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Development of a High Volume Surface Sampler for Pesticides in Floor Dust

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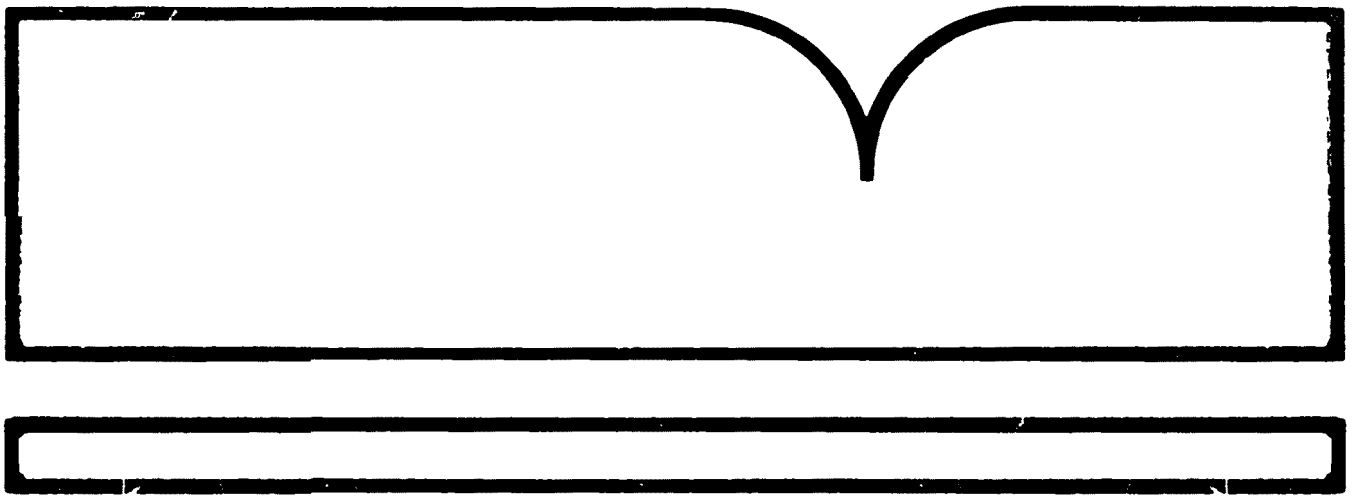

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DEVELOPMENT OF A HIGH VOLUME SURFACE SAMPLER FOR PESTICIDES IN FLOOR DUST

by

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16. ABSTRACT

A high volume surface sampler (HVS2) for the collection of house dust and the semi-volatile organics (including pesticides) in house dust has been designed and tested. The sampler consists of an intake nozzle, cyclone, and filter. The position of the nozzle is regulated by the static pressure in the nozzle. The HVS2 operates at approximately 9.5 L/s (20 cfm) and can collect more than 2 g of floor dust from a rug in an average clean residence in less than 4 min. Over 95% of the sample is retained in the cyclone. The HVS2 collects approximately 30% of the dust less than 150 µm from level loop and plush carpet. It collects 93.4% of the total dust from a smooth bare floor. The variation in the collection efficiency of fine dust in repeat trials on carpets was 8% for level loop carpets and 12% for plush carpets. The variation as the surface loading was changed was similar. Both house dust and a test dust were spiked with 10 or 20 ppm chlorpyrifos and dieldrin and 50 or 100 ppm diazinon. Virtually all the pesticide was retained in the cyclone or on the filter. Although a PUF sorbent does not appear to be necessary, it can be used with the HVS2. Alternative sampling methods were also studied. Conventional vacuum cleaners, small hand-held vacuum cleaners, gloves, semi-sticky paper, and carpet squares were not satisfactory substitutes. A recommended sampling procedure for the use of the HVS2, based on the test experiences reported here, is provided.

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FOREWORD

Measurement and monitoring research efforts are designed to anticipate environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that affect health and the ecology, to provide innovative means of monitoring compliance with regulations, and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina, has responsibility for assessment of environmental monitoring technology and systems, implementation of agency-wide quality assurance programs for air pollution measurement systems, and supplying technical support to other groups in the Agency, including the Office of Air and Radiation, the Office of Toxic Substances, and the Office of Solid Waste.

The determination of human exposure to toxic organic compounds is an area of increasing significance to EPA. The development of a new sampling methodology for a heretofore poorly understood media will permit important new information to be gathered so this potential route of exposure to these compounds can be properly evaluated.

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ABSTRACT

House dust and the pollutants carried with house dust are potentially important contributors to exposure through the pathways of inhalation, ingestion and skin penetration, especially for small children. Pesticides may be one of the more important contaminants of house dust.

A high volume surface sampler (HVS2) for the collection of house dust and the semivolatile organics in house dust has been designed and tested. The sampler consists of an intake nozzle, cyclone, and filter. The position of the nozzle is regulated by the static pressure in the nozzle. The HVS2 operates at approximately 9.5 L/s (20 cfm) and can collect more than 2 g of floor dust from a rug in an average clean residence in less than 4 min. Over 95% of the sample is retained in the cyclone and would, thus, be usable as a bulk sample for bioassays.

The HVS2 collects approximately 30% of the dust less than 150 um from level loop and plush carpets. It collects 93.4% of the total dust from a smooth bare floor. The variation in the collection efficiency of fine dust in repeat trials on carpets was 8% for level loop carpets and 12% for plush carpets. The variation as the surface loading was changed was of the same order.

Previous studies of ambient sampling for pesticides suggested that semivolatile organics in house dust would not be retained on the filter and a polyurethane foam (PUF) absorbent filter would be necessary to collect them. Both house dust and a test dust were spiked with 10 or 20 ppm chlorpyrifos and dieldrin and 50 or 100 ppm diazinon. Virtually all the pesticide was retained in the cyclone or on the filter. Although a PUF filter does not appear to be necessary, it can be used with the HVS2.

Several alternative sampling methods were also studied. The collection efficiency for fine dust of conventional upright and canister-type vacuum cleaners, as well as small hand-held vacuum cleaners, was not sufficient and use as required here would have been difficult or impossible. Gloves, semi-sticky paper, and carpet squares were also found not to be satisfactory substitutes.

A recommended sampling procedure for the use of the HVS2, based on the test experiences reported here, is provided.

This report is submitted in fulfillment of Agreement for Services 7-7009 CKX between Environmental Monitoring and Services, Inc. and Engineering Plus, as a part of Subcontract No. 725-86 with PEI Associates under Contract No. 68-02-4406 with the U.S. Environmental Protection Agency. This report covers the period from 3/1/87 through 8/31/87, and work was completed as of 8/31/87.

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SECTION 1

INTRODUCTION

Recent studies of human exposure to air pollutants have increasingly recognized the importance of pathways other than inhalation (Ott et al., 1986). Ingestion of air pollutants deposited in water or on soil is potentially the source of a significant portion of an individual's total pollutant burden, especially for very young children, with their lower body weight and frequent hand-to-mouth activity. Direct penetration through the skin may be important for some organic materials, particularly pesticides. Failure to consider dust as a pathway for air pollution may result in a significant underestimation of health risks.

Dust can be both a medium for the transfer of pollutants from sources to people and a medium for the accumulation of pollutants. House dust may contain bacteria, viruses, allergens, smoke residues, pesticides, asbestos particles, paint fragments, solvents, flame retardants, cleaners, fragments and residues from synthetic fibers, building products, and a multitude of other materials and pollutants created by activities in the home or tracked in from road dust, soil, or work sites.

At present there is no validated method for sampling the dust present on surfaces, although a wide variety of techniques has been used by various researchers. Unfortunately the variations in the methods used permit little comparison between one study and another.

A useful sampling technique should have a known and reproducible removal rate for dust on various surfaces and be able to achieve a relatively constant efficiency at different loadings of surface dust accumulation. In addition, the procedure should be able to collect and measure the low and medium volatility organics which are expected to be found on dust particles. Finally, the data collected should be capable of being compared to the actual dust uptake by a test subject. This report describes the development of a sampler designed to meet these objectives.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The high volume surface sampler (HVS2) constructed by Cascade Stack Sampling Systems (CS3) is an effective and efficient way to collect samples of fine surface dust. A bulk sample of more than 2 g can be collected in about 4 min in an average clean residence.

The static pressure in the nozzle was found to be the best measure of the appropriate height for the nozzle on carpets. When operated at the defined optimal settings, the fine materials (less than 150 um) collected from carpets by the HVS2 are approximately 6% of the total load of a standard test dust and approximately 30% of the fine materials in the test dust. The test-to-test variation is about 8% on level loop carptets and 12% on plush carpets. Better than 93% of the test dust is collected from a bare, hard surface.

Dust wall losses in the system were approximately 40 mg regardless of the number of tests or the total loading on the system between cleanings. This loss is insignificant in comparison to the greater than 95% of the total mass collected in the cyclone.

Semivolatile organic materials on the test dusts were retained on the collected dust. Experiments with a test dust which contained organic material, elemental carbon, sand, and talc found that a polyurethane foam (PUF) absorbent filter was not necessary for collection of the three pesticides tested. When both house dust and the test dust were spiked with 10 or 20 ppm of chlorpyrifos and dieldrin and 50 or 100 ppm of diazinon, less than 0.1% of the pesticide was found on the PUF filter. A mass balance on the pesticide demonstrated mass closure to within the accuracy of the measurement procedures.

One test done without the cyclone suggests the short sampling time is the primary reason the semivolatile compounds are not stripped from the collected particulate matter by the air stream.

The HVS2 can be used to measure complex mixtures of metals, solids, and organics on a variety of surfaces. Perhaps one of the most obvious uses is in support of studies of the health effects of indoor air pollutants and studies of the relative importance of pollutant pathways. Outdoors, the sampler could be used to measure pollutant accumulations in potentially air-mobilized soil surfaces. This might be useful in investigations of the potential risks associated with fugitive dust from hazardous waste land disposal sites, for example.

A field test of the HVS2 would be an important next step for evaluating this instrument and the recommended procedures provided in this report.

Because surface dust is an integrated record of the pollutants introduced into the air above the surface, it is important that such a field test include air sampling of both dust and gases during a period before and between the collection of surface samples.

There are significant differences between suspended and surface dust. The means of introduction of the dust, the size distribution, the half-life of retention in a space, and the modes of exposure to the dust are quite different. Each of these factors must be considered in designing the sampling program for a field test which compares surface dust and suspended dust.

The size distribution of house dust, the size distribution of dust on the hands of small children, and the size of particles which pass the cyclone and are found on the HVS2 filter should all be measured in order to more properly characterize the results obtained from the HVS2.

Although the tests reported here support a conclusion that no PUF absorbent filter is required for some semivolatile organics, this should be confirmed for more volatile compounds. It is suspected that the same conclusion will be reached, as the more volatile compounds will also be less likely to be found in the dust.

While the tests of alternative procedures did not find a simple procedure which can meet the performance goals for the HVS2, an exploration of such methods should continue, perhaps with the goal of finding a screening method which would not yield data that meet rigorous standards but could be used inexpensively for large, preliminary samples.

SECTION 3

LITERATURE REVIEW

Public Health Implications of House Dust

Particulate matter, especially fine, carbonaceous particulate matter, has been shown to be an efficient scavenger, by adsorption, of semivolatile materials and other particles (Natusch and Wallace, 1974). House dust and carpet fibers, in particular, have been found to be coated with a wide variety of other, smaller particles and droplets of organic materials (Haeske et al., 1957).

