by competing reactions than wet sampling. Reacting aerosols contain compounds that can compete with the derivatization reagent.

Other compounds may react with the derivatization reagent, such as anhydrides. Derivatives formed from such reactions may be mistaken for derivatized isocyanates leading to an inaccurately high analysis results.

10 Other sampling and analytical considerations

During the last few years, increased knowledge regarding the sampling of airborne isocyanates led to better understanding of the issues involved. In many cases, the sampling is routine and more or less straightforward. However, there are a few problematic areas remaining; examples of these are given below.

- For some isocyanate products, the “true” unreacted isocyanate content (determined by back titration with standard hydrochloric acid of DBA added to an isocyanate test mixture) corresponds poorly with the measurement of free isocyanates made using the current analytical procedures. If the isocyanate species present in air is known, the biased air concentration estimates can be corrected.
- If an application employing prepolymers is to be monitored, a sample of the bulk prepolymer may help the analytical laboratory to enable quantification measurements.
- The methods in this guide were developed for airborne isocyanate levels around the OEL. The individual methods specify sufficient excess derivatisation reagent to provide an adequate safety margin for valid sampling at air concentrations somewhat greater than the OEL. There may be occasions when extremely high concentrations of isocyanates are sampled for extended times and sampling results may not be valid because the reagent was consumed to a point where it was no longer effective.

11 Other considerations

Good quality product stewardship is necessary to ensure safe handling of isocyanates. Workplace air measurements may be misleading if representative sampling is not performed. It is important to assess all possible routes and work tasks where there is a potential for exposure, such as infrequent or intermittent handling of isocyanates, cleaning of equipment, maintenance, heating, filling isocyanate containers, etc. It is equally important to assess and be aware of the efficiency of control measures, e.g. respiratory protection devices, ventilation controls, etc. Appropriate personal protective equipment, e.g. overalls, gloves, etc., should always be used whenever isocyanates are handled or used to reduce the risk of dermal exposure. Workers may become skin-sensitized after dermal exposure.

There are several different approaches for the monitoring of isocyanates. Monitoring to demonstrate compliance with national OELs is typically performed using personal samplers. Measurements to minimize exposure (checking of ventilation, etc.) are generally performed by both stationary (area) and personal sampling. If the nature of exposure is not known or if thermal decomposition products or reacting aerosols may be significant, more sophisticated sampling and analysis may be necessary to characterize the different kinds of isocyanate species present. Reacting aerosols are also problematic due to the possible creation of a variety of different isocyanate containing compounds for which reference compounds (necessary for the analysis) are unlikely to be available. For the analytical laboratory involved, it is essential to have access to the material safety data sheet(s) for the isocyanate(s) handled.

In addition to this document, other information regarding sampling and analysis of isocyanates in air is presented in Determination of Airborne Isocyanate Exposure: Considerations in Method Selection.[1]

Once the broad features of the exposure potential are known, sampling and analysis can be simplified. However, changes to the production process (e.g. use of different formulations, modification to the process line, etc.) may require new measurements.

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[1] Streicher R.P., Reh C.M., Key-Schwartz R.J., Schlecht P.C., Cassinelli M.E., O'Connor P.F. Determination of Airborne Isocyanate Exposure: Considerations in Method Selection. *AIHAJ*. 2000, 61 pp. 544–556

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