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Environmental Technology Verification Program

Advanced Monitoring Systems Center

Test/QA Plan for Verification of Alternative Technologies for Sealed Source Radiography Cameras

Test/QA Plan for Verification of Alternative Technologies for Sealed Source Radiography Cameras

May 28, 2010

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APPROVAL:

Name _____

Company _____

Date _____

ACRONYMS AND ABBREVIATIONS

ADQ	Audit of Data Quality
AMS	Advanced Monitoring Systems
ASNT	American Society for Nondestructive Testing
ATI	Alternative Technologies Initiative
DQI	Data quality indicator
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
IAEA	International Atomic Energy Agency
IQI	Image quality indicator
IRRSP	Industrial Radiography Radiation Safety Personnel
LRB	Laboratory record book
NDT	Non-destructive testing
NHSRC	National Homeland Security Research Center
OAR	Office of Air and Radiation
pdf	Adobe portable document format
PE	Performance evaluation
QA	Quality assurance
QC	Quality control
QMP	Quality management plan
SOP	Standard Operating Procedure
TSA	Technical systems audit

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SECTION A
PROJECT MANAGEMENT

A1 VERIFICATION TEST ORGANIZATION

The verification test will be conducted under the U.S. Environmental Protection Agency (EPA) 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 technologies for contaminants and natural species in air, water, and soil.

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 which offer an alternative to sealed radioactive sourced radiography cameras verified. Testing will be conducted at Battelle facilities in West Jefferson, Ohio. Each vendor will provide and operate their respective technology.

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 QA Manager and also by the EPA AMS Center Quality Manager, at her discretion. Because this verification will be referenced by the Office of Air and Radiation's Alternative Technology Initiative, it was decided to establish the testing as a Quality Category II, requiring a QA review of 25% of the test data and additional peer-reviewers (see Section C1).

