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Control of Exposure to Airborne Viable Microorganisms During Remediation of Moldy Buildings; Report of Three Case Studies

AUTHORS
Sirpa Rautiala[a,b]
Tiina Reponen[c,d]
Aino Nevalainen[c]
Tuula Husman[c]
Pentti Kalliokoski[a]

[a]University of Kuopio, Department of Environmental Sciences, PO Box 1627, FIN-70211 Kuopio, Finland; [b]Present address: Kuopio Regional Institute of Occupational Health, PO Box 93, 70701 Kuopio, Finland; [c]Kuopio Regional Institute of Occupational Health, PO Box 93, FIN-70701 Kuopio, Finland; [d]Present address: University of Cincinnati, Department of Environmental Health, Kettering Laboratory, 3223 Eden Ave., Cincinnati, OH 45267-0056; [e]National Public Health Institute, Division of Environmental Health, P.O.Box 95, FIN-70701 Kuopio, Finland

Three different techniques for reducing exposure to microorganisms were tested during remediation of moldy buildings. Concentrations of spores (fungi and actinomycetes) were determined by filter sampling before, during, and after remediation. The local exhaust method used for asbestos dismantling was the most effective control method. In the construction zone, concentrations of microorganisms were 4–25 times higher during remediation than before it. In the adjacent area no increase in concentrations was seen. When the construction zone was placed under negative pressure with a fan and isolated with a plastic barrier, concentrations of microorganisms were about 100 times higher there during remediation work. Nevertheless, levels remained low in the adjacent area. The use of a portable exhaust fan with a side-draft hood decreased concentrations of fungi to one-tenth compared with demolition without the control technology. Furthermore, this method prevented the migration of fungal spores from the construction zone to the adjacent area, although it was less effective in prevention of actinomycete spore migration. It also decreased the levels of microorganisms in the construction zone below the preconstruction level within 2 hours. This study showed that levels of airborne microorganisms, including from the working area to adjacent area, can be reduced with commonly used dust control methods during demolition work. However, microorganism levels in the construction zone remained elevated. Therefore, personal protection of construction workers is needed even with control techniques.

Keywords: actinomycetes, building renovation, fungi, indoor air quality

Exposure to microorganisms can cause allergic diseases such as allergic rhinitis, asthma, and allergic alveolitis, and nonallergic health effects such as irritation of respiratory mucosa, skin, and eyes and chronic bronchitis.[1–3] One reason for these health problems is assumed to be actinomycete and fungal spores and their components, such as allergens and mycotoxins.[4] Mycotoxins are secondary metabolites that have been isolated from the spores of certain toxigenic fungi, e.g., *Stachybotrys*.[5] In some working environments, exposure to fungal and actinomycete spores may become especially high. Concentrations of total (viable and nonviable) spores up to 10^{10} spores/m^3 have been measured in agricultural environments.[6–9] Concentrations of spores almost as high have been measured in saw mills and during wood chip handling.[10–11]

Concentrations of microbial spores have been shown to increase also during demolition of moldy building materials.[12–14] Even though the microbial levels observed during demolition (10^2–10^7 spores/m^3) are not nearly the same orders of magnitude as have been observed in agriculture during handling of moldy hay, exposure to airborne microorganisms has also been found to increase the prevalence of respiratory symptoms and changes in pulmonary function among construction workers during demolition of

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moldy materials.[15] Furthermore, spores can effectively migrate from construction areas to adjacent areas if no control method is used.[14,16] There are only a few studies of any kind on controlling exposure to airborne microorganisms during remediation of moldy buildings.[17–19] In those studies little information about the concentrations of microorganisms with control techniques has been presented.

This study was carried out to test three different techniques for reducing exposure to microorganisms during demolition of moldy materials. The tested methods are commonly used in construction work to prevent dust exposure and included (1) plastic barrier isolation together with negative pressurization, (2) local exhaust method used for asbestos dismantling, and (3) a portable exhaust fan with a side-draft hood. Concentrations of microorganisms (both fungi and actinomycetes) were measured in the air of the construction zone and adjacent areas. Furthermore, fungi isolated from air samples were identified.

