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Environmental Technology Verification Program

Advanced Monitoring Systems Center

Test/QA Plan for Verification of Radio Frequency Identification (RFID) for Tracking Hazardous Waste Shipments across International Borders

Verification of
Radio Frequency Identification (RFID) for Tracking Hazardous Wastes Shipments across International Borders

March 23, 2009

Prepared by

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Test/QA Plan for Verification of Radio Frequency Identification (RFID) for Tracking Hazardous Wastes Shipments across International Borders

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SECTION A
PROJECT MANAGEMENT

A1 VERIFICATION TEST ORGANIZATION

The verification test will be conducted under the auspices of the U.S. Environmental Protection Agency (EPA) through the Environmental Technology Verification (ETV) Program. It will be performed by Battelle, which is managing the ETV Advanced Monitoring Systems (AMS) Center through a cooperative agreement with EPA. The scope of the AMS Center covers verification of monitoring, sampling, characterization, and detection technologies.

The day to day operations of this verification test will be coordinated and supervised by Battelle, with the participation of the vendors who will be having the performance of their technologies for radio frequency identification (RFID) for tracking hazardous waste shipments across international borders evaluated. Testing will be conducted in the Santa Teresa, New Mexico-Jeronimo, Mexico border crossing area. Each vendor will provide their respective technology and will set it up and either operate their technology themselves during the verification test or train verification staff to operate the technology during the verification test. Either way, verification staff will be on-hand during testing to ensure that the test/QA plan is followed.

The organization chart in Figure 1 identifies the responsibilities of the organizations and individuals associated with the verification test. Roles and responsibilities are defined further below. Quality Assurance (QA) oversight will be provided by the Battelle Quality Manager and also by the EPA AMS Center Quality Manager, at her discretion.

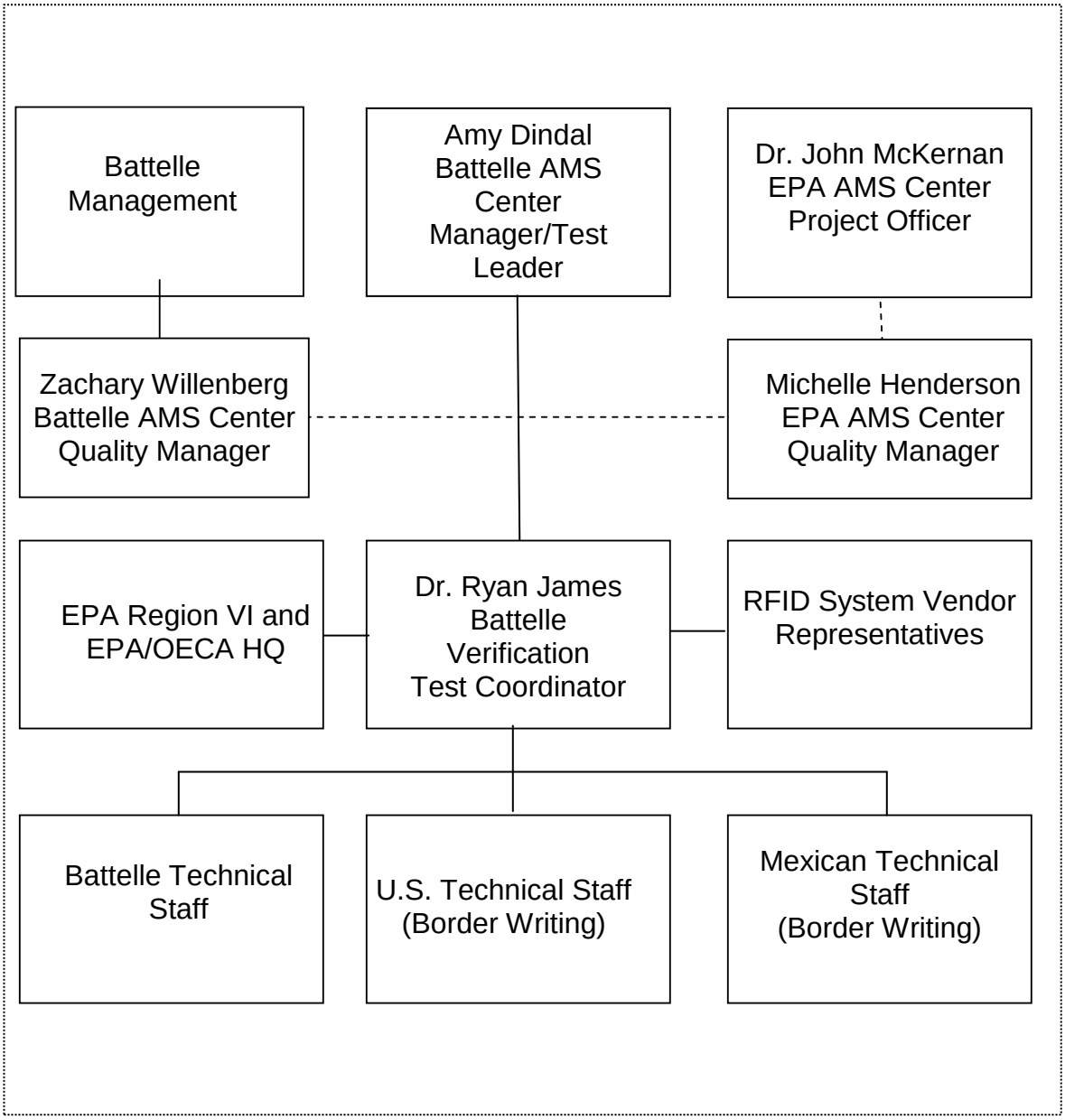

Figure 1. Organization Chart for the Verification Test

A1.1 Battelle

Dr. Ryan James is the AMS Center's Verification Test Coordinator for this test. In this role, Dr. James will have overall responsibility for ensuring that the technical, schedule, and cost goals established for the verification test are met. Specifically, Dr. James will:

- Prepare the draft test/QA plan, verification reports, and verification statements.
- Establish a budget for the verification test and manage staff to ensure the budget is not exceeded.
- Revise the draft test/QA plan, verification reports, and verification statements in response to reviewers' comments.
- Assemble a team of qualified technical staff to conduct the verification test.
- Direct the team in performing the verification test in accordance with this test/QA plan.
- Hold a kick-off meeting, which will be conducted in person or by teleconference approximately one week prior to the start of the verification test to review the critical logistical, technical, and administrative aspects of the verification test. Responsibility for each aspect of the verification test will be confirmed.
- Ensure that all quality procedures specified in this test/QA plan and in the AMS Center Quality Management Plan[1] (QMP) are followed.
- Serve as the primary point of contact for vendor representatives.
- Ensure that confidentiality of sensitive vendor information is maintained.
- Become familiar with the operation and maintenance of the technologies through instruction by the vendors, if needed.
- Respond to any issues raised in assessment reports, audits, or from verification staff observations, and institute corrective action as necessary.
- Coordinate distribution of the final test/QA plan, verification reports, and verification statements.
- Establish subcontract with Border Writing to assist Battelle in coordinating the verification test near the border; especially the tasks requiring coordination with the Mexican government, Mexican maquila, and the Mexican trucking companies.

