

Latex sensitivity: An industrial hygiene perspective

John E. Reiter, CIH *Menomonee Falls, Wis*

As a result of the increase in latex product manufacturing and use during the last 10 to 13 years, latex sensitivity has become an important health issue. Requests for evaluation and control of potential exposure to latex allergens have prompted questions about how to best sample surfaces and the air for the presence and concentration of latex allergens, a search for reasonable occupational exposure limits, and means and methods of control or remediation. In this article, evaluation of latex allergens on surfaces, in residual dust, and in the air is discussed. Interpretation and application of reasonable suggested occupational exposure limits and the need for additional research in this area are also discussed. Suggestions for control and remediation are based on successful programs and projects resulting in elimination of latex and residual latex allergens in health care settings. Measurement of latex allergens on surfaces and in the air and comparison with suggested occupational exposure limits are viable means of risk analysis, and control and remediation can be successful, permitting sensitized individuals to return to the workplace. (*J Allergy Clin Immunol* 2002;110:S121-8.)

Key words: Latex, allergen, sensitization, industrial hygiene, remediation

The practice of industrial hygiene as it applies to latex sensitivity and risk analysis includes some standard field sampling and evaluation techniques, as well as relatively new analytic techniques. Reasonable recommended exposure limits exist, although descriptions of the occupational dose-response relationship are somewhat generic. Control measures to eliminate or reduce worker exposure to latex allergens are common, easily performed, and successful in reducing latex allergen exposure, permitting sensitized workers to return to the workplace.

This article includes discussion of industrial hygiene evaluation requirements and techniques necessary to provide adequate samples to the laboratory for analysis and to report lower limits of detection in nanograms per cubic meter of air or nanograms per gram of dust. It also includes a discussion of the application of recommended occupational exposure limits (OELs) and the need to cultivate those limits into values with stronger correlation to

Abbreviations used

ACGIH:	American Conference of Governmental Industrial Hygienists
HEPA:	High-efficiency particulate air
IPA:	Isopropyl alcohol
NIOSH:	National Institute for Occupational Safety and Health
NRL:	Natural rubber latex
OELs:	Occupational exposure limits
OSHA:	Occupational Safety and Health Administration
PTFE:	Polytetrafluoroethylene

the dose-response relationship of latex in humans. Control techniques and methods to reduce or eliminate latex exposure in health care settings are discussed. Two case studies illustrating the success of these control or remedial techniques are included.

METHODS

This discussion of an industrial hygiene perspective on latex sensitivity is largely based on research and industrial hygiene experience, bringing industrial hygiene technology, methodology, and expertise together with the current medical research on latex sensitivity. The industrial hygiene aspects are based primarily on standard industrial hygiene practices and modifications necessary to accommodate the especially significant sensitivity required for reasonable analytic detection and precision.

DISCUSSION

With the increased use of natural rubber latex (NRL) since about 1987, there has been an increase in reported NRL allergies, primarily in the health care industry, but also in general industry where latex gloves are used and in manufacturing operations that use NRL in production operations. These include manufacturers of gloves, balloons, rubber bands, boots, shoes, protective apparel, and other such products.¹ These allergy cases have ranged from allergic contact dermatitis (type IV delayed hypersensitivity) to anaphylactic shock as a result of severe respiratory sensitization and acute response (type I immediate sensitivity).¹⁻³ The causative agents in these cases have been identified as NRL proteins, which initiate sensitization to NRL and then cause an allergic reaction on future dermal or mucosal exposure.^{4,5}

In an industrial hygiene evaluation of latex sensitivity, the following factors are considered: (1) NRL has the toxicologic capability of causing dermal and respiratory sensitization; (2) skin absorption, as well as inhalation, may cause an allergic reaction^{4,5}; (3) allergy may progress from type IV hypersensitivity to more severe type I im-

From Kisco, Inc, Menomonee Falls, Wisconsin.

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Reprint requests: John E. Reiter, CIH, President, Kisco, Inc, N80 W14038 St George Ct, Menomonee Falls, WI 53051.

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diate sensitivity⁶; (4) sampling can be conducted for conditions that may lead to exposure by skin contact and inhalation; (5) a dose-response relationship describing worker exposure and a measurable biologic response exist⁷; and (6) control measures can be implemented to reduce or eliminate potential employee exposure.

