RESEARCH REPORT

Effectiveness of Clean-up Techniques for Leaded Paint Dust

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REPORT

Effectiveness of Clean-up Techniques for Leaded Paint Dust

for

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DISCLAIMER

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ABSTRACT

Effectiveness of Clean-up Techniques for Leaded Paint Dust

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Most Canadian houses have some degree of lead in the interior paint. When the paint is disturbed during renovation activities, the lead can be spread through construction dust. Leaded paint dust has been identified as a major potential source of lead contamination in housing when houses being renovated have significant quantities of leaded paint. Currently, Canada does not have specific regulations related to construction clean-up requirements for contractors and homeowners.

This report outlines the results of a laboratory study to provide information on the effectiveness of construction dust clean-up activities that would be available to general contractors and homeowners. Vacuuming using a variety of wet/dry systems, sweeping, and wet mopping were done to standard carpet and vinyl flooring samples. Twenty-eight different combinations were investigated. All measurements were conducted in a full scale environmental chamber with controlled humidity and air flow.

A standardized size distribution dust "cocktail" (0.3% Pb) was prepared and used to provide two standard total dust loadings (1.0 and 40.0 g/m^2) on the floor covering samples. The total mass removal efficiency (MRE) of each clean-up method was determined gravimetrically and the recovered dust was analyzed to determine the size distribution and lead content. A laser particle counting system was used to measure airborne dust concentrations in the chamber during the clean-up activities. The ASTM F 608-89 standard for dirt removal effectiveness for vacuum cleaners was used.

Tests resulted in total MRE's for the carpet samples ranging from 18.5% to >90% depending on the dust loading and vacuuming system. Airborne dust concentrations were lowest using an outside exhausted central vacuuming system and highest for portable units with new bags. Agitator tools produced lower airborne dust concentrations than plain tools. The carpet samples showed a strong hygroscopic tendency and precise control of humidity and laboratory procedures was necessary throughout the testing.

Similarly, for the vinyl flooring samples, MRE's ranged from 94.8% to 100% (including the sweeping method). The sweeping method produced among the lowest airborne dust concentrations for the vinyl flooring tests.

KEYWORDS

Lead dust, construction, renovation, vacuum cleaner efficiency, indoor air quality, carpet cleaning.

1.0 EXECUTIVE SUMMARY

This report summarizes the results of a laboratory investigation on the effectiveness of clean-up techniques for leaded paint dust conducted for the Research Division of the Canada Mortgage and Housing Corporation (CMHC).

The Building Science Division (BSD) of the Saskatchewan Research Council (SRC) conducted a laboratory study to measure the relative effectiveness of various leaded paint dust clean-up techniques on carpet and vinyl floor coverings. The study focused on common techniques that would be available to homeowners and general contractors. A typical residential portable vacuum, a central vacuum and a high cost high efficiency particulate air filtration (HEPA) canister vacuum were used. Sweeping and mopping were also used for vinyl flooring tests. Since the project objective was to evaluate the efficiency of clean-up techniques, a large scale laboratory environment provided the optimum balance between flexibility of testing and control over experimental parameters. All testing was performed in a large dynamic chamber under controlled environmental conditions.

The test results indicated a wide variation in the mass removal efficiency of the various vacuuming techniques used to clean carpet samples with overall efficiencies ranging from <20% to 100%. Airborne dust concentrations were also highly variable, with plain floor cleaning tools and new vacuum cleaner bags producing the highest indoor concentrations. Vinyl floor covering mass removal efficiencies were very high for most of the dry and wet cleaning methods, however, some residual surface dust was recovered from all test samples.

2.0 INTRODUCTION

The toxic effects of lead as a potential health hazard have been identified as a public health concern. The group most at risk from exposure to lead are fetuses, infants and children under seven years of age[1]. Adverse health effects including neurological impairment have been noted. The American Public Health Association has given priority to reduced lead exposure levels and improved exposure controls in industries that perform demolition, repair and construction related work.

Many housing units have paint that can contain significant amounts of lead. Lead was a major ingredient in many types of house paint prior to and through World War II. In the early 1950's, other pigment materials became more popular but lead compounds were still used in some pigments and as drying agents. In Canada, the federal government has regulations to control the use of lead in these products. In the United States, the Department of Housing and Urban Development (HUD) has developed a guideline for lead-based paint abatement[1].

Workers and homeowners may be exposed to lead from paint dust which is distributed throughout the house during and after renovation activity. Of particular concern is the deposition of leaded paint dust on floor coverings, since these areas are directly exposed during renovations and can be significant reservoirs of contaminated dust. Cleaning of floor coverings is necessary, however unlike the specialized apparatus being developed for HUD projects, the methods for cleaning available to homeowners are unproven with respect to cleaning effectiveness and recontamination potential. This study investigated the efficiency of leaded paint dust removal from two typical floor coverings and examined the effect of the cleaning method on the airborne and surface dust concentrations in the proximity of the clean-up area.

The overall objective of this study was to obtain preliminary laboratory results on the various leaded paint dust clean-up techniques. This data can be used to select methods of clean-up of leaded paint dust that provide an environment relatively free of lead contamination. Since the study originated from the need to control lead exposure by reducing leaded paint dust contamination of construction areas, both the lead and overall dust mass balances were considered important study considerations.

The terms of reference for this project acknowledged that a study of this type and level of effort can not be expected to yield all of the answers to this complex problem. The intent of this work was to produce a small set of well characterized data which is scientifically credible and reproducible.

All sectors of the construction industry can benefit from this technology since it will facilitate practical, informed decisions about the impact of proposed clean-up methods to the overall indoor environment of the building. Important applications include the pre-screening of equipment (prior to purchase or installation) and problem assessment in post-construction indoor air quality investigations.

This project was conducted in a large environmental chamber (23 m^3) specifically designed for studies of this type. The chamber is a new facility which is unique in Canada. The chamber is completely lined with polished 304 stainless steel and has an independent environmental control system. These specialized features provide accurate control of all of the significant indoor environment parameters (temperature, humidity, air exchange rate, dust particle concentration of the supply air and mass deposition on adjacent surfaces), thereby minimizing experimental errors and improving the reliability of the clean-up effectiveness data.

The specific objectives of this project were to:

1. Measure the dust mass removal effectiveness of various cleaning techniques on two types of floor coverings.

2. Measure the airborne dust concentration in the chamber during testing.

3. Track the lead concentration in the dust throughout the clean-up process to ensure that the primary contaminant was quantified.

4. Provide some input and recommendations regarding how these cleaning techniques, if effective, could be implemented in the building renovation process.

Two floor coverings were studied; a medium height nylon carpet and a lightly textured sheet vinyl. The cleaning efficiency of the various techniques was evaluated by calculating mass removal efficiencies (MRE). The MRE was obtained from a gravimetric determination of the differential dust loading on the sample (mass removed divided by the total mass deposited on the substrate). The impact of the cleaning method on the airborne and surface dust concentration in the chamber was also investigated.

Gravimetric determination provided an absolute measurement of the clean-up efficiency of the various processes and eliminated many of the sources of experimental error associated with total dust recovery techniques. Given the measurement precision of the gravimetric analysis, the measurement protocol was not able to quantify small quantities of residual dust, either embedded in the floor covering or distributed on the surface of the substrate.

3.0 METHODOLOGY AND EQUIPMENT

3.1 Dust Sample Preparation

A representative dust sample was produced by gathering floor debris including wallboard/plaster scraps, dust and paint chips from an existing building renovation. Since the study focused on dust clean-up, it was not considered to be fundamentally important to obtain leaded paint dust. The primary consideration was that the dust be typical of dust created during renovation activities. This approach was favoured over using "general house dust" collected from vacuum cleaner bags since the particle density, shape and size distribution would be much closer to actual construction dust. Sufficient dust was collected to conduct the entire test program.

The initial debris was ground in an all steel ball mill and then screened using standard American Society for Testing and Materials (ASTM) soil sieves. All material not passing an ASTM No. 60 sieve (250 μm) was discarded. The rationale for eliminating the larger particle sizes is that they are assumed to be easily removed and would not pose a direct exposure concern unless they were degenerated into smaller particles.

The size distribution of the "standard" dust (passing ASTM No. 60 sieve) was determined by screening and then the dust was reconstituted and uniformly mixed by gently tumbling in a large drum for 24 hours. After having an initial lead analysis done on the standard dust (no lead was found), lead stearate powder was added to raise the lead content to approximately 0.3% by weight. Lead stearate was selected since it was commercially available as a fine white powder which would blend well with the dust. The dust was remixed by tumbling for an additional 24 hours. Individual dust samples were taken from the mixing drum, weighed (27g or 0.7g) and placed in individual clean plastic containers for use during the testing. A final lead content of 0.28% for one test dust sample was confirmed by a lead analysis done at the Saskatchewan Research Council (SRC) chemical analysis laboratory. All lead content analyses for the study were conducted by nitric acid digestion and atomic absorption spectroscopy using National Institute for Occupational Safety and Health (NIOSH) 7082.

Although there is no formal protocol for preparing "standard dust" for this type of testing, the methodology was a compromise between the Cincinnati study[2] which collected and ground construction dust to pass a 149 μm sieve and the study by Inskip[3] which used construction dust between 20-500 μm.

Table 1 contains the particle size distribution for the standard dust and leaded test dust.

3.2 Flooring Sample Selection and Conditioning

A 2033 g/m^2 (60 oz./yd^2) cut pile, Saxony style 100% nylon carpet was chosen for the study. This general type of carpet is typical of products used for living areas in houses. It was manufactured from a continuous filament fibre and thus, according to the distributor, produced less sloughing of fibres. The vinyl flooring was a "typical, popular" style of flooring of "ordinary" surface texture. Manufacturer's data for the carpet and vinyl flooring are enclosed in Appendix 1.

For the carpet testing, a roll of carpet was purchased, professionally cleaned and cut into test samples. All of the carpet and vinyl flooring samples were stored in a separate clean conditioned room (at the same temperature and relative humidity conditions as the environmental chamber for a minimum of seven days to ensure equilibrium) until used in the chamber. Each carpet test was started with a new sample. The carpet samples were vacuumed in the laboratory for 14 minutes prior to conditioning and actual testing to further remove loose fibres.

For the vinyl floor covering tests, the same samples were used for all of the tests. To ensure a clean starting point for each test, the samples were cleaned with an alkaline detergent, rinsed (twice) with deionized water and allowed to dry completely.