MATERIALS AND METHODS

Sampling Strategy

This study was carried out in three buildings during their remediation. Each building had microbial growth on the surfaces of the building materials, and one of them was contaminated with *Stachybotrys*.

Test 1: Plastic Barrier Isolation and Negative Pressurization

The first control method was tested in an office that had been constructed in the 1960s. The office had suffered from water leaks and was damaged by visible mold growth on a concrete wall (contamination area ~ 1 m²). During the remediation work studied, the contaminated top layer of the concrete wall was removed by grinding. Concentrations of microorganisms were measured the first time before any demolition work was started. Then the construction zone was isolated with a plastic barrier, which was erected from the floor to the ceiling. Negative pressure was created inside the isolated zone with a fan. The exhaust air was blown outside the building. Concentrations of microorganisms were measured simultaneously inside the containment area and immediately outside the containment during the removal of moldy materials. Inside the containment area, where the remediation work was done, both a personal breathing zone sample and a stationary sample were taken, whereas outside the containment only a stationary sample was taken. Stationary samples were taken at a height of 1.5 m as close to the remediation process as possible.

Test 2. Local Exhaust Method Used for Asbestos Dismantling

The local exhaust method used for asbestos dismantling was the second control technique tested. This test was done in the same building (Building 1) as Test 1. This site had an asbestos-containing roof that had been moistened due to leaks from the piping. The roof was visibly contaminated with mold. The study was done during the removal of the old piping and the roof material with an asbestos dismantling technique. The construction zone was again isolated with a plastic barrier. A high-efficiency exhaust fan with a high efficiency particulate air (HEPA) filter was used to remove asbestos fibers and microorganisms during demolition work. The construction workers wore disposable overalls, gloves, and full-mask respirators. Again, a personal breathing zone sample and a stationary sample were taken inside the containment area and a stationary sample was taken just outside the construction zone.

Test 3. A Portable Exhaust Fan with a Side-draft Hood

The third method, a portable exhaust fan with a side-draft hood, was tested in two buildings (Building 2 and Building 3). Building 2 was a row house constructed in the 1980s, where two separate apartments were studied. Moisture problems were mainly caused by incorrect sloping of the ground toward the foundation, which had allowed rain to penetrate into the wooden foundation layers, which lacked a moisture barrier. During the study affected timber was replaced up to the height of 0.5 m from the ground. This renovation was carried out in two adjoining apartments. In the first apartment a high-efficiency (1900 m³/hour) fan with a HEPA-filter was used. The side-draft hood was placed as close to the construction zone as possible, and the exhaust air was removed outdoors. The other apartment was used as a reference; identical work was done, but no dust removal system was used.

Building 3, where a portable exhaust fan with a side-draft hood was tested, was a condominium constructed in the 1950s. It had suffered from roof leaks and had visible mold growth on wall surfaces. The aim of this test was to investigate the concentrations of microorganisms not only in the remediation area but also in the adjacent area during demolition. Furthermore, concentrations of microorganisms were determined 2 hours after the renovation in the construction zone to find out if the concentrations could be reduced by using this technique. The construction zone was again isolated with plastic barrier and the side-draft hood was placed as close to the construction process as possible. Microbial samples were taken during demolition in the construction zone and in the adjacent area outside the construction zone. Samples were also taken 2 hours after the construction in the containment area, with the portable exhaust fan operating continuously. In this experiment, only stationary samples were taken.

Air Sampling

The samples were collected on polycarbonate membrane filters (diameter 37 mm, pore size 0.4 μm; Nuclepore Corp., Cambridge, Mass.) with a flow rate of 2 L/min. The sampling time varied from 30 min to 3 hours. No outdoor air samples were taken, because the indoor air samples were taken in the winter (November to March), when outdoor air levels of fungi and actinomycetes are extremely low due to snow cover, and the contribution of outdoor air to indoor air microorganism levels is negligible.[20]