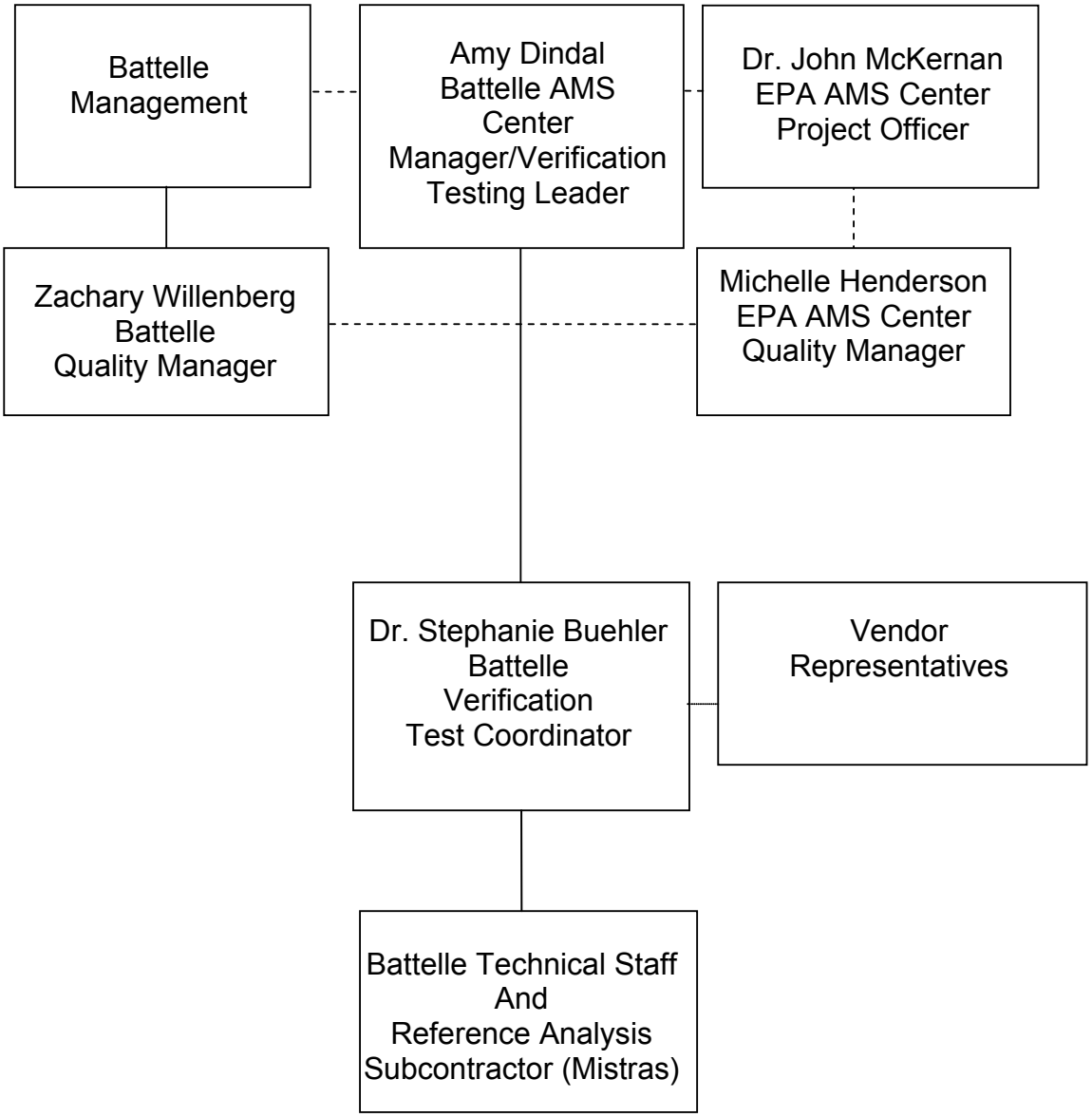

Figure 1. Organization Chart for the Verification Test (dotted lines indicate lines of communication)

A1.1 Battelle

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

- Prepare the test/QA plan, verification reports, and verification statements;
- Revise the test/QA plan, verification reports, and verification statements in response to reviewers' comments;
- Establish a budget for the verification test and manage staff to ensure the budget is not exceeded;
- 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 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;
- Assist vendors as needed during verification testing;
- 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 test staff observations, and institute corrective action as necessary; and
- Coordinate distribution of the final test/QA plan, verification reports, and verification statements.

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

- Support Dr. Buehler in preparing the test/QA plan and organizing the testing;
- Review the final test/QA plan;
- Attend the verification test kick-off meeting;
- Review the draft and final verification reports and verification statements;
- Ensure that necessary Battelle resources, including staff and facilities, are committed to the verification test;
- Ensure that confidentiality of sensitive vendor information is maintained;
- Support Dr. Buehler in responding to any issues raised in assessment reports and audits;
- Maintain communication with EPA's technical and quality managers; and
- 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. Buehler in planning and conducting the verification test. The responsibilities of the technical staff will be to:

- Assist in planning for the test and making arrangements for the receipt of the technologies;
- Attend the verification test kick-off meeting;
- Assist vendor staff as needed during verification testing;
- Conduct and observe verification testing, as appropriate;
- Coordinate and observe reference testing, as appropriate;
- Perform statistical calculations specified in this test/QA plan on the technology data as needed;
- Provide results of statistical calculations and associated discussion for the verification reports as needed; and
- Support Dr. Buehler in responding to any issues raised in assessment reports and audits related to statistics and data reduction as needed.

Mr. Zachary Willenberg is Battelle's QA Manager for this test. Mr. Willenberg 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, or designate other QA staff to conduct the audit;
- Audit at least 25% of the verification data or designate other QA staff to conduct the data audit;
- 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; and
- 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 one unit of their technology for evaluation during the verification test;
- Provide all equipment/supplies/reagents/consumables needed to operate their technology for the duration of the verification test;
- Provide an appropriately trained and licensed (e.g., American Society for Nondestructive Testing (ASNT) Industrial Radiography Radiation Safety Personnel (IRRSP) Certification) person to operate their technology for the duration of the verification test;
- Provide a copy of radiation safety operation license (e.g., ASNT IRRSP Certification, Ohio Radioactive Materials License) or equivalent document for inclusion in the verification test file;

- 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; and
- Provide any applicable documentation related to testing of the vendor's technology, such as calibration, testing results and observations, final images, and supply or reagent certificate of authenticity (COA).