3.3 Environmental Chamber

The dynamic chamber was operated at 0.2 air changes per hour of clean, pre-filtered air (99.7% @ 0.3 microns HEPA panel filters) at 21°C ±0.5°C and 50% ±3% relative humidity. Rigorous control of the indoor environment minimized experimental errors caused by humidity and ventilation rate variations and cross contamination from other sources. Differences in these parameters (especially humidity) may affect the efficiency of the clean-up, however, these conditions are typical for a broad range of dynamic chamber studies of emissions from building materials and were maintained throughout the testing. Providing a constant, well mixed flow of dust free air to the room was essential since the airborne dust concentration measurements obtained during the various tests were compared. Prior to each test, the interior of the chamber was checked to ensure that total airborne dust concentration ($\geq 0.3\ \mu m$) was below 1000 particles per litre.

3.4 Airborne Dust and Surface Deposition Concentration Measurements

All airborne dust measurements consisted of two size distributions; greater than 0.3 microns and greater than 3 microns in diameter. The airborne dust concentration measurements were made using a TSI Model 3753 laser particle counter.

The particle counting system consisted of the counter, a TSI Model 3703 remote processor and a vacuum pump. The counter operates by drawing particles through a sensing volume using an external vacuum; a laser diode illuminates the particle and a solid-state photodetector then measures the light that the particles scatter. The sampling flow rate was preset for 2.8 litres per minute. The new system was shipped from the distributor and had been factory calibrated. The exhaust for the pump was routed outside the chamber. The accuracy of the counter is quoted as $\pm 10\%$ by the manufacturer with a maximum concentration of 35×10^6 particles per cubic metre. All measurements were taken at a height of 1 meter above the floor as described in ASTM F50-83[4].

Surface deposition measurements were taken by using moistened swabs to clean four specific areas (two on the chamber wall and two on the floor) immediately following a cleaning test. The surface areas swabbed ranged from 3500 cm^2 to 9600 $cm^2 \pm 20\ cm^2$. The total recovered lead was determined by thermal ashing followed by lead analysis. The accuracy of the lead content analysis is estimated at $\pm$ 5%.

3.5 General Test Protocol

3.5.1 Carpet

For the carpet samples, the American Society for Testing and Materials Standard Laboratory Test Method for Evaluation of Carpet-Embedded Dirt Removal Effectiveness of Household Vacuum Cleaners, F608-89[5] was used as a basis for the testing. This test method applies only to embedded dirt removal, not the removal of surface litter and debris. The standard includes descriptions of:

- standard carpet and dust
- weighing scale (accurate to 0.1 gram)
- voltage regulator system for controlling the input voltage to the cleaners
- dust embedment tool construction and use

- conditioning test room (21° ± 3°C, 50 ± 5% relative humidity)
- vacuuming protocol (test cleaning pattern and time)

ASTM[5] calls for each test sample to be cut to 690 mm x 1830 mm (27 x 72 inches). The "lay" of the carpet should be indicated on the sample and oriented uniformly for each test. A cleaning test area of 460 mm x 1370 mm (18 x 54 inches) should be marked on the surface.

Three different vacuum cleaners were used in the testing. The systems included a new portable unit, a new HEPA portable and a used central vacuum. Floor tools used included the plain floor tools supplied with the individual units and one power agitator that was supplied with the portable unit but used for both the portable and central vacuum vacuuming tests.

The new vacuum cleaners were pre-conditioned as stated in the ASTM standard.

Dust sample loadings were specified in the scope of work. Specific dust loadings of 40 g/m^2 and 1 g/m^2 were used. Actual dust weights applied to the flooring samples were approximately 27 grams and 0.7 grams. All of the dust samples were pre-weighed and placed in individual containers prior to testing.

Control of the dust loading was achieved by using a standard "charge" of dust. An even distribution of dust to the surface was the goal. The dust was spread by shaking from the container by hand in a uniform pattern. The dust was embedded by dragging and pushing the embedment tool over the test area for 30 strokes at 2.5 seconds per stroke as called for in the ASTM standard.

Gravimetric determination of the pre/post seeding weight of the carpet sample determined the true dust loading.

Each carpet sample was placed on a carpet underlay which was on a plywood backing panel. This arrangement provided a representative amount of flooring for testing while allowing the personnel a walk-around perimeter area that did not disturb or contaminate the flooring sample.

The samples were vacuumed for a total of exactly 16 strokes at the rate of 2.5 seconds/stroke for a total time of 40 ± 1 seconds. The stroke pattern used is defined in the standard. For vacuums with dust collection bags, tests were conducted with the new bags and with bags approximately 10% full of typical household dust recovered from a staff member's home central vacuum system.

3.5.2 Vinyl Flooring

Testing of the clean-up efficiency for the vinyl flooring followed a similar procedure to that used for the carpet. Some specific procedural differences included:

- samples were placed directly on the plywood backing panel
- the dust was not embedded after application to the sample
- sweeping for 40 seconds and wet mopping for approximately 90 seconds were included in the clean-up methods
- the weight of dust applied to the sample was determined by differential weighing of the dust sample container since rolling up and weighing the vinyl flooring would result in a significant amount of dust loss
- only smooth floor tools (no agitator) were used
- additional post-cleaning time was allowed for wet clean-up methods to allow sample to dry and re-establish moisture equilibrium

The test matrix for the two floor coverings and the various cleaning strategies is shown in Figure 1.

4.0 DETAILED TESTING PROTOCOL

Measurement of the removed mass from the substrate was considered to be extremely difficult and error prone since dust losses due to attachment to the cleaning equipment (vacuum cleaner hoses and hardware, brooms, mops and containers) would be impossible to quantify. As an alternative, the use of gravimetric determination of the pre/post cleaning substrates was used to ensure an accurate assessment of the overall clean-up efficiency. All substrate weight measurements were made on a calibrated, digital balance having a precision of 0.1 gram. Conducting the testing in a clean, controlled chamber environment ensured background contamination and losses were minimized and facilitated placement, removal and weighing of the samples.

The carpet sampling involved the most elaborate testing protocol since contamination, reproducibility and obtaining a standard start-up condition was the most difficult. Use of the same carpet sample for different tests was not considered since it is impossible to ensure the same starting point for each test. Residual dust accumulation and carpet fibre deterioration are two major problems associated with re-using the same carpet for subsequent tests.

Each flooring sample cleaning test consisted of the following:

a) Pre-condition all samples in the conditioning room at 21°C and 50% RH. All samples were pre-vacuumed before being placed in the conditioning room. Samples were moved into the dynamic chamber a minimum of 7 days prior to testing. The actual cleaning area was identified using a template and a marker pen.
b) Prior to the cleaning test, wrap the rolled sample in a dedicated plastic bag.
c) Weigh the sample to determine base weight.

d) Weigh the vacuum cleaner bag in a dedicated plastic bag (if used).
e) Record chamber relative humidity and temperature.
f) Weigh the dust container with dust (vinyl floor covering).
g) "Seed" the sample with the lead paint dust.
h) Embed the dust (if carpet sample).
i) Roll the carpet sample into the same plastic bag and re-weigh to determine weight of loaded sample.
j) Weigh empty dust container to determine actual dust weight applied (vinyl floor covering).
k) Clean the sample.
l) Monitor the chamber airborne dust concentration with the laser particle counter while cleaning and for a minimum of 20 minutes after the end of the cleaning time.
m) Roll the sample into the same plastic bag and re-weigh to determine the final weight.
n) Weigh the vacuum cleaner bag to determine weight gain.

Since it was impossible to ensure that all of the dust applied to the carpet could be recovered onto a suitable collection media, it was important that accurate weight balances be used to determine the cleaning efficiency. This type of study could only be undertaken using clean substrates installed in a controlled environment where they could be removed for gravimetric analysis. Although clean-up equipment such as the high volume HEPA vacuum cleaner/surface samplers were expected to have a high cleaning efficiency, this methodology was not used as an experimental benchmark on which other cleaning processes could be evaluated.

All of the substrates which were subjected to wet process cleaning were allowed to dry in the chamber for a sufficient period of time to ensure that their moisture content had stabilized and returned to equilibrium with the chamber humidity conditions. In the case of the professional carpet cleaning, this required approximately one week.

Since the study objective of determining the cleaning efficiency was restricted to a total mass analysis, only the before/after gravimetric analysis was conducted. A brief investigation of particle size distribution effects was conducted by measuring the total mass and size distribution analysis on a few typical samples of the recovered dust. By differential analysis, the retained dust load and size distribution can be estimated by this method. The retained dust load and size distribution will be important considerations for assessing the future contamination potential.

The before and after mass and particle size distribution data resulting from this study will be an indication of how the cleaning methods compare and will provide essential background data for investigations on how they may be improved.

5.0 ANALYSIS

5.1 Experimental Protocol Development

Prior to the detailed testing program, a number of preliminary investigations were undertaken to develop information on the experimental procedures.

Since the flooring samples weighed approximately 2700 g as compared with dust loadings of 27 g and 0.7 g, the accuracy of the mass removal efficiency calculations is highly dependent on control of the test substrate mass throughout the test procedure. Several parameters were investigated:

5.1.1 Effect of Relative Humidity Changes

The conditioning room and environmental test chamber were operated at the same temperature and relative humidity to minimize the effects of water vapour adsorption/desorption on the substrate mass. Prior to transferring the flooring samples they were sealed in individually numbered plastic bags. The need for this level of control is illustrated by the data in Figures 2-4.

Figure 2 shows the variation in the long term carpet sample weight due to changes in the ambient relative humidity. It should be noted that a large time lag between change in RH and change in carpet weight occurs which could seriously confound analysis if the testing was not conducted with the carpet samples in equilibrium. The transient effect was further investigated by allowing a carpet sample to reach equilibrium in the conditioning room (50% RH) and then removing it to an area maintained at 30% RH. The results are presented in Figure 3. As can be seen from the graph, the carpet sample lost approximately 23 g in the first 24 hours and had not yet reached a new weight equilibrium.

The vinyl floor covering did not exhibit a weight change with variation in the relative humidity. In a test similar to that of Figure 3, a vinyl floor covering sample was taken from the conditioning room at 50% RH and placed in an area at approximately 35% RH. As illustrated in Figure 4, there was almost no detectable weight change (maximum variation $\pm$0.15 g) in the sample during an eight hour period.

5.1.2 Handling of the Samples

Weight changes associated with handling of the samples were considered as potential sources of error. Rolling, packaging, installation and removal from the test site could result in fibre shedding or humidity effects. To investigate this source of error, one carpet sample and one vinyl floor covering sample were subjected to sequential rolling/unrolling cycles. The results from the carpet sample are shown in Figure 5. In five out of six handlings, the difference in the weight change was less than 0.2 g. In one handling, loss of carpet yarns from the unfinished carpet edges resulted in a 0.9 g weight change. This observation resulted in the requirement for careful edge conditioning of the carpet samples to ensure that all loose yarns were removed prior to formal testing.