Evaluation of potential exposure to latex allergen requires application of new and modified air and surface sampling technology and techniques. This evaluation also requires a working knowledge of the toxicologic correlations between occupational and measured exposures and the symptoms of human response. Because of the need to monitor allergen concentrations much lower than those found in typical industrial hygiene applications, different air monitoring instrumentation and different analytic procedures for these small concentrations have been developed. Also, surface sampling requirements for latex allergen are somewhat different from those for heavy metal or other more commonly encountered surface contamination.

For many common occupational allergens, much is known about the dose-response relationship of the compounds as they affect the worker through acute and long-term exposure. These are expressed in terms of occupational exposure as permissible exposure limits (Occupational Safety and Health Administration [OSHA]),⁸ threshold limit values (American Conference of Governmental Industrial Hygienists [ACGIH]),⁹ recommended exposure limits (National Institute for Occupational Safety and Health [NIOSH]),¹⁰ and other governmental (domestic and foreign) or agency standards. In cases in which occupational sensitizers such as toluene diisocyanate have OSHA and ACGIH OELs, these limits account for sensitivity, are generally based on the possibility of sensitization, and support the theory that a dose-response relationship exists for sensitizers.¹¹ For these sensitizers, the trend has been to set a single OEL below which no biologic response is expected, even though the concentration range that is believed to trigger the initial sensitization mechanism is thought to be 2 to 3 orders of magnitude greater than the concentration at which an allergic reaction may occur in an individual previously sensitized. This is a reasonable approach when the lower limit chosen is readily measurable and controls can reduce exposure to that limit.

After evaluation and interpretation of sample results and a determination that the potential exists for exposure and sensitization reactions to occur, control methods must be implemented to reduce or eliminate exposure to latex allergen. Traditional industrial hygiene control measures are applicable and successful in reducing exposure. These include removal of the causative agent and replacement with nonlatex substitutes; administrative controls such as creation of latex-free "zones" in facilities where only nonlatex products may be used; changes in formulation to eliminate NRL; changes in manufacturing to minimize protein, dust, and powder from gloves and other latex products; installation of ventilation systems in industrial settings where latex is used as part of

the manufacturing process; use of skin and respiratory protection; and clean-up or remediation techniques designed to remove dust and surface contamination that includes latex allergen particulate.

Evaluation: Air and surface sampling

As with all other occupational health concerns, the chemical and physical nature of the causative agent must be understood, as well as the toxicologic potential of the agent. A trio of needs must be fulfilled: (1) how exposure, which may result in biologic response, occurs; (2) how the agent may be analyzed; and (3) how it may be sampled in the field. The chemical and physical nature of the product and the manner in which the product is used determine how exposure may occur and how the causative agent may be analyzed. This in turn plays a significant role in determining how the agent must be sampled in the field to deliver a sample of great enough size to be accurately and precisely analyzed and how it must be obtained so that the causative agent may be easily removed or extracted from the sampling substrate.

Latex allergens are protein particulates present on latex products and on powders present in latex products in the form of aerosolized protein particles; they may also be adsorbed to the surface of powder particles. Exposure may occur through inhalation or skin contact. Some latex proteins are extractable by normal skin moisture.¹² Latex glove use presents the simplest illustration of how the use of a product affects exposure routes and potential. Use of gloves, by their nature and intent, results in direct skin contact. Excess latex allergen and powder (where used), which may have latex allergen adhered to its surface, become easily airborne from donning and doffing the gloves, resulting in airborne concentrations accessible for inhalation. Use of other NRL-containing products results in exposure in similar ways. Direct skin contact occurs when products are handled or worn. Latex allergen that is leached out or off of the surface of the product affects the skin, and absorption through the skin may cause or contribute to an allergic response in sensitized individuals.¹⁰ Dust or powder containing latex allergen may also collect on skin or become airborne. When the latex allergen or dust becomes airborne, inhalation exposure may occur. Another concern when latex allergens and powder become airborne is that these particulates then settle onto surfaces. Skin contact with this settled dust may occur; or the dust may become re-entrained by air movement, ventilation, or human activity in the area, potentially creating a secondary source of airborne latex allergen, which may result in inhalation exposure. This may require clean-up and remediation for a workplace to be safe for sensitized individuals' return. Because of these routes of potential exposure, monitoring for both airborne and surface contaminants should be considered.