After sampling, concentrations of viable microorganisms were determined by cultivation. Dichloran glycerol agar[21] (DG18) was used for culturing xerophilic fungi and 2% malt-extract agar (2% MEA) for culturing mesophilic fungi. These two media have been recommended in determination of building-associated fungi by an international expert group.[22] Tryptone-yeast-glucose agar[23] (TYG) with cycloheximide was used for actinomycetes. The plates were incubated at 25°C for 7 days for fungi and 5 days for actinomycetes. The concentrations are expressed as colony-forming units/m³ (cfu/m³). The detection limit of this method varied between 100–400 cfu/m³. Fungal colonies were identified to genus with an optical microscope. From TYG plates only actinomycete colonies were counted. Total concentrations of spores were measured using the filter sampling and direct count on microscope.[24] However, in most samples these total concentrations of spores were below the detection limit of the method (10^4–10^5 spores/

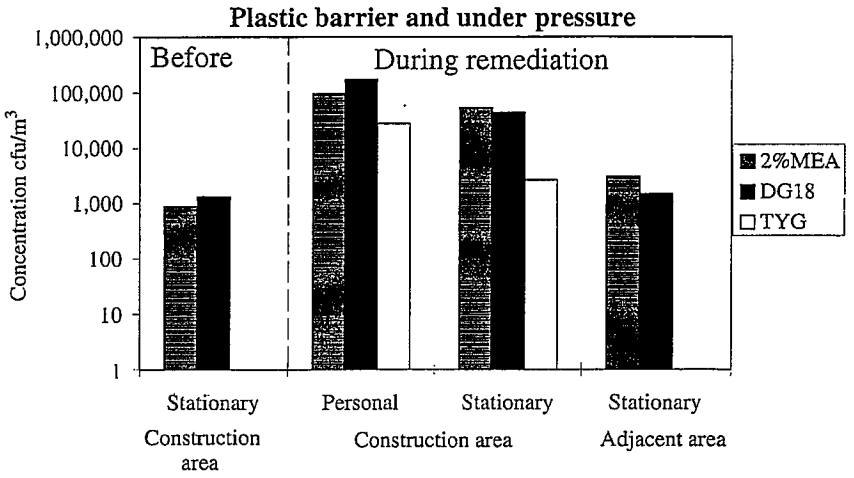

FIGURE 1. Concentrations of viable fungi (2% MEA and DG18) and actinomycetes (TYG) before and during remediation work when a construction zone was placed under negative pressure with a fan and separated with a temporary plastic barrier

m³) due to relatively low concentrations and short work duration and, therefore, short sampling periods.

Evaluation of Data

Currently, there are no occupational exposure standards or threshold limit values for workplace concentrations of microorganisms. In evaluating the effectiveness of the control methods, the authors compared the concentrations of microorganisms during the remediation to those measured right before the remediation. A tenfold increase in concentration was considered to be significant.

RESULTS

Test 1. Plastic Barrier Isolation and Negative Pressurization

Concentrations of fungal and actinomycete spores in the test with plastic barrier isolation and negative pressure are illustrated in Figure 1. Before any remediation work was started, concentrations of fungi were 860–1300 cfu/m³. When the construction zone was under negative pressure and separated with the plastic barrier, the concentrations of viable fungi inside the containment area increased, varying from 4.3×10^4 to 5.3×10^4 cfu/m³ in stationary

