IN-DEPTH SURVEY REPORT:

A LABORATORY EVALUATION OF PROTOTYPE ENGINEERING CONTROLS DESIGNED TO REDUCE OCCUPATIONAL EXPOSURES DURING ASPHALT PAVING OPERATIONS

AT

Dynapac Compaction and Paving
Selma, Texas

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EXECUTIVE SUMMARY

On August 12-13, 1997, researchers from the National Institute for Occupational Safety and Health (NIOSH) evaluated prototype engineering controls designed for the control of fugitive asphalt emissions during asphalt paving The Dynapac engineering control evaluation was completed as a supplement to an existing Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment NIOSH researchers are conducting the research through an interagency agreement with DOT's Federal Highway Administration (FHWA) The National Asphalt Pavement Association continues to play a critical role in coordinating the paving manufacturers' and paving contractors' voluntary participation in the study

The study protocol for the original FHWA project included two major phases During the primary phase, NIOSH researchers visited each participating manufacturer and evaluated their engineering control designs under managed environmental conditions The indoor evaluation incorporated tracer gas analysis techniques to quantify the control's exhaust volume and to determine the capture efficiency Results from the indoor evaluations provided equipment manufacturers with the necessary information to maximize engineering control performance prior to the second phase of the study, a performance evaluation of the prototype engineering controls under "real-life" outdoor conditions during an actual paving operation In March of 1997, the FHWA agreed to fund the evaluation of prototype engineering controls on Dynapac Paving equipment This report signifies the culmination of the phase I evaluation and includes specific design recommendations to improve the Dynapac prototype engineering control design Results and discussion from the Dynapac phase II evaluation will be published in a separate report

The Dynapac evaluation studied the performance of one engineering control design During the testing process, slight modifications to the design were also evaluated to identify their influence on prototype performance The prototype design consisted of a slot hood mounted above the full length of the paver's auger area A partition located inside the plenum at its midpoint, separated the left and right sides of the exhaust plenum Two hydraulically-driven exhaust fans, one at each end of the plenum, provided the exhaust source for the prototype design

During the performance tests, the control system exhaust volume averaged 1476 cubic feet per minute (cfm) The average indoor capture efficiency was 70 5 percent for the stock configuration and 79 6 percent for a modified configuration which included the addition of baffles between the exhaust hood and the rear of the tractor During outdoor stationary performance evaluations, the paver was positioned at varying orientations to the prevailing wind direction Under these conditions, the average capture efficiency reduced to 33 5 percent as wind gusts hampered the control's ability to capture the surrogate contaminant

A design feature requiring further consideration is the position and direction of the engineering

control's exhaust stack The current design has the potential to expose workers located behind the paver to the contaminants captured by the engineering control In their final design, Dynapac engineers should consider redirecting the exhausted contaminant in order to minimize this potential hazard

The Dynapac engineering control design reveals a creative and promising approach to the difficult task of controlling asphalt-generated contaminants However, marginal test results and concerns over exhaust discharge orientation reveal that some limitations exist in the current engineering control design scheme Recommendations to Dynapac design engineers include

- Redirect engine cooling air away from auger area
- Move the exhaust hood closer to the auger-area capture region
- Seal the open area between the front of the exhaust hood and the rear of the tractor
- Extend the rear flange (closest to the screed) to a minimum width of eight inches
- Increase the enclosure surrounding the auger area to minimize wind disruption of the engineering control's capture velocity
- Reorient and extend the exhaust stack to minimize the potential for worker exposure to exhausted contaminant
- Identify the operating specifications of the existing hydraulic fans Depending upon Dynapac's ability to incorporate the previous recommendations, additional exhaust volume may be necessary NIOSH engineers are available to assist Dynapac with their fan specification requirements

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH), a Federal agency located in the Centers for Disease Control and Prevention under the Department of Health and Human Services, was established by the Occupational Safety and Health Act of 1970 This legislation mandated NIOSH to conduct research and educational programs separate from the standard setting and enforcement functions conducted by the Occupational Safety and Health Administration (OSHA) in the Department of Labor An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards

The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering (DPSE), has the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness Since 1976, ECTB has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique The objective of each of these studies has been to document and evaluate control techniques and to determine their effectiveness in reducing potential health hazards in an industry or at specific processes

BACKGROUND

On August 12-13, 1997, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of a prototype engineering control designed for the control of fugitive asphalt emissions during asphalt paving The NIOSH researchers included Leroy Mickelsen, Chemical Engineer, Ken Mead, Mechanical Engineer, and Charles Hayden, Mechanical Engineer, all from the NIOSH Engineering Control Technology Branch (ECTB), Division of Physical Sciences and Engineering (DPSE) The DPSE researchers were assisted by Mr Tom Brumagin of the National Asphalt Pavement Association and Mr David Emerson, Product Manager-Pavers, Dynapac Compaction and Paving

The Dynapac engineering control evaluation was completed as an addendum to an existing Department of Transportation (DOT) project which is evaluating the effectiveness of engineering controls on asphalt paving equipment The NIOSH/DPSE researchers are conducting the research through an interagency agreement with DOT's Federal Highway Administration (FHWA) Additionally, the National Asphalt Pavement Association (NAPA) continues to play a critical role in coordinating the paving industry's voluntary participation in the study The original DOT study consisted of two major phases During the primary phase, NIOSH researchers visited each participating manufacturer and evaluated their engineering control designs under managed environmental conditions General protocols for the indoor evaluations are located in Appendix A Minor deviations from the protocols could occur depending upon available time, prototype design, equipment performance, and available facilities Results from the indoor evaluations are intended to provide equipment manufacturers with the necessary information to maximize engineering control performance prior to their implementation at actual paving sites

DESIGN REQUIREMENTS

When designing a ventilation control, the designer must consider three underlying factors, the level of enclosure, the hood design, and the airflow capacity When possible, the ideal approach is to maximize the level of enclosure in order to isolate and contain the contaminant emissions With a total or near-total enclosure approach, hood design is less critical and the required airflow exhaust rate is reduced Many times, worker access or other process requirements limit the amount of enclosure allowed Under these constraints, the designer must compromise on the level of enclosure and increase attention toward hood design and increased air flow

In the absence of a totally enclosed system, the hood design plays a critical role in determining a ventilation control's capture efficiency Given a specified exhaust volume, the hood shape and configuration affect the ventilation control's ability to capture the contaminant, pull it into the hood, and direct it toward the exhaust duct A well-engineered hood strives to achieve a uniform velocity profile across the open hood face When effective hood design is combined with proper enclosure techniques, cross drafts and other airflow disturbances are less likely to reduce the ventilation control's capture efficiency

In addition to process enclosure and hood design, a third area of consideration when designing a ventilation control is the airflow required to remove the contaminant from the working area For most work processes, the contaminant must be "captured" and directed into the contaminant removal system For ventilation controls, this is achieved with a moving airstream often referred to as a capture velocity The designed capture velocity must be sufficient to overcome process-inherent contaminant velocities, convective currents, cross drafts, or other potential sources of airflow interference in order to maintain a protected environment The minimum required exhaust volume (Q) is easily calculated by inputting the selected capture velocity and process geometry information into the design equations specific to the selected hood design Combining Q with the calculated pressure losses within the exhaust system, the designer can appropriately select the system's exhaust fan