The metals in house dusts, particularly lead and cadmium, have been extensively studied (e.g., Vostal et al., 1974; Solomon and Hartford, 1976; Harrison, 1979; Diemel et al., 1981; Seifert et al., 1984; Rabinowitz et al., 1985). Organic materials in suspended house dusts have also been analyzed (e.g., Haeske et al., 1957; Yocom et al., 1971; Starr et al., 1974; Davies et al., 1975; Imhoff et al., 1982; Lioy et al., 1985).

Activity in the house will resuspend deposited house dust (Anis and Anis, 1972 and Hunt, 1972), which can then be inhaled. Possibly more important, deposited house dust also can be ingested directly, especially by children. Many pesticides and some chlorinated and other organic compounds present in residences can be absorbed directly through the skin, presenting yet another pathway for these housedust-associated pollutants (Wester and Maibach, 1987).

Most children go through a phase of putting things in their mouths. For children in the crawling stage, this means putting into their mouths fingers that have been in contact with the floor or ground. Studies have estimated that between 6 and 12% of small children also compulsively eat non-food material, such as dirt, soap, paper, or paint chips, a practice termed pica (Mahaffey, et al., 1985). The toddler has only about one-fifth the body weight of an adult and ingests an estimated 2.5 times, or more, as much dust, which increases the potential health risk to the child of contaminants in the floor dust at least 12 times (Hawley, 1985). The risk to such children will be further increased by their higher ratio of surface area to body weight and the stage of development of their organs, nervous system, and immune system (IPCS, 1986).

An estimate of average daily soil dust ingestion by small children ranges from 0.10 to 0.50 g, with a potential for higher rates for children with pica who live in a dusty home or who have access to exposed soil (LaGoy, 1987; cf. Binder, et al., 1986). Although the long residence times in the lung of inhaled dust would suggest that a high percentage of inhaled toxic materials will enter the blood stream, studies of children in areas of heavy contamination have found a better correlation between the body burden

of pollutants and the amount of the pollutant on their hands than with the concentrations in the air (Roels et al., 1980; but cf., Davies et al., 1987). Davidson and Elias (1986) estimate that a two year old child could take in forty times as much lead from ingesting dust contaminated by air pollution as from directly inhaling lead particulate matter. Murphy and Yocom (1986) provide a worst case estimate of almost 1000 times as much long-lived soil toxics taken in by dust ingestion as by inhalation for a young child (2.5 years).

The retention on the hands of different size dust particles has been measured by several researchers. Que Hee et al. (1985) found an approximately constant 30 mg of dust retained when hands were presented with dust segregated into different sizes. Dugan and Inskip (1985) and Dugan et al. (1985) measured the particle size of dust removed from hands and found a higher percentage of particles in the sizes less than 10 micrometers. However a re-analysis of their data looking at surface area, suggests a potentially greater importance of the particles between 10 and 100 micrometers, a size range which they did not characterize.

Childhood intake may represent a major source of the total adult body burden of some pollutants. Data developed by Henke et al. (cited by Fox, 1979) suggests that up to one-third of the adult body burden of cadmium may be accumulated by age three. Pinkerton (1973) reports that one-half of the adult body burdens of cadmium and lead accumulate by late adolescence.

The integrated mutagenic activity of house dust has been found by several research teams to be significant, although the implications of the measurements are not clear (e.g., van Houdt and Boleij, 1984; Lioy et al., 1985; Roberts et al., 1987). The measurements of floor dust mutagenic activity by Roberts et al. (1987) are higher but comparable to the results from selected soils (Brown et al.,1985).

Characteristics of House Dust

The sources of house dust are highly variable and studies have not provided any detailed generalization of its composition. Residues from food and food preparation, skin scales and other organic residue from the human and animal occupants of the house, fibers from clothing and household furnishings, fibers and minerals from building materials, organic matter from cleaning compounds, waxes, and other consumer products, fragments of vegetation and humus, and mineral particles, such as clay and sand, have all been identified in house dust.

A study in six U.S. cities found between 37 and 86% of house dust was inorganic (of which about two-thirds was silica and clay), less than 1% to 5% was grease, and the remainder other organics (J.N. Balough, personal communication, 1986). A German study (Haeske et al., 1957) found significant differences in the composition of airborne dust, dust recovered from a horizontal shelf, and carpet dust. More dry organic matter was present in the airborne and horizontal-shelf dust than the carpet dust, which had more silicaceous material. A greater percentage of the airborne dust was soot and other small particles.

A limited survey of 29 homes in two areas in Seattle, WA (Roberts et al., 1985) found an average (removable) accumulation of floor dust of 19 g/m^2 and a (removable) accumulation rate of 1.6 g/m^2/day. In three homes the dust recovered from rugs was found to be from 15 to 140 times greater than that collected from bare floors in the same home.

Schaefer et al. (1972) found a mean indoor dustfall rate of 0.02 g/m^2/day in 100 homes in five cities. The amount of accumulated dust on floors was measured by Solomon and Hartford (1976) in 12 residences and found to be approximately 1.2 g/m^2. The striking difference between the amount of dust observed depositing from the air on the floor and the amount of dust that accumulates on the floor suggests track-in as a major source. One study of lead in house dust, which carefully compared the deposited (9.3 ug Pb/m^2-day) and accumulated (166 ug Pb/m^2-day) dust levels concluded that most of the lead is carried into the house with "dust particles, adhering to shoes, etc." (Diemel et al., 1981).

The accumulation of dust in rugs can be expected to vary with the type of carpet, the frequency and manner of cleaning, the sources of dust inside and outside the home, and the behavior of the occupants. Studies of vacuum cleaner efficiency have found that the addition of a power-driven agitator increases the amount of dust and rug fiber pickup by a factor of 2 to 6. An upright vacuum cleaner, with a power-driven agitator, can be expected to remove approximately 35 to 55% of the accumulated dust from a plush rug and 70 to 80% of the dust from a flat rug. The canister or tank cleaner, without a power-driven agitator, can be expected to remove about 10 % of the dust from a plush rug and 40 to 50% of the dust in a flat rug (J.N. Balough, personal communication, 1986).

It is estimated that about 8% of the homes have no vacuum cleaner and in an additional 17% the vacuum cleaner is broken, or it is operating far below design efficiency because of a loose belt, a full dust bag, or some other maintenance problem (J.N. Balough, personal communication, 1987). A removable (total) dust accumulation of 250 g/m^2 was measured by Roberts et al. (1987) in one home with no vacuum cleaner and an accumulation of 1000 g/m^2 was measured in a high traffic area of a retail store (CAMRASO, 1983). Visible dust can be raised by the stomp of a foot at these accumulation levels.

The size distribution of dust removed from carpets in three studies in 1928, 1961, and 1975 varied little with time. Between 14 and 20% were retained on a 50 mesh (300 um) screen and between 51 and 54% passed a 200 mesh (75 um) screen (J.N. Balough, personal communication, 1986 and Barager, 1961). Roberts et al. (1985) found approximately 40% (by weight) of the house dust collected from 29 homes to be less than 150 um.

Pesticides and other organics with lower vapor pressure or higher polarity are expected to partition more to dust than to air, making house dust a potential major reservoir of persistent pesticides, such as chlordane, and PAH compounds, such as benzo[a]pyrene (BaP). However, the proportion of semivolatile organic compounds partitioned to the dust is not clear. Measurements by Bamesberger and Adams (1966) found between 16 and 98% of the 2,4-D herbicide esters in the particulate phase.

Measurements of chlordane and heptachlor in homes treated for termites found significant levels of the pesticides in carpet swatches placed on the floor in the homes (Wright and Leidy, 1982). Studies of house dust (Davies et al., 1975; Starr et al., 1974) have found significant levels of pesticides in the dust. Both BaP and pesticides have been measured at greater concentrations in house dust than in the soil near the houses (Davies et al., 1975 and Bailey, 1981).

Pentachloraphenol (PCP) and lindane have been found in housedust in homes where wood preservatives had been used (Krause et al., 1987). The dust concentrations of PCP were observed to be correlated to air concentrations in homes where the application had occured within the past two years, but the correlation was absent if the application was older than two years. The concentrations of PCP in the dust tended to remain relatively high, while the concentrations in the air dropped by about a factor of four.

Sampling Techniques

A wide variety of techniques have been used for collecting dust. Use of moistened glass fiber filters wiped across surfaces that may collect dust is a standard technique in industrial hygiene (OSHA, 1977). Moistened towels have been used in a similar manner (Vostal et al., 1974). This procedure has also been used for collecting water-soluble ions from surfaces (Sinclair, 1982). Adhesive tape (Royster and Fish, 1965) has been used to lift dust from surfaces for visual examination. Dust fall jars (Seifert et al., 1982) and other test surfaces (Schaefer et al., 1972 and Anzai and Kikuchi, 1978) have been deployed to collect dust. Accumulated dust has been collected by brushing from seldom-cleaned surfaces (Weschler, 1978). Small test areas have been hand vacuumed using a cut section of tubing as a nozzle and collected on a small, high-efficiency filter (Solomon and Hartford, 1976 and Que-Hee et al., 1985). Dust samples have been collected from family-used vacuum cleaner bags (Angle and McIntire, 1979). Specially adapted (Diemel et al., 1981 and Milar and Mushak, 1982) and standard vacuum cleaners have also been used to collect samples directly, with some analysts sieving the collected dust to remove larger material (Harrison, 1979). With the exception of the work by Que-Hee et al. (1985), there has been very little effort made to validate the collection techniques used.

Vacuuming of dust from surfaces requires the dust at the surface to be mobilized by the air flow into the collector. Gillette et al. (1980) conducted extensive tests of disturbed and undisturbed desert soil surfaces to determine the threshold velocities at the surface required to mobilize particles from the surface. For disturbed soils, which are expected to most resemble the dust layers on floors and in carpets, the threshold velocities for aeolian erosion were between 0.2 and 0.6 m/s (40 and 120 ft/min).

In contrast to surface sampling of dusts, ambient sampling for semi-volatile organic compounds has evolved to a proven sampling train (Lewis et al., 1977; Lewis and Jackson, 1982). Early measurements of ambient pesticides often utilized samplers similar to the high volume sampling system for ambient total suspended particulate (TSP). Study of these samplers led to the conclusion that substantial portions of the organic compounds were being volatilized and blown off the filter over the 24-hr sampling period (Lewis, 1976). In the current ambient pesticide sampler, the particulate filter is

backed up by a trap specific for capture of the semivolatile organics. Open-cell PUF has been found to be an effective collector for some of these compounds, with an overall recovery of 70 to 100 % for many pesticides. Soxhlet extraction of the filter and the 3-in long PUF plug permit analysis by gas chromatography.

SECTION 4

SAMPLER DESIGN

Performance Goals

A useful sampling technique for house dust should have a known and reproducible removal rate of dust on various surfaces and be able to achieve a relatively constant efficiency at different loadings of surface dust accumulation. Essentially all the particulate matter in the house dust (including the very fine materials) should be collected at a high efficiency. The size distribution of the material retained for analysis should be similar to that which would stick to a child's hand or skin. In addition, the procedure should be able to collect and extract the low and medium volatility organics that are expected to be found on dust particles. In order to use the sample in bioassays, it would be desirable to have about 2 g of sample collected in bulk. The technique should permit the collection of the sample in an average clean home in about two to four minutes. Finally, the data collected should be capable of being compared to the actual dust uptake by a test subject.