A similar trend was seen with the vinyl floor covering sample (Figure 6). In three out of four subsequent handlings, no weight change was observed. In one handling, a weight reduction of 0.1 g was recorded with no further weight change.

Checking of the reproducibility of the weighings were also conducted as a subcomponent of this testing. Each sample was re-weighed between five and ten times after each handling cycle to examine the scale output (Figures 5 and 6). In all cases, the replicate weighing results were within 0.1 g.

Based on the results of these investigations, sample handling was not expected to produce experimental errors beyond the 0.1 g measurement precision of the balance.

5.1.3 Carpet Sample Weight Loss Due to Fibre Shedding

Shedding of carpet fibres could contribute to elevated recovered dust mass estimates which would over estimate the mass removal efficiency of the carpet cleaning methods. The ASTM carpet cleaning protocol required cleaning of the samples until a five minute cleaning resulted in less than 2 g weight reduction in the sample. This level of weight uncertainty was unacceptable for this study so an investigation as to the effect of repeated two minute cleanings on the carpet weight loss was undertaken. New carpet samples were subjected to sequential two minute vacuuming cycles and the sample weight was recorded after each cleaning.

Figure 7 gives the results for five carpet samples using the portable vacuum and the agitator cleaning method. In all cases, the incremental weight loss for a two minute vacuuming was less than 0.8 g ($\bar{x}$=0.44 g, σ=0.31 g) after seven cleaning cycles (14 minutes of continuous cleaning). On the basis of these results, all carpet test samples were vacuumed for 14 minutes prior to beginning the testing which would result in an estimated 0.25 g maximum loss for the 40 second test run (mean loss approximately 0.15 g).

5.2 <u>Cleaning Efficiency Calculations</u>

The mass removal efficiency (MRE) was defined as the ratio of the mass of dust removed to the mass of dust deposited on the substrate. From the experimental data, this was calculated as:

5.2.1 for carpets

$$\text{MRE} = \frac{\text{sample mass after loading - sample mass after cleaning}}{\text{sample mass after loading - sample mass before loading}} * 100 \quad (1)$$

5.2.2 for vinyl flooring

$$\text{MRE} = \frac{\text{sample mass before loading + dust mass - sample mass after cleaning}}{\text{dust mass}} * 100 \quad (2)$$

where:

dust mass = dust sample container mass full - dust sample container mass empty (3)

Different MRE calculations were necessary to ensure that procedural requirements did not introduce mass balance errors. For the carpet, the differential weight of the dust sample container could not be used as the dust load since some dust was lost during the embedment process.

One set of 40 second sequential cleaning tests was conducted on carpet samples with initial dust loads of approximately 27 g. The objective of the testing was to determine the increase in MRE that could be achieved by longer cleaning cycles and to identify the maximum MRE that could be achieved if cleaning time was not a limiting factor. The cumulative MRE was calculated based on the total weight loss from the initial starting weight.

5.3 Total Dust and Lead Mass Balance

The project also attempted to develop a mass balance for both the total dust and elemental lead to provide a degree of confidence that all of the initial lead dust loading could be accounted for. Schematically, this mass balance is illustrated in Figure 8. In practical terms, however, analytical and physical constraints restricted detailed mass balances of these parameters. These limitations and the resultant protocols are outlined below.

Only visual inspections of the dust accumulation on the cleaning equipment could be made, however it was apparent that, in some cases, a significant amount of deposition occurred. No practical method for quantifying the accumulated dust could be developed and analysis was limited to measurement of the lead concentration of one dust sample (portable vacuum with plain tool) for comparison with the standard and recovered dust for this test.

5.4 Airborne Dust Concentrations

Airborne particle concentration measurements give a valuable indication of the relative dust exposure caused by the cleaning methods but can not be used to calculate airborne particle mass since only two particle diameter bins are provided by the counter. Since the particle mass will be proportionate to the cube of the diameter, large errors in analysis may occur. Due to the very short test period (40 seconds), it was not possible to obtain standard industrial hygiene measurements of total airborne dust concentration. Typically, these tests must be conducted over a number of hours to obtain enough dust to permit accurate gravimetric analysis.

5.5 Surface Dust Deposition

The normalized surface lead deposition, NSDD (mg/m^2), for each site was calculated as:

$$\text{NSDD} = \frac{\text{mass of lead recovered from swab}}{\text{surface area swabbed}} \qquad (4)$$

6.0 RESULTS

The calculated MRE's for the test matrix (including replicates) are given in Table 2. Table 2 also contains the airborne dust particle concentration for each size range at two minutes from the start of the cleaning method.

The cumulative MRE for the four different vacuum methods is given in Figure 9.

Figures 10 and 11 illustrate the airborne dust particle concentration in the chamber for a typical carpet and vinyl floor covering cleaning test. Figure 10 shows a test on carpet using the portable vacuum with the agitator head and a 10% full bag. In Figure 11, brooming started at minute 120 and mopping started at minute 151.

Table 3 lists the NSDD recorded at each site during one clean-up procedure.

Figure 12 shows the results from the surface wipe testing on the chamber walls and floor following a portable plain tool 27 g dust loading carpet cleaning test.

Table 4 gives the results of the lead analysis of the recovered dust from the vacuum cleaner bags.

Table 5 contains the results of surface wipe tests on the vinyl flooring samples following the clean-up tests.

The size distribution for the recovered dust samples from the vacuum cleaner receptacles is given in Table 6.

7.0 DISCUSSION AND RECOMMENDATIONS

7.1 Mass Removal Efficiency

The main focus of the project was to produce accurate benchmark data on the MRE for various cleaning methods and flooring materials under controlled laboratory conditions. By controlling the environmental conditions, the MRE values provide accurate data on the relative performance of the various clean-up processes. Since there were only single runs for most test conditions (replicates on 25% of tests), the data set is not extensive enough for a detailed statistical analysis of the relative effect of parameters such as bag loading, static pressure, air flow and cleaning tool type. The discussion will be limited to general trends and observations obtained during the test program.

7.1.1 27 g Loading on Carpet

As expected, the 27 g loading tests on carpeting produced fairly consistent results with the vacuum plain cleaning tools giving MRE's in the range of 18.5% to 28.9% for the small portable unit, 57.4% for the large HEPA unit and 65.3% for the central unit. For both of the vacuum units, the agitator tools produced MRE's between 59.2% and 65.3%. The lower air flow/static pressure characteristics of the portable unit would limit its ability to dislodge dust particles without the aid of the mechanical agitator. A major difference in clean-up efficiency was not observed between the new bag and 10% full bag loading tests.

For these tests, the effect of fibre shedding on the overall mass balance and MRE calculations is minimal since the average fibre loss for the first cycle after pre-conditioning was estimated to be approximately 0.1-0.2 g with subsequent cleanings resulting in even lower weight loss.

For the sequential cleaning tests (Figure 9) used to calculate the cumulative MRE's, fibre shedding may contribute to small additional errors in the higher number of cleaning cycles. In all cases the carpet substrates reached weight equilibrium after a finite number of cycles and none of the cumulative MRE values exceeded the theoretical maximum of 100% (within weighing error limits). This data suggests that fibre shedding effects are not producing significant errors in individual analysis or, more importantly, in the interpretation of the relative performance results.

Referring to Figure 9, it is apparent that extended cleaning cycles will result in higher dust mass removal from carpeting. The agitator tool method produced high MRE (> 90 %) values when used for cleaning times in the range of 10-12 minutes per m^2. For full scale clean-up tasks, this process could become very time intensive.

Airborne dust levels exceeded the measurement capacity of the monitor when using the portable vacuum with a new bag but were substantially lower with the bag 10% loaded. The HEPA vacuum with the plain tool produced higher airborne dust levels than the central vacuum or portable vacuum (bag 10% full) with the plain tool. For both the central vacuum and portable vacuum, airborne dust levels were much lower with the agitator than with the plain tool.

For all of the cleaning processes, the airborne dust concentration followed a cyclic pattern related to cleaning activity. The airborne dust levels reported in this study are values after two minutes (including the 40 second cleaning process unless noted) and would probably increase further if the cleaning activity was sustained for longer periods.

A secondary measure of the effectiveness of the low loading carpet cleaning efficiency may be inferred from the results of the sequential 40 second carpet cleaning tests initially performed on the 27 g loading (Figure 9). This series of tests provided data on a progressively lowered dust loading and indicated that only the agitator was successful in producing mass removal in loadings below approximately 5 g. For example, the HEPA vacuum with the plain tool had a maximum MRE of approximately 80%. Therefore, when 20% of the initial dust loading (5.4 g) remained on the carpet, the system was unable to remove any additional dust. The central vacuum and portable vacuum left even higher retained dust loadings on the carpet samples.

7.1.2 0.7 g Loading on Carpet

This series of tests did not result in a reliable data set since the inherent relative errors associated with the weighing of the samples confounded the analysis.

7.1.3 0.7 g and 27 g Loading on Vinyl Flooring

All of the vacuum and wet mopping methods resulted in virtually 100% MRE, with the broom only method having MRE values of approximately 95% to 97%. No noticeable performance difference related to bag loading was observed.

The results in Table 5 show that although the MRE values were very high, some residual lead was recovered from the vinyl floor covering after the cleaning tests were conducted.

7.2 Lead Mass Balance

The mass balance of lead throughout the project could not be fully quantified due to previously mentioned experimental constraints, however the significance of the lead mass balance must be discussed.

By adding lead stearate to the construction dust to produce an overall lead concentration of 0.3%, the initial particle size distribution of the standard dust (6% < 74 μm) was influenced by the addition of the ultrafine (86% < 74 μm) lead stearate powder. It should be noted that the lead stearate was a very small mass component of the test dust. As such, the lead content analysis is artificially skewed towards the fine particle sizes which would show up in elevated proportions in the airborne and surface deposition components. Since the lead in paint would be more likely distributed throughout the particle size range, the total dust mass may give a more useful assessment of the true lead distribution that would be observed during renovation activities.

7.3 Surface Dust Deposition

The surface dust distribution data from Table 3 are plotted in Figure 12. The results highlight some of the dust containment problems associated with leaded dust clean-up techniques. The surface deposition rate was much higher on the floor than the walls, indicating that the majority of the airborne particles will settle out with time. The relatively low wall deposition rate suggests that "plate out" due to surface attraction is a secondary effect after gravity settling. As expected from point source dispersion modelling, the concentration decreased with increasing distance from the source.

8.0 SUMMARY

8.1 MRE Results

8.1.1 Carpet

1) The portable residential vacuum cleaner gave low MRE's with the plain tool and moderate MRE's with the mechanical agitator. - Table 7

2) The more powerful HEPA and central vacuums gave moderate MRE's with both plain tools and mechanical agitators. - Table 7

3) Experimental errors prevented accurate measurements using the low (0.7 g) dust loading.