A1.3 EPA

EPA's responsibilities in the AMS Center are based on the requirements stated in the "Environmental Technology Verification Program Quality Management Plan" (EPA ETV QMP).[2] The roles of specific EPA staff are indicated below.

Ms. Michelle Henderson is EPA's AMS Center QA Manager. For the verification test, Ms. Henderson will:

- Review the draft and approve the final test/QA plan;
- Attend the verification kick-off meeting, as available;
- Review checklists, reports, report responses, and closure statements of TSA, performance evaluation (PE) audits, and audits of data quality systems (ADQs) conducted by Battelle;
- Perform an external TSA of field and/or laboratory activities, PE audits, and/or an audit of data quality during the verification test, as available;
- Notify the EPA AMS Center Project Officer of the need for a stop work order if evidence indicates that data quality is being compromised;
- Prepare and distribute an assessment report summarizing results of any external audit performed;
- Review the first day of data from the verification test and provide immediate comments if concerns are identified; and
- Review the draft and approve the final 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;
- Approve the final test/QA plan;
- Attend the verification kick-off meeting, as available;

- Be available during the verification test to review and authorize test/QA plan deviations by phone and provide the name of a delegate to the Battelle AMS Center Manager should he not be available during the testing period;
- Review the first day of data from the verification test and provide immediate comments if concerns are identified;
- Review the draft 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; and
- Post the test QA plan, verification reports, and verification statements on the ETV website.

A1.4 Radiography Camera Subcontractor

This test will require the use of a radiography camera as the reference instrument. A subcontractor with an appropriate safety license (e.g., ASNT ISSRP) to operate a radiography camera will be selected to conduct all reference measurements. The responsibilities of the subcontractor include the following:

- Conduct all reference measurements using a radiography camera;
- Supply all necessary equipment to obtain images using the radiography camera;
- Supply a licensed (e.g., ASNT IRRSP) technician to operate the radiography camera and ensure that all appropriate radiation safety protocols are being properly followed, including controlling access to areas near the radiological source during operation of the radiography camera;
- Provide a copy of radiation safety operation license (e.g., ASNT IRRSP) to Battelle for inclusion in the verification test file;
- Provide digital images of the selected defects to Battelle, including an accompanying description or analysis of the findings (e.g., defect size, depth, etc.) as appropriate;
- Follow all Battelle radiation safety procedures, as appropriate; and
- Perform testing activities and data acquisition as specified in this test/QA plan.

A1.5 Verification Test Stakeholders

This test/QA plan and the verification report(s) and verification statement(s) based on testing described in this document will be reviewed by experts in the fields related to NDT

pipeline inspections and alternatives to sealed-source technologies. Three stakeholders have been providing input to this test/QA plan and have agreed to provide a peer review.

- Terry Webb, BP, Refining NDT Specialist
- Temeka Taplin, National Nuclear Security Administration, Department of Energy
- Madeleine Nawar, U.S. EPA

The responsibilities of verification test stakeholders include:

- Review and provide input to the test/QA plan; and
- Review and provide input to the verification report(s)/verification statement(s).

A2 BACKGROUND

Radioactive chemicals, such as sealed sources of Cobalt-60 and Cesium-137 oxides, can be found in industrial, commercial and medical devices such as those used for measuring the thickness of materials. Many such devices widely used in industrial and commercial applications are often small in size and thus can be easily lost, stolen, abandoned, or improperly disposed.

In some instances sealed radioactive sources can be replaced by a non-radioactive source of energy to accomplish the same function. For some uses, there exist alternative technologies which can replace devices that use sealed sources.