Initial Configuration

The performance goals set for the surface sampler suggest a sampler which rapidly collects a significant amount of dust in bulk, but which is backed up by almost absolute particle and organic vapor traps. Because volatile organic vapors would not be expected to remain on house dust particles for any significant time, the organic vapor trap can be limited to semivolatile organics (vapor pressure less than 0.1 torr). These requirements can be met by a high volume sampler which immediately separates and isolates the bulk of the catch, possibly by a cyclone, and filters the air stream through a high efficiency particle filter and a PUF vapor filter.

A prototype surface sampler which would meet the performance goals was constructed by CS3. The design was based on a marriage of the high volume stack sampler (Boubel, 1971 and ASTM, 1987c) and the ambient pesticide sampler (U.S. EPA, 1984).

The prototype HVS2 was constructed of stainless steel and aluminum, weighing approximately 50 lbs. It consisted of 1) a primary carriage, on which was mounted a sampling nozzle, a cyclone, filter housings, and air flow measuring instrumentation, and 2) a two speed, one horsepower blower. The remote blower adds about 8 lbs more to the system. With the exception of the slot nozzle, which was made from aluminum, all of the sampling system to and through the PUF vapor filter was constructed of stainless steel. The entire sampling system was designed with quick removal clamps and gas-tight joints to permit easy assembly and cleanup.

The blower permits a maximum flow rate of 14.2 L/s at standard temperature and pressure. The flow can be reduced to about 1.9 L/s if desirable. The flow is measured by a calibrated (NBS traceable) laminar flow element (LFE).

As shown in the schematic in Figure 1, the dust is entrained in the air flow to the slot nozzle, which can be positioned at the desired distance above the surface. A simple slot nozzle was chosen when preliminary tests with conventional vacuum cleaners showed a higher collection efficiency for fine particulate matter with this type of nozzle. The agitating "power head" nozzle used in many conventional vacuum cleaners does collect more mass, but it was primarily larger particles and "carpet fluff". Although agitation may better mimic the activity of a small child, the smaller particle size collected by the slot nozzle is expected to better resemble the particles which are collected on the child's skin.

The sample passes from the nozzle to a 7.6 cm body diameter cyclone which has a calculated particulate cut diameter of 5 micrometers at the maximum flow rate. The larger particles are removed by the cyclone and collected in the jar at its base.

From the cyclone, the sample passes into the filter section, which was a 142 mm diameter quartz fiber filter in the prototype. A PUF plug was located behind the filter to collect the semivolatile organics. The PUF plug is cut 5 cm in diameter and 7.6 cm long.

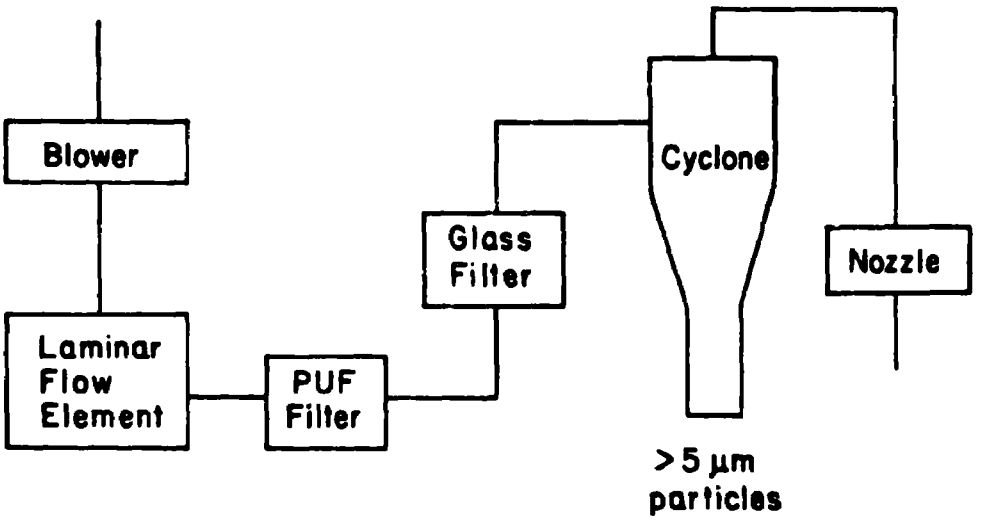

Figure 1. Air flow schematic of the prototype high volume surface sampler.

The blower is connected to the sampler by a flexible hose which allows the blower to be located out of the room being sampled. This prevents disturbance of the air in the area being sampled and also reduces the blower noise.

Modifications

Testing of the HVS2 identified several design problems with the prototype unit. Some of these were resolved by field modifications to the prototype unit and others were resolved in the redesign and construction by CS3 of the final, delivered HVS2 unit. Photographs of the final design HVS2 are provided in Figures 2 and 3.

It was found that the unit must be quite rigid and balanced fore to aft if the nozzle is to be held at a uniform height, independent of the movement of the wheels over a surface. There was a tendency for the front end of the unit to "nose-dive" at the start of a forward movement, which was especially noticeable on plush carpeting. When moving over an uneven surface, such as multi-level carpeting, the unit would bob up and down. In both cases the nozzle could not be maintained at a constant height above the surface.

Several modifications were made in the design to correct these problems. Field modifications included additional braces and clamps at strategic locations on the unit to make it more rigid. A new design of the carriage and the handle solved the problem in final unit. Two additional changes in the design of the final unit also make it easier to use on a soft or uneven surface. The casters on the rear of the carriage have been replaced by larger, non-swiveling wheels. The front wheels are closer to the nozzle, so the nozzle will follow the surface. When the surface is so uneven that it would be better for the nozzle to remain at a constant height, the wheels can be replaced by wheels which fit a rigid frame, which is then laid over the surface to be sampled.

The nozzle can be fixed in its relation to the surface more easily in the final design. The nozzle is held in place by two guides which can be tightened down. A threaded rod is mounted to the nozzle, so turning a knob on the rod provides a fine adjustment to the nozzle height.

Initially, the flow velocity at the nozzle was not sufficient. To correct this problem, the nozzle area was reduced from 24 cm^2 to 12 cm^2. In addition, an approximately 13 mm wide flange was added around the nozzle face. To reduce the pressure drop through the system a series of experiments (described in Section 5) were carried out which established that the PUF plug could be eliminated. Consequently, the final design has no holder for a PUF plug. However, this requires minimizing the face velocity across the particle filter. This was accomplished by replacing the 142 mm diameter filter with an approximately 20 by 25 cm filter, increasing the face area (and reducing the face velocity) by a factor of 3.3.

The most useful measure of the height of the nozzle above carpeted surfaces was the static pressure in the sampling nozzle. As the distance from the top of the surface decreases, or as the nozzle is pushed deeper into less dense materials, such as a plush carpet, the static pressure

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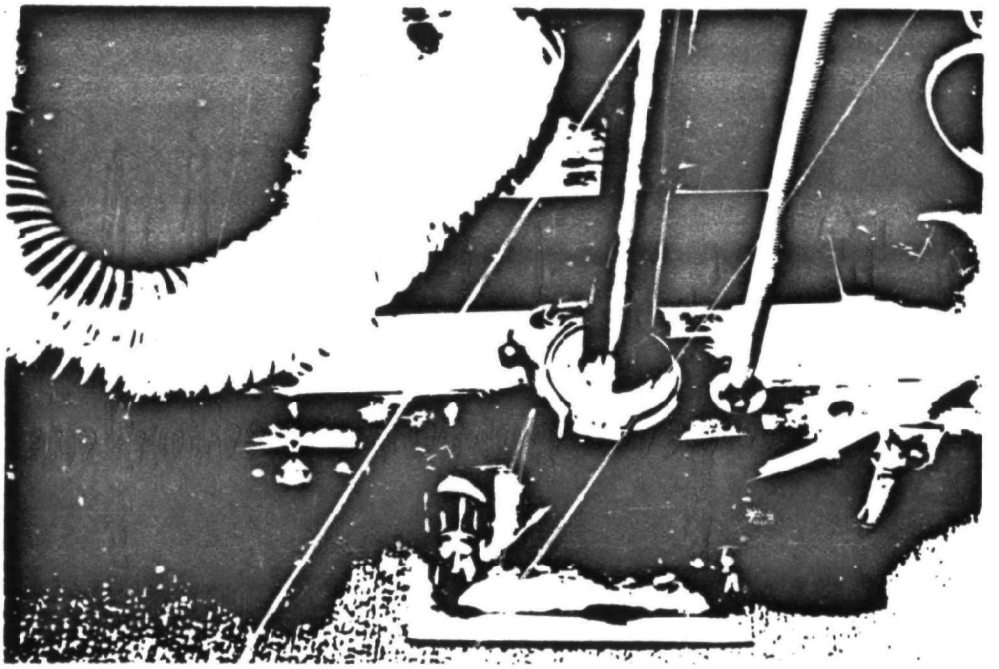

Figure 2. The high volume surface sampler (front view).

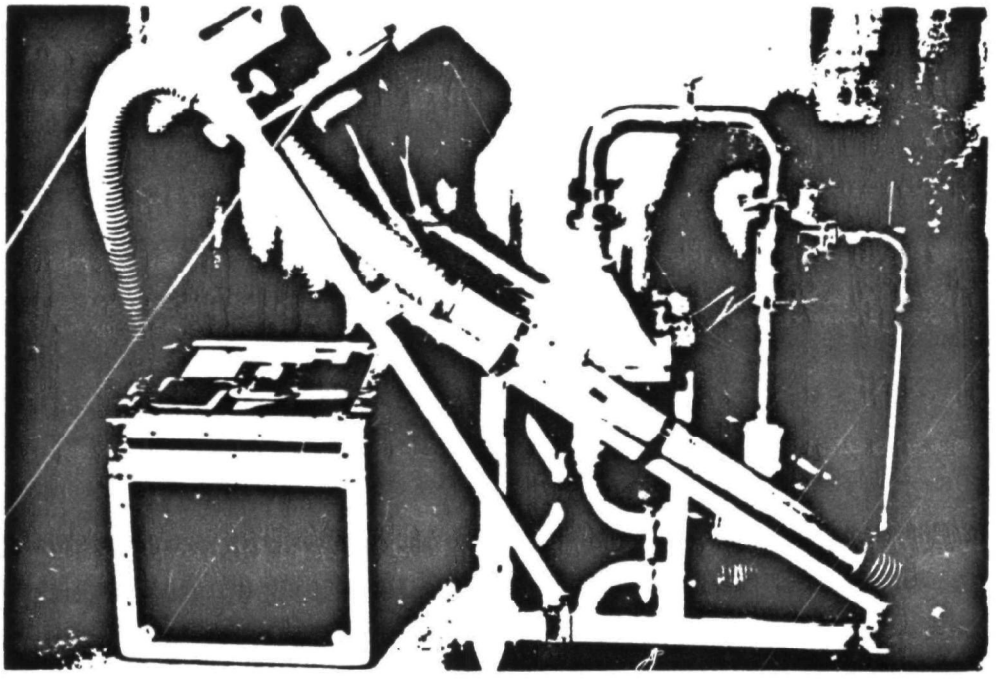

Figure 3. The high volume surface sampler (side view).

increases. This proved to be a sensitive measure which could be used relative to many surfaces. A pressure tap was added to the nozzle and a magnehelic gauge was added to the control panel.

Other minor changes were made in the design to make it more leak-free and to make it easier to assemble, disassemble, carry, and use. Once the correct flow rate had been determined, the LFE could be replaced by a less expensive orifice plate. The motor was placed in a carrying case, to reduce the noise and make it easier to move around.