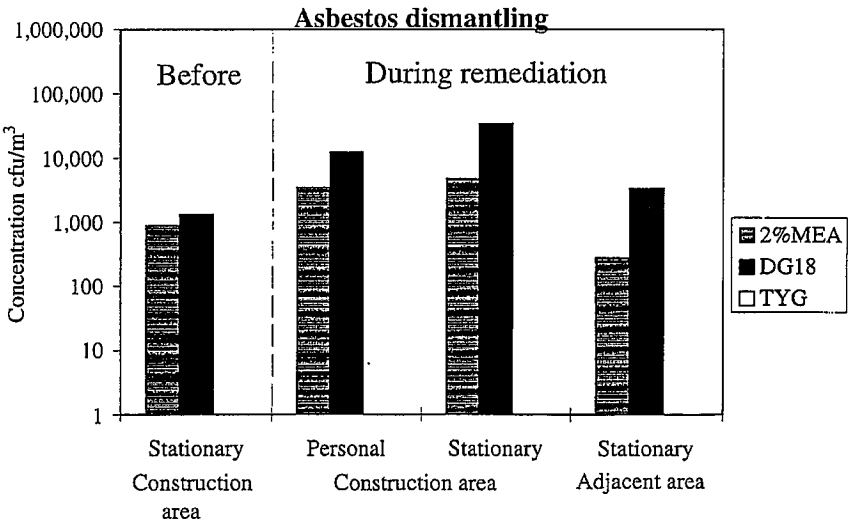

FIGURE 2. Concentrations of viable fungi (2% MEA and DG18) and actinomycetes (TYG) before and during remediation work when local exhaust method for asbestos dismantling was used

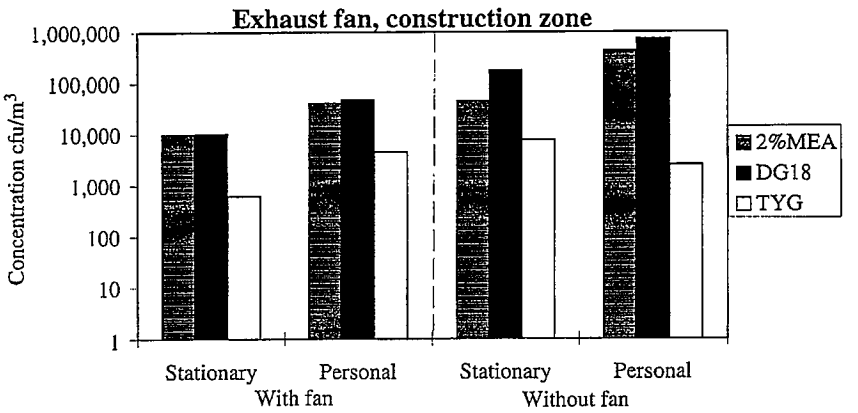

FIGURE 3. Concentrations of viable fungi (2% MEA and DG18) and actinomycetes (TYG) in the construction zone with and without a portable exhaust fan with a side-draft hood

samples and from 9.6×10^4 to 1.7×10^5 cfu/m³ in personal samples. In the adjacent area, concentrations of fungi were 1400–2900 cfu/m³. Thus, they were lower than in the construction zone, but slightly elevated compared with the situation before the remediation. *Aspergillus, Cladosporium, Paecilomyces, Penicillium, Rhodotorula, Stachybotrys, Trichoderma, Sphaeropsidales*-group, yeasts, and nonsporing isolates were found in the containment area, while only species of *Aspergillus, Aureobasidium, Sphaeropsidales*-group, and yeasts were observed outside the containment area. Furthermore, actinomycetes were found only inside the containment area during demolition work, as seen in Figure 1.

Test 2. Local Exhaust Method Used for Asbestos Dismantling

Concentrations of fungi varied from 860–1300 cfu/m³ before the local exhaust method was used for asbestos dismantling. During removal of moldy building materials, the concentrations of viable fungi increased to 4.7×10^3 to 3.4×10^4 cfu/m³ in stationary samples and 3.4×10^3 to 1.2×10^4 cfu/m³ in personal samples in the construction zone (Figure 2). Outside the construction area the levels were about the same as before the remediation, varying from 270 to 3300 cfu/m³. *Aspergillus, Cladosporium, Paecilomyces, Penicillium, Stachybotrys, Trichoderma, Sphaeropsidales*-group, yeasts, and nonsporing isolates were observed inside the construction area. In the adjacent area only *Aspergillus* species and nonsporing isolates were found. No actinomycetes were found before or during asbestos dismantling (Figure 2).