Subcontract language will require Border Writing to comply with all aspects of this TQAP, and therefore, the AMS Center QMP.

Ms. Amy Dindal will serve as Verification Testing Leader and is also Battelle's Manager for the AMS Center. Ms. Dindal will:

- Support Dr. James in preparing the test/QA plan and organizing the testing.
- Review the draft and final test/QA plan.
- Attend the verification test kick-off meeting.
- Review the draft and final test/QA plan.
- Review the draft and final verification reports and verification statements.
- Attend the verification test kick-off meeting.
- Ensure that necessary Battelle resources are committed to the verification test.
- Ensure that confidentiality of sensitive vendor information is maintained.
- Support Dr. James in responding to any issues raised in assessment reports and audits.
- Maintain communication with EPA's project officer.
- Issue a stop work order if Battelle or EPA QA staff discovers adverse findings that will compromise test results.

Battelle Technical Staff will support Dr. James in planning and conducting the verification test. The responsibilities of the technical staff will be to:

- Assist in planning for the test including coordination with vendors.
- Attend the verification test kick-off meeting.
- Conduct reference testing.
- Support Dr. James in the preparation of test/QA plan and reports, as necessary
- Support Dr. James in responding to any issues raised in assessment reports and audits.

Mr. Zachary Willenberg is Battelle's Quality Manager for the AMS Center. Mr. Willenberg or a qualified designee will:

- Review the draft and final test/QA plan.
- Attend the verification test kick-off meeting.

- Conduct a technical systems audit at least once during the verification test.
- Audit at least 10% of the verification data.
- Prepare and distribute an assessment report for each audit.
- Verify implementation of any necessary corrective action.
- Request that Battelle's AMS Center Manager issue a stop work order if audits indicate that data quality is being compromised.
- Provide a summary of the QA/QC activities and results for the verification reports.
- Review the draft and final verification reports and verification statements.

A1.2 Technology Vendors

The responsibilities of the technology vendors are as follows:

- Review and provide comments on the draft test/QA plan.
- Accept (by signature of a company representative) the final test/QA plan prior to test initiation.
- Provide an adequate amount of equipment (e.g., tags, readers, software, etc.) for the verification test.
- Provide all other equipment/supplies/reagents/consumables needed to operate their technology for the duration of the verification test.
- Provide training on the use of the technology, as necessary. If training is provided, provide written consent and instructions for verification staff to carry out verification testing, including written instructions for routine operation of their technology.
- Provide maintenance and repair support for their technology, on-site if necessary, throughout the duration of the verification test.
- Review and provide comments on the draft verification report and statement for their respective technology.

A1.3 EPA

EPA's responsibilities in the AMS Center are based on the requirements stated in the ETV QMP.[2] The roles of specific EPA staff are as follows:

Ms. Michelle Henderson is EPA's AMS Center Quality Manager. For the verification test, Ms. Henderson or her designee will:

- Review the draft and review and approve the final test/QA plan.
- Have the option of performing one external technical systems audit during the verification test.
- Notify the EPA AMS Center Project Officer of the need for a stop work order if the external audit indicates that data quality is being compromised.
- Prepare and distribute an assessment report summarizing results of the external audit.
- Review draft verification reports and verification statements.

Dr. John McKernan is EPA's Project Officer for the AMS Center. Dr. McKernan will:

- Review the draft test/QA plan.
- Review final version of test/QA plan to ensure all applicable comments have been addressed and then approve the final test/QA plan.
- Issue a stop work order if adverse findings are discovered that would compromise data quality.
- Review the draft and final verification reports and verification statements.
- Oversee the EPA review process for the test/QA plan, verification reports, and verification statements.
- Coordinate the submission of verification reports and verification statements for final EPA approval.

U.S. EPA Region 6 personnel and EPA's Office of Enforcement and Compliance Assurance will support the collaboration of U.S. and Mexican localities through existing network of colleagues/acquaintances and provide peer reviewers for the test/QA plan and reports.

A1.4 Maquilas – Foreign corporation-owned manufacturing plants located in Mexican border cities

At least one maquila (e.g., TYCO Electronics) will participate in the verification testing, subject to schedule and availability. These facilities manufacture various products and are

foreign corporation-owned, but Mexican managed and staffed. They are often ISO 9000 certified, and utilize and produce a variety of hazardous materials. Multiple maquila facilities are located in the Bermudez Industrial Park area. Each has its own loading dock, storage area, material handling equipment, and loading personnel that can support the testing. The responsibilities of the maquilas include the following:

- Provide location for readers to be placed during verification activities in their loading dock area.
- Provide 110 volt power for use with the readers.

A1.5 Trucking Companies

Servico de Transporte Internacional y Local (STIL), a company that provides international HAZMAT shipping will collaborate in the verification testing. The responsibilities of the trucking company will include the following:

- Load test packages onto trucks as described in the test/QA plan.
- Drive truck following route described in test/QA plan, stopping to allow for scanning at the specified locations.

A1.6 Border Writing

Border Writing is a small business located in Las Cruces, NM with experience with RFID technologies that will provide verification test staff to record observations and conduct reference measurements at all of the field locations. These staff will be familiar with the area and able to travel back and forth between the U.S. and Mexico. In addition, Border Writing will coordinate collaboration with the New Mexico border authority, the Mexican border authority, the Mexican maquilas, and the trucking companies. All of Border Writing's activities will be guided by the test/QA plan and AMS Center QMP. Border Writing staff will either ride along with the truck or follow the truck in a separate vehicle. They will transport the collision tags so they can be added to the truck at the maquila. Border Writing staff will also be responsible for documenting their experience in setting up and operating the vendor technologies in order to capture the user-friendliness of each technology.