SECTION 5

SAMPLER TESTING

Testing Procedures

The testing procedures to establish the operating characteristics and sampling reproducibility of the HVS2 relied heavily on the established procedures for testing household vacuum cleaners (ASTM, 1987b). This method measures the relative cleaning efficiency of vacuum cleaners on a standard carpet. A standard plush (typical of residential installations) and level loop (typical of commercial installations) carpet were used.

In ASTM Method F608-79, a test dust of 90% sand and 10% talc is spread on and embedded into a test carpet by dragging a large, smooth weight across the surface. The vacuum cleaner is run forward and back over a defined test area, measuring 46 cm by 137 cm, in a specific movement pattern. The efficiency of the cleaning is measured by the fraction of the applied dust which is collected by the cleaner in 16 passes of the length of the test area. The speed of the cleaner movement is specified as 2.5 seconds per pass.

The uniformity of application of the test dust was tested by applying semi-sticky squares of paper to the test area, uniformly pressing them onto the carpet with a weight, and measuring their weight gain. Obvious carpet filaments which adhered to the squares were removed prior to re-weighing. No loss of weight on application to a smooth, clean surface could be measured. The coefficient of variation over 32 sample areas was 15% for the plush carpet and 42% for the level loop. The higher variation for the level loop is clearly a result of the denser surface where the embedment tool has less tendency to even out the distribution.

The ASTM method specifies a procedure for cleaning the test carpet between tests with a conventional upright vacuum cleaner with a power-driven agitator. By using the cleaner first on the top and then on the reverse side of the carpet, the applied test dust can be effectively removed in three pairs of front and back cleaning operations. Tests during preliminary phase of these experiments demonstrated that more than 96% of the mass of the applied dust could be accounted for during an efficiency test-clean cycle.

The ASTM test procedures were modified in several minor ways. First, the carpets were placed directly onto a flat surface, rather than over an open grill. The pads that the ASTM methods suggests using under the carpets were not used. Experience has shown that neither of these changes has any significant effect on the efficiency measurements (J.N. Balough, personal communication, 1986). Because the nozzle was narrower than on a conventional vacuum cleaner, it was necessary to make twice as many passes in twice the time to cover the area. However, the speed of the cleaner was the

same. Only two of the standard test carpets, a plush and a single-level loop were used. In addition, tests were made on a smooth, hard surface.

The standard test method provides for only one level of test dust application to the surface, approximately 160 g/m^2. To provide test levels which were more consistent with the observed loadings in residences, most of the tests were conducted with loadings of approximately 80 g/m^2 and some tests were made at about 32 g/m^2.

Test Dusts

The ASTM testing method defines a test dust which is 90% sand and 10% talc (both with specific size characteristics). The sand used in the tests did not conform to the size distribution given in the ASTM method. As shown in TABLE 1, it contained more fines and less coarse material. However, the available sand was used as supplied rather than being seived and recombined as it was felt the actual distribution provided material in a size range that was not present in the talc and thus would otherwise not be tested. It appears from the literature that this size range is important in adherence to hands.

Four tests of small quantities of the sand, handled in the same manner as when it was mixed with talc for application on a test rug, found a significant sample-to-sample variation in the size distribution. The results of these tests are also shown in TABLE 1. Some of the sample-to-sample variation is the result of varying humidity, which could not be controlled in the room where the sizing was done.

The size distribution of the talc was found to be more than 96% less than 75 um. It was noted that when the talc was mixed with the sand there was actually less material less than 75um than with the talc alone. It was hypothesized that the talc was lost by adhesion to the larger sand particles.

System tests with pesticide-inoculated dusts used a different dust composition. The critical system element in the pesticide collection efficiency tests was assumed to be the filter. Past experience with ambient pesticide collection suggested the pesticides would be stripped off the dust on the filter by the moving air. Thus the amount of fines was increased to put a greater portion of the dust onto the filter. Additionally, an organic

TABLE 1. SIZE DISTRIBUTION OF TEST SAND

Size range	>300um	300-150 um	150-106 um	106-75 um	<75 um
ASTM standard	36 %	61 %	3 %	trace	0 %
Permitted range	26 - 38 %	48 - 64 %	2 - 6 %	< 1 %	0 %
Actual test sand	20 %	70 %	2 %	7 %	1 %
Small sample #1	14 %	69 %	3 %	13 %	1 %
Small sample #2	19 %	69 %	3 %	9 %	1 %
Small sample #3	33 %	65 %	0 %	2 %	0 %
Small sample #4	19 %	72 %	2 %	7 %	0 %

material and a substitute for soot were added to the dust to better match the reported composition of house dusts. The mixture used with the pesticide tests was 45% sand, 45% talc, 9.5% food-grade cornstarch, and 0.5% technical-grade graphite. The cornstarch and graphite were found to be more than 99% less than 75 um.

In the pesticide tests, the pesticides dieldrin, diazinon, and chlorpyrifos were mixed in measured amounts with approximately 30 ml of hexane and the mixture blended with the test dust. The concentration of pesticide in the dust was approximately 10 or 20 ppm (by weight) dieldrin and chlorpyrifos and 50 or 100 ppm (by weight) diazinon (because of an expected lower sensitivity to diazinon in the analytical procedure). The slurry was dried while rotating in a glass flask. Some small, irregularly-shaped Teflon articles were placed in the flask to help break up any agglomerations that might form. Approximately 1 hr at room temperature was required for complete drying. The pesticide-innoculated dusts were used immediately after drying.

Analysis Procedures

A size-specific efficiency was determined for the dust collection efficiency tests. The actual loading applied to the test carpet was determined from the weight of the application container, before and after application. Similarly, the weight of the collected dust was determined by differencing the weight of the cyclone catch cup and the filter before and after use. The Pallflex 2500 QAO-UP quartz fiber air sampling filters were desiccated to constant weight and weighed before and after sampling. Dust from the cyclone catch was weighed and seived according to ASTM Method D422-63 (ASTM, 1987a) to determine the size-specific weight of the catch.

The size range that was found to be the most useful for analysis was for the material passing the 100 mesh (<150 um) screen. Thus, in each of the tests of dust collection efficiency the results are stated as a collection efficiency of fine materials, which is the percent of the total dust applied to the carpet that was recovered and passed the 100 mesh screen. This is only a fraction of the total efficiency for recovery of all material from the surface. For example, in one test with a fines efficiency of 6.1% the total collection efficiency for all sizes is 26.5%.

The fine materials (<150 um) applied to the carpet would be only about 20% of the total load, if the size distribution of the individual test dust sample were the same as the bulk measurement of the dusts (and it too often will not be, as discussed above). That means a reported 5% fines efficiency is approximately equivalent to a 28% recovery of the applied fine materials. The talc (< 44 um) is a constant 10% of the total load and approximately 56% of the total material <150 um.

Sampling train preparation, sample handling, and analysis procedures are similar to those described by Sherma (1981), EPA (1984), and ASTM (1986). The PUF plugs were precleaned by extraction for at least 16 hr with a 5% ethyl ether in hexane solution. After extraction, the plugs were compressed and vacuum desiccated to remove excess solvent. The Pallaflex 2500 QAO-UP quartz fiber filters were baked at 600 C for two hours. After

precleaning the PUF plugs and filters were wrapped and stored in hexane rinsed-aluminum foil.

After each sampling run the sample train was cleaned with hexane, washed with detergent, rinsed with water, cleaned with Chemsolv or nitric acid, rinsed with distilled water, and rinsed with methylene chloride. During the pesticide tests all materials in contact with the test dusts were either glass, aluminum, stainless steel, or Teflon.

Collected pesticide samples were immediately wrapped in hexane rinsed-aluminum foil and cooled to 0 C. Filters were not desiccated. Refrigerated samples were shipped by overnight courier to the analytical laboratory.

Dust and vapors collected during the pesticide collection efficiency tests were analyzed for pesticide content by Environmental Monitoring and Services, Inc. Pesticide levels were determined by solvent extraction of the pesticides from the dust, filter, or PUF plug, reduction of the extract, and measurement by gas chromatography. Samples were extracted for 16 hr with 300 to 500 mL of 15% ether in hexane. The extract was dried in a sodium sulfate column and the volume reduced to 4 mL in a Kaderna-Danish apparatus. Further reduction to 2 mL was accomplished in a stream of dry nitrogen.

The pesticide levels in the samples was determined by gas chromatography with electron capture detection. (The initial determination of diazinon was by flame photometry, however an equivalent response factor was established and further analysis used electron capture for all compounds.) Two columns were used; one for quantitation and one for confirmation of the identity of the peaks. Details of the instrumentation and operating conditions are given in TABLE 2. An example of the chromatogram obtained is shown in Figure 4.

Prior to extraction, each sample was spiked with 200 ng of octachloronapthalene, which provided a known for determination of sample recovery. For 24 samples, the recovery on the known was 84 +/- 11%.

Both field blanks and method blanks were analyzed. In one experiment,

TABLE 2. INSTRUMENTATION AND OPERATING CONDITIONS FOR PESTICIDE ANALYSIS

	Quantitation	Confirmation
Instrument	Varian 3700	Varian 3700
Column	DB-5, 30 m x 0.53 mm	DB-608, 30 m x 0.53 mm
Injector temperature	220 C	220 C
Detector temperature	300 C	300 C
Column program	180 C for 1 min	164 C for 1 min
	180 to 300 C @ 15 C/min	164 to 260 C @ 12 C/min
	Hold 300 C for 1 min	Hold 260 C for 1 min
Carrier flow	10 cc He/min	10 cc He/min
Makeup gas flow	20 cc N_2/min	20 cc N_2/min
Detector	ECD	ECD
Sensitivity	1 x 1	1 x 1

