U.S. EPA Generic Verification Protocol

for Testing Pesticide Application Spray Drift Reduction Technologies

for Row and Field Crops

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List of Acronyms and Abbreviations

ADQ	audit of data quality
ANSI	American National Standards Institute
APCT Center	Air Pollution Control Technology Center
ASABE	American Society of Agricultural and Biological Engineers
ASAE	American Society of Agricultural Engineers (precursor to ASABE)
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BBA	Biologische Bundesanstalt für Land- und Forstwirtschaft (Germany's Federal Biological Research Center for Agriculture and Forestry)
ºC	degrees Celsius
cfm	cubic feet per minute
cm	centimeter
CV	coefficient of variance
DQIG	data quality indicator goal
DQO	data quality objective
DRT	drift reduction technology
$D_{v0.x}$	droplet diameter (µm) at which 0.x fraction of the spray volume is contained in smaller droplets
dyne/cm	dynes per centimeter
EC	emulsifiable concentrates
EPA	United States Environmental Protection Agency
ESTE	Environmental and Sustainable Technology Evaluations
ETV	Environmental Technology Verification
fpm	feet per minute
ft	foot
gal/acre	gallons per acre
Hz	hertz
ISO	International Standards Organization
kPa	kilopascal
L	liter
LERAP	Local Environmental Risk Assessment for Pesticides (UK scheme)
m	meters
mph	miles per hour
min	minute
mg	milligram
mL	milliliter
mm	millimeter
ms	millisecond
m/s	meters per second
µL	microliter
µm	microns
OPP	Office of Pesticide Programs
ORD	Office of Research and Development
PE	performance evaluation

PES	performance evaluation system
PMT	photo multiplier transistor
psi	pounds per square inch
QA	quality assurance
QC	quality control
QM	quality manager
QMP	quality management plan
QSM	quality system manual
RH	relative humidity
RTI	Research Triangle Institute
S	second
SNR	signal to noise ratio
SOP	standard operating procedure
STP	stakeholder technical panel
T/QAP	test and quality assurance plan
TSA	technical systems audit
VMD	volume median diameter
v/v	volume/volume

Preface

This generic verification protocol, *Verification of Pesticide Application Spray Drift Reduction Technologies for Row and Field Crops*, provides a detailed method for conducting and reporting results from a verification test of pesticide application technologies that can be used to evaluate these technologies for their potential to reduce spray drift, hence the term "drift reduction technologies" (DRTs). EPA, through its Environmental and Sustainable Technology Evaluations (ESTE) program, developed this protocol with input by external experts to provide the pesticide application technology industry with a standard method to voluntarily test their technologies for potential reductions in spray drift. This protocol describes the testing approach used to generate high-quality, peer-reviewed data for DRTs, including test design and quality assurance aspects. Evaluation of this protocol has been limited to spray nozzles in low and high speed wind tunnels. (EPA, 2012) Methods for field testing methods have been documented by others. (ISO Standard 22866, 2005) The effect of tank mixes, including adjuvants, was not evaluated as part of this effort.

EPA intends to use this test protocol as part of a program to accelerate acceptance and use of improved and cost-effective application technologies which can significantly reduce spray drift and thereby provide benefits to applicators, the public, and the environment. Applications of most if not all sprays result in some amount of drift from the application site and, depending on the amount of deposition on sensitive sites and organisims, can cause adverse effects and other undesirable consequences. For this reason, the agricultural sector, government, and the general public seek ways to significantly reduce spray drift.

EPA expects the use of verified DRTs to significantly reduce pesticide spray drift and loss from the application site, thereby keeping more of the applied pesticide on the treated field and reducing risks to the surrounding environment, nearby humans, and property, including crops. Pesticide products labeled for use with DRTs may also increase applicators' flexibility in applying those pesticides by reducing the need for more restrictive application measures as compared to those required for the use of standard application equipment.

The pesticide industry and government have conducted considerable research to determine the underlying factors that affect spray drift, including different types of application equipment (spray nozzles for ground boom, air blast, and aerial applications). A number of underutilized commercial technologies exist for managing drift; however, little information exists on their effectiveness in reducing spray drift levels. Verification of the effectiveness of pesticide spray drift reduction technologies is the focus of this protocol document.

EPA will encourage equipment manufacturers to voluntarily participate in this program and to test their equipment using this protocol. EPA will also encourage pesticide registrants to recommend or require the use of verified DRTs for the application of their products. When product labels include the use of DRTs, EPA will include this in its scientific review for risk assessment and risk management decisions for pesticide registration and registration review.

EPA's Office of Research and Development partnered with EPA's Office of Pesticide Programs to complete this project under the ESTE program. The ESTE program is part of EPA's

Environmental Technology Verification Program (ETV) which was created in 1995 to facilitate the commercialization of innovative or improved environmental technologies through performance verification and dissemination of information. In 2005, ETV established the ESTE program to focus these verifications on specific Agency needs. Consistent with other ESTE efforts, a technical panel of knowledgeable and interested stakeholders representing application equipment and pesticide manufacturers and academic and government research scientists assisted by offering technical advice in developing this test protocol.

This protocol is the final product of the ESTE effort and reflects the input of the Stakeholder Technical Panel (STP). Technology has improved in the last decade and there are emerging/alternative methods to measure and model spray drift from ground boom spray equipment using data generated in low speed wind tunnels. Potential alternatives are included as footnotes in Group B of this document. The protocol will evolve as the science of measurement and modeling advances. The EPA's Office of Pesticide Program's DRT program will be responsible for any changes to the protocol and will post the current version at http://www.epa.gov/DRT.

Acknowledgments

Much of this effort was completed by RTI International under Contact EP-C-05-060, Work Assignment 52. EPA thanks RTI for its diligent efforts to develop a coherent test protocol for a complicated and difficult area of testing.

Stakeholder Technical Panel (STP)

The individuals selected to participate on the Drift Reduction Technology Stakeholder Technical Panel are listed below. We want to thank the panel members for contributing their technical expertise to this protocol document.

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Group A: Project Management

A4: Project or Task Organization

The U.S. Environmental Protection Agency's (EPA's) Office of Pesticide Programs (OPP) has responsibility for the DRT Program. It intends to employ this test protocol in the DRT Program. EPA's Office of Research and Development (ORD) has overall responsibility for the Environmental Technology Verification (ETV) Program and for the *Verification of Pesticide Drift Reduction Technologies* project under the Environmental and Sustainable Technology Evaluations (ESTE) Program. The ESTE Program operates as part of the Agency's larger ETV Program. ETV develops testing protocols and verifies the performance of innovative technologies that have the potential to improve protection of human health and the environment. Both OPP and ORD were involved in this protocol development effort.

In 2005, the EPA created a new program element, ESTE, under its current ETV. This program was designed to support specific priority Agency issues to support program and regional efforts to address important environmental issues (and environmental sustainability) and to protect human health. As part of ESTE, innovative, commercial-ready technologies showing potential to significantly reduce risks are selected for verification testing. Testing—conducted with the same commitment to quality assurance, cost-sharing, and stakeholder involvement fundamental to the larger ETV program—provides credible performance data needed for accurate assessment of the effectiveness of these technologies.

Future DRT verification testing programs will be conducted under the sponsorship of EPA with the participation of DRT manufacturers and vendors. Test site-specific test and quality assurance plans (T/QAPs) will be prepared by each testing organization to meet the requirements of the generic verification protocol (this document) and must be approved by EPA.

This protocol developed the procedures to test pesticide DRTs in accordance with quality management documents used by the ETV Program's Air Pollution Control Technology Center (APCT Center). The primary source for this quality system is EPA's Policy and Program Requirements for the Mandatory Agency-wide Quality System, EPA Order CIO2105.0 (May 2000). The quality system that was used to govern testing under this plan is consistent with the following:

- EPA Requirements for Quality Management Plans (EPA QA/R-2)
- EPA Environmental Technology Verification Program, Quality Management Plan (EPA ETV QMP), for the overall ETV program
- APCT Center's Verification Testing of Air Pollution Control Technology - Quality Management Plan (APCT Center QMP)
- Each Testing Organization's Standard Operating Procedures (SOP)
- This protocol.

EPA's ETV QMP provides the definitions, procedures, processes, organizational relationships, and outputs that will ensure the quality of the data and the programmatic elements of ETV. Part A of the EPA ETV QMP includes the specifications and guidelines that are applicable to common or routine quality management functions and activities necessary to support the ETV program. Part B of the EPA ETV QMP includes the specifications and guidelines that apply to test-specific environmental activities involving the generation, collection, analysis, evaluation, and reporting of test data.

APCT Center QMP describes the quality systems in place for the overall APCT Center program. It was prepared by RTI and approved by EPA. Among other quality management items, it defines what must be covered in the generic verification protocols and T/QAPs for technologies undergoing verification testing.

Generic verification protocols are prepared for each technology to be verified. These documents describe the overall procedures to be used for testing a type of technology and define the critical data quality objectives (DQOs). The document herein is the generic verification protocol for pesticide spray DRTs. It was written with input from the technical panel and approved by EPA.

Test and quality assurance (QA) plans are prepared by the testing organization. The T/QAP describes in detail how the testing organization will implement and meet the testing requirements of the generic verification protocol. The T/QAP also sets data quality objectives (DQOs) for supplemental non-critical measurements that are specific to the site of the test. The T/QAP addresses issues such as the test organization’s management organization, test schedule, documentation, analytical methods, data collection requirements, calibration, and traceability. It also specifies the QA and quality control (QC) requirements for obtaining verification data of sufficient quantity and quality to satisfy the DQOs of the generic verification protocol. A test plan addendum will also be developed that describes the specific DRT. For pesticide spray DRT, the critical measurements include the droplet size distribution, the spray flux (low speed wind tunnels only), and deposition (field testing). Other supplemental, non-critical measurements may also be conducted (e.g., application rate, application pressure, air or wind speed, relative humidity, and ambient temperature). EPA provides guidance for writing test/QA plans in *Guidance on Environmental Data Verification and Data Validation, EPA QA/G-8.*

Appendix A lists full citations for these documents. This protocol is in conformance with *EPA Requirements for Quality Assurance Project Plans* (EPA QA/R-5), *EPA Guidance for Quality Assurance Project Plans* (EPA QA/G-5), and the documents listed above.

A testing organization with a quality system as described in Element A8 of this document and with the capability to carry out the methods and procedures contained in this plan will conduct the testing. The testing organization will verify the emissions reductions of drift reduction technologies. The testing organization will perform the testing, evaluate the data, and submit a report documenting the results. The various QA and management responsibilities are divided among the testing organization and key EPA project personnel.

A5: Project Definition and Background

For the purpose of this document and associated testing projects, pesticide spray drift is defined as the movement of spray droplets through the air at the time of application or soon thereafter from the target site to any non- or off-target site, excluding pesticide movements by erosion, migration, volatility, or windblown soil particles after application. Spray drift management is of interest to pesticide and other chemical manufacturers, application equipment manufacturers, pesticide applicators, government agencies, advocacy groups, and the public. Spray drift risks are correlated to deposition in EPA risk assessment. To reduce exposure, DRTs that can reduce drift downwind are beneficial; the results of testing conducted under the DRT Program using this protocol are to be used by EPA to estimate downwind deposition. For example, the testing results from wind tunnel testing (droplet size distribution and spray flux) will be used as inputs to models that will estimate deposition downwind. Any modeling results will be determined outside of this protocol, the T/QAP and verification test report. Information about the use of wind tunnel data and an example calculation are provided at (http://www.epa.gov/DRT).

Industry, including pesticide applicators, and government researchers have developed and employed a variety of pesticide application strategies and technologies to reduce spray drift. Examples include low drift spray nozzles and sprayers, drift control chemical adjuvants, barrier structures, and vegetation. Although these and other technologies have the potential to provide drift reduction, there is often uncertainty about their effectiveness or performance. Verification testing of DRTs provides objective, quality-assured data that can be used to evaluate the effectiveness of the tested technologies to reduce spray drift. Use of these test results by EPA and pesticide and equipment manufacturers will enable pesticide applicators to make more informed and confident DRT selection. Use of these DRTs in the application of pesticides has the potential for significant benefits: reduced spray drift and the associated risks to humans and the environment; greater on-target deposition of pesticides applications; increased efficacy; and applications under a wider range of environmental conditions.