Test 3. Portable Exhaust Fan with Side-draft Hood

Results of the third test are presented in Figures 3–5. In the dwelling where the portable exhaust fan with the side-draft hood was used during removal of moldy materials, the concentrations of fungi varied between 1.0×10^4 to 4.8×10^4 cfu/m³ and the

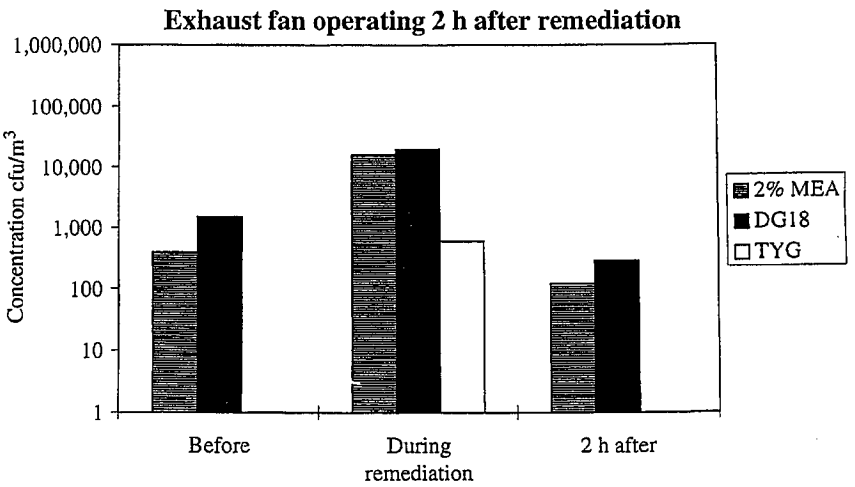

FIGURE 4. Concentrations of viable fungi (2%MEA and DG18) and actinomycetes (TYG) before, during, and 2 hours after the remediation when a portable exhaust fan with a side-draft hood was used

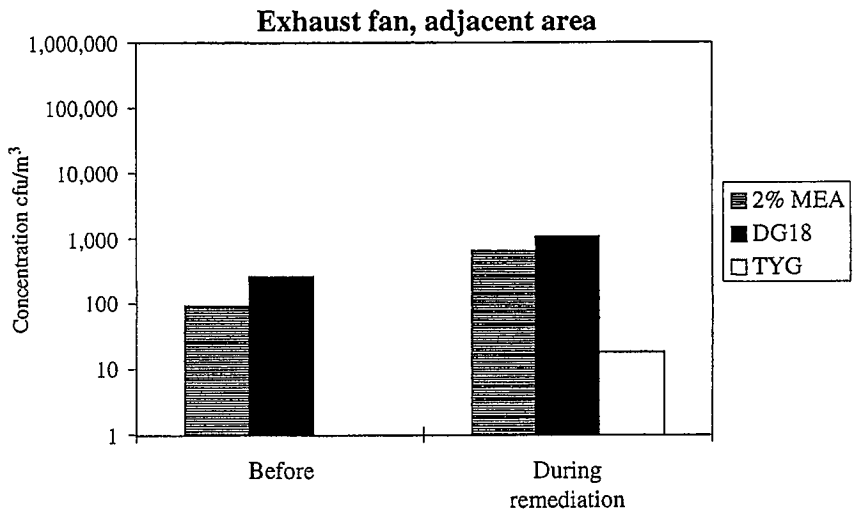

FIGURE 5. Concentrations of viable fungi (2% MEA and DG18) and actinomycetes (TYG) in the adjacent area before and during remediation when a portable exhaust fan with a side-draft hood was used

concentrations of actinomycetes from 630 to 4500 cfu/m³ in the construction zone. In the other dwelling, where no fan was used, the concentrations of fungi and actinomycetes were higher, 4.3×10^5 to 7.7×10^5 cfu/m³ and 2500–7700 cfu/m³, respectively (Figure 3).

In the second building where a portable exhaust fan was tested, concentrations of viable fungi ranged from 390 to 1400 cfu/m³ before remediation. During removal of moldy materials concentrations increased to 7.5×10^3 to 1.5×10^4 cfu/m³. When the portable exhaust fan had operated continuously for 2 hours after the remediation, concentrations of fungi had decreased to 120–290 cfu/m³ in the construction zone. Actinomycetes up to 600 cfu/m³ were found, but only during demolition work (Figure 4).