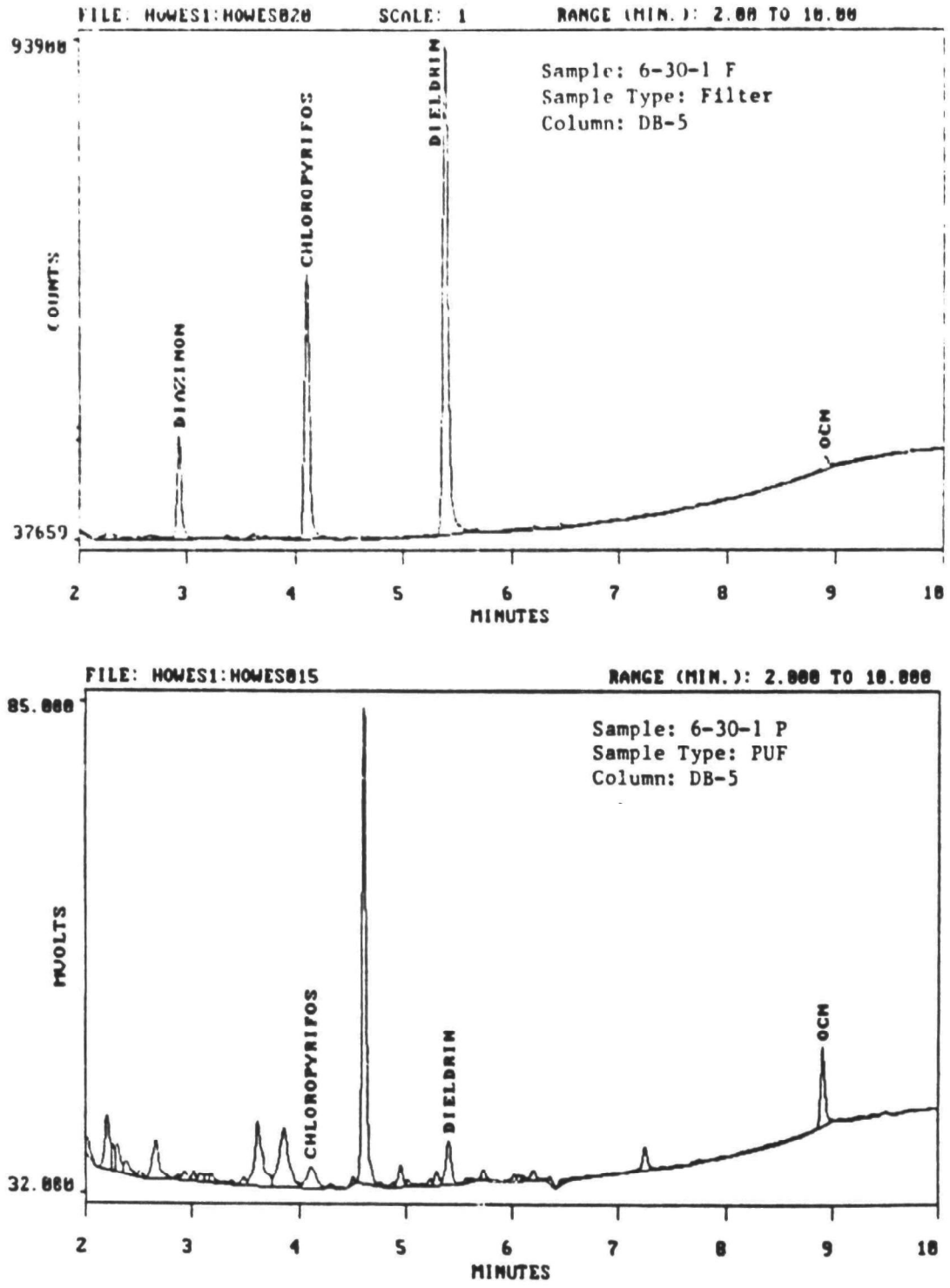

Figure 4. Example chromatograms.

the entire procedure was carried out without the addition of pesticides to the test dust. The reported pesticide levels on the field blank were near or below the detection limit of the analytical method and, in every case, at least a factor of 100 below the pesticide levels measured in the tests dusts and the filter. Method blanks were obtained by performing extractions without samples and then proceeding with sample analysis. In every case the method blank results were below the detection limit.

Sampler Performance

The collection efficiency of the HVS2 was measured using the procedures described above, with variations in two important variables in order to better define the optimal settings. The static pressure in the nozzle and the system volumetric flow rate were each changed while the other was held constant.

The dramatic difference in the dust removal behavior between the level loop and plush carpets is well illustrated by the system response to a change in nozzle volumetric flow, which is essentially a change in the velocity of the flow across and through the carpet. With a nozzle static pressure of -41.7 cm (-16.4in.) H_2O, the collection efficiency for fine material (passed 100 mesh) on the level loop test carpet increased by approximately 17% as the volumetric flow increased 67%. With the nozzle static pressure at -28.5 cm (-11.2 in.) H_2O on the plush test carpet the fines efficiency increased only 4% for approximately the same change in volumetric flow.

Similarly, a change in the nozzle static pressure when the volumetric flow is held constant shows a much greater increase in collection efficiency with the level loop carpet. This is accomplished by setting the nozzle closer to or deeper into the carpet surface. This effectively directs the air flow more and/or deeper into the carpet. With a flowrate of 9.5 L/s (20 cfm), a 45% change in the pressure increased the fines collection efficiency by 23% on the level loop carpet. At the same flowrate on the plush test carpet a 12% increase in the nozzle static pressure (the maximum increase possible) made almost no difference in the fines collection efficiency.

Thus an increase in the operating conditions beyond -28.5 cm (-11.2 in.) H_2O nozzle static pressure and -9.5 L/s (-20 cfm) on the plush carpet would not significantly increase the collection efficiency of fine materials (passing 100 mesh) while it would significantly increase the difficulty of operation. On the other hand, reducing the nozzle static pressure on level loop carpets to -28.5 cm (-11.2 in.) H_2O would substantially reduce the fines collection efficiency. At -41.7 cm (-16.4 in.) H_2O nozzle static pressure on the level loop carpet and -28.5 cm (-11.2 in.) H_2O on the plush carpet, the fines efficiency is approximately the same. For this reason, it was determined that these two values should be used as the nominal operational values in the remainder of the study.

Measurements were made of the actual horizontal velocities within the plush test carpet by inserting the probe of a hot wire anemometer into the carpet, replacing a small plug of fiber that was removed. Values were taken at approximately 3 mm (1/8 in.) and 10 mm (3/8 in.) from the lip of the nozzle

flange, near the center of the nozzle. The static pressure in the nozzle was changed by adjusting the height of the nozzle, with the system volumetric flow re-adjusted to 9.5 L/s (20 cfm) at each setting. The results are shown in Figure 5. The velocities obtained within the carpet are in the same range and generally exceed the velocities determined by Gillette (1980) to be required for mobilization of surface dust.

The loss of material to the walls of the sampling system prior to the filter was measured on several occasions. It was observed that approximately 40 mg of material could be retrieved from the walls irrespective of the number of test runs or quantity of material collected since the last time the walls were cleaned. While this amount is significant by comparison to the amount that is collected on the filter, under average conditions, it is not significant by comparison to the amount collected in the cyclone. Further, since the loss appears to be a dynamic equilibrium it is only important if there are large changes in the amount of material that potentially can be recovered or sensitive analysis techniques are being used and cross-contamination of samples may be possible.

Dust Collection Efficiency Tests

The collection efficiency of the HVS2 was measured on three different surfaces at different surface loadings of test dust to determine the precision of the measurement and the dependence on loading.

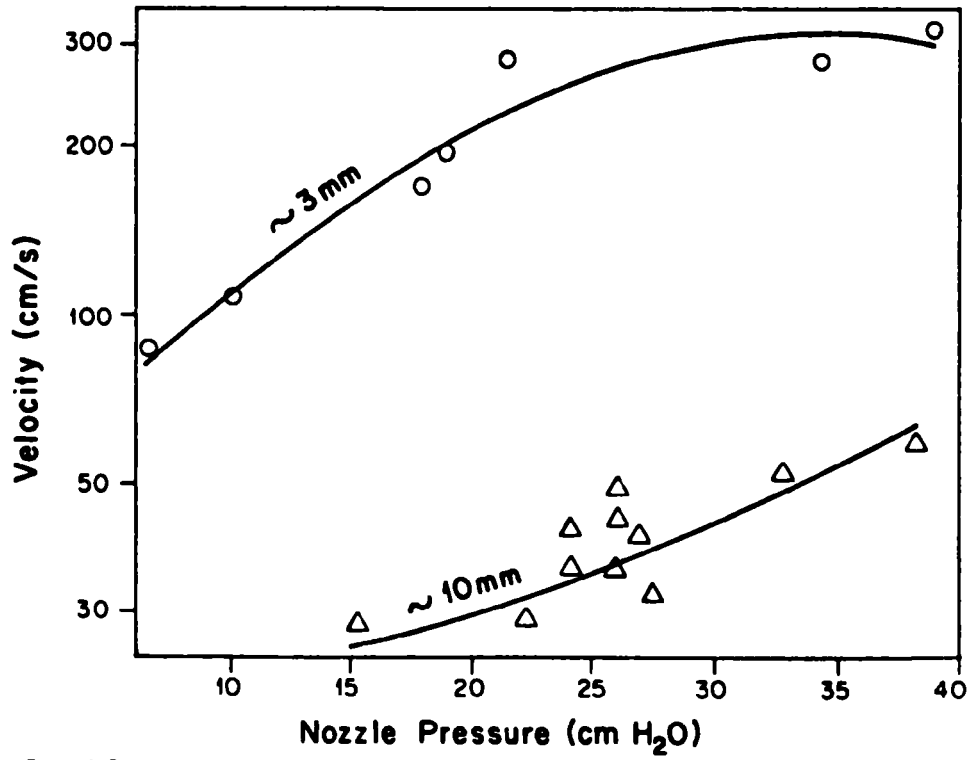

Figure 5. Velocity within the plush test carpet for different nozzle static pressures at 9.4 L/s (20 cfm) flow rate.

The collection efficiency from a smooth painted surface was measured with the nozzle approximately 16 mm (1/16 in.) above the surface. The static pressure in the nozzle was approximately 2.5 cm (1.0 in.) H_2O. The total collection efficiency at a loading of 7.7 g/m^2 was 93.4 +/- 4.3%. This is a coefficient of variation of 4.6%. At the lighter loading of 2.4 g/m^2 the total efficiency was 97.2%. Thus, the HVS2 reproducibly picks up essentially everything from a smooth, hard surface.

The collection efficiency from carpeted surfaces was tested on a plush and on a level loop carpet. The three other types of carpet, flat (or Persian), multilevel, and shag, represent a much smaller fraction of the market and were not tested. Both the total collection efficiency and the fines collection efficiency (the percent of the total surface load collected which passes a 100 mesh, or approximately 150 um, seive) were measured.

The total collection efficiency on the level loop carpet at the nominal settings (nozzle static pressure of -41.7 cm (-16.4 in.) H_2O and 19.4 L/s (20 cfm) volumetric flow at a surface loading of 80 g/m^2) was 24.0 +/- 4.0%. The fines collection efficiency under the same conditions was 5.8 +/- 0.5%. This is a coefficient of variation of 8.0%.

The total collection efficiency on the plush carpet at the nominal settings (nozzle static pressure of -28.6 cm (11.2 in.) H_2O and 19.4 L/s (20 cfm) volumetric flow at a surface loading of 80 g/m^2) was 10.2 +/- 0.5%. The fines collection efficiency under the same conditions was 5.6 +/- 0.7%. This is a coefficient of variation of 12.2%.

The greater consistency between the collection efficiency on the two different carpets for fines, as contrasted to total, may be due to the greater dependence of these particles on air movement for mobilization and collection and a lesser importance of physical movement of the carpet fibers to liberate the particles from the carpet. The latter is significantly different between the two carpets.

The change in collection efficiency with changes in loading are not substantial on either the level loop or plush carpets. Measurements at a loading of 32 g/m^2 on plush were lower, with 4.9% fines collection efficiency. At a loading of 158 g/m^2 the fines collection efficiency was higher, at 6.1%. However, the four measurements at these loadings were all within one standard deviation of the average from the more extended test runs at 80 g/m^2. On the level loop carpets the fines efficiency was 6.2% at 119 g/m^2 and 6.2% at 32 g/m^2. Again, all three measurements at these loadings were within one standard deviation of the nominal loading efficiency values.

Pesticide Collection Efficiency Tests

Previous studies of the retention of organic materials on particles collected on an air sampling filter suggested that it would be necessary to back up the filter with a PUF filter to ensure capture of any semivolatile organics in the surface dust. A series of tests were conducted using the pesticides dieldrin, chlorpyrifos, and diazinon as representative compounds. The physical properties of these compounds are given in TABLE 3.

TABLE 3. PHYSICAL PROPERTIES OF TESTED PESTICIDES

	Boiling	Vapor Pressure
Chlorpyrifos	42 C	1.9×10^{-5} torr
Diazinon	84	1.4×10^{-4}
Dieldrin	176	1.8×10^{-7}

A series of six tests were run to evaluate the distribution of pesticides from the test dust in the HVS2. Samples of the dust collected in the cyclone catch cup and on the filter were analyzed separately. These tests were run with the PUF plug in place and it was also analyzed for pesticides. Two tests were run at a nominal 10 ppm of pesticide in the dust, two tests at double that amount, one test with ordinary housedust, and one test with the cyclone removed from the system.