4) The initial cleaning gave the highest incremental dust removal with subsequent cleaning cycles producing diminishing returns. With the case of the agitator head, MRE's approaching 100% are possible with long cleaning cycles. - Table 8

5) The professional dry/wet cleaning did not produce MRE's above those obtained by the residential units with the agitator tool. - Table 7

8.1.2 Vinyl floor covering

1) All methods gave very high MRE's however the broom alone left a visible dust residue. - Table 7

8.2 Airborne dust

8.2.1 Carpet

1) The portable vacuum cleaner with the plain tool or the mechanical agitator produced the highest airborne dust concentrations when used with a new bag.

2) The portable vacuum with the bag 10% loaded produced airborne dust levels that were comparable to the central and HEPA vacuums.

3) Mechanical agitator cleaning tools produced lower airborne dust concentrations than plain cleaning tools.

8.2.2 Vinyl Flooring

1) Sweeping produced lower airborne dust concentrations than many of the vacuum methods.

2) Wet mopping and wet vacuuming produced the lowest airborne dust concentration.

8.3 General

1) For similar laboratory testing, careful control of humidity, substrate pre-conditioning, test conditions and test protocols is essential.

2) Small changes in vacuum collection bag loading did not produce a demonstrable change in MRE. The effect of high bag loadings was not investigated.

3) Surface wipe testing on the cleaned vinyl flooring samples indicated a wide variation in surface residue although the MRE's were all approaching 100%.

9.0 OPPORTUNITIES FOR FURTHER STUDY

This initial investigation produced some very promising initial results in terms of providing the construction industry with practical solutions to the evaluation and control of dust from leaded paint during renovation work. It also developed a methodology on which to base future work.

Further areas of study required to refine the process and implement the results include:

1) Development of a more comprehensive database on the performance of these and other cleaning techniques on a larger sample of flooring materials,

2) Investigation into the application methods and suitability of the cleaning products,

3) A study to improve the performance of vacuum cleaners would build directly onto the results of this study. It would require delineation of a number of experimental parameters including dust size distribution, tool design, air flow and external static pressure and particle removal system,

4) Investigation of surface dust vs. embedded dust in carpets as a reservoir for human exposure.

10.0 REFERENCES

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2. Que Hee, S.S., Peace, B., Clark, C.S., Boyle, J.R., Bornschein, R.L., Hammond, P.B., "Evolution of Efficient Methods to Sample Lead Sources, Such as House Dust and Hand Dust, in the Homes of Children", Second International Conference on Prospective Lead Studies, Cincinnati, Ohio, April 9-11, 1984.

3. Inskip, M.J., Hutton, M., "Lead-based paint in dwellings:the potential for contamination of the home environment during renovation", Environmental Geochemistry and Health, 9(3-4), 1987, pp. 86-92.

4. Standard Practice for Continuous Sizing and Counting of Airborne Particles in Dust-Controlled Areas Using Instruments Based Upon Light-Scattering Principles, ASTM F50-83 (Re-approved 1989), American Society for Testing and Materials, Philadelphia, PA.

5. Standard Laboratory Test Method for Evaluation of Carpet-Embedded Dirt Removal Effectiveness of Household Vacuum Cleaners, ASTM F608-89, American Society for Testing and Materials, Philadelphia, PA.

Table 1a - Particle size distribution for two "standard" dust samples (without lead stearate powder)

Sieve No.	Sample #1 % Finer than	Sample #2 % Finer than
60	99.9	100.0
100	25.5	42.8
200	5.1	6.1

Table 1b - Average particle size distribution of three "test" dust samples (with lead stearate powder)

Sieve No.	Sample #1 % Finer than	Sample #2 % Finer than	Sample #3 % Finer than
60	99.9	99.4	98.8
100	67.1	53.2	44.4
200	41.7	21.7	14.9

Table 2a - Nominal dust loading of 40 g/m² (27 g) on carpet samples

Cleaning Method	Mass of dust applied to substrate, grams	Mass recovered in cleaning receptacle, grams	Mass of dust removed from substrate, grams	Mass of non-recovered dust, grams	Airborne dust concentration at 2 mins., particles/litre		Mass removal efficiency, % MRE
					≥0.3 µm	≥3.0 µm	
Portable vacuum-plain tool-empty bag	27.0	4.0	5.0	1.0	34674	7415	18.5
	27.1	7.0	7.8	0.8	>35310	4909	28.8
Portable vacuum-agitator head-empty bag	28.1	14.6	17.7	3.1	n.a.	n.a.	63.0
	27.0	13.7	16.8	3.1	>35310	3365	62.2
Portable vacuum-plain tool-10% full bag	26.4	5.5	6.4	0.9	20162	1109	24.2
Portable vacuum-agitator head-10% full bag	27.2	13.0	16.1	3.1	2910	597	59.2
HEPA vacuum	27.0	13.3	15.5	2.2	23905	6815	57.4
Central vacuum-plain tool	25.9	n.a.	16.9	n.a.	15819	2613	65.3
Central vacuum-agitator head	27.1	n.a.	17.7	n.a.	5685	1285	65.3
Professional carpet shampooing	26.4	n.a.	15.2	n.a.	n.a.	n.a.	57.6
	26.7	n.a.	17.9	n.a.	n.a.	n.a.	67.0

Table 2b - Nominal dust loading of 40g /m² (27 g) on vinyl flooring samples

Cleaning Method	Mass of dust applied to sample, grams	Mass recovered in cleaning receptacle, grams	Mass of dust removed from sample, grams	Mass of non-recovered dust, grams	Airborne dust concentration at 2 mins., particles/litre		Mass removal efficiency, % MRE
					≥0.3 μm	≥3.0 μm	
HEPA vacuum	27.0	21.6	26.9	5.4	8792	52	99.6
	27.0	24.0	27.0	3.0	1847	52	100
Portable/ vacuum-plain tool-10% full bag	27.0	24.6	26.9	2.4	8510	2821	99.6
	26.9	20.9	26.8	6.9	22492	2126	99.6
Portable vacuum-plain tool	27.0	23.4	26.8	3.4	34004	830	99.3
Central vacuum-plain tool	27.1	n.a.	27.1	n.a.	17584	438	100
Broom	27.1	n.a.	25.7	1.4	2037	1052	94.8
	27.0	n.a.	26.2	0.8	2753	1462	97
Broom and wet mopping	27.0	n.a.	27.0	0	2733	1462	100
Wet mop and wet vacuum	27.0	n.a.	27.0	0	151	6	100

Table 2c - Nominal dust loading of 1.0 g/m² (0.7 g) on carpet samples

Cleaning Method	Mass of dust applied to substrate, grams	Mass recovered in cleaning receptacle, grams	Mass of dust removed from substrate, grams	Mass of non-recovered dust, grams	Airborne dust concentration at 2 mins., particles/litre		Mass removal efficiency, % MRE
					≥0.3 μm	≥3.0 μm	
Portable vacuum-plain tool-empty bag	0.5	0.7	0.4	0.1	7980	438	80.0
Portable vacuum-agitator head- empty bag	0.7	0.6	1.2	-	>35310	1536	-
Portable vacuum-plain tool-10% full bag	0.4	0.3	0.7	-	30119	1349	-
Portable vacuum-agitator head-10% full bag	0.6	0.6	1.6	-	10981	752	-
HEPA vacuum	0.5	1.1	0.4	0.1	6674	403	80.0
Central vacuum-plain tool	0.4	n.a.	1.0 gain	-	5191	94	-
	0.7	n.a.	1.2	-	971	50	-
Central vacuum-agitator head	0.6	n.a.	0.0	0.6	5861	100	0.0
	0.5	n.a.	0.7	-	982	33	-

Table 2d - Nominal dust loading of 1.0 g/m² (0.7 g) on vinyl flooring samples

Cleaning Method	Mass of dust applied to substrate, grams	Mass recovered in cleaning receptacle, grams	Mass of dust removed from substrate, grams	Mass of non-recovered dust, grams	Airborne dust concentration at 2 mins., particles/litre		Mass removal efficiency, % MRE
					≥0.3 μm	≥3.0 μm	
HEPA vacuum	0.7	0.7	0.7	0.0	20374	79	100
Portable vacuum-plain tool-empty bag	0.7	0.7	0.7	0.0	>35310	1493	100
Portable vacuum-plain tool-10% full bag	0.8	0.2	0.9	0.6	>35310	2910	-
Central vacuum-plain tool	0.7	n.a.	0.7	0	7592	109	100
Broom	0.7	n.a.	0.7	0	1299	614	100
	0.7	n.a.	0.7	0	1540	466	100
	0.7	n.a.	0.7	0	943	378	100
Broom and wet mopping	0.7	n.a.	0.7	0	667	209	100
	0.7	n.a.	0.7	0	943	378	100
Wet mop and wet vacuum	0.8	n.a.	0.8	0	787	8	100

Table 3 - NSDD for various chamber surfaces

Location in Chamber	Lead concentration, mg/m^2
Floor - 0.4 m from vacuum cleaner	1.256
Floor - 3.0 m from vacuum cleaner	0.467
Wall - 1.3 m from vacuum cleaner	0.067
Wall - 3.2 m from vacuum cleaner	0.020

Table 4 - Lead analysis of dust recovered from vacuum cleaner receptacles - 27 gram nominal dust loading

Cleaning Method	Lead concentration µg/g	Lead %
Portable vacuum-plain tool Carpet	4700 4200	0.47 0.42
Portable vacuum-agitator head Carpet	2900 3200	0.29 0.32
HEPA vacuum Carpet	2900	0.29
Portable vacuum-plain tool Vinyl	3700	0.37
HEPA vacuum Vinyl	3500 4000	0.35 0.40

Table 5 - Lead analysis of post-cleaning surface wipes of vinyl flooring samples

Cleaning Method	Nominal dust loading, g	Lead concentration, mg/m^2
Broom and wet mopping	27	0.158
Very wet mopping and wet vacuuming	27	0.048
Broom	27	0.618
Portable vacuum-plain tool-10% full bag	27	0.095
HEPA vacuum	27	0.078
Broom and wet mopping	0.7	0.032 0.048
Very wet mopping and wet vacuuming	0.7	0.049
Broom	0.7	0.103
Portable vacuum-plain tool-10% full bag	0.7	0.016