Testing will be performed on application technologies with one or more of the following test methods: low speed wind tunnel testing, high speed wind tunnel testing, and field testing. Field testing is an acceptable method of testing all DRTs. Low speed would be the speed of the air in the wind tunnel crossing the spray nozzle for ground application, and high speed would be the speed of the air in the wind tunnel crossing the nozzle for aerial application. For certain DRTs, wind tunnel testing may be an appropriate test method. The verification tests will gather information and data for evaluating the performance of the strategies and technologies versus a reference application system and the technologies' associated environmental impacts and resource requirements. The scope will, in most cases, cover two principal study questions:

1. What is the performance of the technology in terms of the manufacturer or vendor's statement of capabilities for reducing downwind deposition? Answering this question is critical to determining the performance of the technology and thus the measurements made to address this question are critical. The specific DQOs for these measurements are included in Element A7.

2. What are the test conditions over which the performance is measured (e.g., spray pressure, formulation type, release height, crop canopy, ambient temperature, wind speed, relative humidity)? The range of conditions under which the technology is evaluated will be used to determine the conditions required for performance in the field. The DQOs for the measurement of the test conditions are described in Element A7.

Two additional study questions are of interest, but not quantified during the verification. The information gathered will be general observations of test conditions to be recorded by the testing organization. The DRT tested will determine specific observations to be made. These details will be specified in the test and quality assurance plan (T/QAP).

3. What are the associated environmental impacts, if any, of operating the technology within this range other than drift reduction (e.g., effects on application rate and material usage, dose, other sources of environmental exposure, worker exposure)? Evaluation of the associated environmental impacts is a supplemental non-critical product of this test plan and as a result available instrumentation may be used to make measurements for this purpose. No DQOs are defined for this question.

4. What are the resources associated with operating the technology within this range relative to standard pesticide application equipment (e.g., energy, waste disposal, and product usage, as well as sprayer handling – for example, some technologies may affect the safety of operation of aircraft or other sprayers)? Measurement of consumption of resources is a supplemental non-critical measurement of this test plan and as a result, available instrumentation may be used to make measurements for this purpose. No DQOs are defined for this question.

This protocol describes the overall procedures to be used. The T/QAP for a pesticide drift reduction technology will describe how test procedures will be specifically implemented for verifying the technology performance. In addition to the procedures described in this protocol, the test procedures to be used can be derived from standard methods (e.g., ISO, ASTM, ASABE, etc.). Each test site or testing organization will need to develop a T/QAP for its test facility detailing its test procedures. Deviations from described protocols must be described by the testing organization in its T/QAP.

A6: Project or Task Description

A6.1 Description

This protocol describes the test and QA procedures that will conform to all specifications of *EPA Requirements for Quality Assurance Project Plans, EPA QA/R-5,* the current EPA ETV QMP, and the current ETV APCT Center QMP. The T/QAP will specifically describe the quality system required of the testing organization and the procedures applicable to meeting EPA quality requirements. T/QAPs, developed for each test site, and test plan addenda, developed for each technology, will be reviewed and approved by EPA prior to testing. The low speed wind tunnel (Group B) and high speed wind tunnel (Group C) portions of this protocol were tested, evaluated and revised during the ESTE project.

The verification tests will gather information and data to evaluate the extent to which the DRT reduces downwind deposition. Also, any other positive or adverse environmental impacts of operating the DRT will be noted as informal observations. The specific operating conditions used during the testing will be documented as part of the verification process. Table 3 in Element B2, Table 6 in Element C2, and Table 9 in Element D3 of this protocol present a summary of all measurements that will be made to evaluate the performance of the DRT and document the test conditions.

A description of a specific technology, the test procedures to be used and test-specific details will be documented as an applicant-specific addendum to the T/QAP that will be prepared and submitted for EPA review and approval prior to the start of testing. The applicant-specific addendum will provide additional information needed to conform to required Elements A5 (Problem Definition/Background) and A6 (Project/Task Description) of EPA QA/R-5.

Categories of DRTs include:

1. Spray nozzles (e.g., nozzles with fewer fines);
2. Sprayer (passive delivery assistance) modifications (e.g., shields and shrouds, wingtip devices);
3. Spray (active) delivery assistance (e.g., air assisted spraying);
4. Spray property modifiers (e.g., formulation and tank mix ingredients that modify spray solution physical properties);
5. Landscape modifications (e.g., artificial or natural hedges and shelterbelts).

The draft version of this protocol (EPA, 2007) was evaluated as described in *Evaluation of the Verification Protocol for Low and High Speed Wind Tunnel Testing* (EPA, 2012, http://www.epa.gov/nrmrl/std/etv/pubs/600etv12010.pdf). The evaluation was limited to testing spray nozzles in low and high speed wind tunnels. Test methods for evaluating the drift reduction impact of spray property modifiers (adjuvants) will be incorporated into this protocol as they become available.

A6.2 Test Facility Description

A description of the test facility will be included in the T/QAP for each test site.

A6.2.1 Test Site Description

Three potential testing sites or approaches are covered in this protocol: low speed wind tunnel, high speed wind tunnel, and field testing. EPA OPP will use the low speed wind tunnel and the high speed wind tunnel test results of droplet size distributions in conjunction with modeling to determine downwind drift deposition reduction. Low speed wind tunnel testing is appropriate for certain types of DRTs intended for use on or with some ground boom sprayers while high speed wind tunnel testing is for certain DRTs, such as nozzles and devices intended to reduce air shear, on aerial application equipment. Field testing is acceptable for testing all types of DRTs.

In Table 1, the DRT categories are matched to the potential testing approaches and a map to the testing procedures laid out in this document is provided.

Table 1. DRT Testing Approach

Test Method	Type of Drift Reduction Technology				
	Spray Nozzle	**Spray Material Property Modifiers**	**Sprayer Modification**	**Spray Delivery Assistance**	**Landscape Modification**
Low speed wind tunnel[1]	Acceptable	Acceptable	Questionable[4] and Supplemental[5]	Not Acceptable	Supplemental[5]
High speed wind tunnel[2]	Acceptable	Acceptable	Not Acceptable	Not Acceptable	Not Acceptable
Field testing[3]	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable

[1] For DRTs intended for use on or with ground boom spray equipment

[2] For DRTs intended for use on or with aerial spray equipment

[3] For DRTs intended for use with either ground boom or aerial spray equipment

[4] It is advisable to confirm with EPA that the test methods will be adequate for verification of these types of DRTs.

[5] Low speed wind tunnel testing may provide information that can reduce the extent of field testing required for validation, or supplement field data; however, field testing is also required.

Low speed wind tunnel testing

A wind tunnel with the following characteristics will be used:

1. The tunnel must be of sufficient width so that the spray pattern does not impinge on the walls of the tunnel. (Wall effects would affect characteristics of spray size distribution and should be discernible in the data.) A wind tunnel with working section dimensions at least 1.75 meter (m) wide x 1.75 m high x 7 m long shall be used for measurement of the droplet size distribution of a spray. [NOTE: For nozzles including boom sprayer nozzles, ISO 22856 specifies a minimum size requirement of 1 m minimum height and 2 m minimum width with a length at least 2 m (1 m at each end) greater than the length over which spray generators and samplers are mounted.]A tunnel with these characteristics may also be suitable for measuring deposition drift potential with the use of monofilament lines. If a testing organization or technology vendor wishes to measure deposition for EPA's consideration, the agency encourages the organization and vendor to consult with the agency prior to conducting the test.

2. An example of a typical inside instrumentation setup for wind tunnel is shown in Figure 1.

3. The airflow characteristics of the wind tunnel shall be known and documented. The air speed at different horizontal and vertical locations in the wind tunnel must be documented in order to identify the distance from the tunnel's surface that edge effects occur and document the space where air flows uniformly in the working section. The wind tunnel working section used for sampling shall have less than 8% turbulence and local variability of air velocity below 5%.

4. Temperature and relative humidity within the wind tunnel shall be monitored to ensure operation within desired specifications.

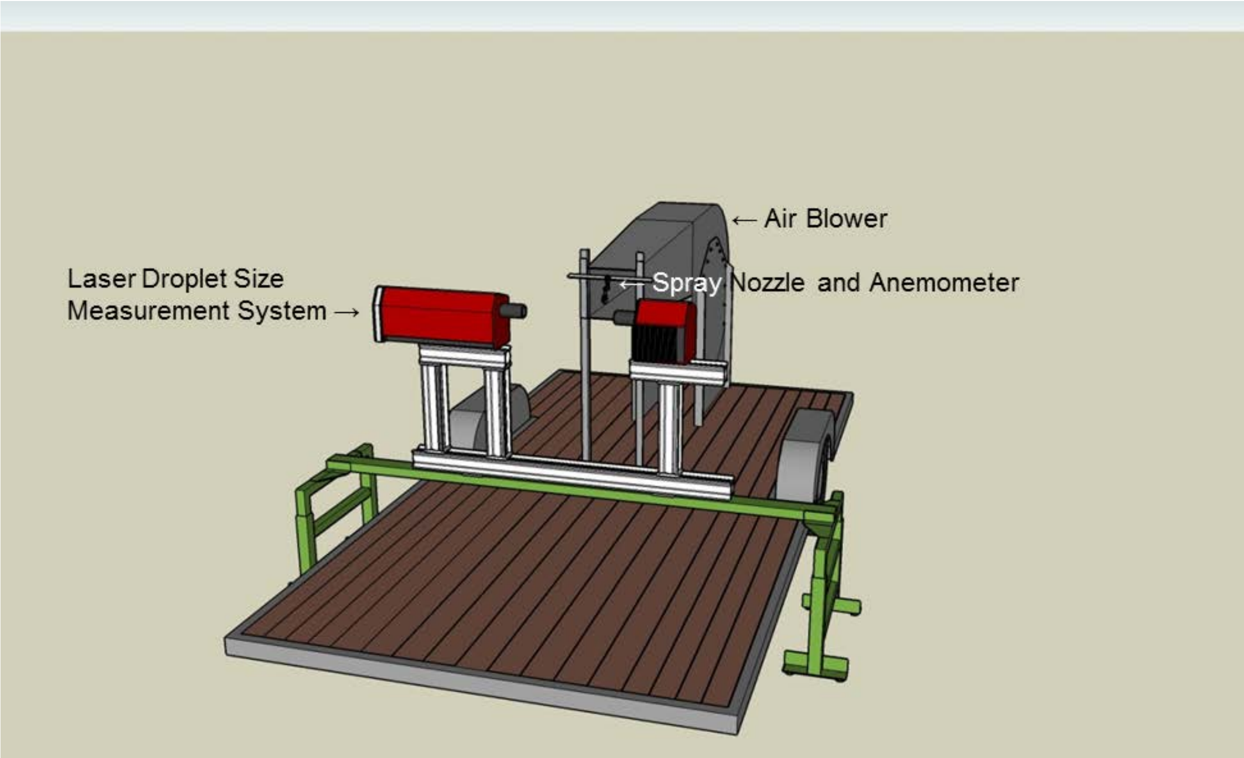

Figure 1: Example of typical inside view of instrumentation setup for wind tunnel for either a low or high speed wind tunnel.

High speed wind tunnel testing

For high speed wind tunnel testing, a wind tunnel of the following characteristics will be used:

1. The tunnel must be of sufficient width so that the spray pattern does not impinge on the walls of the tunnel. (Wall effects would affect characteristics of spray size distribution and should be discernible in the data.) For nozzles including boom sprayer nozzles, ISO 22856 specifies a minimum size requirement of 1 m minimum height and 2 m minimum width with a length at least 2 m (1 m at each end) greater than the length over which spray generators and samplers are mounted.

2. The testing organization should beware of tunnel blockage with the nozzle and fan.

3. The airflow characteristics of the wind tunnel should be known and documented according to ISO 22856. Generally, detailed characteristics are not needed for the high

speed tunnel test since there are no downwind measurements. As always, data requirements will be documented in the T/QAP used for testing.