Since there was no question about the recovery of the pesticide-innoculated dust from the carpets, only a concern that the dust once collected might be stripped of its semivolatile compounds by the air movement through the sampler during testing, there was no need to sample the dust on the carpet. Instead a small tray was constructed of heavy aluminum sheet, where the pesticide-innoculated dust could be evenly distributed and conveniently vacuumed into the HVS2 in the same manner as from any smooth, hard surface.

Alternate spoonfulls of innoculated dust were placed in a sample bottle for analysis and spread onto the tray. The HVS2 was moved slowly over the tray, collecting most of the dust for 4 minutes and back over the tray, possibly collecting more dust, but primarily just letting air flow over the collected dust, for another 4 minutes. This was designed to simulate an extreme condition of surface dust collection.

The reference dust sample, the cyclone catch, the filter, and the PUF plug were placed in containers and immediately refrigerated. The HVS2 was washed down with hexane and the washings poured into storage containers for evaporation. These were retained for possible future analysis. The other samples were shipped in refrigerated containers by overnight courier to Environmental Monitoring and Services, Inc. for analysis.

The analytical results were reported in either total mass or mass concentration terms, depending on the size of the sample. These have been converted to total mass terms for all samples and are presented in TABLE 4. Also included in TABLE 4 is an estimate of the pesticide in the unaccounted for dust (mostly wall loss), the difference between the measured sample weight and the weight of the dust collected by the cyclone and filter. The concentration of pesticides in the sample were used to estimate the amount lost; the concentration in the fines on the filter may have been a more representative of the fine materials which are deposited on the walls. The results show a closure on total mass within the accuracy of the reported sample recovery for the analytical procedure for all samples. If the higher concentrations of the fines had been used in the calculation, the results would have been closer to 100%. The first nominal 10 ppm sample overstates the total amount of pesticide in the system. The unusually low entry for lost material for this sample suggests the recorded weight of either the sample or the cyclone catch may have been in error.

In all of the samples shown in TABLE 4 the amount found in the PUF plug is either less than the analytical detection limit or slightly above it. In no case is the amount even within a factor of 100 of the amount on the filter.

Also to be noted on TABLE 4 are the results of the test with ordinary house dust. This dust was collected by a canister vacuum cleaner from four residences and then sieved through a 50 mesh (passes 300 um) screen. The remainder of the test was carried out the same as the other tests of pesticide-innoculated dust. The lower amount of pesticide recovered on the filters reflects the lower percentage of the dust which was collected on the filter. This suggests the test dust used in the pesticide collection efficiency tests overstated the proportion of fines and thus the proportion of pesticide exposed to air stripping on the filter.

One test was made with the cone of the cyclone blanked off. This eliminated the size discrimination of the cyclone although it did increase the amount of wall loss. The result was to put the entire load onto the filter. A much smaller amount of dust was used to avoid overloading the filter. The high retention of pesticide and continuing low concentrations of pesticide in the PUF plug found in this test suggests the primary reason for the contrast between these tests and the experience with ambient samplers is the dramatic difference in sampling times (8 minutes against 24

TABLE 4. MASS BALANCE OF PESTICIDES IN SAMPLE AND COLLECTED DUST (ug)

Diazinon	Sample	Lost	Cyclone	Filter	PUF	Total	%
Nominal 10-1	502.3	1.7	495.1	44.	0.2	541.0	107.6
Nominal 10-2	533.0	10.7	424.8	35.	nd	470.7	88.3
Nominal 20-1	1140.0	37.0	1038.7	63.	nd	1138.9	99.9
Nominal 20-2	1232.8	22.9	1053.3	23.	nd	1099.4	89.2
House dust	326.0	2.8	287.9	1.2	--	291.9	89.5
No cyclone	31.0	6.6	--	22.5	nd	29.2	94.4
Chlorpyrifos							
Nominal 10-1	80.1	0.3	80.4	7.8	0.1	88.6	110.6
Nominal 10-2	84.0	1.7	73.4	6.5	nd	81.6	97.1
Nominal 20-1	188.0	6.1	165.8	11.0	0.1	183.0	97.3
Nominal 20-2	184.4	3.4	160.8	7.7	nd	172.0	93.3
House dust	249.9	2.1	247.6	0.6	--	250.3	100.2
No cyclone	9.3	2.0	--	5.5	nd	7.6	82.4
Dieldrin							
Nominal 10-1	99.9	0.3	92.0	9.2	0.1	101.6	101.8
Nominal 10-2	114.0	2.3	98.5	9.1	0.0	109.9	96.4
Nominal 20-1	268.0	8.7	232.5	16.3	0.1	257.6	96.1
Nominal 20-2	263.4	4.9	229.5	14.8	0.1	249.3	94.7
House dust	105.0	0.9	96.0	0.2	--	97.1	92.5
No cyclone	11.8	2.5	--	11.8	0.1	14.4	121.9

Notes: nd: not detected

TABLE 5. PESTICIDE CONCENTRATION IN SAMPLE AND COLLECTED DUST (ug/g)

Diazinon	Sample	Cyclone	Filter	Enrichment
Nominal 10-1	50.8	51.1	265.	5
Nominal 10-2	53.3	44.0	239.	4.5
Nominal 20-1	114.0	109.0	423.	3.7
Nominal 20-2	121.7	107.4	172.	1.4
House dust	32.6	29.0	217.	6.5
No cyclone	45.4	--	42.	
Chlorpyrifos				
Nominal 10-1	8.1	8.3	47.	5.8
Nominal 10-2	8.4	7.6	44.	5.2
Nominal 20-1	18.8	17.4	74.	3.9
Nominal 20-2	18.2	16.4	57.	3.1
House dust	25.0	25.0	104.	4.2
No cyclone	13.6	--	10.1	
Dieldrin				
Nominal 10-1	10.1	9.5	55.	5.4
Nominal 10-2	11.4	10.2	62.	5.4
Nominal 20-1	26.8	24.4	109.	4.1
Nominal 20-2	26.0	23.4	110.	4.2
House dust	10.5	9.7	37.	3.5
No cyclone	17.2	--	21.9	

Notes: nd: not detected

hours)..

TABLE 5 reports the same information in terms of concentration. The partitioning of the pesticide by particle size can be seen in the slight reduction in concentration in the cyclone and the substantial increase in the concentration in the filter. The average enrichment factor is 4.4.

Field Cleanup Procedure

The cleanup procedure described above would be prohibitively cumbersome and time consuming for use in a field study, where it can be expected that three to four houses should be sampled in a single day. An alternate cleanup procedure was designed to decrease the time required and the amount of supplies needed.

There are essentially two methods for removing the particulate-adherred pesticides from the HVS2. One may either remove the dust particles themselves by physically dislodging the particles or the organic compounds may be extracted from the particles with a solvent. Both approaches were used.

The field cleanup procedure begins with a rinsedown of the sampling train with a 1:1 mixture of hexane and acetone. A bristle brush is soaked in the solution and the portions of the HVS2 in front of the filter scrubbed down. These parts are then rinsed a second time and allowed to air dry.

The rinsate was collected and retained but not analyzed.

The field cleanup procedure was tested by first collecting with the HVS2 a test dust which had been innoculated with a high concentration of three pesticides. The system was then cleaned with the field cleanup procedure. Next, a clean dust was collected in the system. The cyclone catch and the filter were then analyzed for the pesiticides in the innoculated dust.

The worst case established for the test was a high percentage of fines in the dust and a high concentration of pesticides. The same organic-rich, high fines dust used previously in the pesticide tests was used for this experiment. The concentration of pesticides in the dust was measured at 100 ppm for chlorpyrifos and PCP and 50 ppm and 67 ppm (different runs) of dieldrin. Previous measurements suggested 35 ppm to 42 ppm as a reasonable upper limit for nonoccupationally exposed households (Krause et al., 1987, Starr, 1974).

The dust was innoculated in the same manner as the previous experiment, although methylene chloride was used as the carrier because of the pesticide solutions available. A 3 g sample of the spiked test dust was reserved for analysis. A 10 g sample of the spiked test dust was collected by the HVS2 in the same manner as previously. Next the sampling train was cleaned using the procedure described above. Finally, 10 g of the same dust, but not innoculated, was collected by the HVS2. The cyclone catch and the filter were pooled and analysed for the three pesticides. The procedure was repeated four times.

The test dust, clean cyclone catch, and clean dust filters were analyzed by Analytical Resources, Inc. The samples were extracted by sonication in 50 ml of hexane twice and the solutions combined. After concentration, half of the sample was treated with diazomethane to methylate the PCP. All analyses were performed on a GC with an electron caputre detector using the conditions given in TABLE 6.

The concentrations of the pesticides in the subsequent sample of clean dust was less than 0.3 ug for each of the pesticides, as shown in TABLE 7.

TABLE 6. INSTRUMENTATION AND CONDITIONS FOR FIELD CLEANUP ANALYSIS

	Quantitation	Confirmation
Instrument	HP 5890	HP 5890
Column	DB-5, 15 m x 0.53 mm	DB-608, 15 m x 0.53 mm
Injector temperature	250 C	250 C
Detector temperature	375 C	375 C
Column program	150 C for 1 min	150 C for 1 min
	150 to 240 C @ 3 C/min	150 to 240 C @ 3 C/min
	Hold 275 C for 5 min	Hold 275 C for 5 min
Carrier flow	5 cc He/min	5 cc He/min
Makeup gas flow	30 cc A_rCH_4/min	30 cc A_rCH_4/min
Detector	ECD	ECD
Attenuation	2 degrees	2 degrees

TABLE 7. AMOUNT OF PESTICIDE IN CLEAN DUST SAMPLE AFTER FIELD CLEANUP

	Test 1	Test 2	Test 3	Test 4
PCP	<0.2* ug	<0.2*	0.003	0.012
Chlorpyrifos	0.3	0.08	0.06	0.4
Dieldrin	0.1	0.02	0.014	0.14

* detection limit for this run

The surrogate of bromodichlorophenol was found to have an extraction efficiency of 94% for the dust sample and 47% for the quartz filters.

We can then estimate the possible amount of cross-contamination that might occur from the data in TABLE 7. If we assume the extreme case is represented by the residue at the mean plus three standard deviations (and correcting for extraction efficiency), the upper estimate of the amount that would be found in a clean dust would be 0.437 ug, 0.711 ug, and 0.254 ug, for PCP, chlorpyrifos, and dieldrin, respectively. If the collected sample were 2 g, this would correspond to 0.35 ppm, 0.57 ppm, and 0.20 ppm, in the same order.

Thus under this worst case, using the field cleanup procedure might cause a pristine location to be categorized as a background situation, but would have little if any effect on the classification of sites with any significant amount of pesticides present.

SECTION 6

ALTERNATIVE SAMPLING METHODS

Several alternative test methods were evaluated, both to determine how they compare with the HVS2 method and to determine if any of them should be explored as possibly better approaches to determining the concentration of dust on floors.

Conventional Vacuum Cleaners

Several studies of house dust have collected grab samples from the bags of residents' vacuum cleaners. While this is a quick way to collect a large number of samples in a retrospective study, it provides neither a consistent sampling efficiency nor any assurance that the samples have retained any semivolatile materials.