Currently, radiography cameras are being used to monitor the structural integrity of pipes and tanks in manufacturing and chemical plants, and refineries. Chemical plants, refineries, and other manufacturing facilities are considered visible targets for terrorist attacks. Monitoring the structural integrity of these facilities can help identify intentional damage or potential compromises, and ensure security. However the radioactive sources in these cameras themselves can present a safety risk. Minimizing the number of such radioactive sources in the public domain will decrease the opportunity for terrorists to obtain these sources when they might be inappropriately disposed. In an effort to do so, the EPA's Office of Radiation and Indoor Air in the Office of Air and Radiation (OAR), established the EPA's Alternative Technologies Initiative (ATI) (http://www.epa.gov/radiation/source-reduction-management/alt-technologies.html). Part of the EPA-ATI is fostering the acceptance and voluntary market adoption of non-radioactive technologies; i.e., alternative technologies to those that currently use sealed sources. The EPA-ATI is focusing primarily on alternative technologies for devices

with Category 3 and 4 radioactive sources as classified by the International Atomic Energy Agency (IAEA) . Commercial-ready or available alternatives to radiography cameras (such as pulsed x-ray, ultrasound, and other technologies) are being considered. As with any new technology, the likelihood of acceptance can be significantly increased by independent evaluation and verification of a technology's capabilities.

The purpose of this test/QA plan is to specify procedures for a verification test applicable to commercially available alternatives to radiography cameras which can replace technologies that use sealed radioactive sources. The purpose of the verification test is to evaluate the performance of participating technologies in a simulated field environment. In performing the verification test, Battelle 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 Summary of Technology Category

Radiography cameras are a major component of non-destructive testing (NDT). They are used to inspect materials for hidden flaws using gamma-rays to penetrate the material and provide an image of the flaws. Radiography cameras employ film cassettes to record an image of the pipe or vessel being inspected. Iridium-192 and Cobalt-60 are the most common gamma radiation sources used. Sealed source radiation has significant safety concerns if mishandled or improperly disposed. Specific licensing and regulation requirements must also be met to use these cameras, and large areas must be controlled to restrict access while the camera is in use. The use of non-radioactive sourced alternative technologies, where applicable, could help to eliminate these health and safety concerns. These technologies include x-ray (pulsed or high voltage), ultrasound, and eddy current sources. This verification will be testing x-ray technologies and their ability to conduct defect testing on pipes similar to those that might be found in an oil and gas industry refinery.

Non-radioactive source x-ray devices can be operated more safely than sealed-source radiography cameras and do not have the same waste concerns. However, their ability to perform comparably to sealed-source radiography cameras in all situations is not well characterized. Although non-radioactive source x-ray technologies have been used for decades, isotope based radiography is still commonly used in refineries because the sources are generally

easier to transport and position. One particular area of interest in the capabilities of non-radioactive source x-ray devices is their ability to detect pipeline defects through insulation. This verification test will evaluate the ability of non-radioactive source x-ray technologies to determine defects in a pipeline, particularly to adequately identify defects through insulation.

A3.2 Verification Test Schedule

Table 1 shows the planned schedule of testing and data analysis/reporting activities to be conducted in this verification test. As shown in Table 1, preparation to test the technologies will begin in April 2010. Battelle will be performing the testing. Following testing, a separate ETV verification report will be drafted for each participating technology. The reports will be reviewed by the technology vendor, peer reviewers selected from oil and gas trade groups or industry, and the EPA. The final verification statement(s) will be submitted to EPA for signature, and these documents will be made publicly available on both the EPA/ETV and the Battelle AMS Center websites.

Table 1. Planned Verification Test Schedule

Month Year	Testing Activities	Data Analysis and Reporting
April to May 2010	▪ Coordinate with vendor representative ▪ Coordinate schedules for technologies and reference testing	▪ Begin preparation of ETV report template
June 2010	▪ Perform testing	▪ Compile data from all technologies ▪ Compile testing environment conditions ▪ Collect and analyze data from reference samples
June to July 2010		▪ Analyze and finalize all data ▪ Complete common sections of reports ▪ Prepare draft reports
July to August 2010		▪ Internal review of draft reports ▪ Vendor review of draft reports
August 2010		▪ Revise draft reports ▪ Peer review of draft reports
September 2010		▪ Revise draft reports ▪ Submit final reports for EPA approval

A3.3 Test Sites

Testing will be conducted at Battelle's Pipeline Facility in West Jefferson, Ohio. In performing this verification test, Battelle will follow the procedures specified in the test/QA plan and will comply with quality requirements in the AMS Center QMP.[1]

A3.4 Health and Safety

Battelle will conduct all verification testing and reference measurements following the safety and health guidelines in place for Battelle's Pipeline Facility. This includes maintaining a safe work environment and a current awareness of radiation exposure potential. Testing involving the release of radiation will be performed by appropriately trained personnel under the guidance of Battelle's radiation safety officer in the Environment, Safety, Health & Quality (ESH&Q) Services group.