In the adjacent area, the concentrations of fungi were 90–260 cfu/m³ before the remediation. During demolition, concentrations of fungi increased to 630–1000 cfu/m³. Actinomycetes up to 18 cfu/m³ were found during demolition in the adjacent area (Figure 5).

When a portable exhaust fan with a side-draft hood was used, species of *Aspergillus, Cladosporium, Paecilomyces, Penicillium, Phialophora, Tritirachium, Wallemia,* yeasts, and nonsporing isolates were identified in the construction zone. In the adjacent area, *Aspergillus, Aureobasidium, Penicillium, Phialophora, Tritirachium*, yeasts, and nonsporing isolates were found.

DISCUSSION

There are only a few reports on the effect of remediation on airborne microorganisms and the suitability of asbestos dismantling-type techniques to control this exposure.[17–19] Little data have been available on the effectiveness of other control methods. In this study three different control methods were studied; plastic barrier isolation together with negative pressurization, the local exhaust method used for asbestos dismantling, and a portable exhaust fan with a side-draft hood. The effectiveness of the tested control methods was evaluated by measuring the viable microorganisms and total concentrations of microorganisms, because nonviable microorganisms may also cause health effects. However, the total concentrations of microorganisms were below the detection limit in most samples due to short work periods, which resulted in short sampling times. Thus, only the viable counts could be used for microbial exposure comparison.

Despite the low number of experiments the results suggest that the local exhaust method used for asbestos dismantling was the most effective control method. When this method was used, the concentrations of microorganisms in the construction zone were only 4–25 times higher during remediation than before it. In the adjacent area, the concentrations of microorganisms did not increase due to remediation work. In a previous study, it was found that when no control techniques were used concentrations of microorganisms increased by 100 times in the construction area during demolition work and about 10 times in the adjacent area compared with the situation before.[14] Thus, asbestos dismantling was shown to decrease microbial concentrations both in the construction zone and in the adjacent areas.

When the construction zone was placed under negative pressure with a fan and the zone was separated with the plastic barrier, concentrations of microorganisms in the construction zone were about 100 times higher than before the work was started. Thus, in this case the concentration of fungal spores in the construction zone increased equally high as in the previous study when no control techniques were used.[14] However, similarly to asbestos dismantling, concentrations of microorganisms in the adjacent area were again at the same level during remediation as before it. Thus, the migration of microorganisms from the working area to adjacent areas could be reduced by this method.

The third method tested was the portable exhaust fan with a side-draft hood, which is a common method used for dust control. However, it has not been reported as being used for control of microorganisms. This method clearly reduced the concentration of viable fungi in the construction area. For actinomycetes, the

reduction was not as obvious, probably due to lower initial concentration.

This method prevented the migration of fungi to the adjacent area almost as effectively as the two other control methods. The concentrations of fungi in the adjacent area remained 4–6 times higher during demolition than before it. However, actinomycetes were seen to migrate from the construction zone into the adjacent area. When the portable exhaust fan had been operating 2 hours after the demolition in the construction area, concentrations of microorganisms, both fungal and actinomycete spores, were even lower than before the demolition. In a previous study, when no fan was used, concentrations of microorganisms 2 hours after the renovation were still about two times higher than those before demolition.[14]

There was a more diverse composition of fungal genera in the air during remediation than before it. Some fungal species, such as *Stachybotrys*, were observed only during remediation. Comparison of the differences between genera in the construction area and adjacent area during remediation work is weakened by low counts of some spores, such as *Stachybotrys* and actinomycetes. The limited data on fungal genera shows that asbestos dismantling with the local exhaust method effectively prevented spreading of spores of several fungal genera, including *Stachybotrys*, into the adjacent area. Thus, this confirms the observation reported earlier by Johanning et al. (1993)[17] and Morey et al. (1993)[18], when they used an asbestos abatement technique during remediation of building materials contaminated with *Stachybotrys atra*.

CONCLUSIONS

These case studies showed that concentrations of microorganisms can be reduced with commonly used dust control techniques during remediation of moldy materials. The methods were especially effective at preventing the spread of microorganisms from the working area to an adjacent area, although they could not protect the workers fully. Therefore, personal protection is still needed.

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