Both an upright and a canister vacuum cleaner were tested for cleaning efficiency using the ASTM procedures previously described. In addition, both were evaluated with respect to their usefulness in a sampling program similar to that intended for the HVS2. A number of problems were identified which limited the potential applicability of each.

A convertible upright vacuum cleaner with a power-driven agitator (Hoover Model U4367) was used to to clean the rugs between test runs in this experiment. Although it performed that task quite satisfactorily, its fine materials recovery (less than 150 um) was less than 2.3% of the test dust. It was also observed that about six grams of the collected sample could not be removed from the bag after the test. The material left in the bag may have been a significant fraction of the fines. In addition, the power-driven agitator and nozzle of the upright could not be cleaned without excessive effort.

A canister vacuum (Kenmore Model 87870), without a power-driven agitator head, collected fine materials of 1.3% of the test dust. Problems similar to those with the removal of fines from the bag in the upright were noted with the canister.

The collection efficiency of the paper bag material is not known, however it is undoubtedly less than the air sampling filters used in the HVS2. The face velocity of the air through the bags in the vacuum cleaners is about 30% less than the face velocity across the filter in the HVS2. This is expected to reduce the evaporation of semivolatile materials captured in the bag walls. However, the canister bag design brings almost the entire air flow through the previously collected material which may have the opposite effect. This also results in much of the fine material being captured on larger fibers and hairs, making it difficult to separate and

recover the fines. Further, an examination of the bags found several with questionable seals at corners and with other possibilities of by-pass.

A conventional canister vacuum cleaner may provide a possible alternative to the HVS2. It would require the design and construction of a substitute bag from high efficiency filtering materials (e.g., Gore-Tex laminates) and a test program to determine if semivolatile materials can be retained on the sample. If it is necessary to recover the materials that are trapped on or in the bag surface, it will also be necessary to identify a bag material that can withstand both a pre-sampling clean-up and a post-sampling extraction.

Hand-held Vacuum Cleaners

A small hand-held vacuum cleaner (Black and Decker Dust Buster Plus Model 933) gave a fine materials recovery of 4.7% of the test dust on a level loop carpet but only 0.6% on a plush carpet. This unit may have been even more efficient than the conventional vacuum cleaners in picking up the fine material, but it did not retain it. The fines were observed to pass directly through the unit and exit the exhaust as a white cloud, which was directly into the face of the user. It was not determined if this was due to low efficiency on the filter or a by-pass of the filter.

The use of an industrial hygiene particulate sampling cassette with a cut section of tubing as a nozzle (Solomon and Hartford, 1976 and Que Hee et al., 1985) does appear to avoid most of the problems with the other procedures described in this section. However the time required to collect a sample of sufficient mass in even a marginally clean situation may be prohibitive. The size of the sample would be limited by the volume available in the cassette.

Dust Traps

Three methods of collecting dust directly were explored. White cotton gloves were tried as a surrogate for direct skin contact with a surface, semi-sticky paper was used to pick up surface dust, and two types of carpet were used to trap the dust in a home.

The gloves were tested by embedding 100 g of test dust in the plush test carpet. They were were first weighed and then placed over powderless surgeons' gloves on each hand of the test technician. The gloves were then pressed into the test carpet from 9 to 100 times and weighed a second time. Additional tests were done on hall carpets near the front door of a ten unit apartment and on a sidewalk within ten feet of a busy intersection. None of the tests showed a significant weight gain, even though one showed visible soiling.

Semi-sticky paper (3M Post-Its, Models 7651 and 7652) was used to measure the variation in the application of the test dust, as described earlier. Although it was felt to be useful for this very limited intercomparison of loading, the experience suggested that it would not be useful in any broader analysis of surface dust. Covering the entire test surface area

with the squares was time consuming and recovered less than 0.5% of the dust applied to the surface. It would not have been feasible to make size measurements or any chemical analysis of the recovered particles.

It was hypothesized that carpets in a home act as a sink for dust in the home and will come to a dynamic equilibrium with the house dust in the room. If this is true, then a small carpet sample placed in the home should serve as a representative sample collector that could be brought back to the lab for analysis. Five 35 by 46 cm (14 by 18 in.) cleaned and weighed plush rug samples were placed in three homes for three weeks. The residents were instructed not to vacuum the sample rugs. The rugs were brought back into the lab and reconditioned to the initial relative humidity and re-weighed. Although two rug samples did have a weight gain it was much less than the equilibrium accumulation expected. The other samples did not have a significant weight gain.

Entry rugs are constructed in a different manner, with the specific intention of trapping dirt. An 86 by 132 cm (34 by 52 in.) flat entry rug was placed in two homes for three weeks each. In one home it gained 0.9 g and in the other 0.19 g. The weight gain was determined by inverting the rug on a clean piece of paper and vibrating the back of the rug for four minutes using an upright vacuum. However, none of the dust collected passed through a 200 mesh screen (75 um).

SECTION 7

RECOMMENDED TEST PROCEDURES

The following test procedure is recommended for the use of the HVS2 in sampling surface dust.

1. Scope
 1.1 This method can be used to determine the quantity of surface dust accumulated on a surface and the amount of pesticides present in the surface dust. It may also be used with appropriate modifications to measure metals, organics, or other chemicals present in surface dust. Collection of semivolatile organics may require an absorbent following the filter.
 1.2 The results of this test method should be stated in grams per square meter of recovered surface dust less than 150 um and nanograms of a specific pesticide per meter square of surface and/or parts per billion (ppb) concentration in the collected dust, to aid comparison between tests.
 1.3 This method may be used in areas where hazardous materials are present. However, the method does not address the safety problems associated with such use. It is the responsibility of each user to determine appropriate health and safety practices prior to use.

2. Applicable Documents
 2.1 ASTM Standards
 D 422-63 Particle-size analysis of soils
 D 4536-86 High Volume Sampling for Solid Particulate Matter and Determining of Particulate Emissions
 F 608-79 Carpet-embedded Dirt Removal Effectiveness of Household Vacuum Cleaners
 2.2 Other documents
 Manual of Analytical Quality Control for Pesticides and Related Compounds. U. S. Environ. Prot. Agency (EPA 600/2-81-059)
 Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air (EPA-600/4-84-041, 1984)

3. Significance
 3.1 Dust on the floor or other horizontal surfaces can be suspended into the air by normal activities, where it is available for inhalation. It has been estimated that small children may ingest 0.1 to 0.5 g and adults about 0.1 g of dust per day. Some pesticides and other organics in the dust may be absorbed through the skin. This method will provide a standardized way to measure the concentration and quantity of dust on floors or other horizontal surfaces and help assess exposure and risk from the air, skin, and ingestion pathways of exposure. The particles below 150 um in diameter can be collected from surfaces in a more

reproducible manner. The limited evidence that is available suggests a higher percentage of such small particles will stick to the hands and skin.

4. Apparatus
 4.1 Weighing scale(s) for samples, 0.1 mg to 1000 g.
 4.2 Stopwatch.
 4.3 Masking tape for outlining sample sections.
 4.4 High volume surface sampler (HVS2) train, including a 13 cm (5 in.) aluminum nozzle, an aluminum or stainless steel (SS) cyclone, and an aluminum 20 by 25 cm (8 by 10 in.) filter holder. The filter holder should be followed by a calibrated orifice or SS laminar flow element, flow control valve, flexible tubing, and blower capable of 14 L/s (30 ft^3/min). One magnehelic gauge is used to measure the pressure drop across the flow measuring device and a second to measure the static pressure in the nozzle. The magnehelic gauge for the nozzle should have a range of 0 to 6.23 kPa (25 in. H_2O).
 4.5 Humidity gauge.
 4.6 Humidity chamber.
 4.7 Teflon jar (and lid) for cyclone. A polypropylene jar may be used when only dust accumulation is measured.
 4.8 Glass sample jars.
 4.9 Thermometer.
 4.10 Rubber stoppers for leak check.
 4.11 Sample recovery equipment.
  4.11.1 Brushes equal to size and length of nozzle section and connecting tubing.
  4.11.2 50% hexane-50% acetone solution for cleanup. Approximately 250 ml required per location.
  4.11.3 Wash bottles and storage containers for liquid.
  4.11.4 Standard 100 mesh (passes 150 um) screen, pan, cover, and shaker.
  4.11.5 Aluminum foil and clean manila folders and envelopes for handling and storing filters.
  4.11.6 Ice chest.

5. Summary of method.
 5.1 A sampling nozzle is used to draw air over a surface to mobilize loose material which is collected in a cyclone and on a filter. The cyclone is used to collect material above 5 to 10 um in diameter and to prevent overloading the filter. The cyclone cup can collect 100 or more grams of sample. A total of at least 2 grams of dust are needed in the cyclone to provide sufficient material for chemical analysis and bioassays. The cyclone also removes 95% plus of the dust from the air stream to reduce evaporation of the pesticides on the dust. With a short sampling period of 8 min or less it is estimated that less than 0.5% of the semivolatile pesticide compounds will evaporate and pass through the filter. The flow measuring device is used to measure and maintain a constant air flow sufficient to collect dust particles and to provide a stable cyclone particle size separation. A magnehelic gauge is used to measure and maintain a predetermined static pressure in the nozzle to ensure a constant efficiency of pick-up of particles of various sizes.

6. Reagents and Filters

6.1 Purity of Reagents. Pesticide grade chemicals shall be used to collect and analyze samples when pesticides are to be measured. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the American Chemical Society.

6.2 Filters. Quartz fiber filters without organic binder and with a low carbon background equivalent to Pallflex 2500 QAO must be used when pesticides or other organics are to be measured. When only dust accumulation is measured, air sampling filters with 99.99 % efficiency, using 0 3 um particles, are sufficient.

6.3 Sample Recovery. Pesticide grade acetone, hexane, or methanol in glass bottles shall be used in recovery of sample from the cyclone bottle and HVS2 train. Use of materials other than aluminum, SS, teflon, or glass for handling chemicals or sampling, have been associated with poor results in collecting pesticide samples.

7. Sampling Strategy

7.1 A representative sample of at least 2 g of surface dust shall be collected from a rug by sampling four 46 by 137 cm (18 by 54 in.) sections. On very clean rugs additional sections may be sampled if the cyclone catch jar does not show sufficient sample. If more than one rug is available the rug should be sampled where small children are more likely to play.

7.2 A representative sample shall be collected from a bare or hard-surface covered floor by measuring and sampling all the available area or until 2 g of sample are collected.

8. Calibration and Pretest Preparation

8.1 Calibration- The magnehelic gauge, orifice or laminar flow element, thermometer, humidity gauge, and scale should be calibrated against a primary standard.

8.1.1 Magnehelic gauge. The magnehelic gauge must be calibrated against a manometer or other primary standard in the orientation in which it will be used in sampling. This calibration should be done once a month or after 25 tests whichever comes first. One means to check the magnehelic gauge is to set up a flow through the train. If the manometer and magnehelic gauge do not agree within 3% the magnehelic gauge is leaking or is in need of repair or calibration. A minimum of five flow rates should be used in the calibration.

8.1.2 Orifice or laminar flow element. A full calibration of the orifice should be performed before use and should be done a minimum of once a year. The orifice or laminar flow element should be designed for easy visual inspection and should be cleaned regularly. They should be calibrated by use of either a spirometer with a minimum capacity of 0.3 m^3 (10 ft^3) or a roots meter.

8.1.3 Thermometer. Calibrate thermometers against mercury-in-glass thermometers. Ice bath and boiling water (corrected for barometric pressure) are acceptable reference points.