A4 QUALITY OBJECTIVES

In performing the verification test, Battelle will follow the technical and QA procedures specified in this test/QA plan and will comply with the data quality requirements in the AMS Center QMP.[1] This verification test is designed to evaluate the performance of non-radioactive source x-ray technologies for detecting defects in pipeline commonly used in oil and gas industry refineries. Calibrations of x-ray technologies will follow manufacturer specified procedures and acceptance criteria. If possible, this calibration will be performed on-site prior to testing so that observations on the calibration process can be noted by testing staff. The verification of technology performance will include a comparison of the technology results to results obtained using a radiography camera. In addition, environmental factors and testing conditions, such as weather conditions and temperature, will be documented. The Battelle QA Manager or designee will carry out QA/QC oversight and auditing. This will include a Technical Systems Audit (TSA) and a data quality audit. The planned audit procedures are described in Section C1. The EPA QA Manager also may conduct an independent TSA, at her discretion.

Data quality objectives indicate the minimum data quality required to meet the x-ray technology verification objectives. Data quality objectives for this verification test include those related to the performance of the reference method and x-ray technology, as well as those related to documenting verification testing staff observations. Data quality objectives for the reference

method (see Section B4) are presented in terms of data quality indicator (DQI) criteria for the critical measurements associated with the reference method and are listed in Table 5 (see Section B5). In the field, the reference method data quality relies, in part, on proper operation of the reference technology. The radiography camera subcontractor will follow the manufacturer's instructions and/or any applicable standard operating procedures generated by the subcontractor for the safe operation of the radiography camera.

Battelle will rely on the vendor's data quality objectives for each x-ray technology in order to insure that the technology is performing properly during testing. The technology data quality relies on proper operation and maintenance of the x-ray technologies. The results from these technologies are expected to be qualitative and quantitative, and will be reported as either detecting or not detecting the defect for the test conditions in the field, as well as providing information on the characteristics of the defect (for example number of pits, and depth of pits).

A5 SPECIAL TRAINING/CERTIFICATION

Operation of each technology (radioactive and non-radioactive source) will be carried out by a trained vendor or subcontractor representative during testing. In this scenario, the vendor will verify that the operator is sufficiently trained to safely operate the technology. Documentation of appropriate radiation training, licensing and safe operation approval (e.g., ASNT IRRSP) will be provided by both the vendor and radiography camera subcontractor to Battelle. The Battelle verification test coordinator or assigned Battelle staff will verify the presence of the appropriate licenses (and ensure that they are current) prior to the start of testing.

A6 DOCUMENTATION AND RECORDS

The records for this verification test will be contained in the data collection forms and electronic files (both raw data and spreadsheets). The documents for this verification test will consist of the test/QA plan, the final verification reports and statements, and the audit reports. All of these documents and records will be maintained in the Verification Test Coordinator's office or at the testing site during the test and will be transferred to permanent storage at Battelle's Records Management Office within two months of the finalization of the verification reports, except for audit reports, which are permanently stored with the Battelle QA Manager. All Battelle LRBs are stored indefinitely, either by the Verification Test Coordinator or

Battelle's Records Management Office. EPA will be notified before disposal of any files. Table 2 has further details regarding the data recording practices and responsibilities.

All written records must be in ink. Any corrections to notebook entries, or changes in recorded data, must be made with a single line through the original entry. The correction is then to be entered, initialed, and dated by the person making the correction. In all cases, strict confidentiality of data from each vendor's technology will be maintained. Separate files (including manual records, printouts, and/or electronic data files) will be kept for each vendor's technology.

