Tracing the Chemistry of Household Dust

By Janet Pelley

Researchers are finding an ever-growing list of chemicals in dust and are trying to understand what the compounds mean for our health.

As sure as the sun rises, houses collect dust. It gathers on our knickknacks and dirties the carpets. More than just dirt, house dust is a mix of sloughed-off skin cells, hair, clothing fibers, bacteria, and dust mites, bits of dead bugs, soil particles, pollen, and microscopic specks of plastic. It's our detritus and, it turns out, has a lot to reveal about our lifestyle.

For one thing, dust is far from inert. Those shed hairs and old skin cells can soak up a constellation of contaminants originating from consumer products that we bring into our homes. Other environmental contaminants can be tracked indoors on the soles of our shoes. So in addition to fluffy hair and garden dirt, dust can hold a witch's brew of persistent organic pollutants, metals, endocrine disruptors, and more.

Not only does dust hold a long memory of the contaminants introduced to a house, but it's also a continual source of exposure for the residents. Dust gets resuspended when it's disturbed and will reticulate throughout the house, picking up substances before returning once more to the floor. "Year over year, dust accumulates in the home," says Miriam L. Diamond, an environmental chemist at the University of Toronto. Even after regular cleaning, it still accretes because homes are tightly sealed environments, and the dust gets entrenched in carpets and crevices. Dust from an old house may retain legacy pollutants such as DDT that were banned almost half a century ago, she says.

Scientists study dust to try to get a handle on both of these roles: as a proxy to better understand what chemicals are in our surroundings and how they move, and as a way to characterize what exactly we are exposed to via dust. The relationship between dust and human health remains uncertain. Researchers know that dust is an important source of exposure to certain pollutants—especially for infants and toddlers, who spend 90% of their time indoors, put almost anything in their mouths, and are more sensitive than adults to many of the compounds found in dust. But they haven't nailed down the extent of health risks from dust exposure nor which compounds and sources are of greatest concern. And many compounds remain unknown. “The few to a hundred compounds that we know are in dust don’t encompass the universe of chemicals in commerce, which number in the tens of thousands to over a million,” says P. Lee Ferguson, an environmental chemist at Duke University. To reveal the full spectrum of chemicals in dust, researchers are turning to high-powered analytical tools. Dust is no longer something to sweep under the rug.

Dust bath

Scientists first realized that dust had a story to tell about environmental health in the 1940s when they measured human pathogens stuck to the dust in operating rooms to monitor cleanliness. In the 1970s, researchers began assessing house dust for lead from paint and gasoline as a way to determine the levels children might be exposed to. And in more recent studies, researchers have found carcinogenic compounds such as now-banned polychlorinated biphenyls (PCBs), once used in electrical cables and wood floor finishes, and endocrine disruptors such as phthalates, which soften vinyl flooring and other plastics.

Researchers are still building their understanding of the complex ways that volatile and semi volatile compounds interact in our surroundings, sorbing onto and desorbing from surfaces. They know that consumer products—vinyl flooring, personal care products, electronics, furniture, carpet pads, paints, cleaning products, and more—have a strong driving force to shed compounds into materials with lower concentrations of the substances. For example, a flame retardant might volatilize off the plastic parts of a TV set into the air, stick onto airborne particles, and move into dust, which settles on floors and carpets. The compounds will continue to migrate until they reach equilibrium with the surroundings, says Diamond. And heating the product, such as turning on a computer, also speeds migration into the home environment; a compound will condense in a cooler part of the room, where dust often resides.

High-molecular-weight compounds, such as the flame-retardant decabromodiphenyl ether, don’t volatilize but instead enter dust when people physically knock fibers or minute bits of plastic off couches or computer cases. “Another mechanism that we stumbled on is direct transfer or diffusion into dust,” says Stuart Harrad, an environmental chemist at the University of Birmingham. For instance, if dust settles onto a TV set or Wi-Fi router, there is a very good chance that flame retardants will migrate directly into the dust.

With people in the room, things get even more complicated. “Just like the ‘Peanuts’ comic strip character Pig-Pen, people walk around in a dust cloud all day,” says Heather M. Stapleton, an environmental chemist at Duke University. People add to the dust’s organic load as their warm bodies volatilize deodorant or fragrance compounds from personal care products. “Our skin cells and clothing fibers may also accumulate chemicals from the air before they are then shed to dust, where they can accumulate yet more chemical,” Diamond says. Those compounds can be absorbed through skin, inhaled, or ingested when people put dusty hands to their mouths, complicating the scientist’s task of determining which exposure route is most important.