Research at least anecdotally supports the idea that it may take a significant acute exposure or a series of lesser long-term exposures to initiate the onset of the allergic mechanism process. Once this process has begun and the

latency stage is completed, it may only require concentrations as low as a few nanograms per cubic meter, or even picograms per cubic meter, to precipitate an allergic response by inhalation.¹⁰ Risk evaluation requires detection of minute concentrations of the allergen in air to effectively evaluate conditions.

Latex allergen protein particulate may be present in the air as individual particles, may be agglomerated with other latex particles, or may adhere to the surface of other particulates.^{4,5,13} Traditional analysis of particulates, collected on a filter medium of polyvinylchloride or mixed cellulose ester and analyzed for total mass, is of little value. Latex allergen must be singled out for analysis, or the analysis must be specific for latex allergen. Particle counting is also of little value because large amounts of latex protein may be attached to large particles. The amount of allergen carried on a droplet of 5 μm may be 1000-fold greater than that carried on a droplet 10 times smaller, or 0.5 μm , but each of these particles would only be counted as a single particle.¹⁴

Based on the chemical and physical characteristics of latex allergen, routes of exposure, and the analytic requirements, the sampling method used must be capable of collecting submicron-sized particles efficiently on a medium from which the latex allergen can be stripped or extracted efficiently. The volume of air sampled must be high enough to provide enough latex allergen particulate for precision analysis with sensitivity in the nanogram-per-cubic meter range.

The apparatus must be portable, and the field activities should not involve critical dispensing, mixing, or other wet chemical means. The sample must remain viable and unchanged during handling and shipping. Interferences must be at least accounted for, and preferably discriminated against, during collection or analysis. The instrumentation used for field monitoring must operate within known precision parameters, reducing systematic error. Air-moving devices must be calibrated to an accuracy of $\pm 5\%$ at a 95% confidence level, and this flow must remain unchanged over the course of sampling. Handling collection media must not introduce error by either addition of analyzable material to or removal of analyzable material from the sample. The entire sampling and analytic process must have an accuracy of 25% at a 95% confidence level.¹⁵

When surface sampling is performed, the analytic methods, particularly the need to retain the sample unchanged during handling and shipping and the need to remove or extract the latex allergen efficiently, must also be considered. As a result of direct handling of surface sampling media during application of some surface sampling techniques, additional care must be taken not to introduce it to or remove it from the sample.

As discussed previously, the analytic needs and techniques dictate the sampling methods and techniques. The current analytic technology receiving the greatest support for its reliability, accuracy, and precision is the immunochemical assay of extracted particulates pioneered at the Mayo Clinic.¹⁴ This technique can reliably

detect and quantitate about 50 ng of allergen per milliliter of buffer solution. It requires sampling high volumes of air in occupational settings where latex allergen may be present from glove use or other ancillary use to collect enough allergen to achieve this detection limit. At these high collection volumes, an analytic sensitivity in the 1-ng/ m^3 range can be reached, which is required to quantitate potential exposure risk.

The ambient air collection technique recommended by Reed et al¹⁴ uses a high-volume air blower to move air across a bilaminate filter consisting of a polytetrafluoroethylene (PTFE) membrane stretched over a polyester-spun support backing. Analysis requires that the PTFE surface be stripped from the backing for direct extraction in buffer. The recommended flow rate is 3 L/s (180 L/min) for 2 to 4 hours, for a total of 21,600 to 43,200 L.¹² This is a significant contrast to ambient samples collected for heavy metals, fibers, or most other particulates. Typical heavy metal, asbestos, ceramic, or other ambient particulate monitoring in the workplace is conducted at 2 to 20 L/min, resulting in typical volumes of 480 to 5000 L. Even high-volume monitoring for other bioaerosols uses flow rates of 1 cubic feet per minute (about 28.3 L/min), and only for a few minutes, resulting in volumes of 100 to 200 L.¹⁶

Personal sampling recommended by Swanson et al¹² uses high-volume personal sampling pumps and PTFE filters operated at up to 5 L/min for 4 to 8 hours. This results in volumes of 1200 to 2400 L. These relatively high volumes contrast with volumes obtained by personal sampling for heavy metals, silica, fibers, graphite, and other materials for which high-volume personal sampling pumps, operated at 1.7 to 2.5 L/min, are used. Typical volumes for these samples are 400 to 1200 L.¹⁶ Only a few personal high-volume air sampling pumps on the market today can achieve 5 L/min for the course of an 8-hour sample.

