

US EPA ARCHIVE DOCUMENT

# Environmental Technology Verification

## Baghouse Filtration Products

W. L. Gore & Associates, Inc.  
5117 High Durability PPS Laminate Filtration Media  
(Tested March - April 2012)

Prepared by

RTI International



ETS Incorporated



Under a Cooperative Agreement with  
U.S. Environmental Protection Agency



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EPA Cooperative Agreement CR 83416901-0

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# THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM



## ETV JOINT VERIFICATION STATEMENT

<b>TECHNOLOGY TYPE:</b>	<b>BAGHOUSE FILTRATION PRODUCTS</b>	
<b>APPLICATION:</b>	<b>CONTROL OF PM<sub>2.5</sub> EMISSIONS BY BAGHOUSE FILTRATION PRODUCTS</b>	
<b>TECHNOLOGY NAME:</b>	<b>5117 High Durability PPS Laminate Filtration Media</b>	
<b>COMPANY:</b>	<b>W. L. Gore &amp; Associates, Inc.</b>	
<b>ADDRESS:</b>	<b>101 Lewisville Rd. Elkton, MD 21922</b>	<b>PHONE: 410-506-3348 FAX: 410-398-6624</b>
<b>WEB SITE:</b>	<a href="http://www.gore.com">http://www.gore.com</a>	
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The U.S. Environmental Protection Agency (EPA) created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. The ETV Program seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

The ETV Program works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, permittees, and other interested parties; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Air Pollution Control Technology Center (APCT Center) is operated by RTI International\* (RTI), in cooperation with EPA's National Risk Management Research Laboratory (NRMRL). The APCT Center evaluates the performance of baghouse filtration products (BFPs) used primarily to control PM<sub>2.5</sub> emissions (i.e., particles 2.5 µm and smaller in aerodynamic diameter). This verification statement summarizes the test results for W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate filtration media.

## VERIFICATION TEST DESCRIPTION

All tests were performed in accordance with the APCT Center *Generic Verification Protocol for Baghouse Filtration Products*, available at [http://www.epa.gov/etv/pubs/05\\_vp\\_bfp.pdf](http://www.epa.gov/etv/pubs/05_vp_bfp.pdf). The protocol is based on and describes modifications to the equipment and procedures described in Verein Deutscher Ingenieure (VDI) 3926, Part 2, *Testing of Filter Media for Cleanable Filters under Operational Conditions*, December 1994. The VDI document is available from Beuth Verlag GmbH, 10772 Berlin, Germany. The protocol also includes requirements for quality management and QA, procedures for product selection, auditing of the test laboratories, and the test reporting format.

Outlet particle concentrations from a test fabric were measured with an impactor equipped with appropriate substrates to filter and measure PM<sub>2.5</sub> within the dust flow. Outlet particle concentrations were determined by weighing the mass increase of dust collected in each impactor filter stage and dividing by the gas volumetric flow through the impactor.

Particle size was measured while injecting the test dust into the air upstream of the baghouse filter sample. The test dust was dispersed into the flow using a brush-type dust feeder. The particle size distributions in the air were determined both upstream and downstream of the test filter fabric to provide accurate results for penetration of PM<sub>2.5</sub> through the test filter. All tests were performed using a constant  $18.4 \pm 3.6$  g/dscm ( $8.0 \pm 1.6$  gr/dscf) loading rate, a  $120 \pm 6.0$  m/h ( $6.6 \pm 0.3$  fpm) filtration velocity [identical to gas-to-cloth ratio (G/C\*\*)], and aluminum oxide test dust with a measured mass mean aerodynamic diameter maximum of 1.5 µm (average of three impactor runs). All BFPs are tested in their initial (i.e., clean) condition.

Each of the three test runs consisted of the following segments:

- Conditioning period—10,000 rapid-pulse cleaning cycles
- Recovery period—30 normal-pulse cleaning cycles
- Performance test period—6-hour filter fabric test period with impactor.

## VERIFIED TECHNOLOGY DESCRIPTION

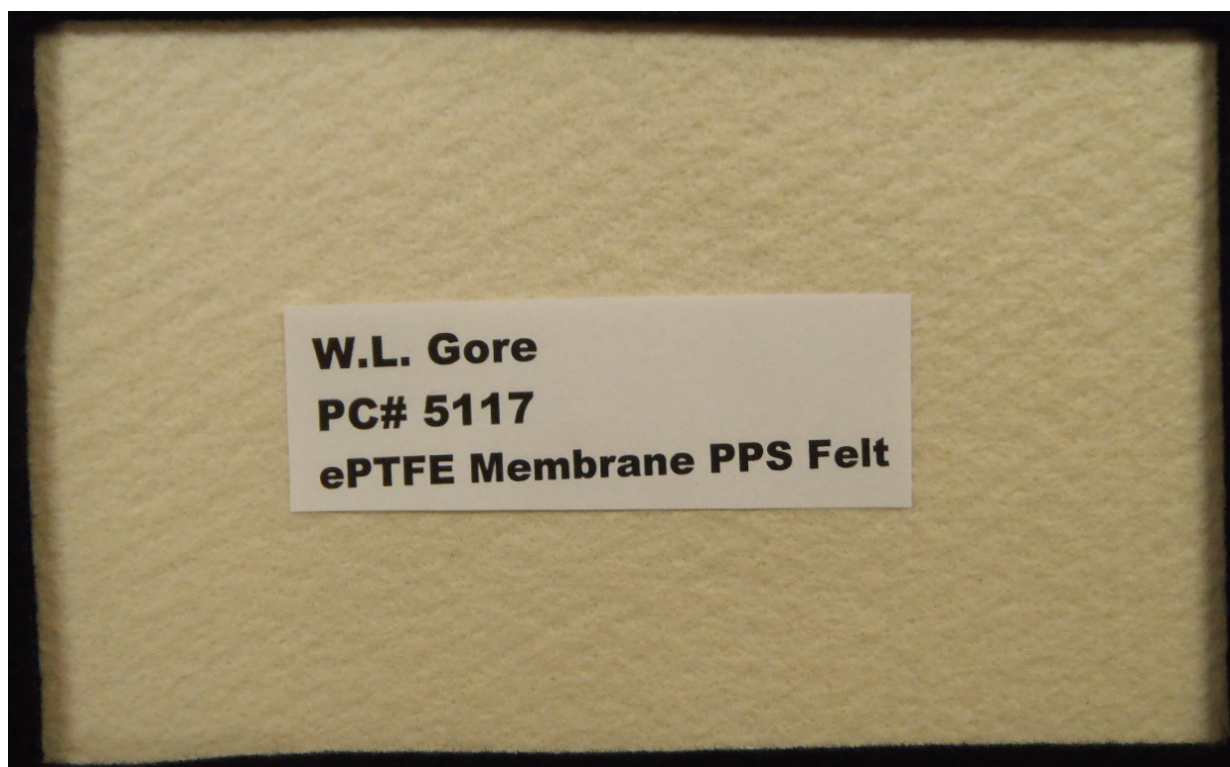
Baghouses are air pollution control devices used to control particulate emissions from stationary sources and are among the technologies evaluated by the APCT Center. Baghouses and their accompanying filter media have long been one of the leading particulate control techniques for industrial sources. Increasing emphasis on higher removal efficiencies has helped the baghouse to be continually more competitive when compared to the other generic PM control devices to the point where the baghouse is now the control option of choice for most industrial applications. The development of new and improved filter media has further enhanced baghouse capability to control fine PM over an expanded range of industrial applications.