A2 BACKGROUND

The ETV Program's AMS Center conducts third-party performance testing of commercially available technologies important to protecting the environment from contamination. The purpose of ETV is to provide objective and quality assured performance data on environmental technologies, so that users, developers, regulators, and consultants can make informed decisions about purchasing and applying these technologies. Stakeholder committees of buyers and users of such technologies recommend technology categories, and technologies within those categories, as priorities for testing.

The purpose of this test/QA plan is to specify procedures for a verification test applicable to commercial RFID technologies. The purpose of the verification test is to evaluate the performance of the participating technologies in a field environment. In performing the verification test, Battelle and its subcontractor will follow the technical and QA/QC procedures specified in this test/QA plan and will comply with the data quality requirements in the AMS Center QMP.[1]

A3 VERIFICATION TEST DESCRIPTION AND SCHEDULE

A3.1 U.S./Mexican Hazardous Material Transport

There are thousands of shipments of hazardous wastes that enter the United States each year. These shipments must be properly handled and recycled or disposed according to appropriate regulatory standards. The Resource Conservation and Recovery Act (RCRA) requires cradle-to-grave tracking of hazardous wastes. At the present time, there is no automated method to track these shipments from the generator facility to the receiving facility and a particular gap exists in EPA's ability to track shipments of hazardous wastes originating in the Mexico border zone and crossing into the U.S.

Therefore, the U.S.-Mexico border area presents a unique opportunity for testing this type of technology, largely because of the presence of the maquila industry. Maquilas are foreign-owned manufacturing plants that are located in Mexican cities that border the U.S. There are more than 4,000 of these manufacturing plants along the border, and many of them produce

hazardous waste as a function of their manufacturing processes, including solvents, solder, plastic, and metal waste – wastes that are historically not tracked as required by RCRA. A maquila is the assembly portion of the manufacturing process, where raw materials, including hazardous materials, are imported into Mexico for assembly. The finished products and wastes are then shipped to the U.S. or other countries.

The La Paz Agreement is between the United States and Mexico for the Cooperation for the Protection and Improvement of the Environment. Under this agreement, all hazardous wastes generated by raw materials shipped into Mexico for use in maquilas must be shipped back to their country of origin. Mexico does not classify the returned material as hazardous, but as a returned product, and therefore does not submit a Notice of Intent (NOI) to the United States for the export of hazardous waste for this material. The current process makes it difficult to develop an accurate accounting of hazardous waste entering the United States from the maquilas and does not provide for timely identification of shipments that do not reach their designated receiving facilities. The lack of tracking of these wastes creates the possibility for waste to be illegally abandoned. An enhanced tracking system that provides accurate, timely data to regulatory officials would be beneficial in preventing this from occurring.

A3.2 RFID Systems

A networked radio-frequency identification (RFID) system may provide the technology to address some of these concerns. RFID is an emerging, commercial-ready commodity tracking technology that is being tested and implemented in a large number of applications worldwide. A typical RFID system consists of four main components: tags, an encoder, readers, and central processing unit. An RFID tag consists of a microchip and a flexible antenna sealed in a plastic-coated inlay, which can be applied to or incorporated into a product for the purpose of identification. The encoder writes information to the tag that is acquired by a reader.

The RFID system operates by transmitting data using radio waves for communication between a tag and a reader, and ultimately to a database. Most tags contain at least two parts. One part is an integrated circuit for storing and processing information, modulating and demodulating an RF signal. The second part is the antenna that receives and transmits the signal. The information being read is provided in the form of a unique Electronic Product

Code (EPC), which links to information in a database, and may be accessed on-site or remotely. RFID tags come in three general varieties: passive, active, or semi-passive.

Passive RFID tags have no internal power supply. A small electrical current is induced in the antenna by the incoming radio frequency signal. These electromagnetic waves received from the reader induce a current within the integrated circuit in the tag to power up and transmit an amplitude-modulated response back to the reader. Active RFID tags have their own internal power source (i.e., battery), which energizes the integrated circuits and broadcast a signal to a reader. Active tags have an increased read range that may increase read accuracy due to their ability to conduct a "session" with a reader. Semi-passive tags are similar to active tags in that they have a battery; however, it only powers the microchip and does not broadcast a signal. The RF energy sent by the reader is transmitted back to the reader, similar to the passive tag. This verification test will include systems that use active RFID tags that are read using readers that are mounted inside the truck and tracked using external tracking systems (cell phone tower or global positioning system based) as well as readers that are mounted outside the truck.

A3.4 Test Description

The verification test will be conducted in the El Paso, Texas/Ciudad Juárez, Mexico trade area, which is among the largest border trade zones in the world. For safety purposes, non-hazardous substances will be used in the field testing. In all other regards, the field testing will reflect actual conditions of shipping hazardous waste across the U.S.-Mexico border. The verification test will simulate shipments of hazardous waste contained in plastic and metal drums and corrugated boxes through routine land transportation routes and across international ports of entry in the El Paso/Ciudad Juárez trade area. RFID tags will be attached to various types of packages and loaded onto trucks at the U.S. loading dock at the New Mexico Border Authority. Semi-trailer trucks from local HAZMAT trucking companies will carry containers in a loose configuration as well as tightly packaged pallets of waste containers along a typical cross-border shipping route. Read points for the RFID technologies will be located at the New Mexico Border Authority (NMBA) loading dock (simulating the U.S. factory), the Mexican port of entry, a maquila, and at the State of New Mexico truck inspection station near the U.S. port of entry. The RFID technologies will be evaluated based on their read accuracy on the various

types of packaging and, if the system requires external readers, with readers placed at various distances from the truck. The verification test will be conducted during March of 2009 with report writing occurring during April and May of 2009. Exact test dates will be determined based on the schedules of the technology vendor participants and the supporting organizations.