Field testing

For field testing, the designated trial or spray site should be an exposed area with no obstructions that could influence the air flow in the areas of application or measurement. There should be a bare ground (or stubble less than 7.5 cm high) treatment area and a similarly bare downwind area for sampling stations. The measurement area should be downwind of the treatment area. The length of the spray track should be at least twice that of the largest downwind sampling distance and should be approximately symmetrical about the axis of the sampling array. All downwind distances should be measured from the downwind edge of the directly sprayed treatment area. The requirements for the field test site are consistent with requirements from United Kingdom's Local Environmental Risk Assessments for Pesticides (LERAP), Germany's Biologische Bundesanstalt für Land- und Forstwirtschaft [Federal Biological Research Center for Agriculture and Forestry (BBA)], the International Standards Organization (ISO), and the American Society of Agricultural and Biological Engineers (ASABE) [formerly known as the American Society of Agricultural Engineers (ASAE)].

A6.2.2 Application and Process Equipment Description

The description of the application and process equipment including photographs will be included in the applicant-specific addendum.

A6.2.3 Control Technology (i.e., DRT) Description

The technology to be verified must be described fully and concisely. The description, provided by the technology manufacturer or vendor, must include: technology name, model number, the DRT principle, key specifications, manufacturer's name and address, serial number or other unique identification, warning and caution statements, capacity or output rate, and other information necessary to describe the specific DRT. The performance guarantee coupled with operating conditions and instructions will be provided. EPA OPP verification reports and statements will be modeled on ETV documents. Examples of ETV verification reports and statements are presented on the ETV Website (http://www.epa.gov/etv/). If combinations of independent technologies are being submitted, the description of the combined technology should completely identify and describe those technologies being combined.

A7: Quality Objectives and Criteria

The data quality objectives (DQOs) of this testing focus on the direct or indirect measurements of spray drift deposition using wind tunnel or field testing. For wind tunnel testing, the testing organization will measure droplet size distribution.. EPA OPP will use these data with spray drift models such as the dispersion models to translate the results using this protocol to downwind deposition. For field tests, measurements of spray drift on horizontal collectors are collected to directly measure spray drift deposition in the area downwind. Test requirements for low speed wind tunnels, high speed wind tunnels, and field testing are found in Groups B, C, and D, respectively.

The rationale for the number of test runs will be included in the site-specific T/QAPs and the applicant-specific addenda, which will conform to required Element B1 of EPA QA/R-5. In general, the number of test runs would include: (1) a minimum of three test runs, (2) additional test runs indicated to meet certain statistical criteria, and (3) additional test runs desired by the applicant vendor or manufacturer. A replicate may only be discarded if proven an outlier by an appropriate statistical test or if the tester can document a human or mechanical error during a particular measurement.

EPA recommends vendors and testing organizations consult with EPA prior to the conduct of tests if the technology and/or test method is unique or complex and deviate from this protocol. Such tests include measuring spray volume using monofilament lines in a low speed wind tunnels and field tests. Also, EPA suggests that testing organizations use Good Laboratory Practices for conducting field studies due to the complexity and expense of these studies.

A7.1 Spray Droplet Size Measurements in Low and High Speed Wind Tunnels

The DQOs and data quality indicator goals (DQIGs) for measurement of spray droplet size distribution are summarized in Table 2. Size distribution data will consist of 30 or more droplet size bins. The standard deviation around volume median diameter (VMD) should be less than 10% as should the standard deviations for the droplet diameter (µm) measurements at which 0.1 fraction of the spray volume is contained in smaller droplets ($D_{v0.1}$) and droplet diameter (µm) measurements at which 0.9 fraction of the spray volume is contained in smaller droplets ($D_{v0.9}$). In addition, droplet size data should also include volume % of ≤105 µm and ≤141µm.

For droplet size distribution at the nozzle, the continuous traverse method is usually the optimal technique for sampling the spray plume, and data should be expressed as mass-balanced average droplet size data across the traverse. Multiple chordal measurements or (for phase-Doppler measurement systems), two- or three-dimensional mapping of droplet size and velocity throughout the spray plume, may also be used. Sampling should occur across a representative cross-sectional sample of the spray. Sampling should occur far enough from the nozzle to allow for both atomization of ligaments and secondary break up of droplets in the air stream to be complete. However, the sampling distance must be close enough to the nozzle that spray is not contacting the wind tunnel’s surfaces. The sampling distance may need to be adjusted for different nozzles, flow rates, and test substances, but in general, the optimal sampling distance is between 20 and 60 cm from a nozzle.

Table 2. DQIGs for Spray Droplet Size Measurements

Parameter	Acceptance Criteria
Standard deviation around volume median diameter (VMD, $D_{v0.5}$), $D_{v0.1}$ and $D_{v0.9}$ for three (minimum) replicate droplet size measurements	Vary by less than 10%.
Spray nozzle and sampling height measurement	Within 5 mm (without airflow)
Standard deviation around volume % of ≤105 µm and ≤141µm for three (minimum) replicate droplet size measurements	Vary by less than 10%.
Sample size per replicate measurement	> 10,000 droplets for particle counting instruments or > 5 s for laser diffraction instruments
Replicate measurements	Measurements to be carried out with a nozzle with a maximum deviation of output rate of ± 2.5% from the value specified by the manufacturer at the nominal rated recommended spray operating conditions. A randomly selected representative nozzle must be used.
Number of size class bands for reported data	≥ 30 bins regardless of the presence of particles.
Spray volume in largest and smallest droplet size class bands in laser diffraction measurements	< 1% of total volume in each case (i.e., < 2% total of the spray volume). To be achieved through selection of appropriate lens and instrument configuration for the dynamic size range of the spray being sampled. Also select air speed to transport sufficient quantity of spray material 2 m from nozzle.
Obscuration for spray measurements across a spray diameter (for laser diffraction systems)	< 60% unless corrected for multiple scattering, whereupon the report shall include the measured obscuration, the algorithm used to correct for multiple scattering, and the manufacturer-stated limits of applicability for that algorithm.
Minimum obscuration for sampling to achieve cross-section average spray (e.g., start or end trigger using traverse with laser diffraction systems)	2%
Diode suppression (laser diffraction systems)	Diodes may not be suppressed (no channels may be killed) in sampling. Correct selection of focal length lens, system alignment, avoidance of vibrations, and cleanliness of optical surfaces should prevent the need for diode suppression (data loss). (If the laser is displaced during sampling, all diodes will measure incorrect scattering angles, and diode suppression is not an appropriate solution to such sampling problems.)
Distance of farthest edge of spray from collecting lens (Malvern instruments)	< 1 lens focal length to avoid vignetting sampling errors

A7.2 Low Speed Wind Tunnel Tests

For low speed wind tunnel testing, the product of this test design will be the measurement of a spray droplet size distribution at the nozzle.. The DQIGs and DQOs for individual low speed wind tunnel measurements are provided in Element B2. Test-specific DQIGs will be documented in each site-specific T/QAP and applicant-specific addenda.

A7.3 High Speed Wind Tunnel Tests

For high speed wind tunnel testing, the product of this test design will be the measurement of a spray droplet size distribution at the nozzle. The DQIGs and DQOs for individual high speed wind tunnel measurements are provided in Element C2. Test-specific DQIGs will be documented in each site-specific T/QAP and applicant-specific addenda.

A7.4 Field Tests

The measure of performance for the DRT in field studies will be directly determined by deposition measured on horizontal fallout collectors according to either ASABE 561.1 APR04 or ISO/DIS 22866:2005(E) standard methods with modifications specified in Element D below. The DQIGs and DQOs for field testing measurements are provided in Element D2. Test-specific DQIGs will be documented in each site-specific T/QAP and applicant-specific addenda.

A7.5 Standards Cited

ANSI/ASHRAE 41.1 (1986) *Standard Method for Temperature Measurement*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. 1791 Tullie Circle, NE, Atlanta, GA 30329.

ASABE S561.1 (2009) *Procedure for Measuring Drift Deposits from Ground, Orchard and Aerial Sprayers*. American Society of Agricultural and Biological Engineers, St. Joseph, MI.

ASABE S572.1 (2009) [revised from ASAE S572 (1999)] *Spray Nozzle Classification by Droplet Spectra*. Standard No. S572.1, American Society of Agricultural and Biological Engineers, St. Joseph, MI.

ASTM E337-02 (2007) *Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures),* ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959.

ASTM E2798-11 (2011) *Standard Test Method for Characterization of Performance of Pesticide Spray Drift Reduction Adjuvants for Ground Application.* ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959.

ASTM WK24544 (2011) *New Test Method for Determining Cross-Section Averaged Liquid Droplet Size Characteristics in a Spray Using Laser Diffraction Instruments*, ASTM Committee E29, ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959.

ISO Standard 22866 (2005): *Equipment for Crop Protection—Methods for Field Measurement of Spray Drift*. ISO.

ISO Standard 22856 (2008): *Equipment for Crop Protection—Methods for the Laboratory Measurement of Spray Drift –Wind Tunnels.* ISO.

A8: Special Training and Certifications

The DRT Program is open to multiple test facilities. All participating facilities, domestic and foreign, , must meet the program's QA requirements and accept on-site audits by EPA or its representatives. The audits may include technical system audits, performance evaluations, assessments of the test laboratory's quality system, and audits of data quality. In order to qualify, a test laboratory must take the following actions:

- Have American National Standards Institute / American Society for Quality Control (ANSI/ASQC) E4 or International Organization for Standardization (ISO) 9000 quality management systems in place;
- Possess the equipment and facilities required to perform tests identified in this protocol;
- Have an EPA-compliant QA system[1];
- Allow on-site audits by EPA or its representatives;
- Have an EPA approved test/QA plan as described in this protocol;
- Provide written health and safety procedures for verification testing; and
- Comply with EPA reporting requirements.

The testing organization may include any registrations, accreditations, qualifications, independently-assessed quality systems of the testing organization in the test site-specific test/QA plan.

A9: Documentation and Records

Test-specific documentation and records will be processed as specified in the testing organization's SOPs, protocols, etc. See Element B10 for details of test data acquisition and management.

Procedures to manage documents and records are taken from the EPA Records Management Policy 2161; Records Management Manual (including specified records schedules); and the ORD Policy and Procedures Manual, Section 13.2 of the ETV program. Accordingly, testing organizations will retain all test-specific documentation and records for 7 years after the final payment of the funding agreement. If test data are submitted to EPA to support an application

[1] The best place to start for information about EPA-compliant QA systems is "Doing Business with EPA: Quality Specifications for non-EPA Organizations" (see http://www.epa.gov/quality/exmural.html). More generally, the EPA Quality System website (see http://www.epa.gov/quality/) has a wealth of information on the topic.

for pesticide registration, the applicant for registration will retain the test-specific documentation and records for as long as the product is registered. These requirements will be updated to conform to any future changes in the EPA Records Management Policy.

Group B: Data Generation and Acquisition for Low Speed Wind Tunnel

B1: Sampling Process or Experimental Design

The measure of performance for the DRT for low speed wind tunnels will be derived from airborne droplet size distribution. The effectiveness of the DRT will be quantified by comparison of the DRT's droplet size distribution to that of the reference test. Information about the use of wind tunnel data and an example calculation are provided at (http://www.epa.gov/DRT). The low speed wind tunnel verification data generation and acquisition procedures were evaluated as described in *Evaluation of the Verification Protocol for Low and High Speed Wind Tunnel Testing* (EPA, 2012, http://www.epa.gov/nrmrl/std/etv/pubs/600etv12010.pdf). The evaluation was limited to spray nozzles with a simple tank mix (i.e., water with surfactant). Procedures for spray modifiers and other adjuvants (spray drift reducing adjuvants) have not been considered in any detail. ASTM E2798-11 addresses this issue.

For nozzles, the basic experimental design will be to measure the droplet size spectrum of a candidate DRT and a reference application system (e.g., nozzle) operating under targeted spray pressure, air speed, boom height, and "ambient" conditions. The measurement of droplet size spectrum at a specified distance downwind of the spray nozzle are the critical measurements for this verification test[2]. Wind tunnel and application conditions establish the bounds of the verification test design.

In order to meet the DQOs, a minimum of three replications will be used for each set of application conditions, such as each combination of release height and nozzle pressure, intended for actual use in the field. As required by the DQOs in Element B2, the product of this test design will be the measurement of a droplet size distribution at the nozzle and a specified distance downwind of the nozzle.