Table 6 - Particle size distribution of dust recovered from dust receptacles

Dust source	Sieve no.	Dust weight on sieve, grams	Total weight finer than, grams	% finer than
Portable vacuum-	60	.035	.461	92.9
27 gram loading-	100	.047	.414	83.5
Carpet-plain tool	200	.069	.345	69.6
	Pan	.345		
	60	.039	2.442	98.4
	100	.158	2.284	92.1
	200	.344	1.940	78.2
	Pan	1.940		
Portable vacuum-	60	.045	7.491	99.4
27 gram loading-	100	.729	6.762	89.7
Carpet-agitator head	200	1.252	5.510	73.1
	Pan	5.510		
Portable vacuum-	60	.004	0.161	97.6
0.7 gram loading-	100	.083	0.078	47.3
Vinyl-plain tool	200	.062	0.016	9.7
	Pan	.016		
Portable vacuum-	60	.012	13.695	99.9
27 gram loading-	100	2.912	10.783	78.7
Vinyl-plain tool	200	3.016	7.767	56.7
	Pan	7.767		

Dust source	Sieve no.	Dust weight on sieve, grams	Total weight finer than, grams	% finer than
Portable vacuum-	60	.013	15.934	99.9
27 gram loading-	100	4.739	11.195	70.2
Vinyl-plain tool	200	3.807	7.388	46.3
	Pan	7.388		
Portable vacuum-	60	.017	.071	80.7
0.7 gram loading-	100	.031	.040	45.5
Carpet-plain tool	200	.028	.012	13.6
	Pan	.012		
Portable vacuum-	60	.036	.077	68.1
0.7 gram loading-	100	.037	.040	35.4
Carpet-agitator head	200	.033	.007	6.2
	Pan	.007		
Portable vacuum-	60	.003	.423	99.3
Dust Recovered	100	.016	.407	95.5
From Surface	200	.131	.276	64.8
Of Plain Tool	Pan	.276		

Dust source	Sieve no.	Dust weight on sieve, grams	Total weight finer than, grams	% finer than
HEPA vacuum- 0.7 gram loading- Vinyl	60	.014	.135	90.6
	100	.061	.074	49.7
	200	.053	.021	14.1
	Pan	.021		
HEPA vacuum- 27 gram loading- Vinyl	60	.019	11.795	99.8
	100	3.005	8.790	74.4
	200	3.391	5.399	45.7
	Pan	5.399		
	60	.015	13.305	99.9
	100	3.146	10.159	76.3
	200	3.233	6.926	52.0
	Pan	6.926		
HEPA vacuum- 0.7 gm loading Carpet	60	0.12	.173	93.5
	100	.050	.123	66.5
	200	.077	.046	24.9
	Pan	.046		

Table 7 Mass removal efficiency results summary (%)

Cleaning Method	Carpet	Vinyl Flooring
	40 g/m²	40 g/m²
PV - PT empty bag	19 29	99
PV - PT 10% full bag	24	100 100
PV - AH empty bag	63 62	-
PV - AH 10% full bag	59	-
CV - PT	65	100
CV - AH	65	-
HEPA vacuum-plain tool	57	100 100
Professional carpet shampooing	58 67	-
Broom	-	95 97
Very wet mopping and vacuuming	-	100
Broom and wet mopping	-	100

PV-portable vacuum
PT-plain tool
CV-central vacuum
AH-agitator head

Double entries are replicate tests.

Table 8 Mass removal efficiency for extended vacuuming cycles

Cycle Number	Mass removal efficiency, % MRE			
	Cleaning method			
	Central vacuum - plain tool	Central vacuum - agitator head	HEPA vacuum	Portable vacuum - plain tool
1	34.7	71.0	55.4	17.5
2	47.0	80.2	61.2	23.0
3	51.9	85.9	66.3	26.6
4	56.0	87.8	69.0	29.4
5	59.3	88.9	72.1	32.5
6	61.6	91.2	74.4	34.9
7	63.8	93.1	76.4	36.5
8	67.5	95.4	77.5	38.1
9	67.5	97.7	78.7	40.1
10	67.2	100.0	80.2	41.7
11		102.3	82.6	43.3
12		104.6	84.1	44.8
13		104.6	84.5	46.8
14		103.8	84.5	48.4
15				49.6
16				50.8
17				52.4
18				53.6
19				54.4
20				55.2

	Carpet		Vinyl Flooring	
	1.0 g/m²	40 g/m²	1.0 g/m²	40 g/m²
Portable vacuum-plain tool-empty bag	✓	✓ ✓	✓	✓
Portable vacuum-plain tool-10% full bag	✓	✓	-	✓ ✓
Portable vacuum-agitator head-empty bag	✓	✓ ✓	-	-
Portable vacuum-agitator head-10% full bag	✓	✓	-	-
Central vacuum-plain tool	✓ ✓	✓	✓	✓
Central vacuum-agitator head	✓ ✓	✓	-	-
HEPA vacuum-plain tool	✓	✓	✓	✓ ✓
Professional carpet shampooing	-	✓ ✓	-	-
Broom	-	-	✓ ✓	✓ ✓
Very wet mopping and vacuuming	-	-	✓	✓
Broom and wet mopping	-	-	✓ ✓	✓