These high air volumes are required to achieve an analytic sensitivity for the high-volume ambient samples of about 1 ng/ m^3 , and for the personal samples, of about 50 ng/ m^3 . Typically, occupational exposure to particulate contaminants is described in milligrams per cubic meter. For some highly toxic metals, such as cobalt, arsenic, cadmium, chromium VI, and beryllium, OELs are expressed in tenths or hundredths of milligrams per cubic meter or in micrograms per cubic meter.^{8,9} The OELs for sensitizers such as toluene diisocyanate and formaldehyde are expressed as about 5 $\mu\text{g}/\text{m}^3$ to 20 $\mu\text{g}/\text{m}^3$. Latex allergen exposure limits must be expressed as nanograms per cubic meter or concentrations 1000 or more times lower than those of the highly toxic heavy metals and other occupational sensitizers.

Surface contaminant sampling may be accomplished by using 3 techniques. The first technique is simply collection of a bulk sample by using forceps and placing the sample in a sterile container or bag. Bulk samples are qualitative and quantitative. They indicate the presence or absence of latex allergen and may also indicate the concentration of latex allergen in nanograms per gram of dust. The primary disadvantage of this method is that

latex allergen and dust are not always visible, or if visible, they are present as scattered particulates rather than large, easily collected clumps.

A second technique is to wipe the filter media across a contaminated surface, collecting the contaminant on the filter. This method is qualitative, indicating the presence or absence of latex allergen, and may also be semi-quantitative, indicating the concentration of latex allergen per square surface area. It is expressed as semi-quantitative rather than quantitative because of inconsistencies in wiping efficiency. Wetting filters before wiping is not believed to be effective in increasing wipe efficiency because the PTFE filters are not absorbent. Use of filter media other than PTFE requires more buffer to effectively extract latex allergen, which decreases analytic sensitivity. PTFE filters are fragile, tearing easily and pulling the PTFE coating away from the polyester-spun support material when used in contact with rough surfaces or even many surfaces that appear smooth.

A third technique is surface vacuuming, which is applicable for sampling surfaces for other hazardous materials such as lead dust, ceramic fibers, asbestos fibers, and other heavy metal contaminants. This method, developed by the American Society for Testing and Materials,¹⁷ uses a small length of Tygon (Norton Performance Plastics, Wayne, NJ) or vinyl tubing cut at one end at a 45° angle; the square end is attached to the inlet of a filter cassette containing a PTFE filter, which connects the downstream (outlet) end to a length of tubing and a high-volume personal sampling pump. The 45° angle tube and filter are used to vacuum a measured surface area thoroughly. The American Society for Testing and Materials recommends methodically moving the vacuum back and forth across the surface a number of times to increase collection efficiency. The flow rate of the pump is important only in that it must draw contaminant off of the surface and onto the filter. This method has the benefits of being qualitative and less destructive to the filter media compared with wipe sampling. Although it is a better choice than wipe sampling for quantitative evaluation, it is still considered semi-quantitative until vacuum efficiency and loss to the inside surface of the sampling tube are determined by additional research.

Surface sampling is applicable for all surfaces, but not all surfaces may be sampled with all of these techniques. Smooth, nonporous surfaces, such as laminate table tops, vinyl-covered examination chairs or tables, tile and vinyl floor covering, painted walls, paper covering on drywall, and the T-grids of suspended ceilings, may be sampled by using any of the surface sampling techniques. However, carpeting, porous block walls, some wall coverings, textiles, and similar surfaces do not lend themselves to any of the surface sampling techniques other than vacuum sampling. Surface sample results may be expressed as detected versus undetected, nanograms per sample, nanograms per gram of dust, or nanograms per square surface area. For control purposes involving cleanup and remediation, samples expressed in nanograms per square surface area may be of the greatest benefit.