Measurements for candidate test systems are compared to a reference spray system based on the ASABE S572 standard for droplet size. For nozzles with a simple tank mix, the reference system is ASABE S572.1 fine/medium boundary reference nozzle [Flat fan 110° at 300 kPa (43.5 psi)]. For adjuvants and other complex tank mixes, the reference system use the ASABE S572 nozzle model associated with the lower (coarse) boundary of the droplet size category (very fine, fine, medium, coarse, very coarse, and extremely coarse) in the which the test system falls.. During drift potential measurements, the height of the reference nozzle (and nozzle spacing, if multiple nozzles are used) should be identical to the candidate test system. The reference nozzle should be directed straight down. The vendor may select the spray angle for the candidate test system nozzle.

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[2] Measurements at the two-meter flux plane were included by the STP in this protocol in anticipation of their use in proposed ground spray drift models. Newer drift models may be able to use spray droplet size data taken near the nozzle with the sprayer flow rate as the flux value. In order to confirm that a fully developed spray pattern has been captured, measurements should be taken at several distances (e.g., between 20 to 60cm) downwind of the nozzle.

In addition to the procedures described in this protocol, the test procedures to be used can be derived from standard methods (e.g., ISO, ASTM, ASABE, etc.). Each test site or testing organization will need to develop a T/QAP for its test facility detailing its test procedures. Deviations from described protocols must be described by the testing organization in its T/QAP and, EPA recommends the vendor and testing organization confer with EPA about the test protocol prior to conduct of the study.

B2: Data Quality Indicator Goals and Data Quality Objectives for Low Speed Wind Tunnel Measurements

The DQIGs for individual low speed wind tunnel measurements will conform to those specified in relevant sections of the test protocols and referenced procedures, as shown in Table 3. The DQOs for this testing are the Table 3 DQIGs. Test-specific DQIGs will be documented in each site-specific T/QAP and applicant-specific addenda.

Table 3. DQIGs for Low Speed Wind Tunnel Tests

Parameter	Standard Operating Procedure (if applicable)	Acceptance Criteria
Low Speed Wind Tunnel Operating Conditions		
Wind tunnel working section width	ISO 22856	Minimum to avoid boundary layer and blockage effects
Spray measurement chamber or wind tunnel cross-section diameter		Cross section at least three diameters larger than plume of nozzle (at measurement location)
Wind tunnel turbulence	ISO 22856	< 8%
Air speed		Between 2 m/s and 10 m/s (minimum), and measured to within 0.1 m/s accuracy, close to nozzle location (with nozzle absent).
Sampling rate for air speed	ASABE S561.1	Sampling should occur over a measuring period of 10 s or less.
Consistency of air speed in wind tunnel working section	ISO 22856	< 5%
Ambient air temperature (dry bulb air temperature)	ASHRAE Standard 41.1	Measured to an accuracy within 0.1 ºC 10 to 30 ºC with less than 5 ºC variation during test
Wet bulb and dew point temperature or Percent relative humidity	Thermohygrometer equivalent to ASTM E337-02(2007); or ASHRAE Standard 41.1	Temperature measured to an accuracy within 0.1 ºC % Relative humidity measured within 3%
LSWT relative humidity	ISO 22856	20 to 80% with maximum variation of 5% during test
Dynamic surface tension of spray liquid (not for use with drift retardant adjuvants)		40 ± 4 dynes/cm at surface lifetime age of 10 to 20 ms

Parameter	Standard Operating Procedure (if applicable)	Acceptance Criteria
Spray material flow rate	ASABE S572.1	± 0.04 L/min of values specified in the ASABE standard for reference nozzles and manufacturer recommended values for the test nozzles.
Spray pressure (nozzle operating pressure)	ASABE S572.1	± 3.4 kPa of values specified in the ASABE standard for reference and manufacturer recommended values for the test nozzles.
Spray material temperature	ASHRAE Standard 41.1	Measured within 0.1 ºC
Relative spray material and air temperatures		Spray material temperature must be within 5 ºC of the air temperature to avoid atomization anomalies
Spray Droplet Size Measurements		
Spray nozzle and sampling height measurement		Within 5 mm (without airflow)
Standard deviation around volume median diameter (VMD, $D_{v0.5}$), $D_{v0.1}$ and $D_{v0.9}$ for three (minimum) replicate droplet size measurements		Vary by less than 10%.

For low speed wind tunnel testing, the product of this test design will be the measurement of a spray droplet size distribution at the nozzle and at a specified distance downwind of the nozzle.

B3: Sampling Methods for Measurement of Droplet Size, Deposition, and Test Conditions for Low Speed Wind Tunnels

Table 4 lists all the measurements required for this verification test. Measurements are categorized in the table as performance factors and test conditions. Performance factors are critical to verifying the performance of the DRT. Test conditions are important to understand the conditions of performance. Further detail is provided in Elements B3.1 through B3.4.

B3.1 Sampling Locations

Spray droplet size shall be sampled using one of several laser measurement systems: laser diffraction, phase- Doppler (excluding multi-phase droplets, e.g., air inclusion or emulsions), or laser imaging and sampling shall occur at a specified distance downwind of the nozzle.

nozzleMeasurement of air temperature and humidity should occur upwind and as close as possible to the nozzle without affecting its performance or the air speed at that location.

B3.2 Process and Application Data Collection

1. Droplet size distribution sampling

– Droplet size at the nozzle: Near the nozzles, see Element B3.3, Measurement of Droplet Size Spectrum Near the Nozzle

Table 4. Summary of Spray and Test Condition Measurements for Low Speed Wind Tunnels

Factors to Be Verified	Parameter to be Measured	Sampling and Measurement Method	Comments
Test Conditions Documentation			
Droplet size at the nozzle and a specified distance downwind form the nozzle	Droplet size distribution produced by the atomizer	Non-intrusive sampling methods appropriate for the spray material such as laser diffraction, phase-Doppler, laser imaging instruments.	Less than 2% total of the spray volume should be contained in the uppermost or lowermost size classes.
Spray pressure	Pressure of spray mix at the nozzle	See ASABE S572.1, section 3.	
Spray materials temperature	Temperature of the spray mixture	Calibrated thermometers accurate within 0.1 ºC.	Temperature of the ambient air and spray mixture should be within 5 ºC.
Spray nozzle height or boom height	Height of the nozzle above the floor of the wind tunnel	Calibrated tape measure accurate within 0.5 cm.	Nozzle height should be within 1 cm of specified height.
Wind tunnel conditions	Air speed	An appropriate and calibrated anemometer such as hot wire or pitot-static tubes. Measurement should occur as close as possible to the nozzle without affecting its performance.	The air speed measured in the wind tunnel will be used to define acceptable field conditions of use. Testing organization conducts air speed, temperature, and humidity measurements simultaneously.
	Ambient air temperature	Calibrated thermometers accurate within 0.1 ºC.	
	Air humidity	Thermohygrometer equivalent to ASTM E337-02(2007); ASHRAE Standard 41.1; or other similar approach.	

2. Wind tunnel conditions

– The following conditions shall be measured at the same height as the nozzle, upwind of the nozzle in the wind tunnel working section at the time of spray release: ambient air temperature, air speed, relative humidity.

3. Sprayer conditions

– Spray pressure shall be measured consistent with ASABE S572.1, section 3.

- The spray flow shall be measured following the method in Table 3 or described in the testing organization's SOP.
- Spray fluid temperature shall be measured with a calibrated thermometer that meets the specifications in Table 3. The measurement method will follow the reference in Table 3 or the testing organization's SOP.

B3.3 Measurement of Droplet Size Spectrum near the Nozzle

The droplet size spectrum of the test system near the nozzle is used to classify its ASABE S572.1 the spray characteristics. The candidate test system is categorized into droplet size category for very fine, fine, medium, coarse, very coarse, and extremely coarse.

1. Droplet size spectra for spray drift tests shall be made under the same conditions (e.g., spray material, spray pressure, nozzle settings) and following the same procedures outlined in Element B3.4.

2. Droplet size may be measured using one of several laser measurement systems: laser diffraction, phase-Doppler (excluding multi-phase droplets, e.g., air inclusion or emulsion) or laser imaging. The instruments and apparatus used in the test shall be listed. Names, model numbers, serial numbers, scale ranges, software version number, and calibration verification shall be recorded.

3. A representative cross-section average sample must be obtained, using a mass-weighted traverse or multiple chordal measurements of the full spray (or half spray for axi-symmetric spray plumes).

4. The sampling distance from the nozzle must be sufficient to ensure that the spray has atomized into droplets, for example through completion of breakup of sheets or ligaments of liquid following discharge from the nozzle. This distance is typically 20-60 cm.

5. The sampling system must be configured to measure the entire dynamic size range of the instrument with less than 2% total of the spray volume contained in the uppermost and lowermost size classes.

6. If a number-density weighted ("spatial") sampling system is used, the setup should minimize the development of a size-velocity profile within the spray (e.g., by using a concurrent airflow if spray discharge is in the horizontal plane) to avoid data bias toward slower-moving (usually smaller) droplets.

7. The droplet size measurements should include assessment and confirmation of the droplet size category of the candidate test system and reference system according to ASABE S572.1, respectively.

B3.4 Wind Tunnel Measurement of Spray Drift Potential

All sampling will follow the requirements of the specific test method being used unless otherwise stated in this document or approved as part of the site-specific T/QAP prior to the verification test. Laser-based measurement devices are used to measure droplet size distribution at a specified distance downwind form the nozzle.

1. The spraying system shall be mounted to minimize effects on airflow.

2. The orientation of the nozzle (predominant spray direction or axis of rotation) that the fan sprays discharge relative to the air flow direction must be measured with a protractor and recorded.

3. Droplet size shall be measured using one of several laser or optical measurement systems: laser diffraction, phase-Doppler (excluding multi-phase droplets, e.g., air inclusion or emulsion) or laser imaging. The instruments and apparatus used in the test shall be listed. Names, model numbers, serial numbers, scale ranges, software version number, and calibration verification shall be recorded.

4. The test spray nozzle(s) shall be mounted at the height defined by the manufacturer's operating conditions and at least 100 mm below the wind tunnel ceiling. Nozzles must be positioned in a place free from edge effects.

5. A representative cross-section average sample must be obtained, using a mass-weighted traverse or multiple chordal measurements of the full spray (or half spray for axi-symmetric spray plumes).

6. For each height, the sampling system must be configured to measure the entire dynamic size range of the instrument with less than 2% total of the spray volume contained in the uppermost or lowermost size classes.

7. The wind tunnel floor shall be covered with an artificial turf surface to minimize droplet bounce and mimic stubble vegetation for field conditions.

8. 9. For testing nozzles without using adjuvants, water containing surfactant may be used. Acceptable surfactants and surfactant concentrations are those that will provide a Newtonian tank mix with dynamic surface tension of 40 dyne/cm at surface lifetime age of 10 to 20 ms.
   - Use of other surfactants or concentrations should be approved as part of the site-specific T/QAP prior to testing.

10. When an adjuvant is included with a nozzle as the DRT combination in the test spray material, a pesticide formulation and spray equipment reflecting the adjuvant's proposed end use should be evaluated during testing. (See ASTM E2798-11 for further details).

11. The spraying system shall be primed with spray prior to measurements to ensure that rinsing liquid is removed from the line and the liquid discharging from the nozzle is the actual intended tank mix. In addition, sprayer systems should be “run-in” for 5 min to ensure removal of machining burrs or plastic mold residue.

12. Spray material flow rate shall be measured at the operating pressure for the tests. The liquid flow rate measurement may include techniques using liquid collected for a known duration, using Coriolis mass flow sensors, calibrated flow turbine, oval displacement meter, weighing system for the spray mix tank, or other method. Nozzle output should remain constant with a maximum deviation of ± 2.5%. These liquid flow rate measurements are consistent with ISO 5682 part 1.

13. The wind tunnel shall be operated during sampling to provide an air speed between 2 m/s and 10 m/s at the nozzle height with a default value of 2 m/s.

14. To minimize evaporation effects on results, the relative humidity in the working section at the time of measurements shall be 20 to 80% with a maximum variation of 5% during each test.