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\* RTI International is a trade name of Research Triangle Institute.

\*\* Filtration velocity and gas-to-cloth ratio are used interchangeably and are defined as the gas flow rate divided by the surface area of the cloth.

W. L. Gore & Associates, Inc. provided the following information about their filter media product. The W. L. Gore & Associates, Inc. 5117 High Durability PPS Laminate is a 16 ounces per square yard (oz/yd<sup>2</sup>) polyphenylene sulfide (PPS) felt laminated with GORE™ Membrane (expanded polytetrafluoroethylene, ePTFE). **Figure 1** is a photograph of the fabric. Sample material was received as nine 46 x 91 cm (18 x 36 in.) swatches marked with the manufacturer's model number, year and month of manufacture, and cake side (the upstream side of the fabric, which is exposed to the particle-laden air on which the filter cake builds up). Three of the swatches were selected at random for preparing three circular test specimens 150 mm (5.9 in.) in diameter.



**Figure 1. Photograph of W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate filtration media**

## VERIFICATION OF PERFORMANCE

Verification testing of the W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate filtration media was performed during the period of March 28 – April 4, 2012, for standard test conditions at the test facility of ETS Incorporated, 1401 Municipal Road NW, Roanoke, VA 24012. Test conditions are listed in **Table 1**. The overall test results summarized in **Table 2** represent the averages of three individual tests.

The APCT Center quality manager has reviewed the test results and the quality control (QC) data and has concluded that the data quality objectives given in the generic verification protocol and test/QA plan have been attained.

This verification statement addresses five aspects of filter fabric performance: filter outlet PM<sub>2.5</sub> concentration, filter outlet total mass concentration, pressure drop, filtration cycle time, and mass gain on the filter fabric. Users may wish to consider other performance parameters, such as temperature, service life, and cost when selecting a filter fabric for their application.

**Table 1. Test Conditions for Baghouse Filtration Products  
Brand/Model: W. L. Gore & Associates, Inc.'s 5117 High Durability  
PPS Laminate Filtration Media**

Test Parameter	Value
Dust concentration	18.4 ± 3.6 g/dscm (8.0 ± 1.6 gr/dscf)
Filtration velocity (G/C)	120 ± 6 m/h (6.6 ± 0.3 fpm)
Pressure loss before cleaning	1,000 ± 12 Pa (4 ± 0.05 in. w.g.)
Tank pressure	0.5 ± 0.03 MPa (75 ± 5 psi)
Valve opening time	50 ± 5 ms
Air temperature	25 ± 2 °C (77 ± 4 °F)
Relative humidity	50 ± 10%
Total raw gas stream flow rate	5.8 ± 0.3 m <sup>3</sup> /h (3.4 ± 0.2 cfm)
Sample gas stream flow rate	1.13 ± 0.06 m <sup>3</sup> /h (0.67 ± 0.03 cfm)
Number of cleaning cycles	—
▪ During conditioning period	10,000 cycles
▪ During recovery period	30 cycles
Performance test duration	6 h ± 1 s

Beginning of table description. Table 1 is titled Test Conditions for Baghouse Filtration Products; the Brand/Model is listed as W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate Filtration Media. The table describes the test conditions that are specified in the QA/QC requirements for the test; all conditions were achieved for this test. The table lists the test parameters in one column and their values in the next column. The test parameters include such items as the dust concentration, filtration velocity, flow rates, air temperature and humidity, and the number of cleaning cycles during the test. End of table description.

**Table 2. Baghouse Filtration Product Three-Run Average Test Results for W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate Filtration Media**

Verification Parameter	At Verification Test Conditions
Outlet particle concentration at standard conditions <sup>a</sup> PM <sub>2.5</sub> , g/dscm (gr/dscf) Total mass, g/dscm <sup>b</sup> (gr/dscf)	<0.0000167 <sup>c</sup> (<0.0000073) <0.0000167 <sup>c</sup> (<0.0000073)
Average residual pressure drop ( $\Delta P$ ), cm w.g. (in. w.g.)	2.09 (0.82)
Initial residual $\Delta P$ , cm w.g. (in. w.g.)	2.06 (0.81)
Residual $\Delta P$ increase, cm w.g. (in. w.g.)	0.07 (0.03)
Filtration cycle time, s	255
Mass gain of test sample filter, g (gr)	0.13 (1.95)
Number of cleaning cycles	84

<sup>a</sup> Standard conditions: 101.3 kPa (14.7 psia) and 20 °C (68 °F). One or more of the impactor substrate weight changes for these results were near the reproducibility of the balance.