Most research has focused on identifying individual classes of compounds in dust, like the polybrominated diphenyl ether (PBDE) flame retardants found in furniture foam, carpet pads, and electronics; phthalates such as those found in vinyl flooring; or pesticides tracked in on shoes or evaporated off pet collars. Now, researchers are trying to get a more comprehensive view of the mixtures people are exposed to by probing the overall contaminant load in house dust. By combining toxicity tests with emerging methods for determining a complete profile of compounds in dust, researchers may be able to determine what chemicals or combinations of chemicals are most toxic, Stapleton says.

In one new approach, scientists combed through two dozen dust studies of 45 compounds to create a snapshot of nationwide exposures, says Robin E. Dodson, an exposure scientist at the Silent Spring Institute. She and Veena Singla, a staff scientist at the Natural Resources Defense Council, ranked the substances according to the amount in dust and estimated intake and health hazard. The phthalate plasticizer di(2-ethylhexyl) phthalate, known as DEHP, topped the list. Phthalate plasticizers make plastic more pliable and are found in vinyl flooring, food containers, and cosmetics. DEHP can disrupt hormone function in human and animal studies and is linked to reduced sperm motility in men. Other compounds on the list include phenol preservatives found in deodorants and cosmetics; flame retardants; a fragrance compound known as Galaxolide, or HHCB; and perfluorinated stain repellents (*Env. Sci. Technol.* 2016, DOI: 10.1021/acs.est.6b02023).

Dust and health

What all this means for health is a sticky question. For some compounds, such as PBDEs, researchers have shown that dust is a major source of human exposure to these potentially endocrine-disrupting chemicals. But for other compounds, dust’s contribution is less certain. So for now, researchers still don’t have a clear picture of house dust’s risk to health. Many of the contaminants identified so far in dust are associated with hormone disruption, cancer, and reproductive damage, according to human epidemiological and cell studies, but “for many of these compounds, governments have not set safe levels,” Singla says. After she and Dodson completed their study, she compared the amounts of contaminants in dust to soil-screening thresholds set by the Environmental Protection Agency that indicate a chemical might pose health risks and thus require further investigation. She found that the concentrations of some phthalates and flame retardants in house dust exceeded these standards.

Meanwhile, Stapleton's work hints that exposure to contaminants in dust could be implicated in weight gain. Her lab found that flame retardants will bind to a human cell receptor that triggers fat storage in human cells. When testing human cells in the lab with extracts of dust at levels that a child might be exposed to, the scientists observe activation of these receptors about 50% of the time, suggesting the dust extracts may increase weight gain (*Env. Sci. Technol*. 2015, DOI: 10.1021/acs.est.5b01524).

Todd P. Whitehead, an environmental scientist at the University of California, Berkeley, is part of the California Childhood Leukemia Study that aims to identify the risk factors for the disease, which has become more common since 1975. He and his team are sampling dust in California homes because his work shows that dust is a useful indicator of exposure to polycyclic aromatic hydrocarbons (PAHs), PBDEs, and PCBs, compounds that are suspected leukemia risk factors. "Compared to homes of healthy control children, the homes of children diagnosed with acute lymphoblastic leukemia tended to have, on average, higher levels of PAHs, PBDEs, and PCBs in dust after adjusting for other relevant factors such as household income," he says.

"This is the strongest type of evidence to suggest that these compounds are risk factors for childhood leukemia," Whitehead says. But researchers can't say if the dust accounts for the increased leukemia risk, or if dust is correlated with the presence of something else in the home. And there are other sources of exposure to these compounds whose importance relative to dust is unknown. "We know that dust exposes us to these chemicals, but at the same time, if someone eats smoked salmon or a grilled burger, there are potentially carcinogenic PAHs on those items," Stapleton says.

A deeper dive into dust

Until now, technology has constrained scientists to study just the few hundred compounds that they know are in dust and for which they have analytical standards. Furthermore, these compounds account for only a small fraction of the toxicity found in tests of household dust. So scientists reason that a substantial number of unknown contaminants in dust exist that could pose health risks.