Table 2. Summary of Data Recording Process

Data to Be Recorded	Where Recorded	How Often Recorded	By Whom	Disposition of Data
Dates, times, and details of test events, technology maintenance, down time, ease of use, etc.	ETV LRBs or data recording forms	Start/end of test procedure, and at each change of a test parameter or change of technology status	Battelle or technology operator	Used to organize and check test results; manually incorporated in data spreadsheets as necessary
Technology calibration information	ETV LRBs, data recording forms, or electronically	At technology calibration or recalibration	Technology operator	Incorporated in verification report as necessary
Technology readings	Recorded electronically by the technology and downloaded to an independent computer, or hard copy data printed by the technology and taped into the ETV LRB, or hand entered into ETV LRBs or data recording forms	Recorded continuously for electronic data, printed after each measurement for hard copy print-outs, or recorded manually with each reading	Technology operator	Converted to or manually entered into spreadsheet for statistical analysis and comparisons
Reference method analysis procedures, calibrations, QA, etc.	LRBs, or other data recording forms	Throughout reference analysis imaging	Subcontractors, Battelle, or others assisting in reference analysis	Retained as documentation of sample collection or reference method performance
Reference method results	Electronically or manually into ETV LRBs or data recording forms	Every image taken	Subcontractors, Battelle, or other reference analysis technician	Transferred to spreadsheets for calculation of results, and statistical analysis and comparisons

SECTION B
MEASUREMENT AND DATA ACQUISITION

B1 EXPERIMENTAL DESIGN

X-ray technologies will be tested at Battelle's Pipeline Facility. This will allow for performance evaluation under simulated "real world" conditions. Overall, the performance of the x-ray technologies will be verified based on the following factors:

- Detection of defects known to be on the pipe;
- Detection of appropriate number and size of components of individual defects; and
- Operational factors (ease of use, sampling time, sampling costs).

The responses to these performance factors will be collected as analog images on phosphor imaging plates. After exposure, the imaging plate is placed into a computed radiography scanner where the image is retrieved using laser light scanning and stored as a digital file. The images will be assessed and evaluated by the vendor or vendor representative to determine specific characteristics of the defect (e.g., pit depth) that will be used for analysis of the technology. Battelle technical staff that specialize in nondestructive testing measurements will also review the images from both the vendor and the reference instrument to confirm the results, to the extent possible. Pipes selected for testing have specific, known defects either manually placed or naturally occurring on the pipe. The geometry of each defect will be known based on previous mapping of the pipe.

Radiographic testing is regulated in the state of Ohio and must be performed by licensed operators following approved safety procedures. The evaluations will be performed according to the vendor's approved procedures as described in the user's instructions or manual and will be carried out by a trained and licensed operator provided by the vendor. Similarly, calibration and maintenance of the technologies will be performed by an operator provided by the vendor. If possible, calibration of the vendor and reference technology will be conducted on-site so that Battelle technical staff can observe the procedure. The technologies will be evaluated based on their ability to characterize features on simulated oil/gas pipe segments. Results from the technologies being verified will be recorded manually by the operator on appropriate data sheets or captured in an electronic data system, and then transferred manually or electronically for further data analysis. The results from each technology will be reported individually. No direct

comparison will be made between tested technologies, but each technology will undergo the same testing so it is convenient for end users to evaluate the ETV results.

B1.1 Test Procedures

The following describes the test procedures that will be used to evaluate non-radioactive source x-ray technologies at the Battelle Pipeline Facility.

Two pipe samples will be examined by both the x-ray device and the radiography camera. These pipe samples are meant to be as similar as possible to pipes that would be encountered in a refinery. Though the test pipes are not identical to those used in refineries (i.e., the verification test pipes likely have thinner walls), they do have a similar radius. Refineries typically use 4 to 12 inch diameter pipes. The pipe samples used in this test will be 6 to 8 inches in diameter. One pipe will be low cost carbon steel, and the other a higher cost alloy steel. The pipes are part of Battelle's Pipeline Facility where inspection technology is tested on a regular basis. The test will be conducted outside in Battelle's pipe specimen storage yard. The pipe will be placed on stands or timbers so that pipes are about 3 feet off the ground. To the extent possible, the same type of x-ray detection plates will be used by both the x-ray device and the radiography camera. The images will be qualitatively and quantitatively compared.