<sup>b</sup> Total mass includes the mass of PM<sub>2.5</sub> and larger particles that passed through the fabric.

<sup>c</sup> The measured value was determined to be below the detection limit of 0.0000167 grams per cubic meter. The detection limit is for a 6-hour test and based on VDI 3926.

Beginning of table description. Table 2 is titled Baghouse Filtration Product Three-Run Average Test Results for W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate Filtration Media. The table lists the verified test results for this product. The table lists the verification parameters in one column and their values at the verification test conditions in the next column. The verification parameters listed include the outlet particle concentration, the pressure drop characteristics, the filtration cycle time, the mass gain of the test sample, and number of cycles during the test. End of table description.



In accordance with the generic verification protocol, this verification statement is applicable to filter media manufactured between the signature date of the verification statement and 3 years thereafter.

signed by Cynthia Sonich-Mullin

8/27/2012

signed by Jason Hill

6/27/2012

Cynthia Sonich-Mullin

Date

Jason Hill

Date

Director

Director

National Risk Management Research Laboratory

Air Pollution Control Technology Center

Office of Research and Development

RTI International

United States Environmental Protection Agency

**NOTICE:** ETV verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and RTI make no express or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of commercial product names does not imply endorsement.

### **Notice**

This document was prepared by RTI International\* (RTI) and its subcontractor ETS Incorporated (ETS) with partial funding from Cooperative Agreement No. CR 83416901-0 with the U.S. Environmental Protection Agency (EPA). The document has been subjected to RTI/EPA's peer and administrative reviews and has been approved for publication. Mention of corporation names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products.

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\* RTI International is a trade name of Research Triangle Institute.

## Foreword

The Environmental Technology Verification (ETV) Program, established by the U.S. Environmental Protection Agency (EPA), is designed to accelerate the development and commercialization of new or improved technologies through third-party verification and reporting of performance. The goal of the ETV Program is to verify the performance of commercially ready environmental technologies through the evaluation of objective and quality-assured data in order to provide potential purchasers and permittees an independent, credible assessment of the technology that they are buying or permitting.

The Air Pollution Control Technology Center (APCT Center) is part of the EPA's ETV Program and is operated as a partnership between RTI International (RTI) and EPA. The APCT Center verifies the performance of commercially ready air pollution control technologies. Verification tests use approved protocols, and verified performance is reported in verification statements signed by EPA and RTI officials. RTI contracts with ETS Incorporated (ETS) to perform verification tests on baghouse filtration products, including filter media.

Baghouses are air pollution control devices used to control particulate emissions from stationary sources and are among the technologies evaluated by the APCT Center. Baghouses and their accompanying filter media have long been one of the leading particulate control techniques for industrial sources. Increasing emphasis on higher removal efficiencies has helped the baghouse to be continually more competitive when compared to the other generic PM control devices to the point where the baghouse is now the control option of choice for most industrial applications. The development of new and improved filter media has further enhanced baghouse capability to control fine PM over an expanded range of industrial applications. The APCT Center developed (and EPA approved) the *Generic Verification Protocol for Baghouse Filtration Products* to provide guidance on these verification tests.

The following report reviews the performance of W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate filtration media. ETV testing of this technology was conducted during March - April 2012 at ETS. All testing was performed in accordance with an approved test/quality assurance (QA) plan that implements the requirements of the generic verification protocol at the test laboratory.

## **Availability of Verification Statement and Report**

Copies of this verification report are available from the following:

- RTI International  
Discovery & Analytical Sciences  
P.O. Box 12194  
Research Triangle Park, NC 27709-2194
  
- U.S. Environmental Protection Agency  
Air Pollution Prevention and Control Division (E343-02)  
109 T. W. Alexander Drive  
Research Triangle Park, NC 27711

Web Site: <http://www.epa.gov/etv/vt-apc.html> (electronic copies)

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## List of Abbreviations and Acronyms

APCT Center	Air Pollution Control Technology Center
BFP	baghouse filtration product
cfm	cubic feet per minute
cm	centimeter(s)
cm w.g.	centimeter(s) of water gauge
dia.	diameter
$\Delta P$	pressure drop
dscmh	dry standard cubic meter(s) per hour
EPA	U.S. Environmental Protection Agency
ePTFE	expanded polytetrafluoroethylene
ETS	ETS Incorporated
ETV	Environmental Technology Verification
FEMA	filtration efficiency media analyzer
fpm	feet per minute
g	gram(s)
g/dscm	gram(s) per dry standard cubic meter
$g/m^3$	gram(s) per cubic meter
G/C	gas-to-cloth ratio (filtration velocity)
gr	grain(s)
gr/dscf	grain(s) per dry standard cubic foot
GVP	generic verification protocol
h	hour(s)
in.	inch(es)
in. w.g.	inch(es) of water gauge
kPa	kilopascal(s)

m	meter(s)
m/h	meter(s) per hour
m <sup>3</sup> /h	cubic meter(s) per hour
mbar	millibar(s)
min.	minute(s)
mm	millimeter(s)
MPa	megapascal(s)
ms	millisecond(s)
oz/yd <sup>2</sup>	ounce(s) per square yard
Pa	pascal(s)
PM	particulate matter
PM <sub>2.5</sub>	particulate matter 2.5 micrometers in aerodynamic diameter or smaller
PPS	polyphenylene sulfide
psi	pound(s) per square inch
psia	pound(s) per square inch absolute
QA	quality assurance
QC	quality control
RTI	RTI International
s	second(s)
t	time
VDI	Verein Deutscher Ingenieure
µm	micrometer(s)
°C	degree(s) Celsius
°F	degree(s) Fahrenheit
°R	degree(s) Rankine



## Acknowledgments

The authors acknowledge the support of all those who helped plan and conduct the verification activities. In particular, we would like to thank Michael Kosusko, U.S. Environmental Protection Agency's (EPA's) Project Officer, and Bob Wright, EPA's Quality Manager, who both work as part of EPA's National Risk Management Research Laboratory in Research Triangle Park, NC. Finally, we would like to acknowledge the assistance and participation of W. L. Gore & Associates, Inc. personnel, who supported the test effort.