For most ventilation controls, including the asphalt paving controls project, these three fundamentals, process enclosure, hood design, and airflow capacity, are interdependent A design which lacks process enclosure can overcome this shortcoming with effective hood design and increased air flow Similarly, lower capture velocities may be adequate if increased enclosure and proper hood design techniques are followed When process geometries do not allow proper hood designs, increased exhaust flow and increased enclosure can compensate for the hood design shortcomings Additional information on designing ventilation controls can be found in the American Conference of Governmental Industrial Hygienists' (ACGIH) ***"INDUSTRIAL VENTILATION: A Manual of Recommended Practice"*** [ACGIH, 6500 Glenway Avenue, Building D-7, Cincinnati, Ohio 45211]

EVALUATION PROCEDURE

The Dynapac engineering control design was evaluated in a large bay area within the Dynapac production facility The evaluation protocol (Appendix A) required the auger area of the paver, also referred to as the capture area, to be separated from the engineering control exhaust and the paver's engine exhaust To accomplish this separation, the paver was parked underneath a large overhead door The screed and rear half of the tractor were positioned within the bay area (referred to as the testing area) and the front half of the tractor was positioned outside the building While this configuration successfully located the engine exhaust outside of the testing area, the engineering control's exhaust was still located within the testing area For testing purposes, each of the engineering control's exhaust ducts were rotated 180 degrees and extended approximately six-feet in order to direct the captured "contaminant" outside of the testing area The overhead garage door was lowered to rest on top of the two duct extensions and the remaining doorway openings were sealed to isolate the front and rear halves of the tractor This setup proved effective at preventing the engine exhaust and the captured surrogate contaminants from reentering the testing area

The first surrogate contaminant used in the evaluation was theatrical smoke produced by a Rosco® smoke generator and released through a perforated distribution tube The tube placement traversed the width of the auger area between the tractor and the screed and rested on the ground under the augers The general smoke test protocol is in Appendix A Initially, this test helped to identify failures in the integrity of the barrier separating the front and rear portions of the tractor After sealing leaks within the barrier, smoke was again released to identify airflow patterns within the test area and to visually observe the control system's performance

The second method of evaluation was the tracer gas evaluation This evaluation was designed to (1) Calculate the total volumetric exhaust flow of the engineering control, and (2) Evaluate the engineering control's effectiveness in controlling and capturing a surrogate contaminant under the "controlled" indoor scenario Sulfur hexafluoride (SF_6) was the tracer gas selected to act as the second surrogate contaminant The tracer gas evaluation procedure is also included in the protocol in Appendix A

The real-time SF_6 detector (Bruel & Kjaer Model 1302) was calibrated in the NIOSH laboratories prior to the evaluation Known amounts of reagent grade SF_6 were injected into 12-liter Milar sampling bags and diluted with nitrogen to predetermined concentrations Seven concentrations, ranging from zero (0) to 100 parts per million SF_6/nitrogen were generated A curve was fit to the data and used to convert detector response to SF_6 concentration Calibration data are included with the testing data in Appendix B

The tracer gas evaluation protocol was originally written for an exhaust system composed of a single fan with one exhaust stack As previously described, the Dynapac engineering control used two fans and each fan had its own exhaust stack Using the protocol listed in Appendix A, the NIOSH engineers evaluated the performance characteristics of the two fans independently and then collectively reported the overall results This entailed adding the two individual fan exhaust volumes together for an overall exhaust volume and averaging the two captured SF_6 concentrations in order to determine an overall capture efficiency

To quantify exhaust volume, a tracer gas discharge tube was placed directly into the suction side of the exhaust duct connected to the fan under evaluation A known volumetric flow rate of SF_6 was released into the duct and the SF_6 detector measured the diluted concentration of SF_6 within the discharge stack of the fan The fan's exhaust volume flow rate was calculated using the following equation

$$Q_{(exh)} = \frac{Q_{(SF6)}}{C_{(SF6)}} X 10^6$$

where $Q_{(exh)}$ = airflow rate exhausted through the fan (lpm or cfm)*
$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm)* introduced into the duct
$C_{(SF6)}$ = Concentration of SF_6 (parts per million (ppm)) detected in the exhaust

* The flow rate in liters per minute (lpm) must be divided by 28 3 liters/cubic-feet to convert the units to cfm

To quantify capture efficiency, SF_6 was released through a ten-foot distribution plenum Each discharge hose fed SF_6 from the tank regulator, through a mass flow controller, and into one side of a single T-shaped pipe fitting The stem of the tee fitting was connected to the end of a ten-foot copper distribution plenum designed to release the SF_6 evenly throughout its length During the capture efficiency test, the discharge plenum was placed directly underneath the screw augers with the discharge holes pointed upwards A known quantity of SF_6 was released through the plenum into the auger area (This quantity was equal to the sum quantity of SF_6 introduced during the two fans' individual exhaust volume evaluations) Moving air, induced by the engineering control system, captured a portion of the SF_6 and carried it through the exhaust system where it was discharged to the outside On the discharge side of the control (downstream of the exhaust fans), the SF_6 detector measured the concentration of SF_6 in each fan's exhaust air stream The capture efficiency was calculated using the following equation

$$\eta = \frac{C_{(SF6_1 + SF6_2)}}{10^6} X \frac{Q_{(exh)}}{Q_{(SF6)}} X 100$$

where η = capture efficiency
$C_{(SF6_1 + SF6_2)}$ = The average concentration of SF_6 (parts per million (ppm)) detected in the two exhaust stacks
$Q_{(exh)}$ = Total airflow rate exhausted through the engineering control (lpm or cfm)*
$Q_{(SF6)}$ = Volume flow rate of SF_6 (lpm or cfm)* introduced into the plenum

* The flow rate in lpm must be divided by 28 3 liters/cubic-feet to convert the units to cfm

The flow rate and capture efficiency tests were repeated four times for a total of five indoor performance tests Two of the five tests evaluated a modified plenum which was created by inserting strips of cardboard to fill the gap between the rear of the tractor and the exhaust plenum

In addition to the indoor evaluation, an outdoor evaluation was also completed With the duct extensions removed and the exhaust orientation returned to the original position, the paver was tested at different orientations relative to the prevailing wind

EQUIPMENT

Smoke Tests

- Rosco® Smoke Generator
- 2" x 10' Schedule-40 PVC perforated distribution pipe

Tracer Gas Tests

- Compressed cylinder of 99 98% SF_6 with regulator
- MKS Mass Flow controllers with control box
- 1/8" ID x 20' Teflon tubing and snap valves for SF_6 distribution
- Gilian Primary Flow Calibrator
- SF_6 distribution plenum (½" x 10' copper pipe w/1/32" dia holes drilled 12" on center)
- Bruel & Kjaer Model 1302 Multi-gas Monitor calibrated for SF_6

Ventilation System Evaluation

- TSI Air Velocity Meter
- Pacer HTA 4200 Hygrothermo Anemometer
- Neotronics Micromanometer w/Pitot Tube
- 8-mm Camcorder
- Tape Measure
- 35-mm Camera

ENGINEERING CONTROL DESIGN DESCRIPTION

The Dynapac asphalt paver engineering control was a local exhaust ventilation system consisting of a hood, two exhaust fans, duct work, and two exhaust stacks The local exhaust ventilation system was designed and installed by engineers at Svedala Compaction and Paving in Wardenburg, Germany The evaluated control system was incorporated into the design of a Dynapac Model F30W Wheeled Paver with screed model VB 1000 V