Figure 1. Matrix showing cleaning method, dust loading and flooring material

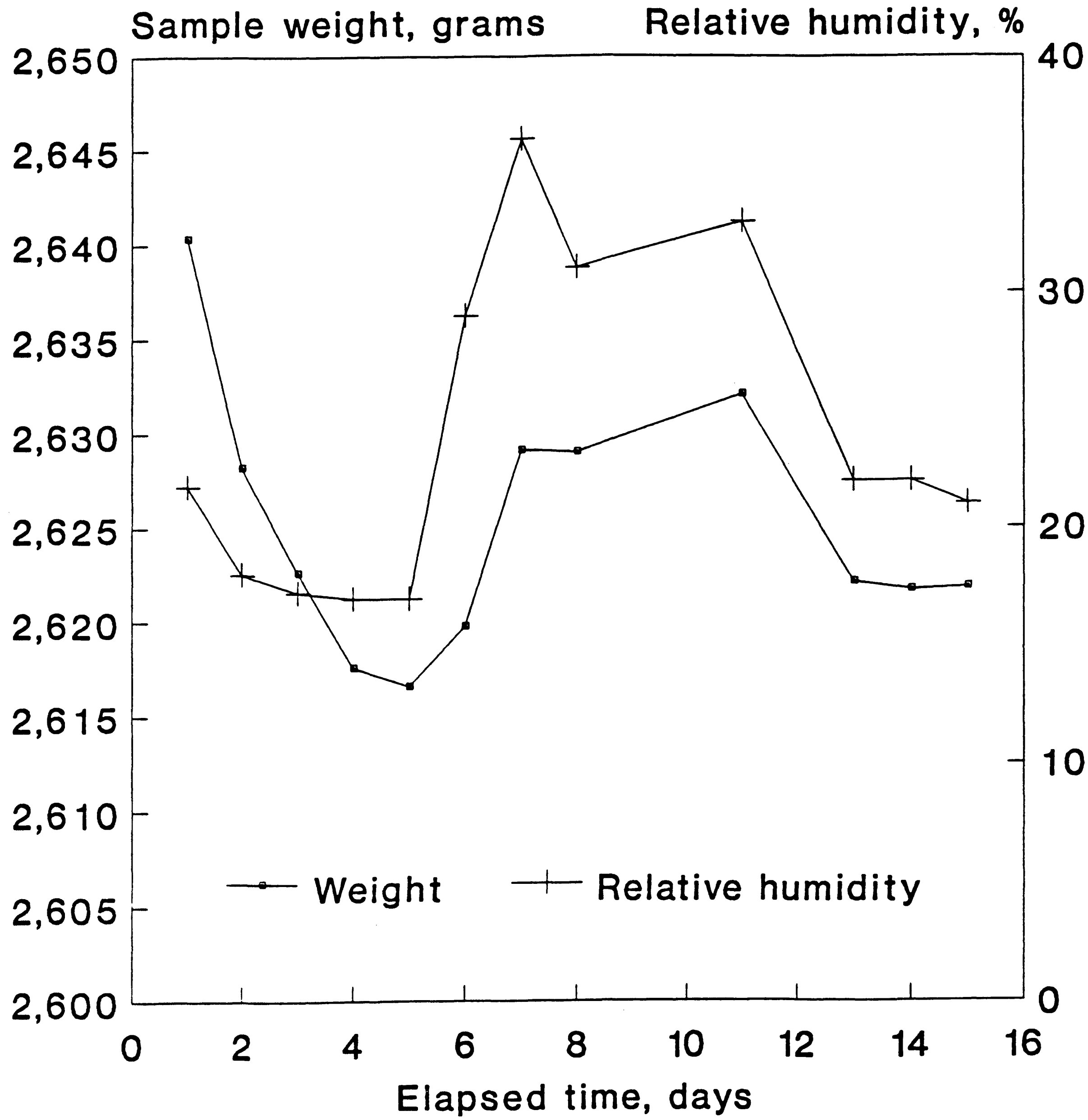

Figure 2. Carpet sample weight vs. relative humidity

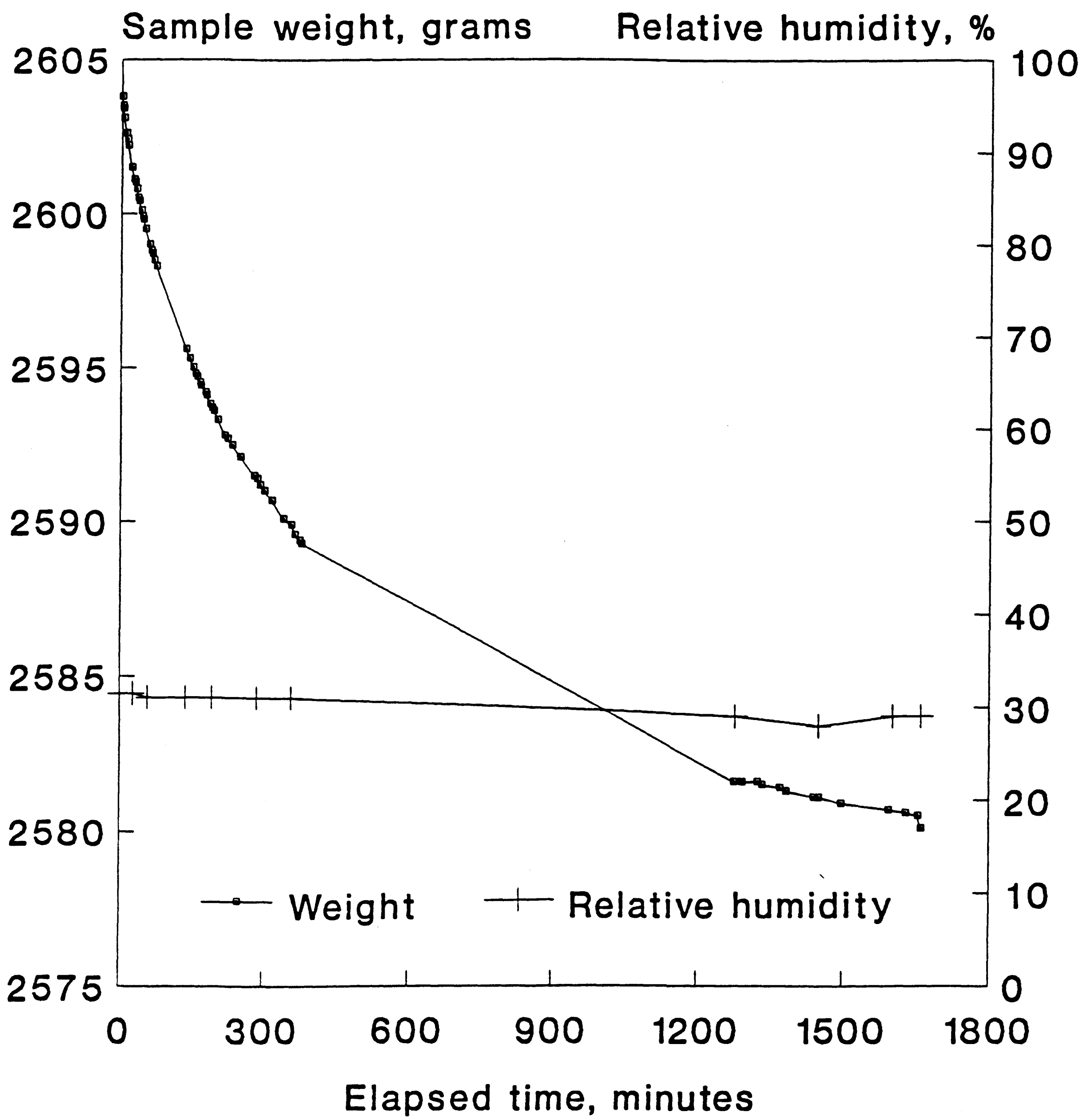

Figure 3. Carpet sample weight after removal from 50% RH conditioning room and placement in 30% RH room

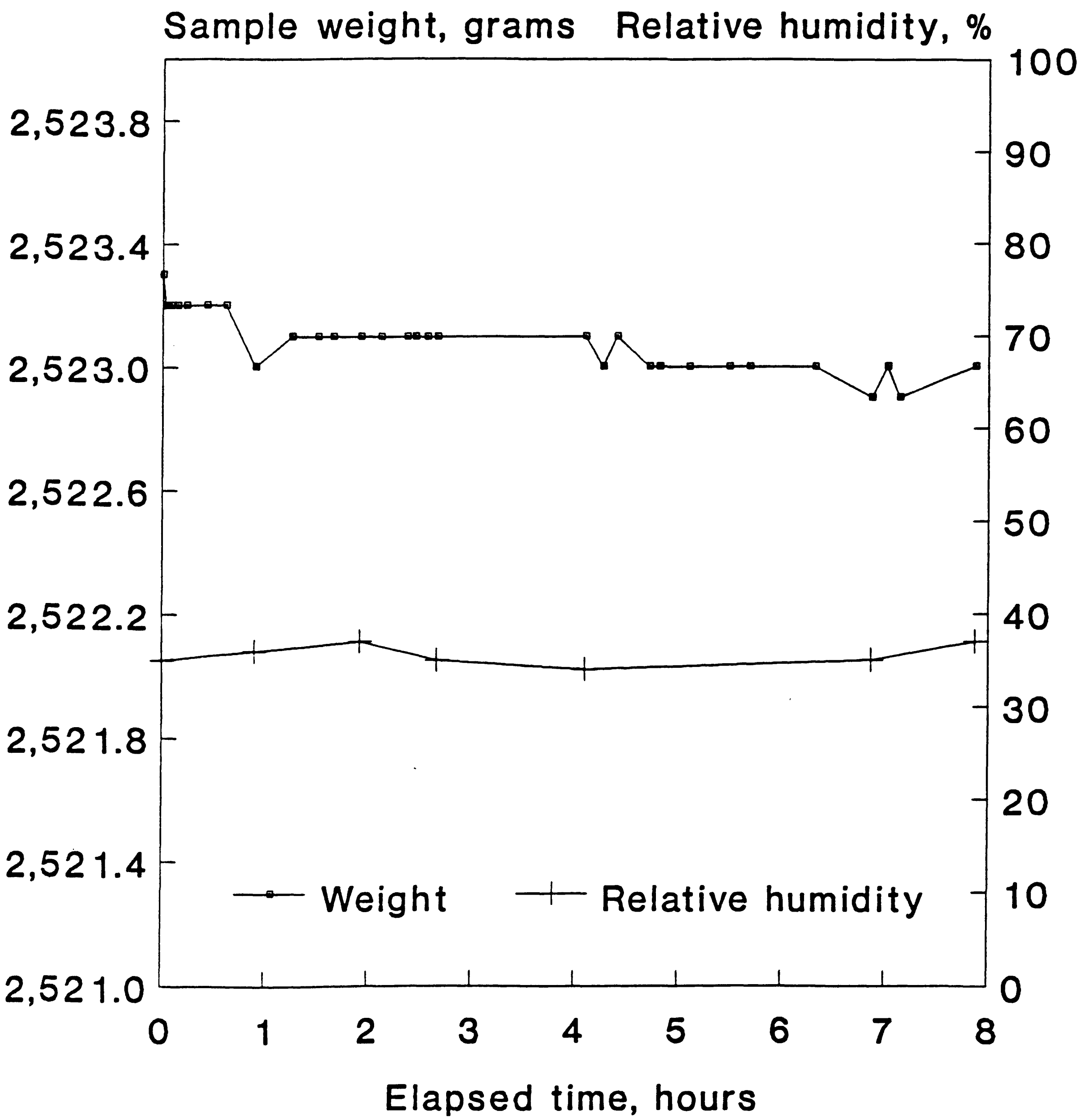

Figure 4. Vinyl flooring sample weight after removal from 50% conditioning room and placement in 35% RH room

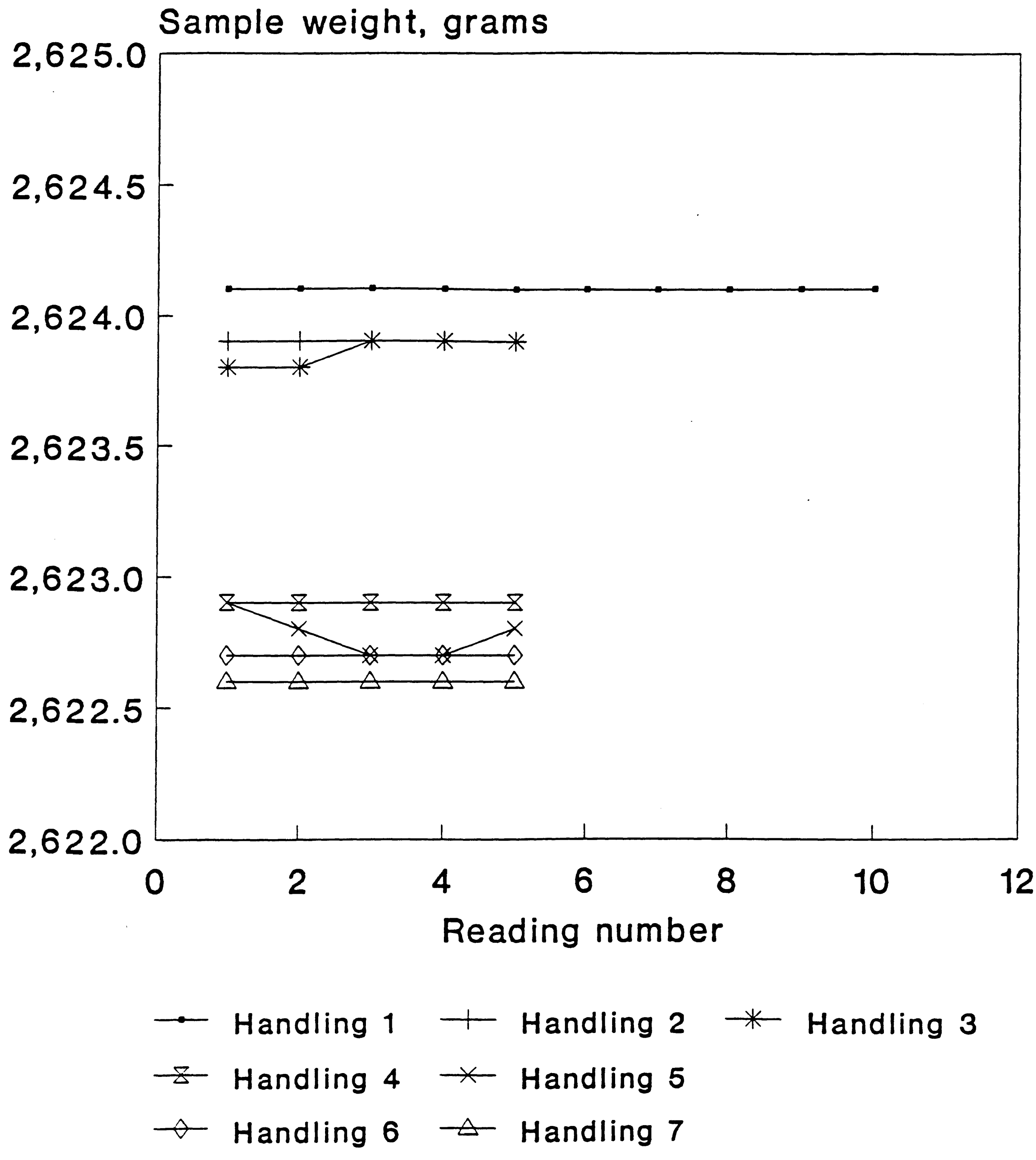

Figure 5. Carpet sample weight change with handling and balance repeatability (same sample unrolled and rerolled)