In the past five years, a new strategy called nontargeted analysis has caught on that promises to uncover the complete swath of compounds we encounter in daily life, says Duke's Ferguson. The strategy combines high-resolution mass spectrometry with data processing tools to tease out the identities of chemicals from a mass of data.

Nontargeted analysis has revealed that chlorinated paraffins, nonylphenol ethoxylates, and azo dyes, many built using 2-bromo-4,6-dinitroaniline as a backbone, are major components of household dust.

Ferguson and his team recently took extracts of household dust, separated the extracts into fractions using high-performance liquid chromatography, and then analyzed each fraction with ultra-high-resolution mass spectrometry. This process generates up to 10,000 candidate molecules, Ferguson says. The team's software interrogates chemical databases such as PubChem, comes back with a list of potential matches, and then predicts their hypothetical mass spectra. Using those data, patent information, and literature references, the researchers prioritize the likelihood of compounds to be in dust samples.

Testing dust with this approach, Ferguson's team found some of the usual suspects, such as flame retardants. "But we also saw compounds we don't usually think of as organic contaminants in dust, such as nonylphenol ethoxylates," he says. These are nonionic surfactants used in household cleaners—and suspected endocrine disruptors. Because most cleaning products get washed down the drain to sewage plants and discharged with treated effluent, scientists have been tracking surfactants in lakes and rivers but haven't looked for them in dust, he says. Ferguson's lab has shown that nonylphenol ethoxylates cause the proliferation of fat cells in a laboratory assay, hinting at a role in obesity. "These surfactants give the highest analytical signal compared to all the other components, such as flame retardants, that we measure in house dust using mass spectrometry," he says.

Ferguson's analysis also uncovered dog and cat flea treatments, fungicides, components of foods including pepper, and even cocaine. The team is working to get standards for these compounds to confirm their identity and quantify them in dust, he says. "This work has the potential to open up our understanding of exposure far beyond the limited set of compounds we've typically studied to date," he concludes.

It's beginning to do so already. In addition to Ferguson's work, researchers at the University of Saskatchewan recently used nontargeted analysis to identify azo dyes as the largest class of brominated compounds in house dust. And Cynthia A. de Wit, an environmental chemist at Stockholm University, and her team can now identify groups of chlorinated paraffins in unknown mixtures with the strategy. This large class of compounds acts as flame retardants, plasticizers, and lubricants for metal parts, appearing in caulking for buildings and windows and even in handheld kitchen mixers. “There are thousands of isomers, and conventional mass spectrometry can’t separate them,” de Wit says.

She and her colleagues ranked concentrations of flame retardants in dust from five countries and found that chlorinated paraffins topped the list at 700 µg/g dust, more than 200 times the level of halogenated flame retardants. The finding is “alarming,” de Wit says. “Chlorinated paraffins have been known as contaminants for several decades, but lack of analytical methods has hindered determining them in environmental samples,” she says.

These new findings are just the start, researchers say. In fact, an international collaboration aims to pick apart dust to get its complete profile, says Pawel Rostkowski, an environmental chemist at the Norwegian Institute for Air Research. Members of the team (called the NORMAN Network), from the European Union, U.S., Canada, Australia, and Japan have each received part of a pooled dust sample from Canadian homes to analyze with nontargeted methods. They will aggregate the results to build an open access library of mass spectra for the thousands of compounds they hope to identify.

“The good news is that when we take action to phase out or ban chemicals of concern, the levels in our bodies go down,” NRDC’s Singla says. She points to PBDE declines in blood and breast milk after PBDE flame retardants began to be phased out more than 10 years ago. Research from Stapleton’s lab and others’ has shown that frequent hand washing, using a vacuum with a high-efficiency particulate air (HEPA) filter to capture the smallest particles, and dusting with a damp cloth will reduce personal exposure to chemicals lurking in dust. Wood floors, which can be easily cleaned with a damp mop, are preferable to carpets, since normal vacuuming only removes about 10% of the dirt entrenched in carpet fibers and pads (*Rev. Environ. Contam. Toxicol.* 2009, DOI: 10.1007/978-1-4419-0032-6_1).

A new California law requires all labels on upholstered furniture to declare the presence or absence of added flame retardants. “We can start thinking about moving more upstream by selecting products without these chemicals and working with manufacturers to remove these compounds from their products,” SSI’s Dodson says. But she adds that ultimately, safety testing needs to be done before, not after, compounds are added to products—before they even have the chance to turn into dust.