A4 QUALITY OBJECTIVES AND CRITERIA FOR MEASUREMENT DATA

Because of the nature of RFID technologies, no traditional reference samples or performance evaluation audit samples (often used during a chemical monitoring verification test) will be analyzed during this verification test. The function of RFID tags will be confirmed by a Rohde and Schwarz FSH6 Spectrum Analyzer, an instrument that measures the frequency and power of a radio signal, at the time of tagging the packages. In addition, the spectrum analyzer will be used to measure the power of the signal at each NMBA and New Mexico truck inspection facility reader. Table 1 shows all of the measurements to be collected throughout the verification test. In addition to the frequency and power measurements, these measurements include hourly outdoor meteorological conditions that will be obtained from the U.S. National Weather Service, "in-trailer" meteorological and shock conditions that will be recorded by the Shocklog™ RD 298 equipped with a humidity, pressure, and temperature sensor. Both these instruments will be factory calibrated and not require additional calibration during the test. Truck speeds at the NMBA, the Mexico POE, and the maquila will not be dictated to the driver. The speeds at those locations will be documented according to the speedometer of the truck (speeds based on safe speeds in those scenarios). However, the truck speeds at the entrance to the New Mexico truck inspection facility will be dictated to the driver and measured by a factory-calibrated Stalker Sport™ Doppler radar gun. The meteorological data will be collected as part of the test, but there are not specific meteorological criteria that will be required for testing to be performed, or conversely, no meteorological criteria would require that testing be discontinued.

Table 1. Data Collected During Verification Test

Measurement	Data Source	Key Measurement	Units	Calibration
RFID Frequency	Rohde and Schwarz FSH6 Spectrum Analyzer	Frequency range from 100KHz to 6.0 GHz; resolution: 1Hz	Frequency megahertz (MHz)	Factory certified calibration
Effective Radiated Power (RF Energy)	Rohde and Schwarz FSH6 Spectrum Analyzer	Maximum power: 20 dBm	Power ratio of Decibel referenced to milliwatt (dBm)	Factory certified calibration
Trailer Conditions	Shocklog™ RD298 Recorder with HPT Sensor	Event-based shock, vibration measurement; temperature, relative humidity, and pressure measured once per minute	Centimeter/second (cm/s), gravitational force (g), °C, %RH, and inches mercury	Factory certified calibration
Environmental Conditions	U.S. National Weather Service, AIRNow reports	Hourly temperature, relative humidity (RH), pressure, wind speed and direction ; daily averages of particulates	Degrees Celsius (°C), parts per million, %RH, bar, miles per hour (mph)	Data from third party sources
Semi-trailer Truck Velocity	Stalker Sport™ Doppler Radar gun	Truck velocity during tag reading	mph	Factory certified calibration

A5 SPECIAL TRAINING/CERTIFICATION

If the vendors request that verification staff operate and maintain their technology during the verification test, the vendors will train the verification staff prior to the start of testing. Battelle will document this training with a consent form, signed by the vendor, which states which specific verification staff have been trained to use their sensor. All truck drivers will be licensed in both the U.S. and Mexico and have experience in crossing the U.S./Mexican border with hazardous waste shipments.

A6 DOCUMENTATION AND RECORDS

The records for this verification test will include the test/QA plan, laboratory record books (LRB), field data sheets, electronic files (both raw data and spreadsheets), and the final verification

report. LRBs and field data sheets will be maintained by verification staff at the field site during the test, upon completion of the field test, will be transferred to the Verification Test Coordinator, then following completion of the reporting process will be transferred to permanent storage at Battelle's Records Management Office. All Battelle LRBs are stored indefinitely, either by the Verification Test Coordinator or Battelle's Records Management Office. Results collected during the field verification test will be transferred electronically to the Verification Test Coordinator on a daily basis by the verification staff working at the field site. Section B10 further details the data recording practices and responsibilities.

SECTION B
MEASUREMENT AND DATA ACQUISITION

B1 EXPERIMENTAL DESIGN

The verification test will allow for performance evaluation under "real world" conditions. Overall, the performance of the RFID technologies will be verified based on the following parameters:

- Accuracy –proper identification of the tagged containers at various locations, truck speeds, package type, packaging configurations conditions, etc. Specifically, proper identification is defined as the retrieval of all information available about the tagged item according to the vendor's standard procedures. For example, if the vendor has database fields available for a container number, container volume, and container description; a proper identification would include the retrieval of all of those pieces of information.
- Precision – repeatability of the ratio of correct to incorrect RFID results
- Interference of other RFID signals (collision test) - ability to discriminate the hazardous waste tags from other commercially-available tags
- Influence of confounding factors (container type, packing configuration and placement of tags/containers, environmental conditions, internal trailer conditions, and semi-trailer truck velocity)
- Operational factors (ease of use, read time, technology cost, user-friendliness of vendor software, troubleshooting/downtime, etc.)

The responses to these parameters will be collected as either qualitative or quantitative observations. The quantitative information will consist of the data from tag readings under each condition, as well as the RFID frequency and power measurements. Qualitative information will include those observations relating to operational factors.

The evaluations will be performed according to the vendor's recommended procedures as described in the user's instructions or manual, or during training provided by the vendor. Calibration and maintenance of the technologies will be performed as specified by the vendor. The results from the technologies will be recorded manually by the verification staff on

appropriate field data sheets or captured in an electronic data system and then transferred manually or electronically for further data workup. The results from each technology will be reported individually, but each technology will undergo the same testing so it is convenient for end users to evaluate the ETV testing results.

B1.1 Setup of RFID Technologies and Field Testing Procedures

In the 1-2 days leading up to the start of the verification test, each participating vendor will be responsible for setting up their RFID technologies according to their recommended configuration for optimal performance. For some technologies, this might include the use of readers that are handheld or mounted to a stand outside of the truck. Others may require a reader mounted on the inside of the truck. Regardless of the technology, the requirement will be that read events need to occur at the NMBA loading dock, arrival/departure area of the NMBA loading dock, as well as the exit drive leading from the NMBA loading dock and at the maquila in Mexico. In addition, one read event will occur at the Mexican port of entry (POE) and read events at 15 ± 3 and 25 ± 3 miles per hour will be conducted on the entrance lane to the New Mexico truck inspection facility. The vendors will need to set up the technologies in a way that will allow for the completion of the scope described in the test/QA plan.

Table 2 provides a summary of the testing route read points. The route is designed to simulate the import of raw materials to the Mexican maquila facilities and the return of the hazardous waste generated by these materials. If the participating RFID technologies consist of readers that are handheld or mounted to a fixed location outside of the truck, vendors can configure the system (e.g., reader angles/heights) for optimal performance.