The exhaust hood measured ninety-four inches long and was centered behind the paver such that 50 percent of the exhaust hood served the right half of the auger area and 50 percent served the left half The plenum inlet was a one-inch slot, located on the bottom of the plenum and running the approximate length of the hood The eight-inch wide plenum varied in height from eleven inches at the two ends to five inches at the center to allow clearance for the auger assembly Five-inch flanges extended from the leading and trailing edges of the exhaust hood across the full length of the hood The open space between the leading flange and the rear of the paver measured five inches

The hood position was fixed With the augers placed in a typical paving height (position #4), the bottom of the hood measured forty-six inches above the floor and approximately twenty-six inches above the top of the augers

A partition, located within the exhaust plenum, separated the right and left halves of the plenum Two hydraulically-driven exhaust fans, one for each half of the plenum, provided the negative pressure and exhaust capacity to the exhaust hood These fans were of German manufacture with German specification plates The nomenclature on the specification plates was unconventional, by U S standards, and was recorded for further inquiry NIOSH engineers forwarded the specification plate information to a Swedish engineering firm which does business throughout Europe Results of this inquiry (see Appendix C) indicate that under the circumstances indicated on the specification plate, each fan is rated at approximately 590 cubic feet per minute (cfm) [1000 cubic meters per hour] The exhaust volumes indicated by the tracer gas tests were moderately higher than this value (ave =729 cfm) To clarify the discrepancy, NIOSH recommends that the German design engineers at Svedala verify the interpretation of the fan specification plates, identify the fans' current operating parameters (fan pressure & rpm), and compare the measured exhaust volumes to a manufacturer-supplied fan curve in order to characterize current & potential fan performance

DATA RESULTS

FLOW VELOCITIES

A hot-wire anemometer was used to measure slot and capture velocities induced by the engineering control's exhaust hood Due to the symmetry of design, these values were averaged across the full length of the hood

TABLE 1. SLOT & CAPTURE VELOCITIES

LOCATION	AVERAGE VELOCITY
Slot Face	1625 feet per minute (fpm)
8" from hood	50 fpm
Top of auger axle	35 fpm
Near Copper Plenum	20 fpm*

*(Note Flow measurements below 30 fpm are below the instrument's specified operating range)

SMOKE EVALUATIONS

The smoke evaluation provided only qualitative information This information assisted the researchers in sealing the separation barrier and reducing air flow around the test area in preparation for the quantitative tracer gas evaluation of the engineering control designs

In a deviation from the smoke evaluation protocol, the theatrical smoke generator was moved to the outdoor side of the separation barrier and positioned such that the smoke discharge fed into the intake of the paver engine's cooling fan Within a matter of seconds, a substantial amount of smoke was visible within the testing area on the indoor side of the separating barrier This test verified that large volumes of cooling air from the paver's engine compartment was escaping back into the auger area

TRACER GAS EVALUATION

(A copy of the tracer gas evaluation data files and associated calculations are included in Appendix B)

INDOOR EVALUATIONS

The indoor evaluations were conducted with the testing area located indoors under semi-controlled conditions In order to meet these protocol requirements, the discharge for each exhaust stack was rotated 180 degrees and duct extensions were added to relocate the exhaust point on the outdoor side of the barrier Since this modification could have potentially altered the exhaust characteristics of the fans, a baseline test was conducted, prior to modification, to identify a baseline exhaust flow The results of this individual test indicated a total system exhaust volume of 1384 cfm There were a total of five indoor tests Three tests evaluated the stock hood/plenum design as delivered from Svedala in Germany The remaining two tests evaluated a modified hood design where strips of cardboard were inserted to fill the gap between the rear of the tractor and the leading hood flange Measured performance results for the stock and modified indoor tests are presented in Tables II and III

TABLE II. INDOOR TRIALS, STOCK HOOD DESIGN

Test	$Q_{(exh)}$	Efficiency
Indoor-2	1484 cfm	66 4%
Indoor-3	1447 cfm	75.3%
Indoor-4	1484 cfm	69 9%
Average	1472 cfm	70 5%

TABLE III. INDOOR TRIALS, MODIFIED HOOD DESIGN

Test	$Q_{(exh)}$	Efficiency
Indoor-1	1484 cfm	83 1%
Indoor-5	1480 cfm	76 0%
Average	1482 cfm	79 6%

OUTDOOR EVALUATIONS

The outdoor evaluation occurred in an open parking area The duct extensions were removed and the exhaust orientation returned to stock configuration The protocol called for four paver orientations to be evaluated however, the paver ran out of fuel during the end of the third orientation Due to refueling constraints, we evaluated the existing data and determined it sufficient to bring the outdoor evaluation to an end The three tests conducted included paver orientations with the wind into the rear, front, and left side Results of these tests are in Table IV

TABLE IV. OUTDOOR TRIALS (Stock Hood Design w/o Duct Extensions)

Wind Into	$Q_{(exh)}$	Efficiency
Rear	1441 cfm	15 8%
Front	1468 cfm	41 6%
Left Side	1369 cfm	43 0%
Average	1426 cfm	33 5%

DISCUSSION

FLOW VELOCITIES

The ACGIH Industrial Ventilation Manual provides guidance to facilitate the selection and design of minimum capture velocities Additionally, NIOSH assistance can be provided in selecting a capture velocity based upon your intended control design In the absence of total enclosure and given the physical properties of the paving process and the generated contaminants, a minimum design capture velocity of 100 feet per minute across the top of the auger area's horizontal plane is recommended This recommendation assumes very good enclosure to minimize wind interference during paving operations

Based upon the current design parameters, the 100 fpm capture velocity recommendation would be required approximately 20 inches away from the face of the hood The velocity measurements shown in Table I indicate an average capture velocity of only 50 fpm at less than half of this distance Thus, using the current hood design, a significantly higher exhaust capacity is required in order to generate the desired capture velocity at the top of the augers

EXHAUST VOLUME MEASUREMENTS

Since the two duct extensions and the 180-degree discharge rotation required by the indoor testing protocol could potentially alter the engineering control's exhaust flow rate, a preliminary baseline test was conducted to measure the engineering control's exhaust flow prior to the duct system modifications As previously reported, the measured exhaust volume was 1384 cfm This individual measurement is approximately 6 percent smaller than the average exhaust volume recorded during the indoor evaluations (Ave = 1476 cfm) This discrepancy is most likely explained by experimental error, cold hydraulic fluid supplying less energy to the hydraulic fans, an improvement in exhaust capacity due to improved discharge characteristics (created by the duct extensions), or any combination of the three Further analyses of this issue can be made by comparing the measured exhaust volumes during the outdoor trials (Table IV - These tests were performed with the exhaust stacks in their stock configuration) with those measured during the indoor trials (Tables II & III) The third outdoor test (wind into left side) shows a lower exhaust volume than the previous two Since this is the test during which the paver ran out of fuel, we speculate that this 6 percent reduction may be related to the low-fuel condition reducing tractor engine performance Comparing the average exhaust volume for the first two outdoor tests (ave =1455 cfm) with the average value for the indoor tests (ave =1476 cfm) reveals that the exhaust volumes for the two exhaust configurations were within two percent of each other Based upon these evaluations, it is clear that the exhaust stack modifications did not negatively affect the exhaust volume capacity of the Dynapac engineering control