OELs

When health risk for exposure to most industrial hygiene stressors, or causative agents, is determined, it is assumed that a dose-response relationship exists describing the extent of exposure and related biologic response to that exposure level. The implication is that there is some threshold concentration of the causative agent below which no measurable biologic response will occur, and that above that threshold concentration, measurable biologic responses and health effects will occur and can be predicted. OELs are based on this presumption, extrapolated to account for occupational exposure criteria. For time-weighted averages, these occupational criteria are 8 to 10 hours of exposure per day, 40 hours per work week, for the duration of a working lifetime, with 14 to 16 hours of nonexposure time away from the workplace each day. Time-weighted averages are applicable to exposure to compounds that do not cause immediate effects at low concentrations or that do not cause long-term effects with continuous or repetitive low-level exposures. For compounds with these low-concentration toxic capabilities, ceiling limits or short-term exposure limits are more applicable. These limits account for the compounds' abilities to cause harm at low concentrations, which may occur if ceilings or short-term exposure limits are exceeded even briefly.⁹

When OELs exist and are well documented, comparison of sample results with these OELs is simple and often all that is necessary to interpret evaluation data. This is especially true of comparison with regulatory standards such as those promulgated by OSHA or well-recognized industrial hygiene agencies such as ACGIH or NIOSH. The interpretation is less simple when one relies on foreign governmental standards, manufacturers' standards, or other less recognized recommendations. This interpretation is even more difficult when the only data are research data, raw toxicologic data (not extrapolated for human exposure, let alone human occupational exposure), or anecdotal information.

Exposure criteria for latex allergen are presently based on research, toxicologic, and anecdotal information but are not yet cultivated in a manner sophisticated enough to permit simple comparison or to draw a conclusion about whether overexposure is occurring and whether certain biologic responses are expected. However, the occupational exposure data that we do have do correlate well with other research data on sensitization.^{11,18} The exposure data most often cited and recommended are expressed in Table I (M. C. Swanson, Mayo Clinic and Foundation, Rochester, written and oral communication, June 1999 and Dec. 1999).¹⁴

The relative risk levels listed in Table I are described as follows: *low*, should preclude provocation of an allergic response; *moderate*, could cause an allergic reaction in sensitized individuals; and *high*, likely to cause an allergic reaction in sensitized individuals but likely not high enough to cause the onset of the initial sensitization mechanism.

These levels embrace a two-tiered limit (which may be desirable for sensitizers): a fairly high concentration,

below which onset of the initial allergic response mechanism (sensitization) is not expected to begin, and a second limit, set much lower, below which an allergic response is not expected to occur in previously sensitized individuals. The current trend by regulatory and consensus organizations to set an OEL at the lower range is appealing, particularly in light of the ability to sample and detect these minute concentrations predictably and to control exposure to concentrations below these levels.

Although it may not be necessary to apply a two-tiered approach to OEL development, it is desirable to have knowledge of acute exposure potential, perhaps a one-time exposure to very high concentrations that causes onset of the allergic reaction mechanism process to begin and high-concentration long-term exposure potential that also causes onset of the allergic reaction mechanism to begin. Also, values determined from air monitoring are average concentrations for the duration of the sample. Two of the research needs are to determine whether acute exposure to a high concentration should be represented as a ceiling limit and to determine the duration of exposure required at low concentrations to trigger an allergic reaction in sensitized individuals.

Application of recommended OELs

The research community is pursuing definition of the dose-response relationship of exposure to airborne concentrations to measurable biologic response. However, there is still value to application of the current recommended exposure limits in Table I. On the most fundamental level, air sample results can be interpreted as detected versus undetected based on the lower limit of detection of the analytic procedure. For high-volume samples collected as recommended by Reed et al,¹⁴ this would be a detected/undetected cut point of about 1 ng/m³, plus or minus the precision factor expressed by the analyst. However, we know that there is a dose-response relationship even for allergens. This is expressed in the ranges of relative risk (Table I), where it can at least be said that certain measured concentrations are more or less potentially risky than others in causing or triggering an allergic reaction. This is a simple comparative relationship. Further definition of relative risk gives greater meaning to low, moderate, and high risk levels.