Each container will be tagged with a vendor's RFID tag and loaded onto the trailer. Two readers attached to a portable stand will be used at read point (RP)1A, the loading dock of the NMBA. At this location, the truck will be stopped and several reads will be collected at increasing distances from the truck. The two separate readers will be situated on a stand at 20° and 45° with respect to the plane of the truck with the stand placed four feet from the side of the parked truck even with the front bumper (similar to the stand being alongside a road). Then, for the various distance reads, the stand with the readers will be moved straight forward from that point five, 15, and 30 feet (determined by a tape measure). RP1B is the entrance/exit lane of the NMBA loading dock. The same stand with the two readers will be moved to the exit lane prior to the truck exiting the

Table 2. Summary of Testing Route Read Points

Location	Read Points	Description
1. NMBA Loading Dock	RP1A	Arrival/departure area: if readers required, two separate readers will be situated on a stand at 20° and 45° with respect to the plane of the truck with the pole placed four feet from the side of the parked truck even with the front bumper (similar to the stand being alongside a road) and then for the various distance reads, the readers will be moved straight forward from that point five, 15, and 30 feet; while the truck will be stopped for these reads, they are mimicking the scenario of a truck approaching a reader 30, 15, and five feet away on the side of the road;..
	RP1B	Readers (20° and 45° with respect to the road) for a slow-moving read at the exit of the NMBA loading dock
2. Jeronimo Mexico POE	RP2	Readers (20° and 45° with respect to the road) placed at POE.
3. Maquila facility at Cd. Juárez	RP3	Readers (20° and 45° with respect to the road) placed at entrance/exit lane of the maquila for a slow moving read upon entrance and exit of the maquila facility. Collision tags will be added at maquila.
4. NM Truck Inspection Facility	RP4	Readers (20° and 45° with respect to the road) placed at entrance. Truck will make one pass at 15 mph and another pass at 25 mph. Collision tags will be removed after first pass at 15 mph. Truck will drive around block and return two times to pass at 15 and 25 mph
5. NMBA Loading Dock	RP5A.	Readers (20° and 45° with respect to the road) for a slow-moving read at the entrance of the NMBA loading dock.
	RP5B	Repeat of five, 15, and 30 feet reads as performed at Location 1.
Unexpected Route Deviaton		At one point during each round-trip, the truck will deviate from the planned route by at least one mile. Following the deviation, the truck will turn around and return to the planned route at the same location it left.

facility. There, a slow-moving read upon exit of the storage facility will take place. No specific speed will be dictated for this read event, just whatever speed the driver would normal drive in that situation of exiting the NMBA.

RP2 will be at the Mexican POE. Two readers (20° and 45° with respect to the road) will be situated next to the road for a slow moving read upon entrance into Mexico. Again, no speed will be dictated for this read point, but the driver will document the speed the truck is traveling when it passes the read point. RP3 will be at the maquila. This read event will be performed in a similar way as RP1B at the exit of the NMBA storage facility. There will be a read upon the

entrance of the maquila facility. Then, after having the door of the trailer opened and the collision tags added to the load and any load shifting documented, the truck will turn around and there will be another read event as the truck exits the maquila facility and returns to the U.S. following the same route. RP4 will be near the U.S. POE at the New Mexico truck inspection facility. Two readers (20° and 45° with respect to the road) will be placed on a stand alongside of the entrance to the truck inspection facility. The trucks will enter the facility and pass the readers once at 15 ± 3 mph. The truck will then stop and the collision tags will be removed from the trailer. Then, the truck will drive around the block and pass the reader once again at 15 ± 3 mph and then make another pass at 25 ± 3 mph. RP5 will be back at the NMBA where the truck started. RP5A will be at the entrance lane to the storage facility (this location is the same as RP1B). A slow moving read event will take place upon return to the NMBA. RP5B will be conducted in the same location and in a similar way as was RP1A. The read events will be conducted at five, 15, and 30 feet from the front of the truck. When possible, the vendors may be able to utilize the same readers at several of the read point locations. At this time, the round trip will be completed and all the read points will have been collected. The trucks used during the test will either be the same truck across the duration of the verification test or at least of the same size and construction. This process will be performed twice with loosely packed containers and twice with tightly palletized containers for a total of four round trips for each vendor.

Both technologies being tested have a feature that alerts the user if the shipments leave the route that is planned and entered into the vendor's system. In order to verify the performance of that feather, route at some point during each round trip the truck will deviate from the planned route by at least one mile, but not more than 3 miles. Following the deviation, the truck will return to the planned route at the same point it left to deviate from the route. The vendors will not be informed of where the deviation in route will occur.

B1.2 HAZMAT Containers and Packing Configuration

According to current shipping practices, most of the hazardous materials entering Mexico from the United States are contained in either polyethylene (poly) or steel 55-gallon drums, and much of the hazardous waste returning from the maquila and entering the United States is solid and packed in one cubic yard corrugated boxes or drummed liquids. Accordingly, testing will be completed using three different containers: 55-gallon poly drums, 55-gallon stainless steel drums,

and one cubic yard corrugated box. In the interest of safety, no actual hazardous waste will be transported during this verification test, but containers that are typically used for hazardous material transport will be used to best simulate actual conditions. The 55-gallon drums will be filled with tap water and the corrugated boxes will contain non-hazardous cloth rags. The verification of each technology will include four total round trips that will begin at the NMBA loading dock.

Two round-trip shipments will include tightly packed, palletized poly and steel drums and corrugated boxes and the other two round-trip shipments will include poly and steel drums and corrugated boxes loosely packed on the floor of the trailer. It is anticipated that there will be at least four of each type of container included with each truck run (for a total of 12 containers) and that each vendor will be tested using the same HAZMAT containers. Upon loading of the trucks, the vendors will attach one RFID tag to each container. Therefore, there will be a total of four tags for each container type. The tags will be attached such that one container of each type will have a tag that faces towards the front of the truck, one container will have a tag that faces towards the rear of the truck, one container will have a tag that faces towards the passenger side of the truck, and one container will have a tag that faces towards the driver side of the truck. This configuration is meant to provide performance information about whether or not tag placement is critical to the results. The packing configuration will be checked at the mid-point of the route (at the maquila) and any shifting of the containers or damage to tags will be documented. If any tags are damaged, we will consult with the vendor and consider replacing them before progressing with the test.