For more information on W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate, contact the following:

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Elkton, MD 21922  
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For more information on verification testing of baghouse filtration products, contact the following:

Mr. Jason Hill  
RTI International  
P.O. Box 12194  
Research Triangle Park, NC 27709-2194  
919-541-7443  
[APCTVC@rti.org](mailto:APCTVC@rti.org)

## 1.0 INTRODUCTION

This report reviews the pressure drop ( $\Delta P$ ) and filtration performance of W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate filtration media. Environmental Technology Verification (ETV) testing of this technology/product was conducted during a series of tests in March – April 2012 by ETS Incorporated (ETS), under contract with the Air Pollution Control Technology Center (APCT Center). The objective of the APCT Center and the ETV Program is to verify, with high data quality, the performance of air pollution control technologies. Control of fine-particle emissions from various industrial and electric utility sources employing baghouse control technology is within the scope of the APCT Center. An APCT Center program area was designed by RTI International (RTI) and a technical panel of experts to evaluate the performance of particulate filters for fine-particle (i.e.,  $PM_{2.5}$ ) emission control. Based on the activities of this technical panel, the *Generic Verification Protocol for Baghouse Filtration Products*<sup>1</sup> was developed. This protocol was chosen as the best guide to verify the filtration performance of baghouse filtration products (BFPs). The specific test/quality assurance (QA) plan for the ETV test of the technology was developed and approved in May 2000, followed by an approved update in February 2006<sup>2</sup>. The goal of the test was to measure filtration performance of both  $PM_{2.5}$  and total particulate matter (PM), as well as the  $\Delta P$  characteristics of the W. L. Gore & Associates, Inc. technology identified above.

Section 2 of this report documents the procedures used for the test and the conditions over which the test was conducted. A description of W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate filtration media is presented in Section 3. The results of the test are summarized and discussed in Section 4, and references are presented in Section 5.

This report contains summary information and data from the test and the verification statement. Complete documentation of the test results is provided in a separate data package report and an audit of data quality report. These reports include the raw test data from product testing and supplemental testing as well as QA and quality control (QC) activities and results. Complete documentation of QA/QC activities and results, raw test data, and equipment calibration results are retained in ETS's files for 7 years.

## 2.0 VERIFICATION TEST DESCRIPTION

The BFPs were tested in accordance with the APCT Center *Generic Verification Protocol for Baghouse Filtration Products*<sup>1</sup> and the *Test/QA Plan for the Verification Testing of Baghouse Filtration Products*.<sup>2</sup> These documents incorporate all the requirements for quality management, QA, procedures for product selection, auditing of the test laboratories, and reporting format. The Generic Verification Protocol (GVP) describes the overall procedures used for verification testing and defines the data quality objectives. The protocol is based on and describes modifications to the equipment and procedures described in Verein Deutscher Ingenieure (VDI) 3926, Part 2, *Testing of Filter Media for Cleanable Filters under Operational Conditions*, December 1994.<sup>3</sup> The values for inlet dust concentration, raw gas flow rate, and filtration velocity used for current verification testing have been revised in consultation with the technical panel since posting of the GVP. These revisions are documented in Section 4.1. The test/QA plan details how the test laboratory at ETS implemented and met the requirements of the GVP.

### 2.1 Description of the Test Rig and Methodology

The tests were conducted in ETS's filtration efficiency media analyzer (FEMA) test apparatus (**Figure 1**). The test apparatus is based on the VDI 3926 Type 1 vertical duct design. The test apparatus consists of a brush-type dust feeder that disperses test dust into a vertical rectangular duct (raw-gas channel). The dust feed rate is continuously measured and recorded via an electronic scale located beneath the dust feed mechanism. The scale has a continuous readout with a resolution of 10 g. A radioactive polonium-210 alpha source is used to neutralize the dust electrically before its entry into the raw-gas channel. An optical photo sensor monitors the concentration of dust and ensures that the flow is stable for the entire duration of the test. The optical photo sensor does not measure absolute concentration, and is, therefore, not the primary concentration measurement for the test. A portion of the gas flow is extracted from the raw-gas channel through the test filter, which is mounted vertically at the entrance to a horizontal duct (clean-gas channel). The clean-gas channel flow is separated into two gas streams, a sample stream and a bypass stream. An aerodynamic "Y" is used for this purpose. The aerodynamic "Y" is designed for isokinetic separation of the clean gas with 40% of the clean gas entering the sample-gas channel without change in gas velocity. The sample-gas channel contains an Andersen impactor for particle separation and measurement. The bypass channel contains an absolute filter. The flow within the two segments of the "Y" is continuously monitored and maintained at selected rates by adjustable valves. Two vacuum pumps maintain air flow through the raw-gas and clean-gas channels. The flow rates, and thus the gas-to-cloth ratio (G/C) through the test filter, are kept constant and measured using mass flow controllers. A pressure transducer is used to measure the average residual  $\Delta P$  of the filter sample. The pressure transducer measures the differential pressure across the filter samples every 3 seconds; the residual  $\Delta P$  measurements are those taken 3 seconds after the cleaning pulse. The  $\Delta P$  measurements are then averaged, as described in Appendix C, Section 4.4.1 of the GVP.<sup>1</sup> High-efficiency filters are installed upstream of the flow controllers and pumps to prevent contamination or damage caused by the dust. The cleaning system consists of a compressed-air tank set at 0.5 MPa (75 psi), a quick-action diaphragm valve, and a blow tube [25.4 mm (1.0 in.) dia.] with a nozzle [3 mm (0.12 in.) dia.] facing the downstream side of the test filter.