15. The type of nozzle being tested must be documented as follows:
    - Flat fan, cone (hollow or full), impingement (deflector), and solid stream nozzles: manufacturer, fan angle at reference operating pressure, orifice size, material of manufacture.
    - Other types of nozzles (e.g., rotary, electrostatic, and ultrasonic): the type of nozzle must be described in the T/QAP provided to EPA prior to testing in order to identify the appropriate parameters to be recorded.
    - Include a close-up photograph of the nozzle and manifold and a cross-sectional drawing.
    - Include the manufacturer nozzle part number.
    - Document the type of nozzle body and cap used in the tests.
    - Manufacturer-recommended nozzle settings including spray height and angle.

B4: Sample Handling and Custody Requirements

No physical samples are collected.

B5: Analytical Methods

No analytical methods are used.

B6: Quality Control

Data quality will be assessed with a series of multiple test nozzles, blank samples, spiked samples, collocated duplicate samples, and duplicate analyses as described in Table 5.

B7: Instrument and Equipment Testing, Inspection, Maintenance, and Calibration Frequency

The site-specific T/QAP resulting from this protocol will reference the testing organization's SOP for testing, inspection, and maintenance of instruments and equipment. Equipment to be included in the T/QAP are the laser diffraction or phase Doppler particle sizing instrument, anemometers, pressure gauges, rotometers, viscometers, and tensiometers used. Standard calibration methods (e.g., ASTM or equivalent methods) will be followed.

Calibration verification of some laser diffraction particle size analyzers can be achieved using ASTM Standard Test Method E 1458 "Test Method for Calibration Verification of Laser Diffraction Particle Sizing Instruments using Photomask Reticles." All analyzers will be calibrated against appropriate NIST-traceable standard reference materials.

Alternative techniques include reference particles and sprays of known size distribution.

B8: Inspection and Acceptance of Supplies and Consumables

The primary supplies and consumables for this exercise consist of monofilament lines, tracer materials, adjuvants, water, hoses, tubing, and tank. Prior to use, each sampler is visually inspected and is discarded for use if any damage is found. The tracer selected should allow for adequate sensitivity to measure deposition at all test distances. The tracer should be stable and nonvolatile in the test frame for testing and analysis. Background measurement samples from the testing site should demonstrate negligible levels of tracer or other interfering compounds. The hardness of water used in spray tanks should be documented. Adjuvants should be in original manufacturer's packaging.

Table 5. Quality Control Samples for Low Speed Wind Tunnels

Sample	Description	Acceptance Criteria
Multiple nozzles	For evaluating nozzles as DRTs, conduct size distribution measurements at the nozzle and 2 meters with three randomly selected nozzles from a batch of ten.	< 10% variation in $D_{v0.5}$, $D_{v0.1}$, and $D_{v0.9}$
Blank spray liquid	Three samples of the spray liquid without tracer will be analyzed fluorometrically to determine any background fluorescence.	Acceptable fluorescence will be less than three times the minimum detection limit of the fluorometer.
Replicate fluorometric analyses	Multiple aliquots of extraction fluid will be analyzed to quantify analytical error.	< ± 5% variation in fluorometry results

B9: Non-Direct Measurements

If applicable, data that are not gathered directly by the testing organization may be used, however, the testing organization must describe these measurements in the T/QAP or the applicant-specific addendum.

B10: Data Management

It is expected data will be collected on paper datasheets and in electronic format. The data collection format will depend on the testing organization's data acquisition systems. Paper datasheets will be signed by the technician responsible for collecting the data. The datasheet will be reviewed for completeness and approved by the testing organization technical leader immediately after an experiment. The testing organization technical leader will review electronic data for compliance with DQIGs immediately after an experiment. Data from paper datasheets and electronic data will be consolidated into a single database with reference to the DRT tested and all experimental conditions.

B10.1 Data Flow

Data measurement and collection activities are shown in Figure 2. This flow chart includes all data activities from the initial pretest QA steps to the passing of the data to EPA.

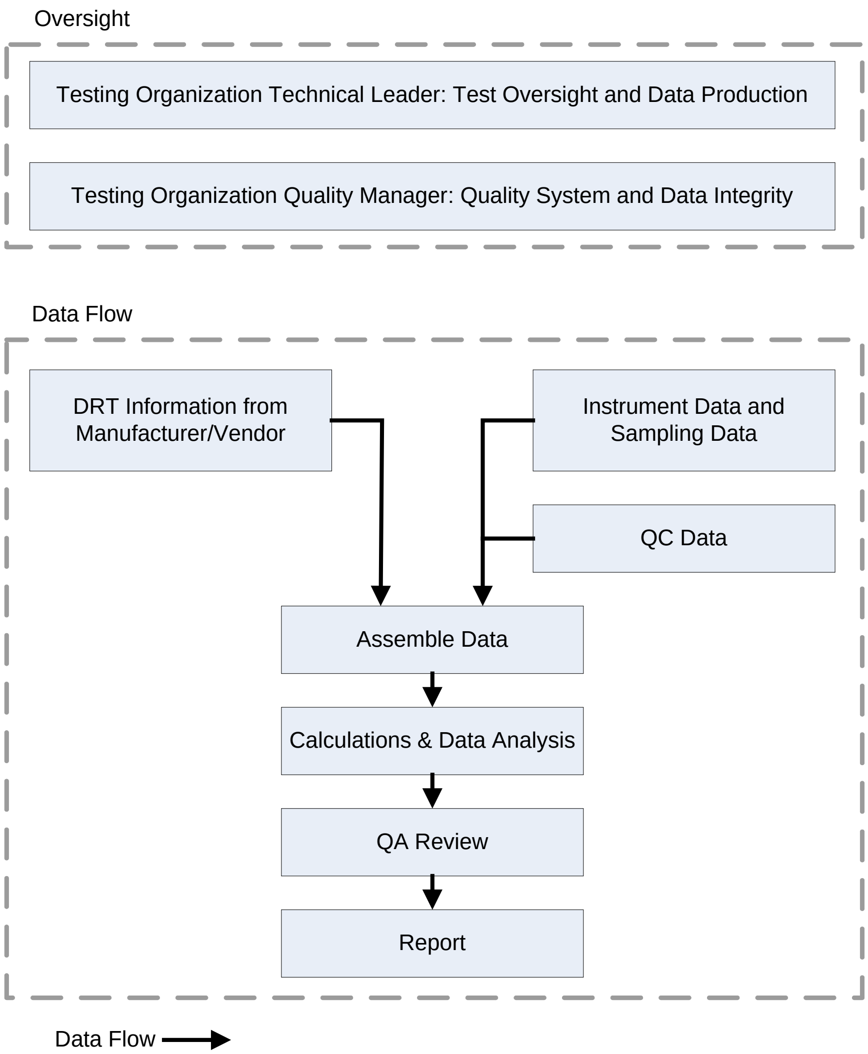

Figure 2. Data management system.

B10.2 Data Reduction

Data from each measurement for droplet size from the verification test will be reported as the incremental and cumulative volumes of 30 appropriately spaced and described bins of droplet diameter (microns). The $D_{v0.1}$, $D_{v0.5}$, $D_{v0.9}$, and relative span will also be presented. An example of a presentation of the output data is shown in Table B-1 in Appendix B. Raw data of droplet sizing instrument output should be provided as an appendix.

.B10.3 Analysis of Verification Data

Measurements should be presented separately (raw data) and as an average across repetitions for the following types of measurements.

1. Downwind measurements:
    - Volume per droplet size category (i.e., each of the 30 or more droplet size categories) at each height
2. Droplet size at the nozzle: Volume per droplet size category and reference spray type.

Group C: Data Generation and Acquisition for High Speed Wind Tunnel Tests

C1: Sample Process Experimental Design

The measure of performance for the DRT for high speed wind tunnels will be derived from droplet size distribution measurements. The high speed wind tunnel verification data generation and acquisition procedures were evaluated as part of an ESTE project. These values will be used by EPA to model deposition from 0 to 61 m downwind. Information about the use of wind tunnel data and an example calculation are provided at (http://www.epa.gov/DRT). The high speed wind tunnel verification data generation and acquisition procedures for spray nozzles with a simple tank mix (i.e., water with surfactant) were evaluated as part of the ESTE project. Procedures for spray modifiers and other adjuvants have not been considered in any detail. It is anticipated that ASTM and ISO standard test methods will be developed, such as ASTM E2798-11.

The basic experimental design will be to measure the droplet size spectrum under targeted test conditions with the DRT operating at specified spray pressure, air speed, and the "ambient" conditions. Droplet size spectrum is the critical measurement for this verification test. Wind tunnel conditions and application conditions are important measurements for establishing the bounds of the verification test design. .

In order to meet the DQOs, at least three replications will be used for each set of application conditions intended for actual use in the field. For instance, at least three replications will be conducted for each combination of air speed and nozzle pressure. The product of this test design will be the measurement of a droplet size distribution consisting of 30 or more droplet size bins for the specified operating range. The DQIGs for appropriate parameters identified in Table 6 must be met. Measurements for candidate test systems are compared to a reference spray system based on the ASABE S572 standard for droplet size. For nozzles with a simple tank mix, the reference system is the method ASABE S572.1 fine/medium boundary reference nozzle [Flat fan 110° at 300 kPa (43.5 psi)]. For adjuvants and other complex tank mixes, the reference system should use the ASABE S572 nozzle model associated with the lower (coarser) boundary of the droplet size category (very fine, fine, medium, coarse, very coarse, and extremely coarse) in which the test system falls. See ASTM E2798-11.

During drift potential measurements, the spray angle of the candidate test system does not need to be identical to that of the reference spray system. The vendor may select the spray angle for the candidate test system nozzle. Acceptable nozzles, associated wind tunnel air speeds, and nozzle angles relative to air direction are identified below. The orientation angle of both the reference spray system and the candidate test system, however, should both be the same.

In addition to the procedures described in this protocol, the test procedures to be used can be derived from standard methods (e.g., ISO, ASTM, ASABE, etc.). Each test site or testing organization will need to develop a T/QAP for its test facility detailing its test procedures. Deviations from described protocols must be described by the testing organization in its T/QAP.

C2: DQIGs and DQOs for High Speed Wind Tunnel Measurements

The DQIGs for individual high speed wind tunnel measurements will conform to those specified in relevant sections of the test protocols and referenced procedures, as shown in Table 6. The DQOs for this testing are the Table 6 DQIGs. Test-specific DQIGs will be documented in the site-specific T/QAPs and its applicant-specific addenda.

Table 6. DQIGs for High Speed Wind Tunnel Testing

Parameter	Standard Operating Procedure (if applicable)	Acceptance Criteria
High Speed Wind Tunnel Operating Conditions		
Spray measurement chamber or wind tunnel cross-section diameter		Cross section at least three diameters larger than plume of nozzle (at measurement location)
Air speed		Between 50 mph (22 m/s) and 165 mph (73 m/s), and measured to an accuracy within 5 mph (2 m/s), close to nozzle location (with nozzle absent)
Ambient air temperature	ASHRAE Standard 41.1	Measured within 0.1 ºC 10 to 30 ºC with less than 5 ºC variation during test
Ambient relative humidity	ASHRAE Standard 41.1	Measured within 3%
Spray material temperature	ASHRAE Standard 41.1	Measured within 0.1 ºC
Relative spray material and air temperatures		Spray material temperature must be within 5 ºC of the air temperature to avoid atomization anomalies
Spray material flow rate	ASABE S572.1	± 0.04 L/min of values specified in the ASABE standard for reference nozzles and manufacturer recommended values for the test nozzles.
Spray pressure (nozzle operating pressure)	ASABE S572.1	± 3.4 kPa of values specified in the ASABE standard for reference and manufacturer recommended values for the test nozzles.
Dynamic surface tension of spray liquid (not for use with drift retardant adjuvants)		40 ± 4 dynes/cm at surface lifetime age of 10 to 20 ms
Replicate measurements		Measurements to be carried out with a nozzle or nozzle with a maximum deviation of output rate of ± 2.5% from the value specified by the manufacturer at the nominal rated recommended spray operating conditions. A randomly selected representative nozzle must be used.
Spray Droplet Size Measurements for High Speed Wind Tunnels		

Parameter	Standard Operating Procedure (if applicable)	Acceptance Criteria
Standard deviation around volume median diameter (VMD, $D_{v0.5}$), $D_{v0.1}$ and $D_{v0.9}$ for three replicate droplet size measurements		< 10% for measurements with the same nozzle in HSWT tests.
Standard deviation around volume % of ≤105 µm and ≤141µm for three (minimum) replicate droplet size measurements		Vary by less than 10%.