B1.3 Trucking Route

As depicted on the map in Figure 1, the trucking route will occur between the NMBA loading dock near Santa Teresa, New Mexico and the maquila(s) in Ciudad Juárez Mexico and back again. It will also include passage through the Santa Teresa, New Mexico and Jeronimo, Mexico International POE. The selected route replicates the typical HAZMAT routes across

Figure 2. Trucking Route Map (read points labeled)

the U.S.-Mexico border zone: it mixes urban and highway driving; it starts at the NMBA near the Santa Teresa POE, comes to the half way point at the maquila in a heavily industrialized section of Cd. Juarez, and then returns following the same route. The length of this route is approximately 40 miles round-trip so we anticipate that it will take about one hour.

B1.4 Other Measurements

B1.4.1 Spectrum Analyzer Measurements

As described in Section A4, the frequency and power of each tag placed on packages will be verified by the spectrum analyzer (at short distances) upon being applied to the packages. In addition, the power level of the tag signals will be read at each NMBA and New Mexico truck inspection facility reader placement. The spectrum analyzer antennae will be placed next to the readers prior to each read event at those locations.

B1.4.2 Collision Test

To evaluate the ability for readers to discriminate the tags used for tracking the simulated hazardous waste containers from other commercially available tags (not from the vendors being tested), a collision test will be completed along the truck route. This will be done by placing a wooden block (or other available support) containing commercially obtained tags (not from the vendor being verified) on the semi-trailer truck after completing the initial tag reading at the maquila facility. The door of the trailer will be open and the tags will be placed adjacent to the location at which the other tagged containers are located. At the NMBA read point, the vendor tags will be read upon the initial 15 mph pass. After this reading, the block will be removed from the truck, the doors closed up again, and the truck will make passes at 15 and 25 mph without the collision tags. This collision test will be performed with each round trip. Therefore, eight reads will be made with the collision tags within the truck, all at the NMBA read point at a truck speed of 15 mph.

B1.4.3 Weather and Particulate Data

The temperature, precipitation, dew point, barometric pressure, humidity, wind speed, fine particulate matter ($PM_{2.5}$), and ozone will be recorded at the time the tags are read by the RFID system. The temperature, precipitation, dew point, barometric pressure, humidity, and wind speed will be recorded from the U.S. National Weather Service website for the El Paso/Juárez region (www.srh.noaa.gov/elp/). The particulate and ozone readings will be based on the hourly reading of the air quality monitors in the El Paso region as recorded on AIRNow, a U.S. cross-agency government air quality control Web site (www.airnow.gov). The weather and particulate data will be correlated with the read accuracy to assess their possible influence on the RFID performance, should there exist sufficient variance in weather conditions or particle concentrations during field testing.

B1.4.4 Internal Trailer Conditions

The operating and storage temperature, vibration, and shock will be recorded for each test using appropriate electronic monitoring devices such as Shocklog™. This data will be correlated with the read rate/accuracy data, humidity, temperature, barometric pressure, and shock events to assess their possible influence on the RFID performance.

B1.4.5 Semi-Trailer Truck Velocity

Tag readings will be performed at four locations while the truck is traveling at a low velocity upon entrance and exit of the NMBA loading dock, the maquila, and at the Mexico POE. Truck speeds at these locations will not be dictated to the driver. The driver will document the speed (according to the speedometer of the truck) at which it was practical to drive in those scenarios. In addition, the New Mexico truck inspection facility read points will include reads at 15 ± 3 mph and 25 ± 3 mph. These speeds will be dictated to the driver and confirmed through measurement by a Stalker Sport™ Doppler radar gun.

B1.4.6 Operational Factors

Operational factors such as maintenance needs, ease of use, data output, and software requirements will be documented by the verification staff. LRBs or field data sheets will be used to document observations. Examples of information to be recorded include the expertise required for equipment setup and operation, the format of data exported by the technology and method by which to obtain that data, ease and durability of tag, quality of tag attachment, difficulty of set-up, required repair or maintenance, the duration and causes of any technology down time or data acquisition failure, user-friendliness of any needed software, and the overall convenience of the technologies and accessories/consumables. These observations will be summarized qualitatively to aid in describing the technology performance in the verification report on each technology.

B1.5 Statistical Analysis

The statistical methods and calculations used for evaluating quantitative performance parameters are described in the following sections.

B1.5.1 Accuracy

Accuracy is a measure of the agreement between a measured value and the "true" value. A primary objective for this verification test is to determine the accuracy of RFID system performance with reading tags under critical variables and test conditions. For this verification, accuracy will be determined as a percentage according to the following formula:

$$A = (1 - E/N) \times 100 \quad (1)$$

where A is the percent accuracy of the RFID system reader, E is the total number of tags that were not properly recognized by the reader, and N is the total number of tagged HAZMAT containers. Tag reader accuracy will be determined for each read point and packaging type for each vendor's system. The highest percent accuracy possible is 100%.

Result of the collision test will be reported as false positive and false negative results. For example, the presence of the non-vendor RFID tags cause the vendor's tags not be read successfully, that will reported as a false negative result. Alternatively, if the presence of the collision tags cause additional readings that are not linked to a vendor tag, that will be reported as a false positive result. The accuracy of the RFID systems will be reviewed in the context of all the possible confounding factors (e.g., packaging type, direction of tag, trailer environmental conditions, etc.). If possible, correlations will be considered through statistical approaches such as linear regressions, analysis of variance, etc.

B1.5.2 Precision

Precision is a measure of the agreement among repeated measurements. Each tag will be read at least two or three times at each read point (depending on the read frequency of the vendor systems), each read point creating a set of replicate results. At the read points where the truck is moving, there will likely be fewer results than for the read points when the truck is stopped. Each of these results can either be correct or incorrect identification of the tag. In order to evaluate precision for this verification testing program, these number of correct identifications within each read set will be reported. For example, throughout one truck trip, a single tag will be read at seven different instances (RP1A, RP1B, RP2, RP3, RP4, RP5A, and RP5B). Therefore, if there would happen to be the same ratio of correct to incorrect results for each result set, that would indicated a high level of precision. However, if the ratio of correct to incorrect results fluctuated between sets of results, that would indicate poor repeatability. The ratio of correct to incorrect results will be reported for each set of results.