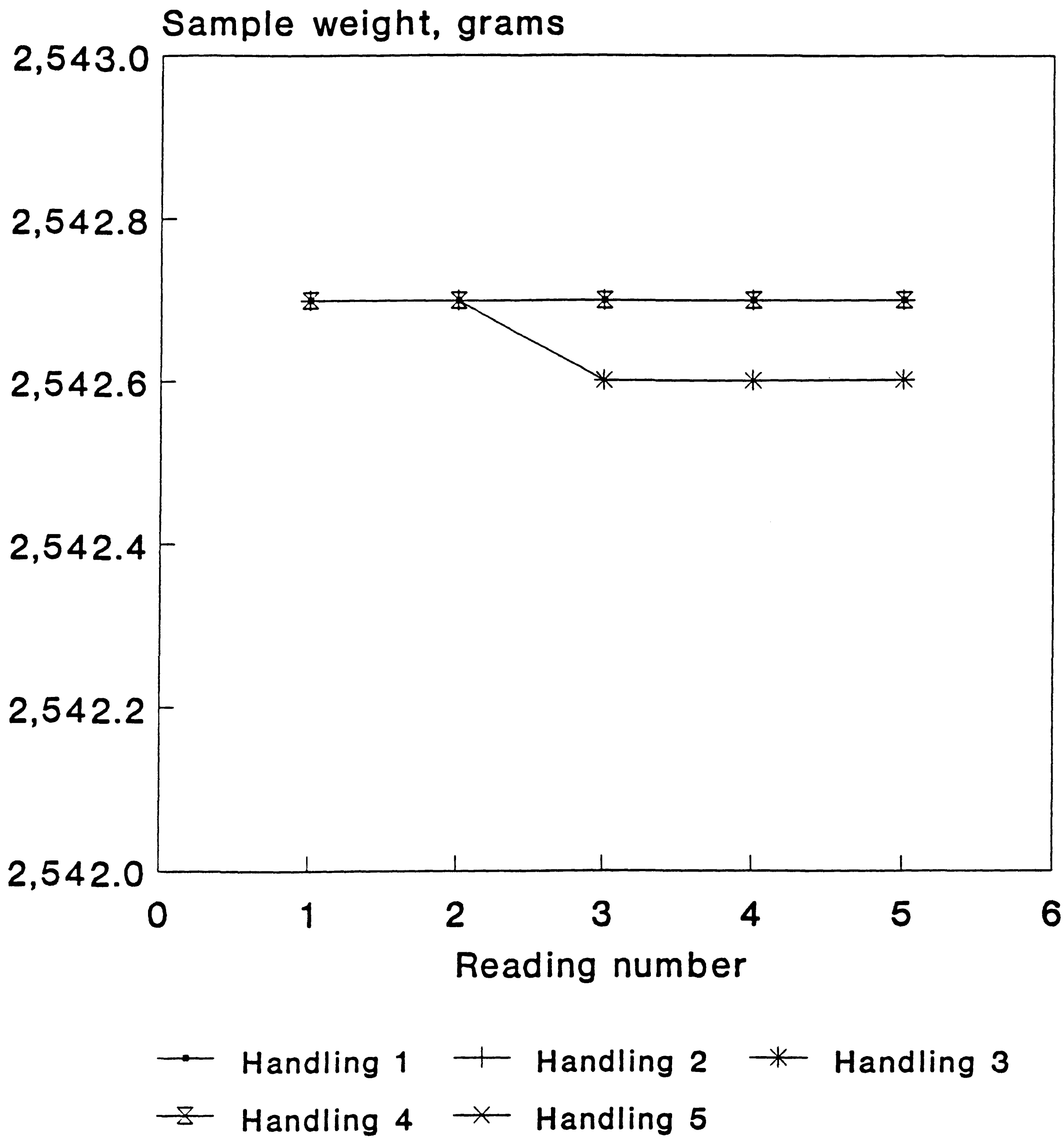

Figure 6. Vinyl flooring sample weight change with handling and balance repeatability (same sample unrolled and rerolled)

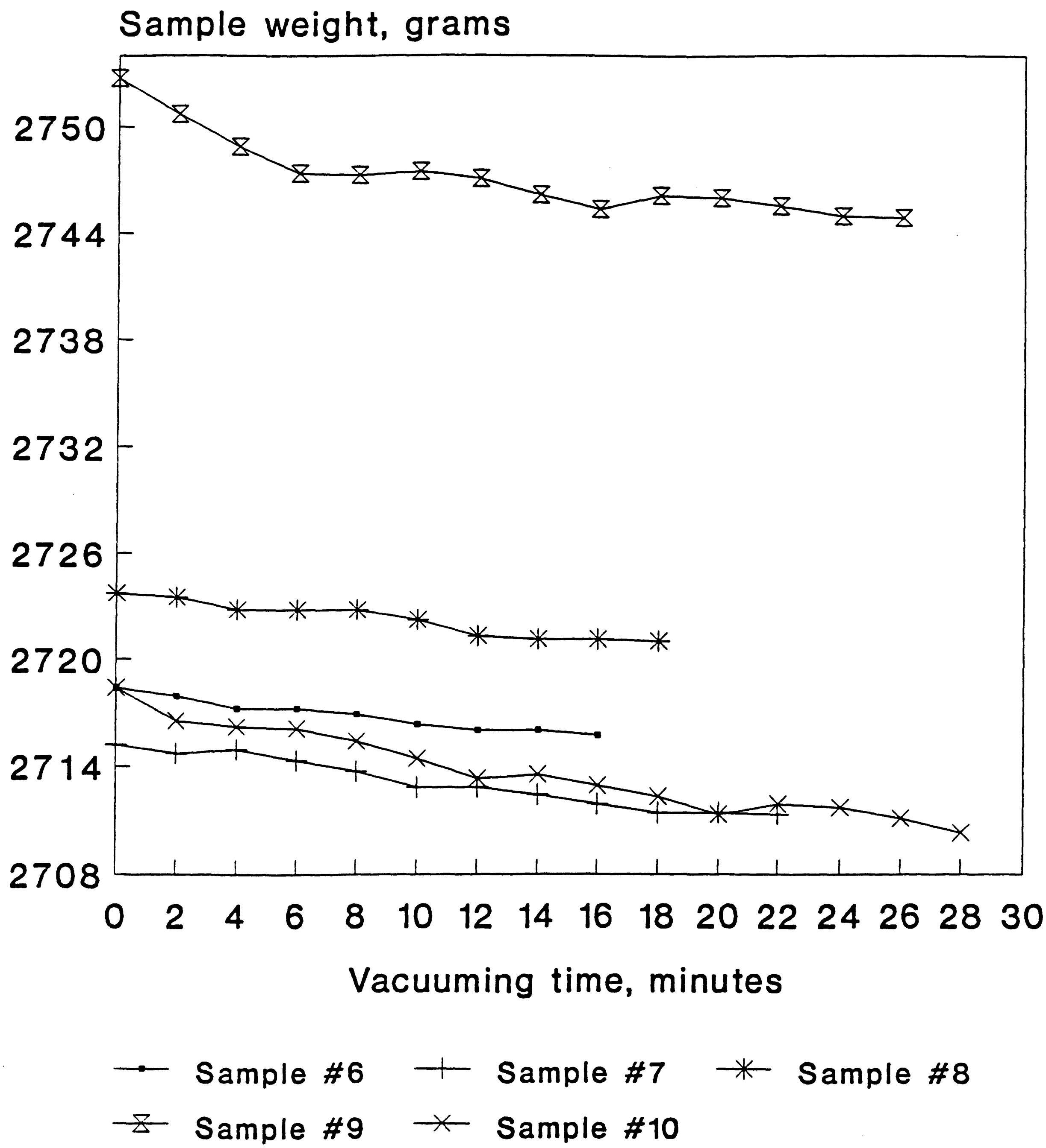

Figure 7. Carpet sample weights after repeated 2 minute vacuuming periods

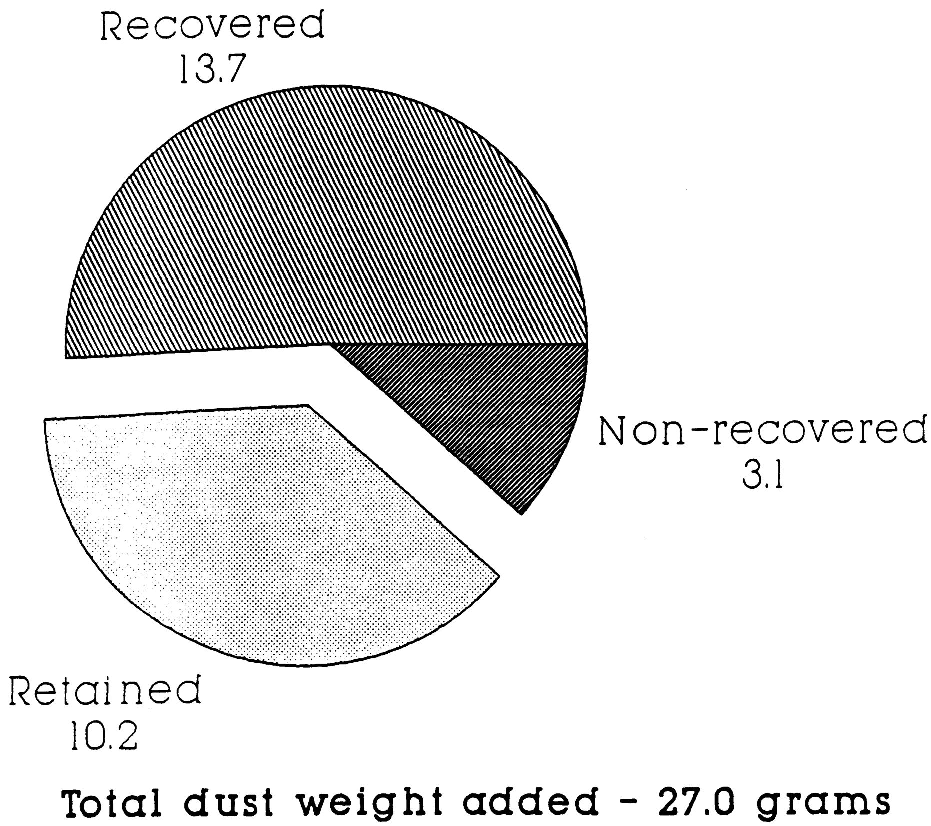

Figure 8. Mass balance schematic (values for portable vacuum - agitator head - empty bag)