C3. Sampling Methods for Measurement of Droplet Size and Test Conditions

Table 7 lists all the measurements required for this verification test. Measurements are categorized in the table as performance factors and test conditions. Performance factors are critical to verifying the performance of the DRT. Test conditions are important to understand the conditions of performance. Further detail is provided in Elements C3.1 through C3.3.

Table 7. Summary of Spray and Test Condition Measurements for High Speed Wind Tunnels

Factors to Be Verified	Parameter to Be Measured	Sampling and Measurement Method	Comments
Performance Factors			
Droplet size at the nozzle	Droplet size distribution produced by the nozzle	Non-intrusive sampling methods appropriate for the spray material such as laser diffraction, phase-Doppler, laser imaging instruments.	The range of droplet size categories measured must account for at least 99% of the spray volume.
Test Conditions Documentation			
Spray pressure	Pressure of spray mix at the nozzle	See ASABE S572.1, section 3.	
Spray materials temperature	Temperature of the spray mixture	Calibrated thermometers accurate within 0.1 ºC	Temperature of the ambient air and spray mixture should be within 5 ºC.
Wind tunnel conditions	Air speed	An appropriate and calibrated anemometer such as hot wire or pitot-static tubes. Measurement should occur as close as possible to the nozzle without affecting its performance.	The air speed measured in the wind tunnel will be used to define acceptable field conditions of use and should reflect the proposed application of the DRT (e.g. rotary wing vs. fixed wing aircraft).
	Ambient air temperature	Calibrated thermometers accurate within 0.1 ºC	

Factors to Be Verified	Parameter to Be Measured	Sampling and Measurement Method	Comments
	Air humidity	Thermohygrometer equivalent to ASTM E337-02(2007); ASHRAE Standard 41.1; or other similar approach	Testing organization conducts air speed, temperature, and humidity measurements concurrently.

C3.1 Sampling Locations

Spray shall be sampled using one of several laser measurement systems: laser diffraction, phase-Doppler (excluding multi-phase droplets, e.g., air inclusion or emulsions) or laser imaging.

Measurement of air temperature and humidity should occur upwind of the nozzle and as close as possible to the nozzle without affecting its performance or the air speed at the nozzle.

C3.2 Process and Application Data Collection

1. Droplet size distribution sampling
   - Droplet size at the nozzle: Near the nozzles, see Element C3.3, Wind Tunnel Measurement of Spray Drift Potential (Droplet Size Distribution at Aerial Application Air Speeds at the Nozzle).
2. Wind tunnel conditions
   - The following conditions shall be measured at the same height as the nozzle, upwind of the nozzle in the wind tunnel working section at the time of spray release: ambient air temperature, air speed, relative humidity.
3. Sprayer conditions
   - The spray pressure shall be measured at the nozzle tip using a capillary connected to a pressure gauge.
   - The spray flow shall be measured following the method in Table 6 or described in the testing organization's SOP.
   - Spray fluid temperature shall be measured with a calibrated thermometer that meets the specifications in Tables 6 and 7. The measurement method will follow the reference in Table 6 or the testing organization's SOP.

C3.3 Wind Tunnel Measurement of Droplet Size Distribution at Aerial Application Air Speeds at the Nozzle

All sampling will follow the requirements of the specific test method being used unless otherwise stated in this document or approved by EPA prior to the verification test. Laser-based measurement devices are used to measure droplet size distribution at the nozzle in the wind tunnel.

1. The spraying system shall be mounted to minimize effects on airflow.

2. The orientation of the nozzle (predominant spray direction or axis of rotation) that the fan sprays discharge relative to the air flow direction must be measured with a protractor and recorded.

3. Droplet size shall be measured using one of several laser or optical measurement systems: laser diffraction, phase-Doppler (excluding multi-phase droplets, e.g., air inclusion or emulsion) or laser imaging. The instruments and apparatus used in the test shall be listed. Names, model numbers, serial numbers, scale ranges, software version number, and calibration verification shall be recorded.

4. Nozzles must be positioned in a place free from edge effects.

5. A representative cross-section average sample must be obtained, using a mass-weighted traverse or multiple chordal measurements of the full spray (or half spray for axi-symmetric spray plumes).

6. The sampling system must be configured to measure the entire dynamic size range of the instrument with less than 2% total of the spray volume contained in the uppermost or lowermost size classes.

7. If a number-density weighted ("spatial") sampling system is used, the setup should minimize the development of a size-velocity profile within the spray (e.g., by using a concurrent airflow if spray discharge is in the horizontal plane) to avoid data bias toward slower-moving (usually smaller) droplets.

8. For testing nozzles without using adjuvants, water containing surfactant may be used. Acceptable surfactants and surfactant concentrations are those that will provide a Newtonian tank mix with dynamic surface tension of 40 dyne/cm at surface lifetime age of 10 to 20 ms. Use of other surfactants or concentrations should be approved as part of the site-specific test plan prior to testing.

9. When an adjuvant is included as the DRT in the test spray material, a pesticide formulation and spray equipment reflecting the adjuvant's proposed end use should be evaluated during testing. (See ASTM E2798-11 for further details).

10. The spraying system shall be primed with spray prior to measurements to ensure that rinsing liquid is removed from the line and the liquid discharging from the nozzle is the actual intended tank mix. In addition, sprayer systems should be "run-in" for 5 min to ensure removal of machining burrs or plastic mold residue.

11. Spray material flow rate shall be measured at the operating pressure for the tests. The liquid flow rate measurement may include techniques using liquid collected for a known duration, using Coriolis mass flow sensors, calibrated flow turbine, oval displacement meter, weighing system for the spray mix tank, or other method. Nozzle output should remain constant with a maximum deviation of ± 2.5%. These liquid flow rate measurements are consistent with ISO 5682 part 1.

12. The air speed in the working section of the wind tunnel must be measured as close as possible to the nozzle without affecting nozzle performance or allowing the nozzle to influence the air speed measurement. Air speed must be maintained between 50 and 165 mph minimum.

13. The type of nozzle being tested must be documented as follows:
    - Flat fan, cone (hollow or full), impingement (deflector), and solid stream nozzles: manufacturer, fan angle at reference operating pressure, orifice size, material of manufacture.
    - Other types of nozzles (e.g., rotary, electrostatic, and ultrasonic): the type of nozzle must be described in the T/QAP provided to EPA prior to testing in order to identify the appropriate parameters to be recorded.
    - Include a close-up photograph of the nozzle and manifold and a cross-sectional drawing.
    - Include the manufacturer nozzle part number.
    - Document the type of nozzle body and cap used in the tests.
    - Manufacturer-recommended nozzle settings including spray height and angle.

C4: Sample Handling and Custody Requirements

No physical samples are collected.

C5: Analytical Methods

No analytical methods are used.

C6: Quality Control

At least three replicates for each set of test conditions should be conducted. Measured volume median diameter (VMD) should vary by less than 10%. $D_{v0.1}$ and $D_{v0.9}$ (the droplet diameter bounding the upper and lower 10% fractions of the spray) should vary by less than 10%.

Air speed should vary by less than 5% within a trial and less than 5% across replicates. Air speed is anticipated to be maintained between 50 and 165 mph (minimum).

C7: Instrument and Equipment Testing, Inspection, and Maintenance

The site-specific T/QAP resulting from this protocol needs to reference the testing organization's SOP for testing, inspection, and maintenance of instruments and equipment.

C8: Instrument and Equipment Calibration and Frequency

The site-specific T/QAP resulting from this protocol will reference the testing organization's SOP for testing, inspection, and maintenance of instruments and equipment. Equipment to be included in the T/QAP are the laser diffraction or phase Doppler particle sizing instrument, anemometers, pressure gauges, rotometers, viscometers, and tensiometers used. Standard calibration methods (e.g., ASTM or equivalent methods) will be followed.

Calibration verification of some laser diffraction particle size analyzers can be achieved using ASTM Standard Test Method E 1458 "Test Method for Calibration Verification of Laser Diffraction Particle Sizing Instruments using Photomask Reticles." Alternative techniques include reference particles and sprays of known size distribution.

C9: Inspection and Acceptance of Supplies and Consumables

The hardness of water used in spray tanks should be documented. Adjuvants should be in original manufacturer's packaging.

As there are no other supplies and consumables, additional inspection and acceptance requirements are not a required part of this verification test protocol.

C10: Non-Direct Measurements

If applicable, data that are not gathered directly by the testing organization may be used, however, the testing organization must describe these measurements in the T/QAP or the applicant-specific addendum.

C11: Data Management

It is expected data will be collected on paper datasheets and in electronic format. The data collection format will depend on the testing organization's data acquisition systems. Paper datasheets will be signed by the technician responsible for collecting the data. The datasheet will be reviewed for completeness and approved by the testing organization technical leader immediately after an experiment. The testing organization technical leader will review electronic data for compliance with DQIGs immediately after an experiment. Data from paper datasheets and electronic data will be consolidated into a single database with reference to the DRT tested and all experimental conditions.

C11.1 Data Flow

Data measurement and collection activities are shown in Figure 2 in Element B10. This flow chart includes all data activities from the initial pretest QA steps to the passing of the data to EPA.

C11.2 Data Reduction:

Data from each measurement for droplet size from the verification test will be reported as the incremental and cumulative volumes of 30 appropriately spaced and described bins of droplet diameter (micrometers). The $D_{v0.1}$, $D_{v0.5}$, $D_{v0.9}$, and relative span will also be presented. An example presentation of the output data is shown in Table B-1 of Appendix B. Raw data of droplet sizing instrument output should be provided in an appendix.

C11.3 Analysis of Verification Data:

Size distribution measurements for each size bin will be presented as raw data and as descriptive statistics across repetitions. The descriptive statistics include the average, standard deviation and coefficient of variation. Descriptive statistics for the $D_{v0.1}$, $D_{v0.5}$, and $D_{v0.9}$ will also be presented.

Two tables of supplementary data will also be presented. One table will document the wind tunnel operating conditions, spray nozzle conditions (type, pressure, flow) and test fluid conditions (temperature, surface tension, viscosity, etc.) for the experimental parameters described in Table 7. The second table will describe the pass or fail status of non-critical measurements to indicate whether DQIGs in Table 6 were achieved. If a DQIG is not achieved, an explanation of the cause for failure and the impact on verification test data will be provided.

Group D: Data Generation and Acquisition for Field Studies

D1: Sampling Process Design (Experimental Design)

The measure of performance for the DRT in field studies will be directly determined by deposition measured on horizontal fallout collectors according to either ASABE 561.1 APR04 or ISO/DIS 22866:2005(E) standard methods with modifications specified in Element D below. The modifications discussed below have not been evaluated during field testing. The specific placement of collectors will allow for an estimate of the integrated deposition from 0 to 61 m (200 ft) and the point deposition at 30.5 m (100 ft) downwind of the application site.

The treatment area and spray track must be at least 100 m long and perpendicular to wind direction. This arrangement allows for the outermost samplers to be downwind of the treatment area when the wind direction approaches ± 30 degrees relative to the length of the treatment area.

The conditions of the study will be selected to allow for the measurement of the DRT and the reference spray systems under identical or similar conditions (e.g., wind speed, wind direction, temperature, relative humidity, release height). The measurements of deposition are the critical measurements for this verification test. Measurements of field and application conditions are important for establishing the limitations of the verification test design. As required by the DQO in Element A7, the DQIGs for the parameters identified in Table 8 must be met.

Measurements of candidate test systems are compared to a reference spray system based on the ASABE S572.1 standard for droplet size. For nozzles, the reference system is the method ASABE S572.1 fine/medium boundary reference nozzle. The spacing of the reference nozzles should be appropriate for the spray angle produced with the height equal to the candidate test system. The reference nozzles should be directed straight down.