B1.6 Reporting

The data obtained in the verification test will be compiled separately for each vendor's technology, and the data evaluations will be applied to each vendor's technology without reference to any other. Following completion of the data evaluations, a draft verification report will be prepared for each vendor's technology, stating the verification test procedures and

documenting the results. For example, descriptions of the data acquisition procedures, use of vendor-supplied proprietary software, consumables used, repairs and maintenance needed, and the nature of any problems will be presented in the draft report. Each report will briefly describe the ETV Program, the AMS Center, and the procedures used in verification testing. Each draft verification report will be submitted for review by the respective technology vendor and by EPA and other peer reviewers. Battelle will compile all the comments and revise the reports as necessary. The reporting and review process will be conducted according to the requirements of the AMS Center QMP.[1]

B2 SAMPLING REQUIREMENTS

B2.1 Sample Collection, Storage and Shipment

Because of the nature of RFID measurements, there will be no physical reference samples collected during the verification testing.

B3 SAMPLE HANDLING AND CUSTODY REQUIREMENTS

Because of the nature of RFID measurements, there will be no physical reference samples collected during the verification testing.

B4 FIELD TEST REFERENCE METHOD

Because of the nature of RFID measurements, there will be no physical reference samples for which standard measurement methods can serve as reference methods. However, as described in previous sections, various measurements (e.g., the spectrum analyzer, the meteorological conditions recorded by the NWS, “in-trailer” conditions measured by the Shocklog™, Stalker Sport™ Doppler radar gun, etc.) will be made to support the verification test.

B5 REFERENCE METHOD QUALITY CONTROL

Because of the nature of RFID measurements, there will no physical reference samples collected during the verification testing. However, the instruments used for the various measurements mentioned in Section B4 will be certified accurate by the manufacturer. In addition to the factory calibration, the spectrum analyzer will be run through a daily preliminary electronic diagnostic sequence before use in the verification testing. Completion of the diagnostic sequence will be documented in the field data sheets.

B6 INSTRUMENT/EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE

The RFID technologies will be setup and maintained by the vendors or at the direction of the vendors according to their specifications. If the verification staff encounters problems with the operation of the technology, the vendor representative will be contacted immediately.

B7 TECHNOLOGY CALIBRATION

As described throughout this test/QA plan, the spectrum analyzer will be used to confirm the frequency and power of the technologies being verified. The RFID technologies being verified will be supplied ready for use by the vendor and will not require calibration.

B8 INSPECTION/ACCEPTANCE OF SUPPLIES AND CONSUMABLES

All materials, supplies, and consumables will be ordered by the Verification Test Coordinator or designee. Where possible, Battelle will rely on sources of materials and consumables that have been used previously as part of ETV verification testing without problems. Battelle will also rely on previous experience or recommendations from EPA advisors, host facilities, or the RFID vendors.

B9 NON-DIRECT MEASUREMENTS

As described previously, the NWS meteorological data will be used during this verification test. Similarly, the AIRNow atmospheric particulate data will also be used. Both of these data sources are highly regarded and are routinely used in government projects.

B10 DATA MANAGEMENT

Various types of data will be acquired and recorded electronically or manually by Battelle during the verification test. Table 3 summarizes the types of data to be recorded. All maintenance activities, repairs, and operator observations relevant to the technology operation will be documented by technical staff in LRBs or on field data sheets.

Records received by or generated by any technical staff during the verification test will be reviewed by a Battelle staff member within two weeks of generation or receipt, before the records are used to calculate, evaluate, or report verification results. If a Battelle staff member generated the record, this review will be performed by a Battelle technical staff member involved in the verification test, but not the staff member who originally generated the record. The review will be documented by the person performing the review by adding his/her initials and date to the hard copy of the record being reviewed. In addition, any calculations performed by technical staff will be spot-checked by Battelle QA and/or technical staff to ensure that calculations are performed correctly. Calculations to be checked include any statistical calculations described in this test/QA plan. The data obtained from this verification test will be compiled and reported independently for each technology.

Among the QA activities conducted by Battelle QA staff will be an audit of data quality. This audit will consist of a review by the Battelle AMS Center Quality Manager (or his designee) of at least 10% of the test data. During the course of any such audit, the Battelle AMS Center Quality Manager will inform the technical staff of any findings and any need for immediate corrective action. If serious data quality problems exist, the Battelle AMS Center Quality Manager will request that Battelle's AMS Center Manager issue a stop work order. Once the assessment report has been prepared, the Verification Test Coordinator will ensure that a response is provided for each adverse finding or potential problem, and will implement any

necessary follow-up corrective action. The Battelle AMS Center Quality Manager will ensure that follow-up corrective action has been taken.

Table 3. Summary of Data Recording Process

Data to Be Recorded	Where Recorded	How Often Recorded	By Whom	Disposition of Data
Tag ID and location (what package and location on package)	Field data sheet	Tag attachment	Field verification staff	Verification test binder
Spectrum analyzer results	Field data sheet	Tag attachment After all U.S. read points	Field verification staff	Verification test binder
Read results	Vendor software	During read events	Automated	Files provided to verification staff on thumb drive or disk
"In trailer" shock and environmental condition	Shocklog™ RD298 Recorder	Continuously during transport	Automated	Files provided to verification staff on thumb drive or disk
Environmental conditions	U.S. National Weather Service (NWS) web site-El Paso area, www.srh.noaa.gov/elp/	Daily	Field verification staff	Verification test binder
Environmental conditions	www.airnow.gov	Daily	Field verification staff	Verification test binder
Speed of truck	Field data sheet	During read events	Field verification staff	Verification test binder
Operational factors	Field data sheet or LRB	Throughout verification testing	Field verification staff	Verification test binder or LRB

SECTION C
ASSESSMENT AND OVERSIGHT

C1 ASSESSMENTS AND RESPONSE ACTIONS

Every effort will be made in this verification test to anticipate and resolve potential problems before the quality of performance is compromised. One of the major objectives of this test/QA plan is to establish mechanisms necessary to ensure this. The procedures described in this test/QA plan, which is peer reviewed by a panel of outside experts, implemented by the technical staff and monitored by the Verification Test Coordinator, will give information on data quality on a day-to-day basis. The responsibility for interpreting the results of these checks and resolving any potential problems resides with the Verification Test Coordinator. Technical staff have the responsibility to identify problems that could affect data quality or the ability to use the data. Any problems that are identified will be reported to the Verification Test Coordinator, who will work with the Battelle AMS Center Quality Manager to resolve any issues. Action will be taken to control the problem, identify a solution to the problem, and minimize losses and correct data, where possible. Independent of any EPA QA activities, Battelle will be responsible for ensuring that the following audits are conducted as part of this verification test.