INDOOR CAPTURE EFFICIENCY

Test results from the Dynapac engineering control evaluations show that the stock design, as delivered from Svedala Compaction and Paving in Wardenburg, Germany, will not meet the indoor collection efficiency criteria of 80 percent which is recommended in the NIOSH Engineering Control Guidelines for Hot Mix Asphalt Pavers A modified design, which added cardboard baffles to seal the open area between the exhaust hood and the rear of the paver, improved the average indoor capture efficiency from 70 5 percent up to 79 6 percent While the modified flange extensions did improve collection efficiency performance, the average collection efficiency remained slightly less than the recommended 80 percent criterion However, the 80 percent minimum collection efficiency criterion appears clearly within reach after incorporating minimal design improvements Some recommended improvements are identified in the ***Conclusions And Recommendations*** section of this report

OUTDOOR CAPTURE EFFICIENCY

Test results from the outdoor evaluations reveal that the Dynapac prototype's design performance is significantly hampered by the lack of enclosure around the auger area, an insufficient exhaust volume, an excessive distance between the face of the hood and the capture region, and the presence of engine cooling air blowing back into the capture region These factors collectively allowed the ambient wind to play a predominant role in determining contaminant dispersion and resulted in an average outdoor capture efficiency of only 33 5 percent

Interpretation of the outdoor results is somewhat difficult There are no recommended or consensus criteria for the outdoor tracer gas capture efficiency evaluations Admittedly, some of the wind which disrupts the engineering control's capture efficiency may also carry airborne contaminant away from the occupied work area but in other cases, the escaped contaminant may collect within a working area, creating an increased opportunity for elevated exposure Thus, the safest solution is to remove as much contaminant as is reasonably possible at the source (the auger, in this case) and not allow it to enter the working areas The recommendations forwarded in the ***Conclusions And Recommendations*** section of this report aim to reach this goal

EXHAUST DISCHARGE

One final consideration is the position and direction of the engineering control's exhaust stack The current design incorporates a horizontal discharge which has the potential to expose workers located behind the paver to the contaminants captured by the engineering control This potential could be greatly reduced by reorienting the exhaust stacks to a vertical discharge and extending them to a discharge height at least three feet above the paver operator's breathing zone

CONCLUSIONS AND RECOMMENDATIONS

The Dynapac engineering control evaluation was completed as a supplement to an existing Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment The study protocol for this evaluation was based upon that used in the original DOT study The intent of the phase I evaluation protocol was to evaluate engineering control performance characteristics and identify potential areas for improvement This evaluation was performed within a controlled environment, void of the many interfering variables which frustrate performance evaluations during typical paving operations The Dynapac study has been successful in this regard Implementation of the provided recommendations will improve the performance of the Dynapac engineering control prior to field implementation and testing

The Dynapac engineering control design reveals a creative and promising approach to the difficult task of controlling asphalt-generated contaminants However, indoor capture efficiencies below 80 percent and outdoor capture efficiencies as low as 16 percent reveal some limitations in the tested engineering control design scheme Recommendations to Dynapac design engineers include (1) Redesigning the engine compartment such that engine cooling air is not discharged back into the auger region, (2) Evaluate the exhaust hood and exhaust duct configuration to identify how the exhaust hood can be lowered closer to the auger-area capture region, (3) Extend the width of the exhaust hood's leading flange in order to seal off the open area between the front of the exhaust hood and the rear of the tractor, (4) Extend the rear flange (located between plenum hood and front of screed) width to a minimum of 8 inches, (5) Increase the enclosure surrounding the auger area to minimize the wind effects, especially near the ends of the auger area and under extended-screed conditions, (6) Reorient and extend the exhaust stack to reduce the potential for worker exposure to exhausted contaminant, (7) Identify the operating specifications of the existing hydraulic fans Depending upon Dynapac's ability to incorporate the previous recommendations, additional exhaust volume may be necessary If additional exhaust volume is necessary and the operating parameters of the existing fans are known, design engineers can determine if the existing fans can be modified to meet the new performance requirements NIOSH engineers are available to assist Dynapac with their fan specification requirements

ACKNOWLEDGMENTS

We would like to thank the Dynapac management and staff for their gracious hospitality and assistance during our visit to the Dynapac facility Their commitment to the design and implementation of engineering controls to reduce occupational exposures is an admirable pledge which will benefit workers throughout the asphalt paving industry

APPENDIX A

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

STATIONARY EVALUATION PROTOCOL

PURPOSE To evaluate the efficiency of ventilation engineering controls used on highway-class hot mix asphalt (HMA) pavers in an indoor stationary environment

SCOPE OF USE This test procedure was developed to aid the HMA industry in the development and evaluation of prototype ventilation engineering controls with an ultimate goal of reducing worker exposures to asphalt fumes This test procedure is a first step in evaluating the capture efficiency of paver ventilation systems and is conducted in a controlled environment The test is not meant to simulate actual paving conditions The data generated using this test procedure have not been correlated to exposure reductions during actual paving operations

For the laboratory evaluation, we will conduct a two-part experiment where the surrogate "contaminant" is injected into the auger region behind the tractor and in front of the screed For part A of the evaluation, smoke from a smoke generator is the surrogate contaminant For part B, the surrogate contaminant is sulfur hexafluoride, an inert and relatively safe (when properly used) gas, commonly used in tracer gas studies

SAFETY In addition to following the safety procedures established by the host facility, the following concerns should be addressed at each testing site

1 The discharge of the smoke generating equipment can be hot and should not be handled with unprotected hands
2 The host may want to contact building and local fire officials in order that the smoke generators do not set off fire sprinklers or create a false alarm
3 In higher concentrations, smoke generated from the smoke generators may act as an irritant Direct inhalation of smoke from the smoke generators should be avoided
4 All compressed gas cylinders should be transported, handled, and stored in accordance with the safety recommendations of the Compressed Gas Association
5 The Threshold Limit Value for sulfur hexafluoride is 1000 ppm While the generated concentrations will be below this level, the concentration in the cylinder is near 100 percent For this reason, the compressed cylinder will be maintained outdoors whenever possible Should a regulator malfunction or some other major accidental release occur, observers should stand back and let the tank pressure come to equilibrium with the ambient environment

__Laboratory Setup__ The following laboratory setup description is based on our understanding of the facilities available at the asphalt paving manufacturing facilities participating in the study The laboratory evaluation protocol may vary slightly from location to location depending upon the available facilities

__Paver Position__ The paving tractor, with screed attached, will be parked underneath an overhead garage door such that both the tractor exhaust and the exhaust from the engineering controls exits into the ambient air The garage door will be lowered to rest on top of the tractor and plastic or an alternative barrier will be applied around the perimeter of the tractor to seal the remainder of the garage door opening

Laboratory Ventilation Exhaust For this evaluation, smoke generated from Rosco Smoke Generators (Rosco, Port Chester, NY) is released into a perforated plenum and dispersed in a quasi-uniform distribution along the length of the augers Due to interferences created by the auger's gear box, this evaluation may require a separate smoke generator and distribution plenum on each side of the auger region Releasing theatrical smoke as a surrogate contaminant within the auger region provides excellent qualitative information concerning the engineering control's performance Areas of diminished control performance are easily determined and minor modifications can be incorporated into the design prior to quantifying the control performance Additionally, the theatrical smoke helps to verify the barrier integrity separating the front and rear halves of the asphalt paver A video camera will be used to record the evaluation The sequence from a typical test run is outlined below