D2: DQIGs and DQOs for Field Test Measurements

The DQIGs data and measurements collected during field tests will conform to those specified in relevant sections of the test protocols and referenced procedures, as shown in Table 8. The DQOs for this testing are the Table 8 DQIGs. Test-specific DQIGs will be documented in the site-specific T/QAPs and its applicant-specific addenda. Testing organizations may wish to conduct field tests using Good Laboratory Practices.

D3: Sampling Methods for Measurement of Droplet Size, Deposition, and Test Conditions

Table 9 lists all the measurements required for this verification test. Measurements are categorized in the table as performance factors and test conditions. Performance factors are critical to verifying the performance of the DRT. Test conditions are important to understand the conditions of performance. Further detail is provided in Elements D3.1 through D3.3.

Table 8. DQIGs for Field Testing

Parameter	Standard Operating Procedure (if applicable)	Acceptance Criteria
Dry bulb air temperature	ISO 22866	Between 5 and 35 °C, measured to an accuracy within 0.5 °C
Wet bulb and dew point temperature or Percent relative humidity	ASABE S561.1	Measured to an accuracy within 0.5 ºC or within 5% [3% from ASHRAE Standard 41.1]
Horizontal wind speed	ISO 22866	At least 1 m/s for all applications, measured at an accuracy within 0.2 m/s at nozzle height
Horizontal wind direction	ASABE S561.1	90° ± 30° to the spray track or the downwind edge of the sprayed area during the spray application
Nozzle flow rate	ASABE S561.1	Repeat measurements for individual nozzles within ± 2.5%
Horizontal wind angle relative to sample line	ASABE S561.1	Mean angle between the sample line and the horizontal wind direction should not exceed 30º
Frequency of meteorological measurement sampling	ASABE S561.1	≥ 1.0 Hz sampling rate
Dynamic surface tension of spray liquid		Measured to within ± 5% at surface lifetime age of 10 to 20 ms
Surface vegetation height	ASABE S561.1	< 7.5 cm absolute height for all vegetation surface heights in drift sampling areas with typical uniformity not to exceed ± 10% standard deviation.
Sample line and collection station locations		± 2.5% of required location distances (at a minimum 2 m downwind of nozzle)
Sampling media area for individual collectors	ASABE S561.1	≥ 1000 cm² for deposition cards
Collector orientation for flat card or plate or cylindrical collectors		Horizontal ± 15º relative to spirit level instrument or for vertical towers (optional additional collector), vertical ± 15º
Diameter of cylindrical collectors (if used)	ASABE S561.1	2 mm ± 5%
Number of samples at each sampling location		Determined from tests for the specific setup to produce confidence interval of ± 10%
Boom length (swath width) and boom height above ground		Measured with accuracy within 1.0 cm when stationary
Application rate of tank mix in treated area		Within 2.5% of intended application rate
Forward speed of sprayer		Within 10% of target speed throughout entire application period. For aerial, at least 140 mph, and measured to an accuracy within 5 mph.

Parameter	Standard Operating Procedure (if applicable)	Acceptance Criteria
Solvent volume for extraction of tracer if using collectors		5% of volume required for analytical recovery and assessments (i.e., all samples should be washed with the same volume of solvent within 5% of the target volume)
Stability of tracer under conditions of study (light intensity, relative humidity, temperature, sampling media, storage conditions and duration, etc.) measured as the amount recovered relative to the amount mixed for control samples		Tracer must exhibit adequate photostability (documented or published) allowing within 10% of the initial mixture detection values for all samples (note: samples should be collected in minimum possible time after exposure to drift sampling, stored in dark containers, and analyzed as soon as possible after collection)

D3.1 Sampling Locations

Three parallel lines of horizontal collectors within the sampling array should be used. Collector lines in the sampling array should be spaced at least 15 m apart. The center collector line in the sampling array should be in the center of the application area. Horizontal deposition samplers should be placed at a minimum of 4 m, 8 m, 16 m, 30.5 m, and 61 m from the downwind edge of the treated area. At least one collector should be placed in the swath and upwind of the treatment area.

The placement of the station(s) for measuring meteorological conditions should be located in the open within 30 m of the treatment area and away from any obstruction or topographical irregularities.

A map should be provided showing the treatment area, sampler placements, position of the meteorological station(s), and any obstructions or identifying features of the test area.

D3.2 Process and Application Data Collection

All sampling will follow the requirements of the specific test method being used, either ASABE 561.1 APR04 or ISO/DIS 22866:2005(E) standard methods, unless otherwise stated in this document or approved by EPA prior to the verification test. Example sampling locations for field testing are shown in Figure 3.

D3.3 Ambient Data Collection

Meteorological conditions will be measured with at least one weather station during applications. The sampling rate for wind speed and direction should be at least four samples per minute. The wind speed must be at least 1 m/s for all applications.

Table 9. Summary of Spray and Test Condition Measurements for Field Testing

Factors to Be Verified	Parameter to Be Measured	Sampling and Measurement Method	Comments
Performance Factors			
Deposition	Tracer deposit at multiple locations downwind of the treatment area	Sampled using smooth horizontal surface collectors such as filter paper.	Deposition should be described in terms of mass of nonvolatile tracer per unit area
Test Conditions Documentation			
Spray pressure	Pressure of spray mix at the nozzle	See ASABE S572.1, section 3.	
Spray materials temperature	Temperature of the spray mixture	Calibrated thermometers accurate within 0.1 ºC	
Flow rate	Volume per unit time produced by the nozzle under test conditions.	See ASABE S561.1	Repeat measurements for individual nozzles within ± 2.5%
Release height	Height above the ground the spray materials are released		
Travel speed	Rate of speed for the equipment used to apply the spray material		
Meteorological conditions	Wind speed	See ASABE S561.1, section 3.2.3	Ambient air temperature of 10 to 30 ºC with less than 5 ºC variation during test
	Wind direction	See ASABE S561.1, section 3.2.4	
	Ambient air temperature	See ASABE S561.1, section 3.2	
	Ambient pressure	See ASABE S561.1, section 3.2	
	Relative humidity	See ASABE S561.1, section 3.2.2	

D4: Sample Handling and Custody Requirements

The date and time of sample collection and analysis must be recorded. Sample holding conditions (e.g., temperature, containers, light) must be noted for the period between sample collection and analysis.

The samples collected during the test program will consist of horizontal samplers (for example, filter paper). Tracer materials and sample processing techniques should be selected to meet the specified DQIGs. Analysis of these samples will be conducted as described in Element D5.

The media for collecting samples shall be horizontal sample collectors. Each test lab will document its approach to collecting, storing, and analyzing horizontal sample collectors in its site specific test/QA plan. Immediate analysis of samples is strongly encouraged. If data collection and analysis will not be done on-site, sample custody requirements are a required part of the test/QA plan.

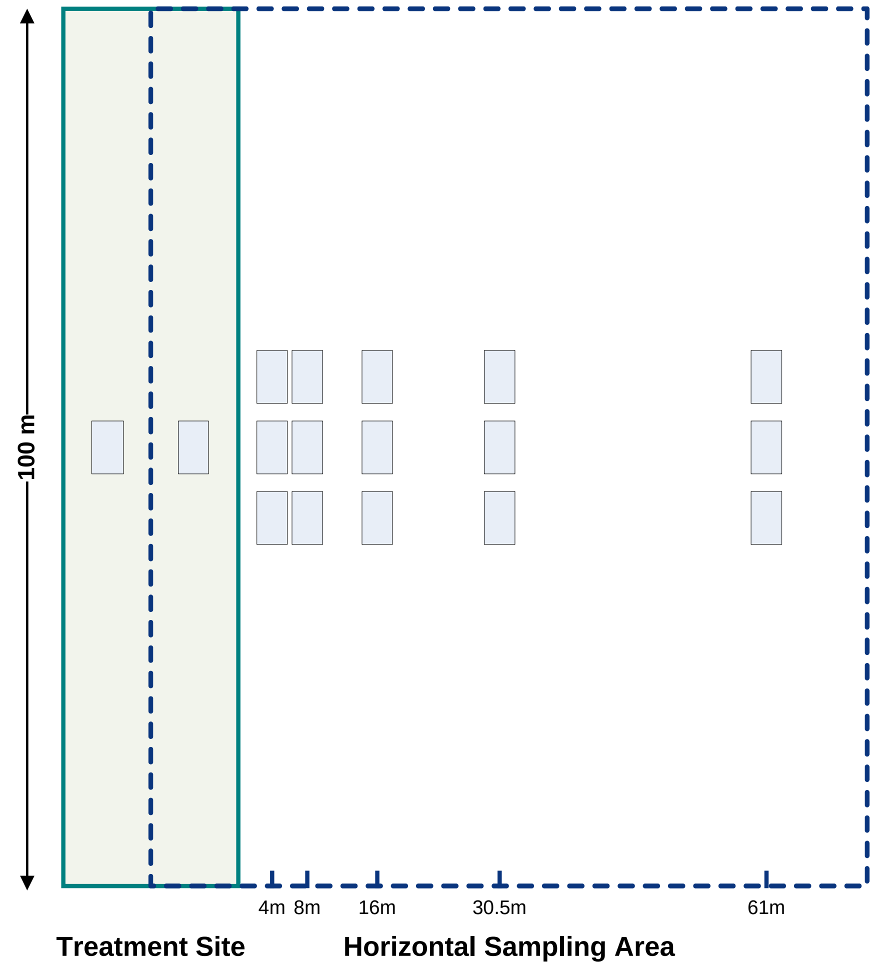

Figure 3. Sampling locations for field testing.

D5: Analytical Methods

Measurement of deposited material will occur by extracting tracer from the horizontal sample collectors followed by measurement of the amount of tracer in the extract. Tracer measurements should be expressed as the amount of material per unit area of sampler. Instruments used to measure tracer (e.g., gas chromatographs) should be of adequate sensitivity to measure deposition at the most distant sampler.

D6: Quality Control

The boom width, intended swath width, nozzle placement, and nozzle orientation of the application equipment will be reported. Wind direction during and for 2 minutes after application should be ± 30 degrees perpendicular to the swath. Drive speed for ground equipment is anticipated to be between 4 and 24 km/h (2.5 to 15 mph). Aerial application equipment speed is anticipated to be maintained between 50 and 165 mph.

Randomly selected, unused horizontal sample collectors should be spiked with tracer at 2 and 200 times the level of quantitation for the analytical equipment to be used for measuring tracer. Tracer recovery should be within 80 to 120% of the spiked amount. Stock solutions used in testing should also be tested. Linearity of deposition relative to measurement instrumentation response should be demonstrated in the deposition range measured.

Tracer concentration in the spray material tank will be measured and reported before and after testing on each test day and for each tank mix used.

D7: Instrument and Equipment Testing, Inspection, and Maintenance

The site-specific T/QAP needs to reference the testing organization's SOP for testing, inspection, and maintenance of instruments and equipment.

D8: Instrument and Equipment Calibration and Frequency

Analytical instruments used to measure tracer extracts from collectors will be calibrated on the same day of analysis. Calibration will use a standard curve consisting of at least three points spanning the level of quantitation and the highest measured concentration level. The standard curve should be linear (r^2 greater than 0.95).

D9: Inspection and Acceptance of Supplies and Consumables

The primary supplies and consumables for this exercise consist of the horizontal samplers and tracer materials. Prior to labeling, each sampler is visually inspected and is discarded for use if any damage is found. The tracer selected should allow for adequate sensitivity to measure deposition at all test distances. The tracer should be stable and nonvolatile in the test frame for testing and analysis. Background measurement samples from the testing site should demonstrate negligible levels of tracer or other interfering compounds.

The hardness of water used in spray tanks should be documented.

D10: Non-Direct Measurements

If applicable, data that are not gathered directly by the testing organization may be used, however, the testing organization must describe these measurements in the T/QAP or the applicant-specific addendum.

D11: Data Management

Results will be calculated as deposition for each set of sampling conditions at downwind positions at 4 m, 8 m, 16 m, 30.5 m, and 61 m, including a summary of meteorological conditions and application conditions. Requirements for the verification test report, verification statement, and data storage and retrieval are provided in Group E, Data Reporting.