8.1.4 Relative humidity gauge. Calibrate the relative humidity gauge against the wet and dry bulb hygrometer method on at least two points once each six months.

8.1.5 Analytical scale. Calibrate according to manufacturers instructions.

8.2 Pretest preparation.

8.2.1 Contact the householder to explain the purpose of the test, obtain informed consent, and set a date for the test. Attempt to schedule the test so there will be a decent interval between the test and the last vacuuming by the householder, or ask them to refrain from vacuuming prior to the test.

8.2.2 Each filter should be exposed to a light source and inspected for pinholes, particles, or other imperfections. Filters with visible imperfections should be rejected. A small brush may be used to remove particles loosely adhering to the filters. Latex gloves should be used when handling the filters.

8.2.3 Filters should not be numbered or folded before collection of the sample if pesticides, organics, or metals are to be determined. (The organic compounds and metals in the ink could affect the results.) This includes filters required for blanks and trial runs. If pesticides or organics are to be measured the filters should be conditioned by being baked for two hours at 600 C to remove organic compounds and placed in a humidity chamber free from pesticide contamination for 24 hr where the humidity is maintained at 50% +/- 5%. Blanks need to be run to determine background levels of contamination. The filters should be weighed to the nearest 0.1 mg and placed in hexane-rinsed heavy aluminum foil and double folded on each side. The identification number should be written on the outside of the foil and the foil placed in a numbered envelope.

8.2.4 Clean the aluminum nozzle, aluminum or SS cyclone, cyclone cup, glass sample jars, SS connecting tubing, and aluminum filter holder. A thorough cleaning with methanol, washing with detergent, and rinsing with distilled water is sufficient when only dust accumulation is measured. A thorough cleaning with hexane may be sufficient for field clean-up between samples. When pesticides or organics are to be measured the following cleaning schedule should be followed prior to collecting a sample:

8.2.4.1 Glass should be rinsed in hexane and placed in a hot (50 C) detergent solution (Sparkleen or equivalent) for 10 min and scrubbed with a nylon brush. Clean with a Chemsolv 2157 solution, rinse with hot water, rinse with distilled/ deionized water, and finally rinse with methylene chloride. Store the glass in cleaned aluminum foil and rinse with methanol if more than 24 hr passes between cleaning and use. Methylene chloride, methanol, and hexane should be applied with a Teflon squeeze bottles. Teflon and rubber gaskets should be cleaned in the same way that glass is cleaned.

8.2.4.2 SS should be cleaned the same as glass except a 15% solution of nitric acid is substituted for Chemsolv.

8.2.4.3 Aluminum should be cleaned the same as glass except the Chemsolv wash should be omitted.

8.2.5 Assemble the sampling train and place a filter in the filter holder. Check for leaks by plugging the entrance to the cyclone, start the blower, and place the control valve in the open position. The system volumetric flow should be no greater than 0.5 L/s (1 cfm). If the flow is greater than 0.5 L/s, the leaks must be located, sealed and the sampling train rechecked.

9. Sampling procedure

9.1 Fill out test data form (see Figure 7) recording all data.

9.2 Select a rug or bare floor for sampling where small children are more likely to play. Use approximately 2 cm (3/4 in.) masking tape and a steel measuring tape or template to lay out eight 46 by 137 cm (18 by 54 in.) squares in an approximately 1.8 by 2.7 m (6 by 9 ft) sampling area (see Figure 6) if there is sufficient space. The 46 by 137 cm squares can be placed on a rug or floor in any convenient layout.

9.3 Connect the blower to 125 volt AC house electric circuit that has 10 amp of spare capacity. Make certain there are no other large loads on the circuit such as an electric heater, iron, or air conditioner. Assemble the HVS2 train. Adjust the flow rate to 9.5 L/s (20 cfm) while adjusting the static pressure (delta P) in the nozzle to match that recommended for the following carpets or bare floor:

Plush	28.4 cm (11.2 in.) H_2O
Level loop	41.7 cm (16.4 in.) H_2O
Flat	41.7 cm (16.4 in.) H_2O
Bare Floor	2.5 cm (1.0 in.) H_2O (approximately 1/16 in. above floor)

If the delta P on a plush carpet cannot be adjusted to 28.4 cm (11.2 in.) H2O, it should be adjusted to the maximum that still allows the HVS2 to be pushed without excess effort. The nozzle delta P for the multilevel, shag, and other types of deep pile carpets should be adjusted to the maximum which still allows the HVS2 to be pushed at the same speed as specified in section 9.4.

9.4 Sample each 46 by 137 cm (18 by 54 in.) segment for 80 s moving the nozzle eight times over each section of rug and completing a forward and return stroke of the HVS2 in 5 s. A stop watch should be used to time the strokes. A 13 by 137 cm (5 by 54 in.) section of surface should be sampled with eight strokes of 2 1/2 s each before moving to the next section. When one 46 by 137 cm (18 by 54 in.) segment is sampled stop the HVS2 and move to the next segment as shown in Figure 6, alternating from one side of the 1.8 by 2.7 m rectangle to the other until four segments have been completed. If it appears that less than 2 g of dust have been collected in the cyclone catch bottle, sample additional segments. Adjust the flow control valve to maintain a constant 9.4 L/s (20 cfm) flow and nozzle height to maintain a constant pressure drop across the nozzle. A portable electronic scale (0.1 to 300 g) may be used to measure the approximate amount of dust in the cyclone jar. Run the HVS2 blower for 20 s with the nozzle at least 3 in. above the floor to remove loose material in the train at the end of the test. Do not do a leak check at the end of sampling as the high vacuum may cause volatilization of the pesticide. Record the nozzle delta P at the beginning and end of sampling. A change of more than 10% in the delta P indicates a potential leak.

9.5 Sample recovery. The following procedures assume an intent to analyse the sample for pesticides or other trace materials. If only particle mass accumulation is being measured, many of the items may be relaxed and performed in a manner similar to the handling of ambient high volume filter samples.

9.5.1 Open the filter holder and use a fine brush to remove any particulate matter deposited on the front side of the holder onto the

filter. Any filter fibers adhering to the filter holder gasket must be removed with a sharp edged blade and placed with the filter. Fold the filter twice lengthwise with the particle side in. Replace the folded filter in the numbered aluminum foil until it is weighed. Then place the filter (in the numbered aluminun foil) in a numbered clean glass bottle so it is supported and cannot move around. Record the bottle number on the test data sheet. Place a layer of clean aluminum foil inside the lid so that it provides a seal when the lid is screwed on. Place in the ice chest. Remove and cap the cyclone bottle using clean aluminum foil inside the lid and label it with a number corresponding to the number on the filter. Place it in the ice chest.

9.5.2 Wash the nozzle, cyclone, filter holder, and connecting tubing with a 50% hexane-50% acetone rinse. Brush down the same parts of the HVS2 with a stiff brush. Follow the brushing with another rinse. Allow the system to air dry for 4 minutes before reassembly. The small amount of sample lost to the walls (usually less than 0.5%) makes analysis of the washings unnecessary.

9.5.3 Taking care to minimize the exposure of the samples to sunlight and high ambient temperatures, seive the contents of the cyclone catch bottle as described in ASTM method D422-63 (without drying). Weigh the material that passes the final 150 mesh screen and prepare it for chemical analysis. Place it in a clean, folded aluminum package inside a clean glass jar and store it with the filter in a refrigerator at 0 C or in an ice chest with dry ice. Do not cool the filter or cyclone catch prior to seiving or weighing.

10. Analysis for pesticides and other organics

10.1 The filter, and dust from the cyclone should be extracted together. The filter may be weighed before extraction but should not be placed in the humidity chamber or desiccated. The removal of water from the filter may also remove pesticides. If the relative humidity of the sampled air is similar to that found in the humidity chamber (45 to 55%) there will be only a small change in weight in the humidity chamber.

10.2 The results should be recorded in nanograms of each specific compound measured along with sensitivity, precision, and accuracy of the measurement.

11. Calculations

11.1 The concentration in ng/m^2 for each compound is found by dividing the total ng of the compound in the sample by the area sampled.

11.2 The ppb for each compound is found by dividing the ng of the compound in the sample by the number of grams of dust passing the final screen and on the filter which were analyzed.

12. Precision

12.1 The percent coefficient of variation of the test method is about 12% for plush carpets and 8% for level loop for particles under 150 um. These values for the rugs were determined by running a series of identical tests on standard test carpets using a standard test dust similar to that specified in ASTM Method F608-79.

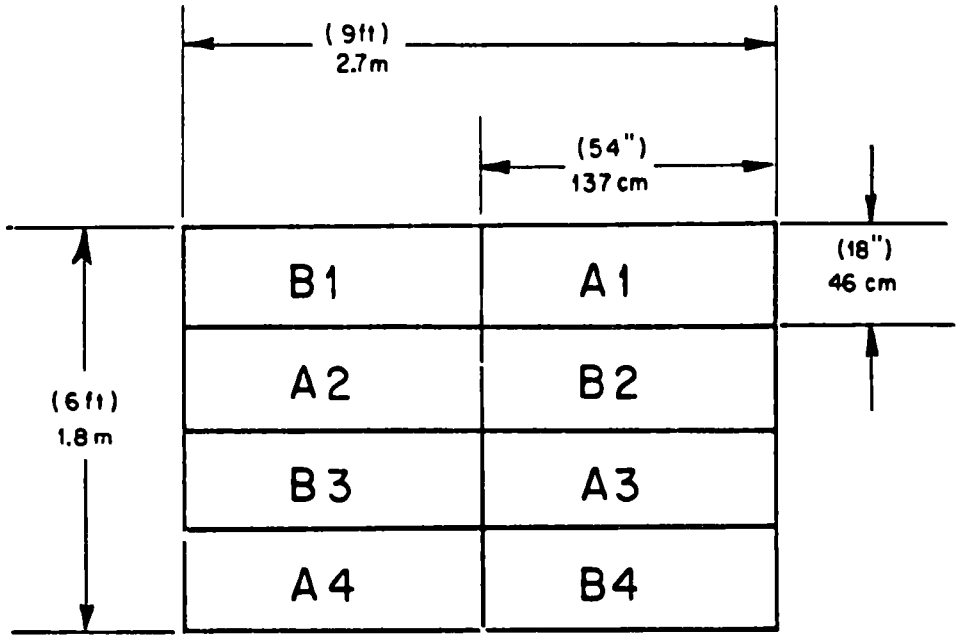

Figure 6. Ideal arrangement of test segments in 1.8 by 2.7 m (6 by 9 ft) area. Sample either A or B segments.

HIGH VOLUME SURFACE SAMPLER DATA SHEET

Operator _____ Date _____ Sample Ident. No. _____

Sampling site _____

Type of surface ____Rug ____Hard floor Other_____

Type of rug ___Plush ___Level loop ___Flat ___Multilevel ___Shag

Last vacuumed _____ Temp _____ Humidity ____% Comments _____

Location of area sampled _____ Area _____

Sketch of area sampled:

Total sample time ____ min ____ sec Flow rate _____ Nozzle dP _____

Filter final wt _____ g Filter tare wt _____ g Net wt _____ g

Cyclone final wt _____ g Cyclone tare wt _____ g Net wt _____ g

Sieve size _____ Wt passed sieve _____ g % passed sieve _____ %

Wt sieving + filter _____ Accumulation wt _____ g/m^2

Filter sample no. _____ Cyclone sample no. _____

Lab sample no. _____

Name of compound	wt	conc (ng/m^2)	conc (ppm)

Figure 7. Recommended data sheet.

SECTION 8

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