During the evaluation phase of an industrial hygiene study, air sample results that exceed 50 ng/m³ should be reported as having a high risk potential for triggering an allergic reaction, and control measures should be implemented to reduce potential airborne exposure. Similarly, air samples indicating a moderate risk potential, between 10 ng/m³ and 50 ng/m³, should be reported as such, and it should be indicated that persons previously sensitized may have some risk of an allergic reaction. The difficulty comes when air sample results of <10 ng/m³ are described. The risk for an allergic reaction is low, but there is still some risk, depending on an individual's immunologic predisposition. This predisposition may include whether a person is primed or in a hypersensitive state. However, the low-risk category still provides a rea-

TABLE I. Recommended exposure limits for latex exposure

Relative risk	Airborne exposure	Dust contamination
Low	<10 ng/m ³	<10 µg/g
Moderate	10-50 ng/m ³	10-100 µg/g
High	>50 ng/m ³	>100 µg/g

sonable goal when engineering controls are implemented to reduce exposure to latex allergen. The focus would be to reduce high and moderate risk conditions to below the upper limit of the low-risk category.

Surface sample results can be similarly interpreted. The values in Table I refer to the risk of exposure by skin contact but can be applied to the potential for re-entrainment and inhalation as well. Certainly, the greater the concentration on surfaces, the greater the inhalation exposure will be if the dust becomes airborne. Risk analysis in the case of possible re-entrainment must include consideration of air currents in the space, ventilation, level of activity in the room, cleaning or lack of cleaning, and use of vacuum cleaners with no high-efficiency particulate air (HEPA) filters.

Controls

Control of latex allergen exposure can be separated into 5 categories. The first category is elimination of latex products and/or latex products containing powder and substitution with other products. This also includes changing formulations in manufacturing processes to eliminate NRL in favor of different polymeric or synthetic products.

The second control category includes engineering controls that reduce the amount of latex allergen that becomes airborne or that is available for exposure to workers, assuming that latex cannot be removed from the process. Such controls include installation of local exhaust ventilation equipment, installation and use of automated systems, construction of enclosures, and latex glove manufacturing refinements. Some of these are common industrial hygiene control measures, which may be more applicable to industry than health care settings.

The third category consists of administrative controls to reduce potential exposure. These administrative controls include the recommendations developed by NIOSH⁶ and the American Academy of Allergy and Immunology¹⁹ and include facility and product controls such as elimination of latex-containing products in specified areas of the facility and placement of sensitized individuals in these areas.

The fourth method of control is the use of personal protective equipment in industrial settings where NRL is used. This includes skin protection and respiratory protection. When these levels of control are unsuccessful, sensitized individuals may need to be removed from the work areas.

In cases in which sensitized personnel are removed, there may be a need to return an individual to the workplace, and replacement of latex products with nonlatex substitutes is unsuccessful in reducing air-

TABLE II. Dental office remediation results

Location/description	Concentration (air [ng/m ³]; surface [ng/sq in])	
	Before remediation	After remediation
Air: north end of front registration office	3	1 (<LLD)
Air: south end of examination room	8	1 (<LLD)
Air: northwest corner of examination room	2 (<LLD)	1 (<LLD)
Air: center of main examination room	12	5
Air sample field blank	ND (<LLD)	ND (<LLD)
Vacuum: upper surface of ceiling tiles, north section of main examination room	32	6
Wipe: ceiling T-grid upper surface	47	30
Wipe: ceiling T-grid upper surface (after recleaning)	30	6
Wipe: visible dust inside radiator cabinet along east wall of main examination room	>4000	19
Wipe/surface sample field blank	59	<30

Air sample results are estimated to be accurate $\pm 25\%$ with a 95% confidence level. Surface sample results are estimated to be accurate $\pm 50\%$ at a confidence level of 95%. All samples are blank-corrected.

LLD, Lower limit of detection; ND, not detectable.

borne latex allergen; thus, the fifth category of control measure, remediation, is required. In cases in which latex products have been replaced by nonlatex products and allergic reactions persist, there may be latex allergen particulate on surfaces and in areas otherwise thought to be clean or at least unexposed. This material may become airborne under certain ventilation or activity conditions, and enough allergen may be present to cause an allergic response.

Remediation is simple but must be thorough to be successful. Studies of dental offices and various offices in hospital settings have led to the discovery of latex allergens on surfaces, embedded in carpeting, in drawers, on shelves, behind cabinets, and even on the upper surfaces of suspended ceilings and the T-grids supporting the ceiling tiles. Literally every surface and space may contain latex allergen particulates.