Mean outlet particle concentration is determined when a portion of the gas flow is extracted from the raw-gas channel through the test filter, which is mounted vertically at the entrance to a horizontal duct (clean-gas channel). The clean-gas flow is separated using an aerodynamic "Y" so that a representative sample of the clean gas flows through an Andersen impactor that determines the outlet particle concentration. Outlet particle concentrations were determined by weighing the mass increase of dust collected in each impactor filter stage and dividing by the gas volumetric flow through the impactor.

The particle size was measured while a fine dust was injected into the air stream upstream of the filter fabric sample. The particle size distributions in the air were determined both upstream and downstream of the test filter fabric to provide accurate results for penetration through the test filter of  $PM_{2.5}$ .

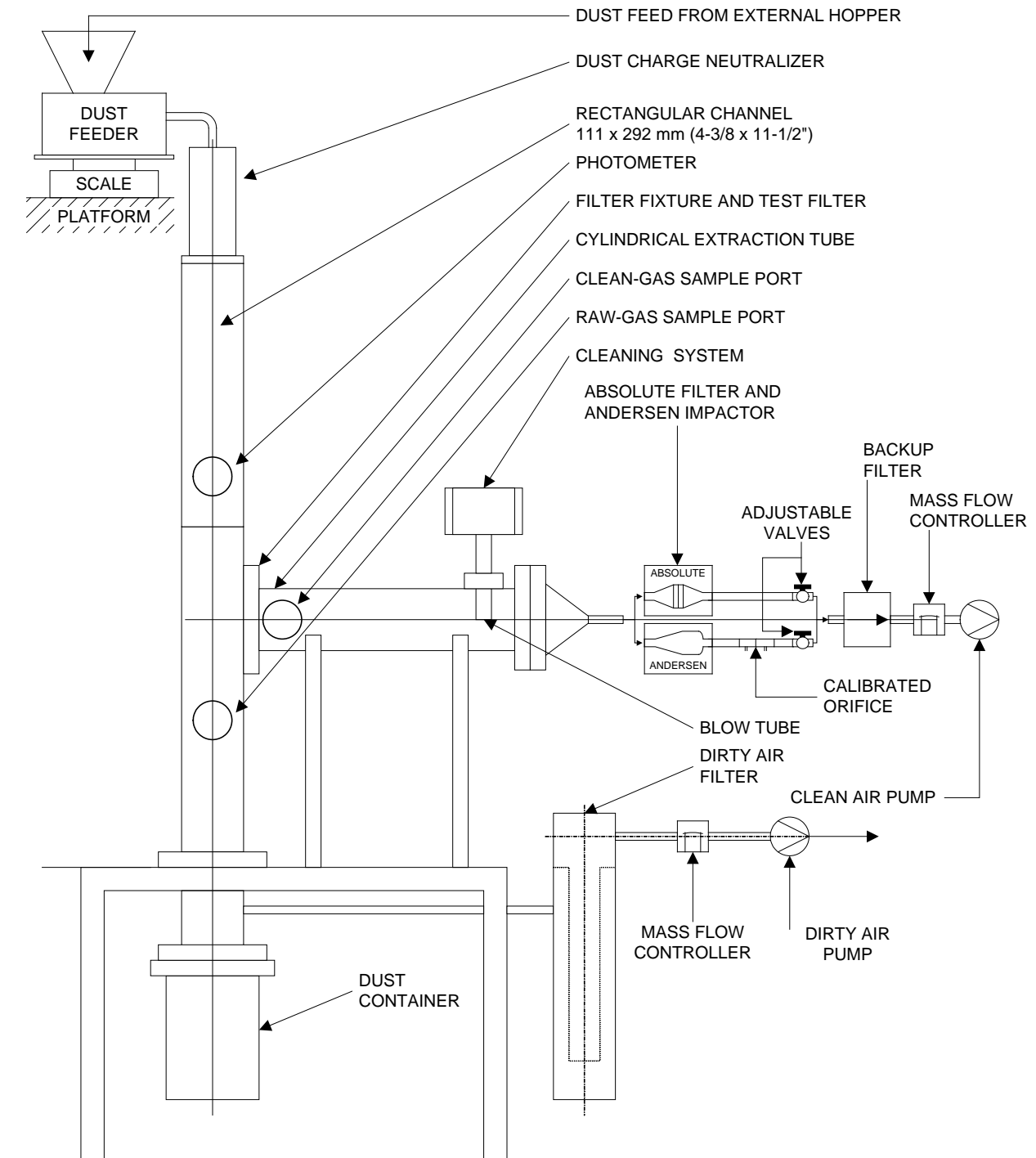


Figure 1. Diagram of filtration efficiency media analyzer test apparatus.

The following series of tests was performed on three separate, randomly selected filter fabric samples:

- Conditioning period
- Recovery period
- Performance test period.

To simulate long-term operation, the test filter was first subjected to a conditioning period, which consists of 10,000 rapid-pulse cleaning cycles under continuous dust loading. During this period, the time between cleaning pulses was maintained at 3 seconds. No filter performance parameters are measured in this period.