1 Position paving equipment within door opening and lower overhead door
2 Seal the remaining door opening around the tractor
3 Place the smoke distribution tube(s) directly underneath the auger
4 Connect the smoke generator(s) to the distribution tube(s)
5 Activate video camera, the engineering controls, and the smoke generator(s)
6 Inspect the separating barrier for integrity failures and correct as required
7 Inspect the engineering control and exhaust system for unintended leaks
8 De-activate the engineering controls for comparison purposes
9 De-activate smoke generators and wait for smoke levels to subside
10 End the smoke test evaluation

Evaluation Part B (Tracer Gas) The tracer gas test is designed to (1) Calculate the total exhaust flow rate of the paver ventilation control system, and (2) Evaluate the effectiveness in capturing and controlling a surrogate contaminant under a "controlled" indoor conditions SF_6 will be used as the surrogate contaminant

Quantify Exhaust Volume: To determine the total exhaust flow rate of the engineering control, a known quantity of sulfur hexafluoride (SF_6) is released directly into the engineering control's exhaust hood, thus creating a 100 percent capture condition The SF_6 release is controlled by two Tylan Mass Flow controllers (Tylan, Inc , San Diego, CA) Initially, the test will be performed using a single flow controller calibrated at 0 35 lpm A hole drilled into the engineering control's exhaust duct allows access for a multi-point monitoring wand into the exhaust stream The monitoring wand is oriented such that the perforations are perpendicular to the moving air stream A sample tube connects the wand to a Bruel & Kjaer (B&K) Model 1302 Photo acoustic Infra-red Multi-gas Monitor (California Analytical Instruments, Inc , Orange, CA) positioned on the exterior side of the overhead door The gas monitor analyzes the air sample and records the concentration of SF_6 within the exhaust stream The B&K 1302 will be programmed to repeat this analysis approximately once every 30 seconds Monitoring will continue until approximate steady-state conditions are achieved The mean concentration of SF_6 measured in the exhaust stream will be used to calculate the total exhaust flow rate of the engineering control The equation for determining the exhaust flow rate is

$$Q_{(exh)} = \frac{Q_{(SF_6)}}{C^*_{(SF_6)}} \times 10^6 \qquad \textbf{Equation 1}$$

where $Q_{(exh)}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

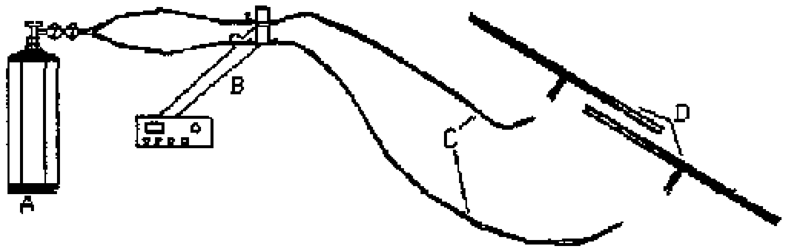
$C^*_{(SF6)}$ = concentration of SF_6 (parts per million) detected in exhaust

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28 3]

In order to increase accuracy, the exhaust flow rate will be calculated a second time using two mass flow controllers, each calibrated at approximately 0 35 lpm of SF_6 Sufficient time will be allowed between all test runs to allow area concentrations to decay below 0 1 ppm before starting subsequent test runs

Quantitative Capture Efficiency: The test procedure to determine capture efficiency is slightly different than the exhaust volume procedure The mass flow controllers will each be calibrated for a flow rate approximating 0 35 liters per minute (lpm) of 99 8 percent SF_6 The discharge tubes from the mass flow controllers will each feed a separate distribution plenum, one per side, within the paver's auger area The distribution plenums are designed to distribute the SF_6 in a uniform pattern along the length of the auger area (See Figure 1) The B&K multi-gas monitor analyzes the air sample and records the concentration of SF_6 within the exhaust stream until approximate steady-state conditions develop Once this occurs, the SF_6 source will be discontinued and the decay concentration of SF_6 within the exhaust stream will be monitored to indicate the extent in which general area concentrations of non-captured SF_6 contributed to the concentration measured in the exhaust stream

FIGURE 1



LEGEND
A—Tracer Gas Cylinder with regulator
B—Tylon Mass Flow Controllers with Control Box
C—PTFE Distribution Tubes
D—Tracer Gas Distribution Plenums

A capture efficiency can be calculated for the control using the following equation

$$\eta = 100 \times \frac{\frac{C_{(SF_6)} \times Q_{(exh)}}{10^6}}{Q_{(SF_6)}} \qquad \text{Equation 2A}$$

where η = capture efficiency

$C_{(SF6)}$ = concentration of SF_6 (parts per million) detected in exhaust

$Q_{(exh)}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28 3]

NOTE When the flow rate of SF_6 [$Q_{(SF6)}$] used to determine the engineering control's capture efficiency is the same as that used to quantify the exhaust flow rate, equation **2A** may be simplified to where the definitions for $C^*_{(SF_6)}$, η, and $C_{(SF_6)}$ remain the same as in equations 1 and 2A

$$\eta = \frac{C_{(SF_6)}}{C^*_{(SF_6)}} \times 100 \qquad \text{Equation 2B}$$

The sequence from a typical test run is outlined below

1. Position paving equipment and seal openings as outlined above
2. Calibrate (outdoors) both mass flow meters at approximately 0 35 lpm of SF_6
3. Drill an access hole in the engineering control's exhaust duct on the outdoor side of the overhead door, and position the sampling wand into the hole
4. While maintaining the SF_6 tanks outdoors, run the discharge hoses from the mass flow meters to well-within the exhaust hood(s) to create 100 percent capture conditions
5. With the engineering controls activated, begin monitoring with the B&K 1302 to determine background interference levels
6. Initiate flow of SF_6 through a single mass flow meter
7. Continue monitoring with the B&K for five minutes or until three repetitive readings are recorded
8. Deactivate flow of the SF_6 and calculate exhaust flow rate using the calculation identified above
9. Repeat steps #2 through #8 using both mass flow controllers
10. Allow engineering control exhaust system to continue running until SF_6 has ceased leaking from the discharge hoses then remove the hoses from the hoods
11. End the exhaust flow rate test
12. Locate an SF_6 distribution plenum on each side of the auger area, and connect each plenum to the discharge hose of a mass flow meter
13. Initiate B&K monitoring to establish background interference levels until levels reach 0 1 ppm or below
14. Initiate SF_6 flow through the mass flow meters and monitor with the B&K until approximate steady state conditions appear
15. Once steady state is achieved, discontinue SF_6 flow and quickly remove the distribution plenums and discharge hoses from the auger area
16. Continue monitoring with the B&K to determine the general area concentration of SF_6 which escaped auger area into the laboratory area
17. Discontinue B&K monitoring when concentration decay is complete
18. Calculate the capture efficiency
19. Repeat steps 11 - 18 as time permits

APPENDIX B

TRACER GAS EVALUATION :

B&K Calibration Data, Data Files, And Calculation Results

DYNAPAC SHOP TEST
12-13 August 1997

EXHAUST FLOW TEST

(Stationary Outdoor Test No duct extension)

Left Fan	693 cfm
Right Fan	691 cfm
Total	1384 cfm

Indoor Performance Test Summary

(All tests incorporated duct extensions to meet protocol requirements)

MODIFIED ENCLOSURES (Cardboard Baffles added between back of paver and front of hood)

TEST	Efficiency	Exhaust Flow (cfm)
Indoor-1	83 13%	1484
Indoor-5	75 96%	1480
Average	79 55%	1482

STOCK ENCLOSURES (As delivered from Germany)