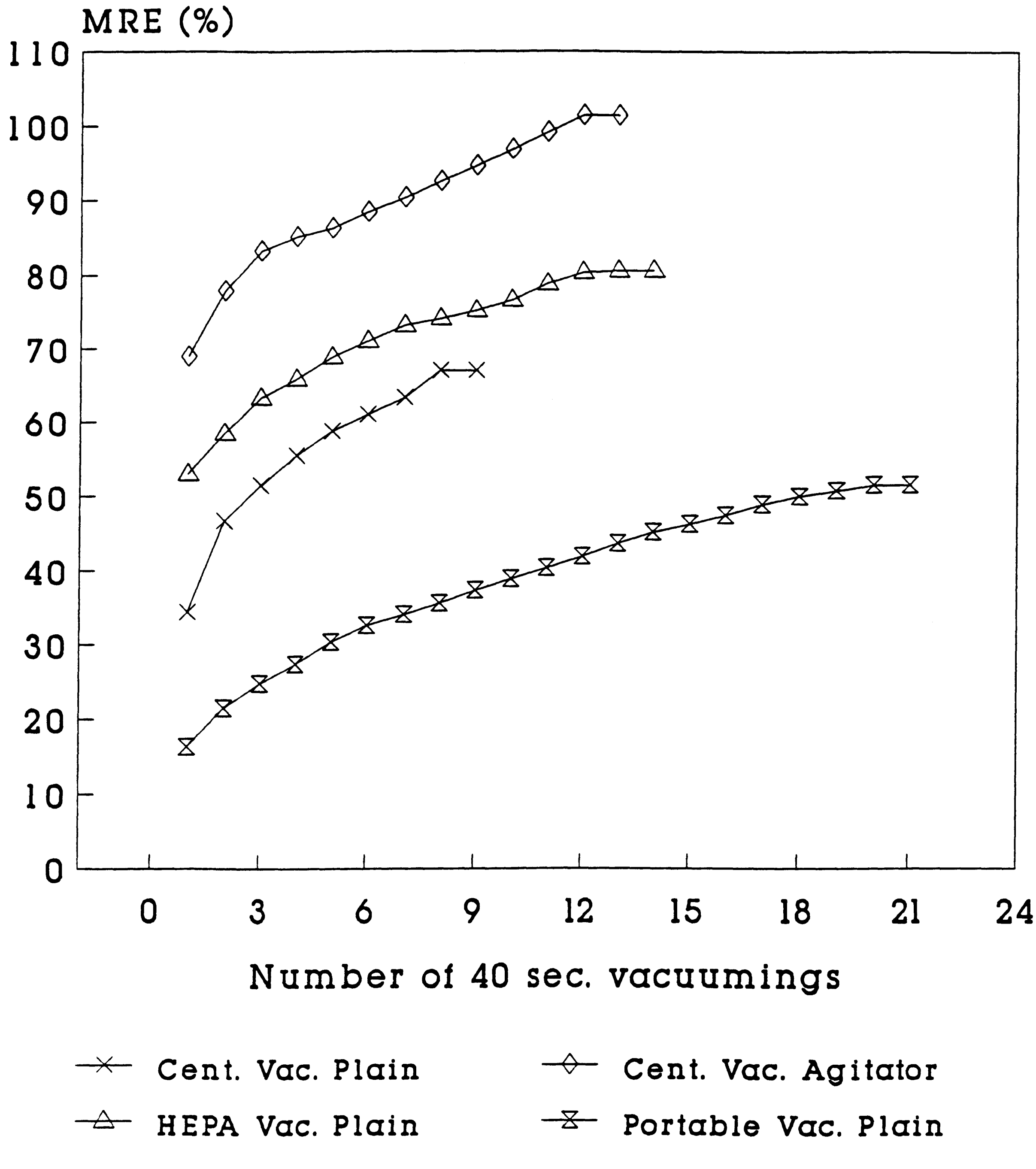

Figure 9. Sequential 40 second vacuumings on carpet samples - 27 g dust loading

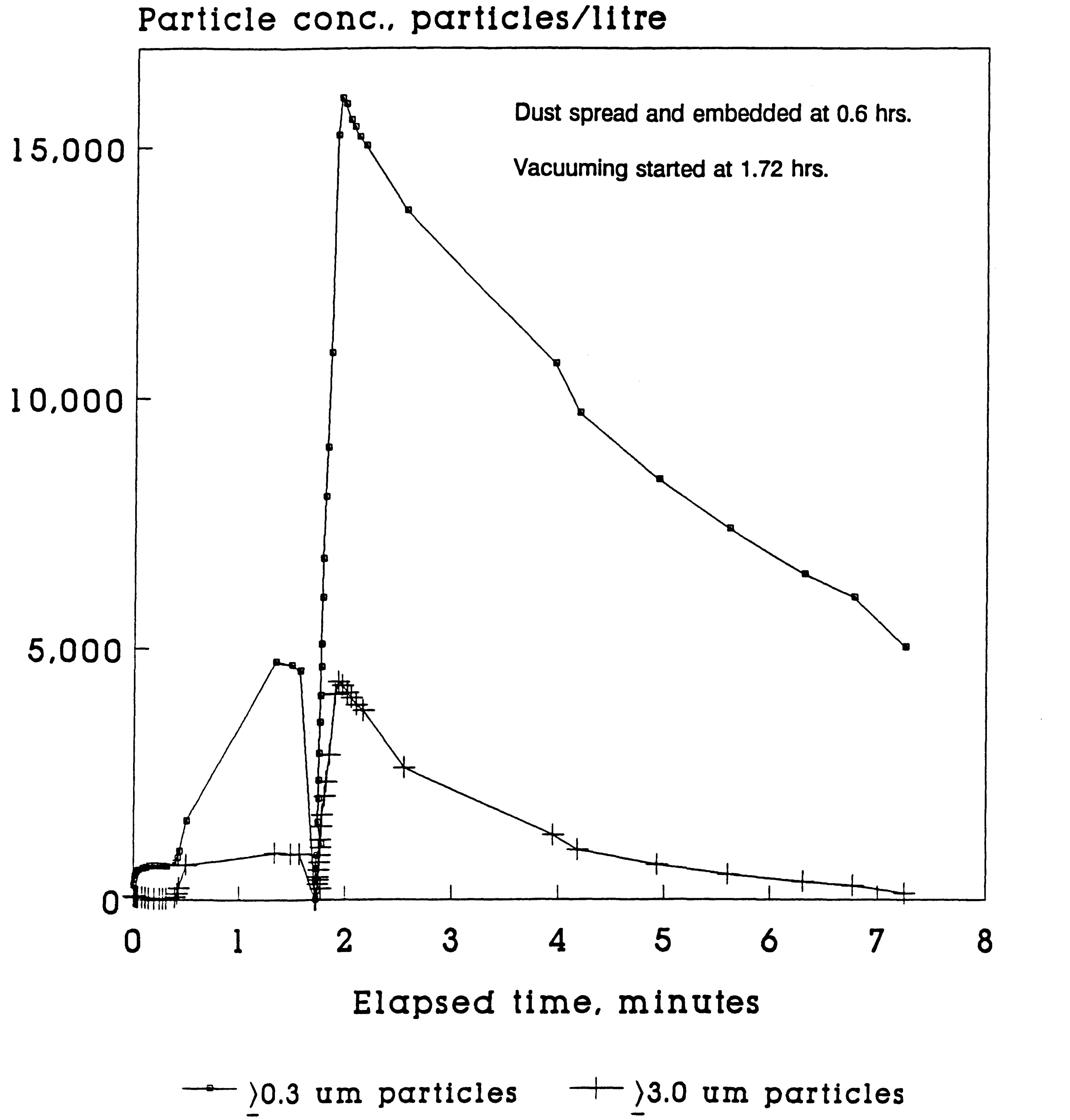

Figure 10. Airborne dust particle concentration for carpet sample (portable vacuum - agitator head - 10% full bag)

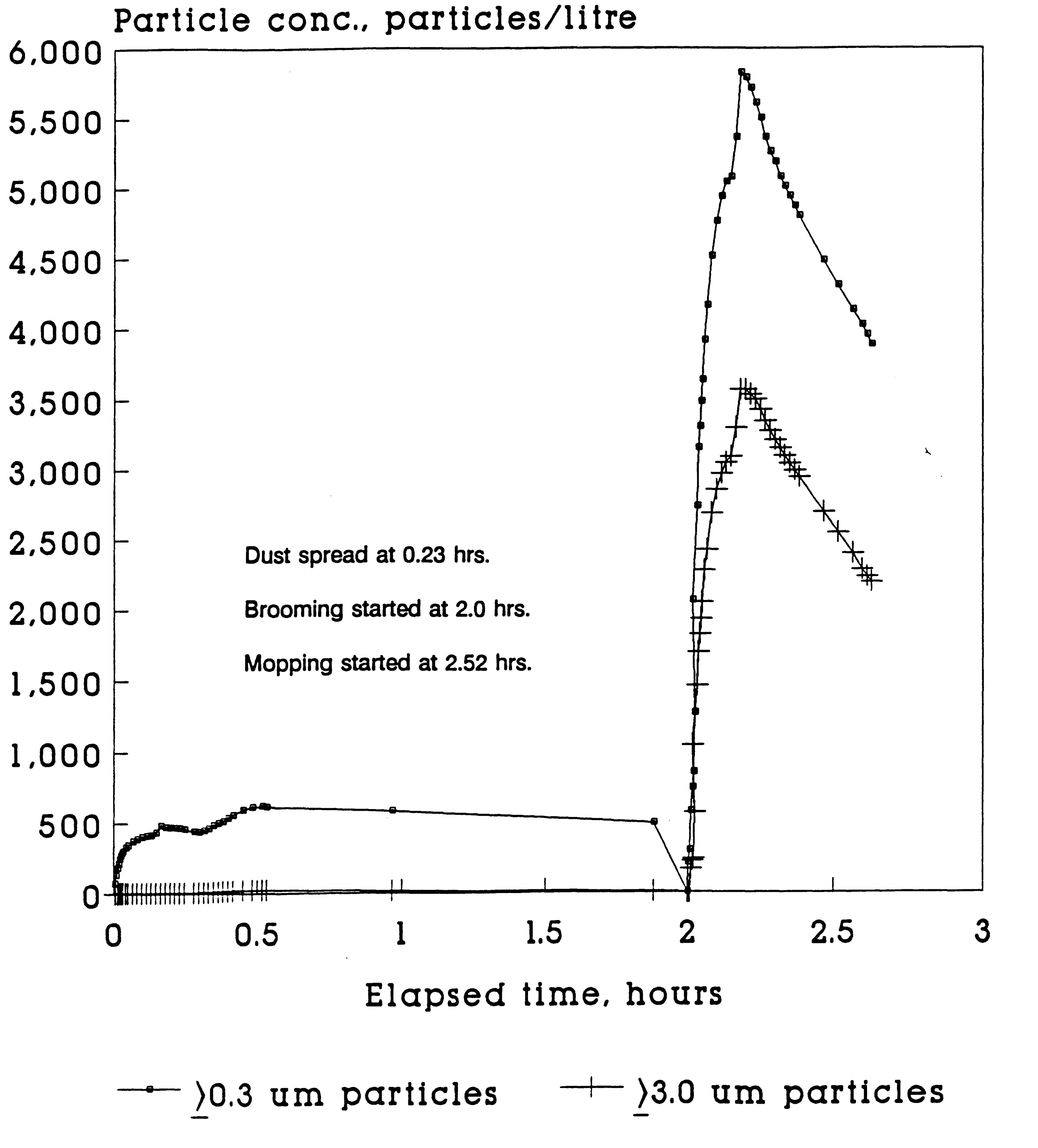

Figure 11. Airborne dust particle concentration for vinyl flooring (27 g loading - broom and wet mopping)

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