C1.1 Performance Evaluation Audits

Because of the nature of RFID measurements, a performance evaluation audit, as is usually performed to confirm the accuracy of the reference method, will not be applicable during this verification test.

C1.2 Technical Systems Audits

The Battelle AMS Center Quality Manager will perform a technical systems audit (TSA) at least once during this verification test. The purpose of this audit is to ensure that the verification test is being performed in accordance with the AMS Center QMP,[1] and this test/QA plan. In the TSA, the Battelle AMS Center Quality Manager or a designee may compare actual test procedures to those specified or referenced in this plan, and review data acquisition and handling procedures. The Battelle Quality Manager will tour the test sites, observe and review the test procedures, and review LRBs/field data sheets. He will also check calibration

certifications for test measurement devices. A TSA report will be prepared, including a statement of findings and the actions taken to address any adverse findings. The EPA AMS Center Quality Manager will receive a copy of Battelle's TSA report. At EPA's discretion, EPA QA staff may also conduct an independent on-site TSA during the verification test. The TSA findings will be communicated to technical staff at the time of the audit and documented in a TSA report.

C1.3 Data Quality Audits

The Battelle AMS Center Quality Manager will audit at least 10% of the verification data acquired in the verification test. The Battelle AMS Center Quality Manager will trace the data from initial acquisition, through reduction and statistical comparisons, to final reporting. All calculations performed on the data undergoing the audit will be checked.

C1.4 QA/QC Reporting

Each assessment and audit will be documented in accordance with Sections 3.3.4 and 3.3.5 of the AMS Center QMP.[1] The results of the TSA will be submitted to EPA. Assessment reports will include the following:

- Identification of any adverse findings or potential problems
- Response to adverse findings or potential problems
- Recommendations for resolving problems
- Citation of any noteworthy practices that may be of use to others.

C2 REPORTS TO MANAGEMENT

The Battelle AMS Center Quality Manager, during the course of any assessment or audit, will identify to the technical staff performing experimental activities any immediate corrective action that should be taken. If serious quality problems exist, the Battelle AMS Center Quality Manager is authorized to request that Battelle's AMS Center Manager issue a stop work order. Once the assessment report has been prepared, the Verification Test Coordinator will ensure that a response is provided for each adverse finding or potential problem and will implement any necessary follow-up corrective action. The Battelle AMS Center Quality Manager will ensure that follow-up corrective action has been taken. The test/QA plan and final report are reviewed

by EPA AMS Center Quality Manager and EPA AMS Center Project Officer. Upon final review and approval, both documents will then be posted on the ETV website (www.epa.gov/etv).

SECTION D
DATA VALIDATION AND USABILITY

D1 DATA REVIEW, VALIDATION, AND VERIFICATION REQUIREMENTS

The key data review requirements for the verification test are stated in Section B10 of this test/QA plan. In general, the data review requirements specify that the data generated during this test will be reviewed by a Battelle technical staff member within three weeks of data generation. The reviewer will be familiar with the technical aspects of the verification test, but will not be the person who generated the data. This process will serve both as the data review and the data verification, and will ensure that data have been recorded, transmitted, and processed properly. Furthermore, this process will ensure that the RFID technology data are collected under appropriate testing conditions.

D2 VALIDATION AND VERIFICATION METHODS

As part of the normal data and report review process the US EPA and ETV peer reviewers will have the opportunity to review the draft final report and provide comments. Data verification is conducted as part of the data review, as described in Section B10 for this test/QA plan. A visual inspection of handwritten data will be conducted to ensure that all entries were properly recorded or transcribed and that any erroneous entries were properly noted (i.e., single line through the entry with an error code and the initials of the recorder and date of entry). Electronic data from the technologies and other instruments used during the test will be inspected to ensure proper transfer from the data logging system. Data manually incorporated into spreadsheets for use in calculations will be checked against handwritten data to ensure that transcription errors have not occurred. All calculations used to transform the data will be reviewed to ensure the accuracy and the appropriateness of the calculations. Calculations performed manually will be reviewed and repeated using a handheld calculator or commercial software (e.g., Excel). Calculations performed using standard commercial office software (e.g., Excel) will be reviewed by inspecting the equations used in calculations and verifying selected calculations by handheld calculator. Calculations performed using specialized commercial

software will be reviewed by inspection and, when feasible, verified by handheld calculator, or standard commercial office software.

To ensure that the data generated from this test meet the goals of the test, a number of data validation procedures will be performed. Section C of this test/QA plan provides a description of the validation safeguards employed for this verification test. Data validation and verification efforts include the completion of QC activities and the performance of a TSA audit as described in Section C. A data quality audit will be conducted by the Battelle AMS Center Quality Manager to ensure that data review, verification, and validation procedures were completed, and to assure the overall data quality.

D3 RECONCILIATION WITH USER REQUIREMENTS

The purpose of a verification test performed following this test/QA plan is to evaluate the performance of commercial RFID technologies for tracking hazardous waste shipments across international borders. The data obtained in such a verification test will include thorough documentation of the technology's performance during the verification test. The data review, verification, and validation procedures described above will assure that verification test data meet these requirements, are accurately presented in the verification reports generated from the test, and that data not meeting these requirements are appropriately flagged and discussed in the verification reports. Additionally, all data generated using the reference method, which are used to evaluate technology results during the verification test, should meet the QA requirements of any applicable standard operating procedures or instrumentation instruction manuals.

This test/QA plan and any resulting ETV verification report(s) generated following procedures described in this test/QA plan will be subjected to review by participating technology vendors, ETV AMS Center staff, test collaborators, EPA, and external expert peer reviewers. These reviews will assure that this test/QA plan, verification test(s) of RFID technologies, and the resulting report(s) meet the needs of potential users and regulators. The final report(s) will be submitted to EPA in 508 compliant Adobe Portable Document Format (pdf) and subsequently posted on the ETV website.

SECTION E

REFERENCES

E1 REFERENCES

1. Quality Management Plan for the ETV Advanced Monitoring Systems Center, Version 7.0, U.S. EPA Environmental Technology Verification Program, Battelle, Columbus, Ohio, November, 2008.

2. Quality Management Plan for the Environmental Technology Verification Program, Version 3.0, U.S. EPA, Cincinnati, Ohio, January, 2008.