TEST	Efficiency	Exhaust Flow (cfm)
Indoor-2	66 44%	1484
Indoor-3	75 29%	1447
Indoor-4	69 85%	1484
Average	70 53%	1472

Outdoor Performance Test Summary

(All tests were with stock enclosures & no duct extensions)

Wind Into.	Efficiency	Exhaust Flow (cfm)
Rear	15 77%	1441
Front	41 63%	1468
Left Side	43 00%	1369
Average	33 47%	1426

BASELINE EXHAUST VOLUME CALCULATION

(Measured Outdoors without duct extensions)

[x=(y+0 00093)/0 964051]

Sample #	Time	BnK Positio	Comment	BnK Response	Calculations	Average
1	11 09 10	Open air	*Background*	-0 003	-0 011	Background
2	11 10 16			-0 005	-0 010	Calib Corrected
3	11 11 10			-0 011		
4	11 12 04			-0.011		
	11 12 04		*User Event Number 1*			
5	11 12 58	LHS	100% SF6 - 219 4 cc/min	10 800	10 780	Average (ppm)
6	11 13 54	LHS		10.800	11 183	Calib Corrected
7	11 14 48	LHS		10.800	11 193	BG Corr
8	11 15 42	LHS		10.800	693	CFM
9	11 16 35	LHS		10.700		
	11 17 40		*User Event Number 2*			
10	11 17 40			0 258		
11	11 18 37			0 026	0 007	Background
12	11 19 30			-0 008	0 009	Calib Corrected
13	11 20 24			0.007		
	11 21 18		*User Event Number 3*			
14	11 21 18	RHS	Transition point	10 500		
15	11 22 15	RHS	100% SF6 - 219 4 cc/min	10.800	10 820	Average (ppm)
16	11 23 08	RHS		10.800	11 224	Calib Corrected
17	11 24 02	RHS		10.900	11 216	BG Corr
18	11 24 56	RHS		10 700	691	CFM
19	11 25 50	RHS		10 900		
	11 26 44		*User Event Number 4*			
20	11 26 44		(End of test)	11 200		
21	11 28 09			0 027		
22	11 29 06			-0 007		
					Total Exh (cfm)=	**1384**

Performance Test #1 (Modified Enclosure)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Calculations	
1	16 57 09	0 008	Background	-0 003	Background
2	16 58 15	0 003		-0 002	Calib Corrected
3	16 59 09	-0 006			
4	17 00 03	0 003			
5	17 00 57	-0 001			
6	17 01 51	-0 006			
7	17 02 44	-0 015	-0 003		
8	17 03 38	-0 007			
9	17 04 43	-0 006			
10	17 05 37	-0 003			
Event 1	17 05 37				
11	17 06 31	10 300	100% Capture LHS	10 250	Average (ppm)
12	17 07 27	10 300		10 633	Calib Corrected
13	17 08 21	10 200		10 635	BG Corr
14	17 09 15	10 200		741	CFM
15	17 10 09	10 200			
16	17 11 02	10 300			
Event 2	17 11 02				
Event 3	17 11 56				
17	17 11 56	10 400	100% Capture RHS	10 457	Average (ppm)
18	17 12 50	10 400		10 848	Calib Corrected
19	17 13 45	10 500		10 850	BG Corr
20	17 15 10	10 500		743	CFM
21	17 16 04	10 400			
22	17 16 58	10 500			
23	17 17 52	10 500			
Event 4	17 18 46				
24	17 18 46	0 064	BG in RH Duct	0 004	Background
25	17 19 42	-0 003		0 005	Calib Corrected
26	17 20 36	0 005			
27	17 21 30	0 004			
Event 5	17 22 24				
28	17 22 24	0 006	Transition points	8 470	Average (ppm)
29	17 23 18	0 043		8 787	Calib Corrected
30	17 24 12	2 160	% Capture RHS	8 782	BG (duct) Corr
31	17 25 25	6 270			
32	17 26 21	10 400			
33	17 27 15	10 200			
34	17 28 09	10 400			
35	17 29 03	8 990			
36	17 29 57	11 100			
37	17 30 51	8 240			
Event 6	17 30 51				
38	17 31 45	9 580			
Event 7	17 32 39				
39	17 32 39	7 720	Wand Orientation Problem		
40	17 33 33	10 600			
41	17 34 37	6 490			
42	17 35 32	9 050	% Capture LHS	8 756	Average (ppm)
43	17 36 26	9 460		9 083	Calib Corrected
44	17 37 19	7 730		9 078	BG (duct) Corr
45	17 38 13	8 120			
46	17 39 07	9 420			
Event 8	17 39 07				

Capture Eff = **83 13%**

Performance Test #2 (Stock Enclosure)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Calculations	
Event 9	17 40 01				
47	17 40 01	6.340	% Capture LHS	6 428	Average (ppm)
48	17 40 55	9 790		6 669	Calib Corrected
49	17 41 49	9.090		6 354	BG Corr (Post-sample Ave
50	17 42 43	5.410			
51	17 43 37	0.824			
52	17 45 04	4.360			
53	17 46 00	7 000			
54	17 46 54	7.210			
55	17 47 48	5.170			
56	17 48 42	5.630			
57	17 49 36	3.070			
58	17 50 30	5.690			
59	17 51 23	11.400			
60	17 52 17	9.010			
Event 10	17 53 11				
61	17 53 11	6 940			
62	17 54 05	0 206			
Event 11	17 55 21		% Capture RHS		
63	17 55 21	10.700		7 939	Average (ppm)
64	17 56 17	10.500		8 236	Calib Corrected
65	17 57 11	7.990		7 921	BG Corr (Post-sample BG)
66	17 58 05	5.180			
67	17 58 59	7.140			
68	17 59 53	6.080			
69	18 00 47	7.980			
Event 12	18 00 47		Background in RH Duct		
70	18 01 41	11 900		0 302	Average (ppm)
71	18 02 35	0.540		0 314	Calib Corrected
72	18 03 31	0 243			
73	18 04 36	0 356			
74	18 05 30	0 282			
75	18 06 24	0 325			
76	18 07 17	0.270			
77	18 08 11	0.099			
Event 13	18 09 05				