The ultimate goal of remediation measures is a work space containing no measurable latex allergen particulate on surfaces or in spaces where it could become airborne. Remediation efforts include removal of all moveable items from drawers, shelves, cabinets, countertops, and other surfaces. Of these materials, those that are not used and sterilized regularly should be vacuumed with a HEPA-filtered vacuum, and where applicable, wet-wiped. Success has been achieved with isopropyl alcohol (IPA) as a wiping agent. Latex proteins are reasonably soluble in IPA, and IPA dries a little more quickly than water. Drawer insides, shelves, cabinets, radiator cabinets, heating, ventilating, and air conditioning supply and return grilles, countertops, floors, light fixtures, x-ray equipment, examination tables, and chairs—literally almost every surface—must be HEPA-vacuumed and wet-wiped, except for textiles, carpeting, paper products, and other similar materials, which cannot be wet-wiped.

A two-stage wet-wiping process works well. After HEPA vacuuming is done, the surface is wet-wiped with an absorbent, disposable wipe. After it dries, the surface is wet-wiped again with a new disposable wipe.

After HEPA vacuuming and wet-wiping has been done, surfaces that were found to be difficult to clean should be lightly sprayed with an encapsulant paint. These surfaces include upper surfaces of ceiling tiles, wall cavities and pipe chases, and areas behind cabinets and inside radiator cabinets. The encapsulant, or lock-down, essentially glues any remaining particulate to the substrate, keeping it from becoming airborne again.

Air and surface sampling is generally performed to determine the successfulness of the remediation procedure. Samples are compared with samples taken before the project began, and the level of cleanliness is gauged.

CASE STUDIES

Two case studies are presented to illustrate the success of remediation: a dental practice facility that was already latex-free and a hospital administration office area in which all latex products were eliminated and glove use, storage, and donning or doffing were prohibited.

Dental office

A pediatric dental office was evaluated for airborne and surface latex allergen after an interview with a dentist who had to stop practicing in this facility because of his latex allergy. He was able to work in the office for only a couple of hours once or twice per week without experiencing allergic reactions. Initial sampling determined that airborne concentrations of latex allergen exceeded 10 ng/m³ in one area and were below 10 ng/m³ in the other sampled areas. Because the office had become latex-free some months previously and the dentist still experienced allergic reactions in this space, it was speculated that some areas of the office may have had surface contamination that was becoming airborne. Surface sampling was conducted on carpeting, on examination chairs, inside drawers, under cabinets, behind a large set of cabinets, and above the ceiling on suspended ceiling tiles and T-grids. Table II shows the concentrations of some of these samples before and after remediation.

TABLE III. Hospital administration office: Remediation results

Location/description	Concentration (air [ng/m ³]; surface [ng/sq in])	
	Before remediation	After remediation
Air: corridor outside administration office	6	<1 (ND)
Air: center of administration office	12	<1 (ND)
Air sample field blank	ND (<LLD)	ND (<LLD)
Wipe: east countertop along windows	49	4
Wipe: east shelving under countertop	51	9
Wipe: drawer in storage closet	62	9
Wipe/surface sample field blank	ND (<LLD)	ND (<LLD)

Air sample results are estimated to be accurate $\pm 25\%$ with a 95% confidence level. Surface sample results are estimated to be accurate $\pm 50\%$ at a confidence level of 95%.

ND, Not detectable; LLD, lower limit of detection.

Based on the sample results from the testing conducted before remediation, the decision was made to clean all surfaces, including those inside drawers and on shelves, however; the primary focus would be on the upper surfaces of the ceiling tiles and T-grids and the space behind the large set of cabinets along the east wall. Surface sample results indicated excessively high concentrations of latex allergen behind the cabinets (>4000 ng/sq in) and somewhat high concentrations above the ceiling tiles (just below 50 ng/sq in). The procedures noted previously were used: removal of all stored items, HEPA vacuuming of surfaces, double wet-wiping with IPA, and lockdown of the upper ceiling surfaces and the space behind the cabinet. After cleaning was completed, air and surface samples were collected in the same locations as before. Based on findings from these new samples, air concentrations were acceptable, but some of the ceiling surfaces required recleaning. These surfaces were identified by quantitative wipe sampling, with results expressed in nanograms per square inch of surface area. After recleaning was completed, the sensitized dentist was able to practice once again in his now latex-free office. No subsequent allergic reactions were noted by this dentist in his work area.