The conditioning period is immediately followed by a recovery period, which allows the test filter fabric to recover from rapid pulsing. The recovery period consists of 30 normal filtration cycles under continuous and constant dust loading. During a normal filtration cycle, the dust cake is allowed to form on the test filter until a differential pressure of 1,000 Pa (4.0 in. w.g.) is reached. At this point, the test filter is cleaned by a pulse of compressed air from the clean-gas side of the fabric. The next filtration cycle begins immediately after the cleaning is complete.

Performance testing occurred for a 6-hour period immediately following the recovery period (a cumulative total of 10,030 filtration cycles after the test filter had been installed in the test apparatus). During the performance test period, normal filtration cycles are maintained and, as in the case of the conditioning and recovery periods, the test filter is subjected to continuous and constant dust loading.

The filtration velocity (G/C) and inlet dust concentrations were maintained at  $120 \pm 6$  m/h ( $6.6 \pm 0.3$  fpm) and  $18.4 \pm 3.6$  g/dscm ( $8.0 \pm 1.6$  gr/dscf), respectively, throughout all phases of the test.

## 2.2 Selection of Filtration Sample for Testing

Filter fabric samples of 5117 High Durability PPS Laminate filtration media were supplied to ETS directly from the manufacturer (W. L. Gore & Associates, Inc.), with a letter signed by John F. McMillan, Business Leader, W. L. Gore & Associates, Inc., attesting that the filter media were selected at random in an unbiased manner from commercial-grade media and were not treated differently in any manner from the media provided to customers. The manufacturer supplied the test laboratory with nine 46 x 91 cm (18 x 36 in.) filter samples. The test laboratory randomly selected three samples and prepared them for testing by cutting one test specimen of 150 mm (5.9 in.) diameter from each selected sample for insertion in the test rig sample holder. The sample holder has an opening 140 mm (5.5 in.) in diameter, which is the dimension used to calculate the face area of the tested specimen.

## 2.3 Control Tests

Two types of control tests were performed during the verification test series. The first was a dust characterization, which is performed monthly. The reference dust used during the verification tests was Pural NF aluminum oxide dust. The Pural NF dust was oven dried for 2 hours and sealed in an airtight container prior to its insertion into the FEMA apparatus. The criteria for the dust characterization test are a maximum mass mean diameter of  $1.5 \pm 1.0$   $\mu\text{m}$  and a concentration between 40% and 90% of particles less than 2.5  $\mu\text{m}$ . These criteria must be met in order to continue the verification test series.

The second control test, the reference value test, is performed quarterly using the reference fabric and the FEMA apparatus. The reference value test determines the weight gain of the reference fabric, as well as the maximum  $\Delta\text{P}$  (final residual pressure drop). The results of the test verified that the FEMA apparatus was operating consistently within the required parameters. The average fabric maximum  $\Delta\text{P}$  (average of the repeated measurements of final residual pressure drop conducted during the quarter applicable to this

test) in a reference value test must be 0.60 cm w.g.  $\pm$  40%, and the fabric weight gain average must be 1.12 g  $\pm$  40%. Three reference value control test runs were conducted. The results of the control tests are summarized in **Table 1**.

**Table 1. Summary of Control Test Results**

—	Requirement	Measured Value	Criteria Met
Mass mean diameter, $\mu\text{m}$	1.5 $\pm$ 1.0	2.33	Yes
% Less than 2.5 $\mu\text{m}$	40%–90%	52.79%	Yes
Weight gain, g	1.12 $\pm$ 40%	0.71	Yes
Maximum pressure drop, cm w.g.	0.60 $\pm$ 40%	0.51	Yes

Beginning of table description. Table 1 is titled Summary of Control Test Results. The table lists the results of measurements meant to characterize the operation of the test apparatus. The mass mean diameter of the challenge aerosol, the percent less than 2.5 micrometers in diameter, the weight gain of a reference fabric and the maximum pressure drop of the reference fabric were measured. In columns, the table lists the QA/QC requirements, the values measured during the control tests, and whether or not the criteria were met. For this test, all criteria were met. End of table description.

## 2.4 Analysis

The equations used for verification analysis are described below.

$A_f$	=	Exposed area of sample filter, $\text{m}^2$
$C_{ds}$	=	Dry standard outlet particulate concentration of total mass, g/dscm
$C_{2.5ds}$	=	Dry standard outlet particulate concentration of $\text{PM}_{2.5}$ , g/dscm
dia.	=	Diameter of exposed area of sample filter, m
$F_a$	=	Dust feed concentration corrected for actual conditions, $\text{g}/\text{m}^3$
$F_s$	=	Dust feed concentration corrected for standard conditions, g/dscm
G/C	=	Gas-to-cloth ratio, m/h
$M_t$	=	Total mass gain from Andersen impactor, g
$M_{2.5}$	=	Total mass gain of particles equal to or less than 2.5 $\mu\text{m}$ diameter from Andersen impactor, g. This value may need to be linearly interpolated from test data.
N	=	Number of filtration cycles in a given performance test period
$P_{avg}$	=	Average residual $\Delta\text{P}$ , cm w.g.
$P_i$	=	Residual $\Delta\text{P}$ for $i^{\text{th}}$ filtration cycle, cm w.g.
$P_s$	=	Absolute gas pressure as measured in the raw-gas channel, mbar
$Q_a$	=	Actual gas flow rate, $\text{m}^3/\text{h}$
$Q_{ds}$	=	Dry standard gas flow rate, dscmh
$Q_{2.5ds}$	=	Dry standard gas flow rate for 2.5 $\mu\text{m}$ particles, dscmh
$Q_{st}$	=	Standard gas flow rate for a specific averaging time, t, dscmh
t	=	Specified averaging time or sampling time, s
$t_c$	=	Average filtration cycle time, s
$T_s$	=	Raw-gas channel temperature, $^{\circ}\text{F}$

- $w_f$  = Weight of dust in feed hopper following specified time, g. Because of vibrations causing short-term fluctuations to the feed hopper, this value is measured as a 1-min. average.
- $w_i$  = Weight of dust in feed hopper at the beginning of the specified time, g. Due to vibrations causing short-term fluctuations to the feed hopper, this value is measured as a 1-min. average.