From Test #1 C (RHS) @ 100% Capture = 10 850

From Test #1 C (LHS) @ 100% Capture = 10 635

Capture Eff = 66 44%

Performance Test #3 (Stock Enclosure)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Calculations	
Event 12	18 00 47		Background in RH Duct		
74	18 05 30	0 282		0 099	Background
75	18 06 24	0 325		0 104	Calib Corrected
76	18 07 17	0 270			
77	18 08 11	0.099			
Event 13	18 09 05		100% Capture RHS		
78	18 09 05	0 217			
79	18 09 59	15 700			
80	18 10 55	11.100		10 957	Average (ppm)
81	18 11 49	11.000		11 367	Calib Corrected
82	18 12 43	10 900		11 263	BG Corrected
83	18 13 37	10 900		715	CFM
84	18 15 02	11.100			
85	18 15 56	10.800			
86	18 16 50	10.900			
Event 14	18 17 44				
87	18 17 44	10 700			
88	18 18 37	0 209			
89	18 19 34	0 155			
Event 15	18 20 28		100% Capture LHS		
90	18 20 28	0 096			
91	18 21 22	9 460			
92	18 22 16	10 400		10 478	Average (ppm)
93	18 23 12	10 400		10 869	Calib Corrected
94	18 24 06	10 400		10 766	BG Corrected
95	18 25 19	10 100		732	CFM
96	18 26 13	10 400			
97	18 27 07	10 700			
98	18 28 01	10 700			
99	18 28 54	10 700			
100	18 29 48	10.500			
Event 16	18 29 48				
101	18 30 42	5 000			
Event 17	18 31 36		% Capture LHS		
102	18 31 36	8 170		7 335	Average (ppm)
103	18 32 30	6 490		7 609	Calib Corrected
104	18 33 24	5 970		7 506	BG Corr
105	18 34 17	6 870			
106	18 35 23	8 560			
107	18 36 17	7 950			
Event 18	18 36 17				
108	18 37 11	0 052			
Event 19	18 38 07				
109	18 38 07	7 710			
Event 20	18 39 03				
110	18 39 03	8 800	% Capture RHS	8 853	Average (ppm)
111	18 39 57	8 010		9 184	Calib Corrected
112	18 40 51	11.500		9 080	BG Corr
113	18 41 45	9 010			
114	18 42 39	8 590			
115	18 43 33	7 250			
116	18 44 58	8.810			
Event 21	18 44 58		Background (Meas in RHS)		
117	18 45 52	0 221		0 286	Average (ppm)
118	18 46 48	0.324		0 298	Calib Corrected
119	18 47 42	0 313			
120	18 48 36	0 337			
121	18 49 30	0 245			
122	18 50 24	0 102			
123	18 51 17	0.515			
124	18 52 11	0 197			
125	18 53 05	0 329			
126	18 53 59	0.278			

Capture Eff = 75 29%

Performance Test #4 (Stock Enclosure)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Calculations	
124	18 52 11	0 197	BG (Meas In RHS)	0 278	Background
125	18 53 05	0 329		0 289	Calib Corrected
126	18 53 59	0.278			
Event 22	18 55 12		100% in RHS		
127	18 55 12	0 306		10 880	Average (ppm)
128	18 56 06	10 900		11 287	Calib Corrected
129	18 57 02	11 000		10 997	BG Corr
130	18 57 56	10 900		733	CFM
131	18 58 50	10 800			
132	18 59 44	10.800			
Event 23	18 59 44				
133	19 00 38	0 047			
Event 24	19 01 34		100% in LHS		
134	19 01 34	10 300		10 400	Average (ppm)
135	19 02 30	10 500		10 789	Calib Corrected
136	19 03 24	10.300		10 499	BG Corr
137	19 04 29	10 300		751	CFM
138	19 05 23	10 600			
139	19 06 17	10 400			
140	19 07 11	10.400			
Event 25	19 07 11				
141	19 08 05	2 770			
Event 26	19 09 01		% Capture LHS		
142	19 09 01	3 360			
143	19 09 57	5 100		5 493	Average (ppm)
144	19 10 51	4 330		5 699	Calib Corrected
145	19 11 45	8 220		5 410	BG Corr
146	19 12 39	4 700			
147	19 13 33	4 290			
148	19 14 58	6 320			
Event 27	19 14 58				
149	19 15 52	0 283			
Event 28	19 16 48		% Capture RHS		
150	19 16 48	11 100		9 539	Average (ppm)
151	19 17 45	7 700		9 895	Calib Corrected
152	19 18 39	9 820		9 606	BG Corr
153	19 19 32	8 820			
154	19 20 26	11.500			
155	19 21 20	6.630			
156	19 22 14	11 200			
Event 29	19 22 14		BG (Meas In RHS)		
157	19 23 08	0.504		0 359	Average (ppm)
158	19 24 04	0.525		0 374	Calib Corrected
159	19 25 17	0 467			
160	19 26 11	0 350			
161	19 27 05	0.263			
162	19 27 59	0.311			
163	19 28 55	0.275			
164	19 29 51	0.180			
Event 30	19 30 45				

Capture Eff = 69 85%

Performance Test #5 (Modified Enclosure)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Calculations	
Event 29	19 22 14				
157	19 23 08	0 504			
158	19 24 04	0 525			
159	19 25 17	0 467			
160	19 26 11	0 350	Background in RHS		
161	19 27 05	0 263		0 250	Background
162	19 27 59	0 311		0 260	Calib Corrected
163	19 28 55	0 275			
164	19 29 51	0 180			
165	19 30 45	0 250			
Event 30	19 30 45		100% Capture RHS		
166	19 31 39	10 900		10 850	Average (ppm)
167	19 32 35	10 800		11 256	Calib Corrected
168	19 33 29	10 800		10 995	BG Corr
169	19 34 34	10 900		733	CFM
Event 31	19 34 34		Transition		
170	19 35 28	9 590			
171	19 36 22	0 215			
Event 32	19 37 18		100% LHS		
172	19 37 18	10 300		10 417	Average (ppm)
173	19 38 14	10 400		10 806	Calib Corrected
174	19 39 08	10 400		10 546	BG Corr
175	19 40 02	10 400		747	CFM
176	19 40 56	10 500			
177	19 41 50	10 500			
Event 33	19 41 50		Transition		
178	19 42 44	4 850			
Event 34	19 43 38		% Capture LHS		
179	19 43 38	5 070		5 183	Average (ppm)
180	19 45 03	8 060		5 377	Calib Corrected
181	19 45 57	3 330		5 117	BG Corr
182	19 46 50	7 440			
183	19 47 44	4 620			
184	19 48 38	5 660			
185	19 49 32	4 330			
186	19 50 26	5 490			
187	19 51 20	6 110			
188	19 52 13	8 310			
189	19 53 07	3 140			
190	19 54 01	4 730			
191	19 55 14	6 090			
Event 35	19 55 14		Transition		
Event 36	19 56 08		% Capture RHS		
192	19 56 08	10 100		11 092	Average (ppm)
193	19 57 02	12 100		11 507	Calib Corrected
194	19 57 56	13 700		11 247	BG Corr
195	19 58 50	10 200			
196	19 59 44	8 040			
197	20 00 37	12 700			
198	20 01 31	13 200			
199	20 02 25	11 000			
200	20 03 19	8 790			
Event 37	20 04 13		BG (Meas in RHS)		
201	20 04 13	1 030		0 853	Average (ppm)
202	20 05 20	0 671		0 885	Calib Corrected
203	20 06 14	1 530			
204	20 07 08	0 179			

Capture Eff = **75 96%**

Outdoor Performance Test (13 Aug 97)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Wind Into	Calculations	
1	11 35 21	-0 003	Background	Rear	-0 009	Background
2	11 36 27	-0 001			-0 008	Calib Corrected
3	11 37 32	-0 009				
4	11 38 26	-0 011				
5	11 39 19	-0 009				
6	11 40 13	-0 011				
7	11 41 07	-0 003				
8	11 42 01	-0 007				
9	11 42 55	-0 008				
10	11 43 48	-0 010				
11	11 44 42	-0 011				
12	11 45 36	-0 016				
13	11 46 30	-0 014				
14	11 47 55	-0.009				
Event 01	11 47 55		100% Capture LHS		10 100	Average (ppm)
15	11 48 49	2 690			10 478	Calib Corrected
16	11 49 45	10.000			10 486	BG Corr
17	11 50 39	10 100			732	CFM
18	11 51 33	10.200				
19	11 52 27	10.100				
Event 02	11 53 20					
20	11 53 20	0 167				
Event 03	11 54 17		100% Capture RHS		10 650	Average (ppm)
21	11 54 17	10.700			11 046	Calib Corrected
22	11 55 13	10.700			11 056	BG Corr
23	11 56 07	10 600			709	CFM
24	11 57 20	10 600				
Event 04	11 57 20		% Capture RHS		2 663	Average (ppm)
25	11 58 15	0 276			2 763	Calib Corrected
26	11 59 11	3 040			2 771	BG Corr
27	12 00 07	0.370				
28	12 01 04	0 085				
29	12 01 57	1 060				
30	12 02 51	5 970				
31	12 03 48	7 840				
Event 05	12 04 42					
32	12 04 42	0 591				
33	12 05 38	0 065				
Event 06	12 06 32		% Capture LHS		0 595	Average (ppm)
34	12 06 32	1 610			0 618	Calib Corrected
35	12 07 37	-0 003			0 626	BG Corr
36	12 08 31	0 035				
37	12 09 25	0 737				
			Capture Eff = (Wind into rear of paver)	**15 77%**		