Hospital administration office

An urban hospital employed an individual who was diagnosed with a severe latex allergy (type I immediate sensitivity). At one point, she experienced a severe response, which resulted in unconsciousness, during a surgical procedure. The hospital desired to retain this individual's services and determined that she was amicable to a move into an administrative position. The administration office was small, about 650 sq ft. Before this individual was moved into the office, air and surface sampling was conducted, and activities were observed. Air sample results were generally low, and most surfaces were acceptably clean of latex allergen. However, observation of activities revealed that a few boxes of latex gloves were stored there and that workers did occasionally take gloves from this storage area for immediate use. Powder was observed on the floor of this space near the glove storage area.

Before the sensitized individual was moved into the office, all latex products, materials, and stored gloves were removed; a rule was established that nobody would bring into this office any latex products, particularly gloves; and the space was cleaned. The previous surface samples indicated that some countertops, shelving, and drawers had surface contamination. Although the entire space was cleaned, these contaminated areas were given priority. Moveable materials were removed and cleaned by HEPA vacuuming and wet-wiping with IPA. All remaining surfaces were similarly cleaned by HEPA vacuuming and wet-wiping.

Air and surface sampling conducted after remediation indicated that concentrations were below the level of quantification, and the space was deemed acceptable for the sensitized individual to enter for work. No subsequent allergic reactions were noted by this individual in her work area.

Research needs

Toxicologic research should continue, with the purpose of better defining a dose-response relationship that would be applicable to occupational exposure to latex allergen particulate. Researchers should determine whether a resultant OEL should be a two-tiered limit, or if single, whether a low concentration limit would be appropriate, as is the current trend for occupational sensitizers. A two-tiered system would include an upper limit below which the initial onset of the allergic response mechanism would not be expected to be triggered and a lower limit below which previously sensitized individuals would not be expected to experience an allergic reaction. This research should identify whether the upper limit for acute exposure should be a ceiling limit. Research is also required to determine the duration of exposure at various levels for a measurable biologic response to occur. In particular, are time-weighted averages applicable? Will exposure for a full work shift exceeding the lower limit cause an allergic reaction, or would an allergic reaction be expected to occur from only a short duration of exposure exceeding the lower limit? Research is also needed to determine the efficiency of vacuum and wipe sampling and to describe the pre-

cision of the sampling and analytic processes recommended for latex allergen collection and analysis.

CONCLUSIONS

Evaluation of potential exposure to latex allergens by collection of air and surface samples is a readily performed industrial hygiene task. Based on the chemical and physical characteristics of latex allergen particulate, a reliable, accurate, and precise analytic method that is specific for latex allergens has been developed. Based on the needs of the analyst and necessarily high sensitivity requirements, an air sampling protocol has been devised. This method requires drawing air at a rate of about 180 L/min across a PTFE membrane filter supported by a polyester-spun backing. Volumes of air for ambient samples exceed 20,000 L to reach a lower level of quantification of 1 ng/m³. Personal sampling can also be done by using a PTFE filter and drawing air at a rate of 5 L/min for 4 to 8 hours. Volumes for personal samples are 1200 to 2400 L. The lower level of quantification is about 50 ng/m³.

The current OEL suggestions discussed here are appropriate to risk analysis and industrial hygiene interpretation.

Control of latex exposure can be accomplished by substituting nonlatex products for latex products removed from the workplace; administrative controls such as delineating nonlatex zones where sensitized personnel can expect to work without encountering latex; engineering controls such as local exhaust ventilation, process enclosure, and automation; and personal protection in industrial settings with skin protection and respirators.

Remediation of spaces where latex-containing gloves and other materials were used can be successfully accomplished after the latex products are removed and the area has become essentially latex-free. Moveable materials are removed and cleaned with HEPA vacuuming and wet-wiping techniques. Remaining surfaces are HEPA-vacuumed and wet-wiped. Concealed areas and areas where it was difficult to clean surfaces are sprayed with an encapsulating paint to lock down any remaining latex allergen particulate. Cleaning and remediation efforts resulted in air concentrations below 10 ng/m³, and in some cases, below the lower limit of quantification and surface concentrations below 10 ng/sq in. Two case studies have been presented to illustrate how remediation can be successfully accomplished.

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