Conversion factors and standard values used in the equations are listed below.

- 460 = 0 °F, in °R  
 1,013 = Standard atmospheric pressure, mbar  
 528 = Standard temperature, °R

Area of Sample Fabric,  $A_f$

$$A_f = \frac{(\pi * d^2)}{4}$$

Actual Gas Flow Rate,  $Q_a$

$$Q_a = Q_{ds} * \left[ \frac{(T_s + 460) * 1013}{P_s * 528} \right]$$

Gas-to-Cloth Ratio, G/C

$$\frac{G}{C} = \frac{Q_a}{A_f}$$

Standard Dust Feed Concentration,  $F_s$ , for a specified time,  $t$

$$F_s = \frac{(w_i - w_f)}{(Q_{st} * t)}$$

Actual Raw Gas Dust Concentration,  $F_a$

$$F_a = F_s * \left[ \frac{(T_s + 460) * 1013}{P_s * 528} \right]$$

Dry Standard Clean Gas Particulate Concentration, Total Mass,  $C_{ds}$

$$C_{ds} = \frac{M_t}{\left[ Q_{ds} * t * \left( 1 - \frac{\% H_2O}{100} \right) \right]}$$

Dry Standard Clean Gas Particulate Concentration,  $PM_{2.5}$ ,  $C_{2.5ds}$

$$C_{2.5ds} = \frac{M_{2.5}}{\left[ Q_{2.5ds} * t * \left( 1 - \frac{\% H_2O}{100} \right) \right]}$$

Filtration Cycle Time,  $t_c$

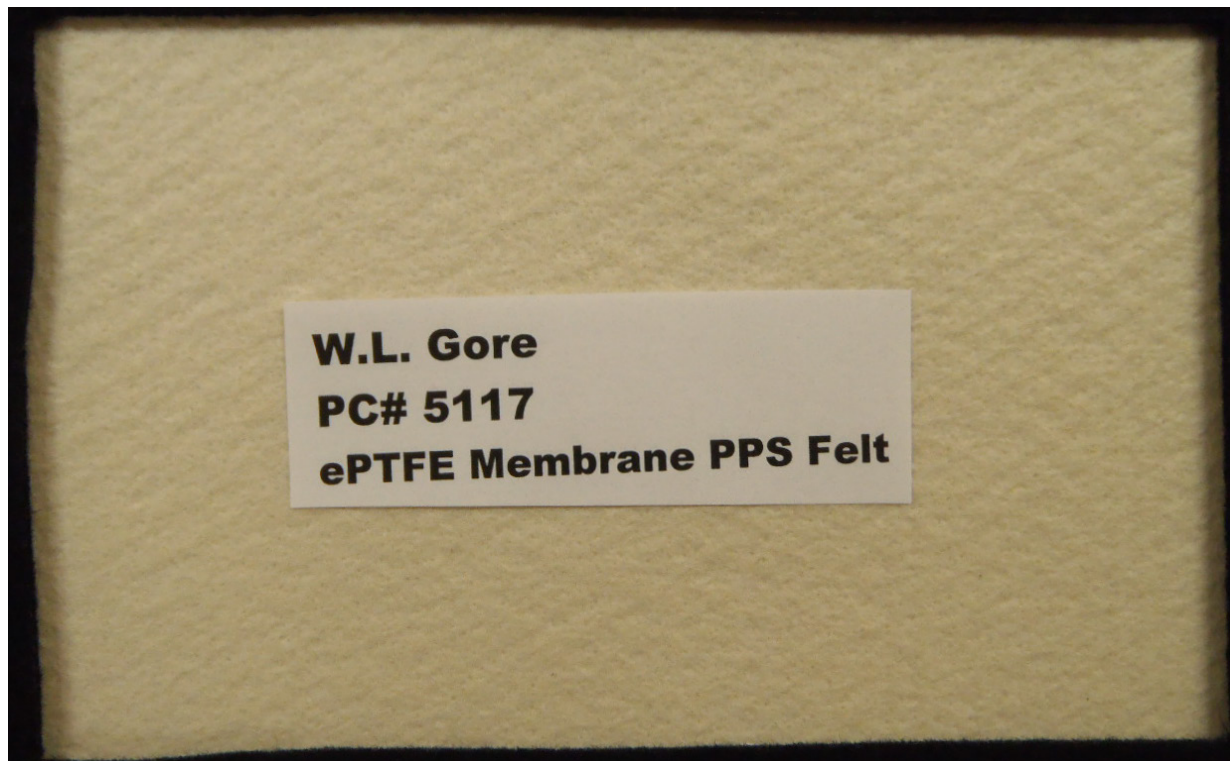
$$t_c = \frac{t}{N}$$

Average Residual Pressure Drop,  $P_{avg}$

$$P_{avg} = \frac{\sum P_i}{N}$$

### 3.0 DESCRIPTION OF FILTER FABRIC

The W. L. Gore & Associates, Inc. 5117 High Durability PPS Laminate is a 16 ounces per square yard (oz/yd<sup>2</sup>) polyphenylene sulfide (PPS) felt laminated with GORE™ Membrane (expanded polytetrafluoroethylene, ePTFE). **Figure 2** is a photograph of the fabric. Sample material was received as nine 46 x 91 cm (18 x 36 in.) swatches marked with the manufacturer's model number, year and month of manufacture, and cake side (the upstream side of the fabric, which is exposed to the particle-laden air, on which the filter cake builds up). Three of the swatches were selected at random for preparing three circular test specimens 150 mm (5.9 in.) in diameter.