Outdoor Performance Test (13 Aug 97)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Wind Into	Calculations	
Event 07	12 10 18		Transition Data			
38	12 10 18	0 097				
39	12 11 13	-0 008				
40	12 12 07	0 101				
41	12 13 01	0 035				
42	12 13 55	-0 008				
43	12 14 48	0 044				
44	12 15 42	-0 005				
45	12 17 07	0 075				
46	12 18 01	0 203				
47	12 18 55	0 335				
Event 08	12 18 55		100% Capture LHS	Front	10 325	Average (ppm)
48	12 19 49	10.300			10 711	Calib Corrected
49	12 20 45	10.400			10 594	BG Corr
50	12 21 39	10 400			724	CFM
51	12 22 33	10.200				
Event 09	12 22 33		Background LHS		0 112	Background
52	12 23 27	0 239			0 117	Calib Corrected
53	12 24 23	0 205				
54	12 25 17	0 122				
55	12 26 11	0 141				
56	12 27 24	0.112				
Event 10	12 27 24		% Capture LHS		6 048	Average (ppm)
57	12 28 18	1 380			6 274	Calib Corrected
58	12 29 12	7.580			6 157	BG Corr
59	12 30 08	3 590				
60	12 31 02	6 860				
61	12 31 55	5 410				
62	12 32 49	6 800				
Event 11	12 32 49					
63	12 33 43	2 490				
Event 12	12 33 43		% Capture RHS		2 785	Average (ppm)
64	12 34 38	0 390			2 890	Calib Corrected
65	12 35 34	2.560			2 642	BG Corr
66	12 36 28	2 920				
67	12 37 35	2 980				
68	12 38 29	2 680				
Event 13	12 39 23		Background RHS		0 238	
69	12 39 23	1 180			0 248	
70	12 40 19	0 200				
71	12 41 13	0 238				
Event 14	12 42 07		100% Capture RHS		10 400	Average (ppm)
72	12 42 07	0 274			10 789	Calib Corrected
73	12 43 01	10.500			10 541	BG Corr
74	12 43 57	10.400			744	CFM
75	12 44 51	10.400				
76	12 45 45	10.300				
Event 15	12 45 45		Background Decay			
77	12 47 10	0 126				
78	12 48 06	0 128				

Capture Eff = **41 63%**

(Wind into front of paver)

Outdoor Performance Test (13 Aug 97)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Wind Into	Calculations	
Event 16	12 49 00		Transition Data	Left Side		
79	12 49 00	0 240				
80	12 49 54	0 009	Background		-0 003	Average (ppm)
81	12 50 48	0 009			-0 002	Calib Corrected
82	12 51 42	0.003				
Event 17	12 52 35		100% Capture RHS		10 733	Average (ppm)
83	12 52 35	0 073			11 135	Calib Corrected
84	12 53 29	10 800			11 137	BG Corr
85	12 54 25	10 900			704	CFM
86	12 55 19	10 800				
87	12 56 13	10 900				
88	12 57 26	10.500				
89	12 58 20	10.500				
Event 18	12 58 20		% Capture RHS		4 275	Average (ppm)
90	12 59 14	2 820			4 435	Calib Corrected
91	13 00 08	3 130			4 437	BG Corr
92	13 01 02	0 639				
93	13 01 58	9.820				
94	13 02 54	4 240				
95	13 03 48	4 900				
Event 19	13 03 48					
Event 20	13 04 42		% Capture LHS		5 120	Average (ppm)
96	13 04 42	7 120			5 312	Calib Corrected
97	13 05 36	2 230			5 314	BG Corr
98	13 06 32	1.220				
99	13 07 37	5 590				
100	13 08 33	8 260				
101	13 09 27	6 670				
102	13 10 21	4 750				
Event 21	13 10 21		100% Capture LHS		11 125	Average (ppm)
103	13 11 15	11 700			11 541	Calib Corrected
104	13 12 09	11 300			11 543	BG Corr
105	13 13 02	11 100			665	CFM
106	13 13 56	11.200				
107	13 14 50	11 000				
108	13 15 44	11 200				
Event 22	13 17 09		Paver ran out of fuel			
109	13 17 09	10 700				
Event 23	13 18 03		Background Decay			
110	13 18 03	0 051				
111	13 18 59	0 332				
112	13 19 53	0 196				
113	13 20 47	0 120				
114	13 21 41	0 119				

Capture Eff = 43.00%
(Wind into left side of paver)

Overall Average Outdoor Capture Eff. = 33.47%

APPENDIX C

DYNAPAC ENGINEERING CONTROL FAN SPECIFICATIONS: CORRESPONDENCE AND CALCULATIONS

The Dynapac engineering control design used two exhaust fans to supply the negative pressure to the exhaust hood. Each of the fans was hydraulically driven, appeared to be of German manufacturer, and appeared to be of the same model.

A fan specification plate was mounted to the fan housing on each of the two fans. The information on each plate was identical and is shown below.

Hubert Vogel	Typ	HBC 200/D	Fabr Nr	970139
Lufttechnische Anlagen	V	1 200 kg/m^3	ΔP_{ges}	60 Pa
42279 Wuppertal	n	2840 Upm	γ	1,2 kg/m^3
RUF 0202/642097/99	N_w	0,4 kW	η	80%

During an internet search to identify the Hubert Vogel fan manufacturer, NIOSH engineers identified a Swedish Engineering Design firm operations throughout the European Union. In response to our inquiry, the interpretation of the fan specification information was provided via an email message. A copy of the reply is included in this appendix.

(Copy of text from email message)
Dear Mr Kenneth,

Thank you for your inquiry I hope my following information will help you

Typ HBC 200/D means an internal name for the fan with in- or outlet of 200 mm diameter

Fabr Nr 970139 this is the fabrication number from the manufacturing company

V normally it means the volumen to transport but 1200 kg/m**3 is an old description for the volume today it is specified by m**3/h (cubicmeter per hour) if we divide that with Gamma with should have a transport volume of 1000 m**3/h (can be possible)

Delta Pges this is the total pressure difference Pascal (difference between the dynamic (environment) and static (pressure in the system) pressure

n 2840 Upm are the turns per minute --> rpm = upm

Gamma is the specific weight of air

Nw 0,4kW is the old description of power, your fan has an input power of 0,4 kiloWattage

Efficiency 80% is the economical value for the fan, this means form 100% inputed energy, 80% is used by the fan and 20% are lost (more for figures and statistics)

Again, I hope this information will be helpful, if you could tell me the manufacturer there is maybe more information available If you have an further questions, please do not hesitate to contact me (did you already visit our homepage at http //www kncag com)

Yours sincerely,

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