D11.1 Data Flow

Data measurement and collection activities for deposition are shown in Figure 2 of Element B10. This flow chart includes all data activities from the initial pretest QA steps to the passing of the data to EPA.

D11.2 Data Reduction

Data from each measurement for deposition from the verification test will be reported in units of mass/area for each downwind distance and the meteorological and application conditions will clearly be reported.

D11.3 Analysis of Verification Data

Measurements should be presented separately (raw data) and as an average across repetitions for each downwind measurements for the deposition on horizontal samplers at each downwind distance.

Group E: Data Reporting

E1: Outline of the Verification Test Report

- Verification statement
  - DRT manufacturer or vendor information
  - Summary of verification test program including testing location and type (LSWT, HSWT, or Field)
  - Results of the verification test
  - Droplet size classification, using ASABE S572.1 and the reference system used
  - Any limitations of the verification results
  - Brief QA statement
- Introduction
- Description and identification of the DRT
- Procedures and methods used in testing
  - The instruments and measurement apparatus used for droplet size measurement (including name and type, model number, serial number, scale ranges, software version number, and date of most recent calibration verification)
  - Deposition sampling Tracer types and concentration in test spray materials, if used.
- Statement of operating range and testing conditions over which the test was conducted including:
  - Nozzle orifice height
  - Spray pressure at nozzle
  - Volume/unit time produced by nozzle
  - Test spray material composition
  - Source of spray materials (including water)
  - Sampling locations
  - Temperature
  - Humidity
  - Air speed – wind tunnel testing only
  - Flight speed or ground equipment speed – field testing only
  - Wind speed and direction – field testing only
  - Atmospheric stability – field testing only

  - Results of the ASABE S572.1 droplet size measurement
- Summary and discussion of results
  - Results supporting verification statement
  - Deviations and explanations from test plan
  - Discussion of QA and QA statement
- References
- Appendices
  - QA/QC activities and results
  - Raw test data
  - Equipment calibration results
  - Sample handling
  - Description of the use of the data to determine drift reduction and a link to an example calculation on OPP's DRT website.

E2: Draft Report Preparation

The testing organization will develop a verification report that verifies and summarizes the DRT test results. EPA will review the draft report and provide comments to the testing organization. The draft report will be edited by the testing organization to address EPA comments. The final report will be submitted to EPA for approval, distribution, and publication.

E3: Data Storage and Retrieval

This section describes the handling and storage of the data. After the completion of a verification test, labeled three-ring binders containing manually recorded information and data output generated from instrumentation will be stored with a copy retained by the testing organization. This is called the 'data notebook' in the ETV and APCT Center QMPs. After completion of a verification test, a CD-ROM or other storage media containing the T/QAP, spreadsheet data files and the report will be generated by the testing organization for distribution. The testing organization and the EPA will retain copies of the electronic data on a system with at least monthly back-up in perpetuity.

Group F: Assessment and Oversight

F1: Assessments and Response Actions

F1.1 Internal Audits

Internal audits by the testing organization are conducted as specified in the testing organization's SOP, which must conform to required Element C1 (Assessments and Response Actions) and C2 (Reports to Management) of EPA QA/R-5. The testing organization SOP documents must be identified in the site-specific T/QAP.

F1.2 Audits of Data Quality

The testing organization QM will conduct an ADQ of at least 10% of all of the verification data. The ADQ will be conducted in accordance with EPA's *Guidance on Technical Audits and Related Assessments for Environmental Data Operations, EPA QA/G-7*, including:

- a written report detailing the results of custody tracing,
- a study of data transfer and intermediate calculations,
- a review of QA and QC data, including reconciliation to user requirements, e.g., DQOs and DQIGs, and
- a study of project incidents that resulted in lost data, and a review of study statistics.

The ADQ report ends with conclusions about the quality of the data from the project and their fitness for their intended use.

F1.3 External Audits

The testing organization will cooperate with any external assessments by the EPA. EPA assessors may conduct a quality and technical systems assessment of the testing organization before or after the start of the first test for each test facility. They may conduct optional witness assessments during the first test or any subsequent test. The external assessments will be conducted as described in EPA QA/G-7.

F1.4 Corrective Action

Corrective action to any audit or assessment is performed according to the testing organization's SOPs, which must conform to required Elements B5 (Quality Control) and C1 (Assessments and Response Actions) of EPA QA/R-5.

F2: Reports to Management

Internal assessment reports will be reviewed by the testing organization QM, who will respond as noted in Element C1 of EPA QA/R-5. The written report of the ADQ will be submitted for review as noted in Element F1.2 of this protocol.

Group G: Data Validation and Usability Elements

G1: Data Review, Verification, and Validation

Data review and validation will primarily occur at the following stages:

- On site following each test run – by the test technician
- On site following completion of the test program – by the testing organization technical leader
- Before writing the draft verification test report – by the testing organization QM
- During QA review of the draft report and audit of the data – The criteria used to review and evaluate the data will be the QA/QC criteria specified in each test procedure, protocol, guideline, or method (e.g., see Tables 3 and 4 for low speed wind tunnel testing) and the DQIG analysis of the parameter test data. Those individuals responsible for onsite data review and validation are noted in Figure 2, Element B10, and above. The testing organization technical leader is responsible for verification of data with all written procedures. Finally the testing organization QM reviews and evaluates the data and the draft report using the site-specific T/QAP, test methods, general SOPs, and project-specific SOPs.

The data review and data audit will be conducted in accordance with the testing organization's SOP.

G2: Verification and Validation Methods

Data are verified by the data collector. The goal of data verification is to ensure and document that the data are what they purport to be (i.e., the reported results reflect what actually was done). When deficiencies in the data are identified, then those deficiencies should be documented for the data user's review and, where possible, resolved by corrective action. Data verification applies to activities in the field as well as in the laboratory. Validated data are reported in verification reports and statements along with any limitations on the data and recommendations for limitations on data usability. All validated data arising from testing under the DRT Program are disclosed in verification reports, even if the technology did not perform to the expectations of the technology provider. Results of the testing are conveyed to the data users through verification statements and verification reports.

G3: Reconciliation with Data Quality Objectives

DQO requirements have been defined (in Tables 2, 3, 6, and 8). This reconciliation step is an integral part of the test program and will be done at the test site. Attainment of the DQO is confirmed by analyzing the test data as described in Element A7 and will be completed by the testing organization test technician and testing organization technical leader at the conclusion of the scheduled test runs. The DQO is defined as meeting the DQIG in Tables 2, 3, 6, and 8.

The reconciliation of the results with the DQO will be evaluated using the data quality assessment process. This process started with the review of the DQO and the sampling design to assure that the sampling design and data collection documentation are consistent with those needed for the DQO. When the preliminary data is collected, the data will be reviewed to ensure that the data are consistent with what was expected and to identify patterns, relationships, and potential anomalies. The data will be summarized and analyzed using appropriate statistical procedures to identify the key assumptions. The assumptions will be evaluated and verified with all deviations from procedures assessed as to their impact on the data quality and the DQO. Finally, the quality of the data will be assessed in terms of precision, bias, and statistical significance as they relate to the measurement objectives and the DQO.

Results from verification testing of the DRT will be presented in a verification statement and a verification report as described in Element E.

Appendix A: Applicable Documents and Procedures

1. EPA Documents

EPA. *Policy and Program Requirements for the Mandatory Agency-wide Quality System*. EPA Order CIO2105.0. http://www.epa.gov/irmpoli8/policies/21050.pdf, U.S. Environmental Protection Agency. May 2000.

EPA. *EPA Requirements for Quality Management Plans*. *EPA QA/R-2*, EPA Publication No. EPA/240/B-01/002. http://www.epa.gov/quality/qs-docs/r2-final.pdf, U.S. Environmental Protection Agency, Office of Environmental Information. Washington, DC. March 2001.

EPA. *Environmental Technology Verification Program, Quality Management Plan.* EPA Publication No. EPA/600/R-08/009. http://www.epa.gov/etv/pubs/600r08009.pdf, Office of Research and Development, U.S. Environmental Protection Agency. Cincinnati, OH. January 2008.

EPA. *Guidance on Environmental Data Verification and Data Validation, EPA QA/G-8.* EPA Publication No. EPA/240/R02/004. http://www.epa.gov/quality/qs-docs/g8-final.pdf, Office of Environmental Information, U.S. Environmental Protection Agency. 2002.

EPA. *EPA Requirements for Quality Assurance Project Plans. EPA QA/R-5*, EPA Publication No. EPA/240/B-01/003. http://www.epa.gov/quality/qs-docs/r5-final.pdf, Office of Environmental Information, U.S. Environmental Protection Agency. March 2001.

EPA. *Guidance for Quality Assurance Project Plans. EPA QA/G-5*, EPA Publication No. EPA/240/R-02/009**Error! Hyperlink reference not valid.**. http://www.epa.gov/quality/qs-docs/g5-final.pdf, Office of Environmental Information, U.S. Environmental Protection Agency. December 2002.

EPA. *Records Management*. EPA Classification No. 2161. http://www.epa.gov/records/policy/2161/rm_policy_2161_archive.htm, Office of Environmental Information, U.S. Environmental Protection Agency. May 2009.

EPA. *Guidance on Technical Audits and Related Assessments for Environmental Data Operations. EPA QA/G-7*, EPA Publication No. EPA/600/R-99/080. http://www.epa.gov/quality/qs-docs/g7-final.pdf, Office of Environmental Information, U.S. Environmental Protection Agency. January 2000.

EPA. *Evaluation of the Verification Protocol for Low and High Speed Wind Tunnel Testing*. EPA Publication No. TBD. http://www.epa.gov/nrmrl/std/etv/pubs/600etv12010.pdf, Office of Research and Development, U.S. Environmental Protection Agency. Cincinnati, OH. April 2012.

2. Verification Organization Documents

RTI International. *Verification Testing of Air Pollution Control Technology - Quality Management Plan*, Revision 2.3. RTI International. Research Triangle Park, NC. http://www.epa.gov/nrmrl/std/etv/pubs/600etv10011.pdf, March 2010.

3. Other Literature

Fritz, B.K., Hoffmann, W.C., Jank, P. 2011. *A Fluorescent Tracer Method for Evaluating Spray Transport and Rate of Field and Laboratory Spray Applications*. J. of ASTM Int. 8(3):1-9.

American National Standard Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs (ANSI/ASQ E4-1994)

Appendix B: Example Format for Test Data

Table B-1. Example of Test Data Report Format

Droplet Size Bin No.	Measures of droplet size categories (μm)			Mass Fraction	
	Largest	Arithmetic Mean	Smallest	Incremental	Cumulative
1	1504	1400.5	1297	0	0
2	1297	1208.5	1120	0	0
3	1120	1042.5	965	0	0
4	965	899	833	0	0
5	833	776	719	0	0
6	719	669.5	620	0.01	0.01
7	620	577.5	535	0.01	0.02
8	535	498	461	0.02	0.04
9	461	430	399	0.03	0.07
10	399	371.5	344	0.01	0.08
11	344	320	296	0.06	0.14
12	296	276	256	0.05	0.19
13	256	238	220	0.06	0.25
14	220	205.5	191	0.09	0.34
15	191	177.5	164	0.09	0.43
16	164	152.5	141	0.08	0.51
17	141	131.5	122	0.12	0.63
18	122	113.5	105	0.11	0.74
19	105	97.95	90.9	0.08	0.82
20	90.9	84.7	78.5	0.06	0.88
21	78.5	73.1	67.7	0.03	0.91
22	67.7	63.05	58.4	0.02	0.93
23	58.4	54.4	50.4	0.03	0.96
24	50.4	46.95	43.5	0.01	0.97
25	43.5	40.5	37.5	0.01	0.98
26	37.5	34.95	32.4	0.01	0.99
27	32.4	30.15	27.9	0.01	1.0
28	27.9	26	24.1	0.0	1.0
29	24.1	22.45	20.8	0.0	1.0
30	20.8	19.35	17.9	0.0	1.0
31	17.9	16.7	15.5	0.0	1.0
32	15.5	9.75	4.0	0.0	1.0
$D_{v\,0.1}$ (μm)	74				
$D_{v\,0.5}$ (μm)	160				
$D_{v\,0.9}$ (μm)	335				
Relative Span	0.82				