**Figure 2. Photograph of W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate filtration media.**



## 4.0 VERIFICATION OF PERFORMANCE

### 4.1 Quality Assurance

The verification tests were conducted in accordance with an approved test/QA plan.<sup>2</sup> The EPA quality manager conducted an independent assessment of the test laboratory in June 2005 and found that the test laboratory was equipped and operated as specified in the test/QA plan.

The ETS QA officer and the APCT Center's QA staff have reviewed the results of this test and have found that the results meet the overall data quality objectives as stated in the test/QA plan. It should be noted that, because of the highly efficient nature of the filter medium being tested, one or more of the impactor substrate weighings for these results were below the reproducibility of the balance. The relative percent error in the post-filter weighing measurements cannot be computed because some of the values were near zero. As a result of this occurrence, the tests do not meet the data quality objectives (DQOs) stated in the test/QA plan for mass gain associated with outlet concentrations. However, as stated in the test protocol, "for highly efficient fabrics, the mass gains stated for these quality objectives may not be achieved in the specified test duration. For these tests it is acceptable for the indicated DQO not to be met."

Data on calibration certificates for the flow meters, flow transducers, weights, low- and high-resolution balances, thermometer, and humidity logger are maintained at ETS in a separate data package.

Deviations from the test plan include organizational personnel changes.

The ETS QA officer and the APCT Center's QA staff have also reviewed the results of the control tests, which are summarized in Section 2.3, Table 1. The dust characterization control test met the appropriate requirements of the test/QA plan and verification protocol. The reference fabric tests met maximum  $\Delta P$  and weight gain requirements established for reference fabric performance in the GVP, indicating the measurement system is operating in control.

### 4.2 Results

**Table 2** summarizes the mean outlet particle concentration measurements for the verification test periods. Measurements were conducted during the 6-hour performance test period. The performance test period followed a 10,000-cycle conditioning period and a 30-cycle recovery period.

Table 2 summarizes the three verification tests that were performed under standard verification test conditions. The average residual  $\Delta P$  across each filter sample at the nominal 120 m/h (6.6 fpm) filtration velocity [for a flow rate of 5.8 m<sup>3</sup>/h (3.4 cfm)] is also shown in Table 2. This  $\Delta P$  ranged from 1.81 to 2.33 cm w.g. (0.71 to 0.92 in. w.g.) for the three filter samples tested. The residual  $\Delta P$  increase ranged from 0.06 to 0.08 cm w.g. (0.02 to 0.03 in. w.g.) for the samples tested. All three standard condition verification runs were used to compute the averages given in Table 2. The PM<sub>2.5</sub> outlet particle concentration average for the three runs is < 0.0000167 g/dscm. The total PM concentration average for the three runs is < 0.0000167 g/dscm.

**Table 2. Summary of Verification Results for W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate Filtration Media**

Test Run Number	6V1-R1	6V1-R2	6V1-R3	Average <sup>a</sup>
PM <sub>2.5</sub> (g/dscm) <sup>b</sup>	<0.0000167 <sup>c</sup>	<0.0000167	<0.0000167	<0.0000167
Total PM (g/dscm)	<0.0000167 <sup>c</sup>	<0.0000167	<0.0000167	<0.0000167
Average residual ΔP (cm w.g.)	1.81	2.13	2.33	2.09
Initial residual ΔP (cm w.g.)	1.78	2.11	2.30	2.06
Residual ΔP increase (cm w.g.)	0.08	0.06	0.06	0.07
Mass gain of sample filter (g)	0.14	0.10	0.14	0.13
Average filtration cycle time (s)	270	243	252	255
Number of cleaning cycles	79	88	85	84

<sup>a</sup> All three verification runs were used to compute averages.

<sup>b</sup> One or more of the impactor substrate weight changes for these results were near the reproducibility limit of the balance.

<sup>c</sup> The measured value was determined to be below the detection limit of 0.0000167 grams per cubic meter. The detection limit is for a six-hour test and based on VDI 3926.

Beginning of table description. Table 2 is titled Summary of Verification Results for W. L. Gore & Associates, Inc.'s 5117 High Durability PPS Laminate Filtration Media. The table lists the verified test results for the three replicate test runs and their averages. The table lists the particle concentrations downstream of the sample filters, the pressure drop characteristics, the mass gain of the sample filter, the average filtration cycle time, and the number of cleaning cycles during the test. In separate columns, results for these parameters are listed for each of the three test runs and their averages. End of table description.

### 4.3 Limitations and Applications

This verification report addresses two aspects of BFP performance: outlet particle concentration and ΔP. Users may wish to consider other performance parameters, such as service life and cost, when selecting a baghouse filtration fabric for their application.

In accordance with the GVP, the verification statement, which summarizes this test report, is applicable to BFPs manufactured between the signature date of the verification statement and three years thereafter.

## 5.0 REFERENCES

1. RTI International. 2001. *Generic Verification Protocol for Baghouse Filtration Products*, RTI International, Research Triangle Park, NC, February. Available at [http://www.epa.gov/etv/pubs/05\\_vp\\_bfp.pdf](http://www.epa.gov/etv/pubs/05_vp_bfp.pdf) (accessed April 20, 2012).
2. ETS Incorporated and RTI International. 2006. *Test/QA Plan for the Verification Testing of Baghouse Filtration Products (Revision 2)*, ETS Incorporated, Roanoke, VA, and RTI International, Research Triangle Park, NC, February. Available at <http://www.epa.gov/etv/pubs/600etv06095.pdf> (accessed April 20, 2012).
3. Verein Deutscher Ingenieure (VDI). 1994. VDI 3926, Part 2, *Testing of Filter Media for Cleanable Filters under Operational Conditions*, December 1994. Available from Beuth Verlag GmbH, 10772 Berlin, Germany.