Pipe Sample 1 will be a seam-welded carbon steel pipe measuring approximately 35 feet in length. The wall thickness is 0.188 inches. This sample consists of three pipe sections welded together (two circumferential welds) and contains simulated corrosion defects set along two test lines 180° apart. The simulated corrosion was created using electrochemical etching techniques. A five foot section in the middle of Pipe Sample 1 also contains natural corrosion from a pipe pulled from service. The pipe sections with the simulated corrosions were manufactured to API specification X-52. The API grade of the pipe section with natural corrosion is not known.

While Pipe Sample 1 has over a dozen corrosion areas and three welds, a subset of the welds and corrosion will be used to assess the x-ray technologies. This assessment will include collecting images of a variety of features.

- Three simulated corrosion defects - two images of each defect will be taken with the x-ray beam oriented 90 degrees to the centerline of the pipe. One image will assess the length and width of the corrosion, and the other will assess the length and depth.
- One weld - two images will be taken 90 degrees to the centerline.
- One natural corrosion area - two images will be taken 90 degrees to the centerline.

The natural corrosion is close to the weld and both areas can possibly be assessed from the same image. We plan to use three simulated corrosion defects (P1-18, P1-7 and P1-23), one natural corrosion defect (P1-9), and the weld next to this natural corrosion defect.

Pipe Sample 2 is stainless steel alloy of unknown composition measuring approximately 52 inches in length. The wall thickness is about 0.5 inch. The surface is nominally in the original manufactured condition. Since there are no corrosion anomalies, three holes of varying diameter and depth will be drilled into the pipe using handheld tools. The actual diameter and depth of these defects will be determined after they are made using a micrometer and calipers. The depth of the defects will be measured using a Starrett 449 or equivalent depth micrometer. The diameter of the defects will be measured using a Starrett 120 or equivalent slide caliper. The accuracy of these measurements should be within +/- 10% of the wall thickness of the Pipe Sample 2 (0.018 inches). Accuracy will be measured to +/- 0.002 inches. Two images will be taken of Pipe Sample 2 by the x-ray technology and the radiography camera; one to assess the diameter of the drilled hole, and the other to assess the depth.

To simulate the refinery environment, the pipes will be insulated with calcium silicate material. The insulation will be jacketed with either aluminum or stainless steel sheet metal. The jackets will be held on by steel banding material.

B1.1.3 Testing Parameters

A total of 10 images will be taken by each the x-ray technology and the reference instrument on Pipe Samples 1 and 2. Qualitative and quantitative assessments will be made. The images acquired using the radiography camera will be used as the reference. It is not expected that the images from the x-ray device and the radiography camera will be identical since small positioning differences between the source, detector and pipe as well as exposure time will cause differences in image intensity at anomalies. The following sections describe in detail the evaluation of the testing parameters.

B1.1.3.1 Detection of Defects – Qualitative Results

In general, the detection of a single defect will be determined by viewing the resulting image(s) of the defect and assessing that the technology did indeed discover a defect in the appointed area. The defects location, size, and shape will be known from a previous mapping of the pipe. Whether or not the defect was under insulation will be noted. The ability of the x-ray

technology to detect the defect will be compared to the radiography camera's findings and the results will be discussed.

The weld images for Pipe Sample 1 will also be compared qualitatively. The weld region will be divided into 10 zones, isolating weld anomalies such as lack of penetration in the root pass, undercut in the crown, slag inclusion, and porosity as well as regions of acceptable welds. These welds are not high quality, rather they were fabricated to hold the pipe together; therefore weld defects are expected with the potential for the entire weld to be defective. The weld would be divided into 10 areas or zones as partially illustrated in Figure 2. Zone numbers continue from 6 to 10 in the lower part of the arc as well. The presence or absence of defects in each zone will be noted by the technology operator and then reported in a tabular format (see Table 3). Both weld images will be assessed. The number and type of weld defects found by the x-ray technology will be compared qualitatively to the number and type of weld defects found by the radiography camera, and the results will be discussed.

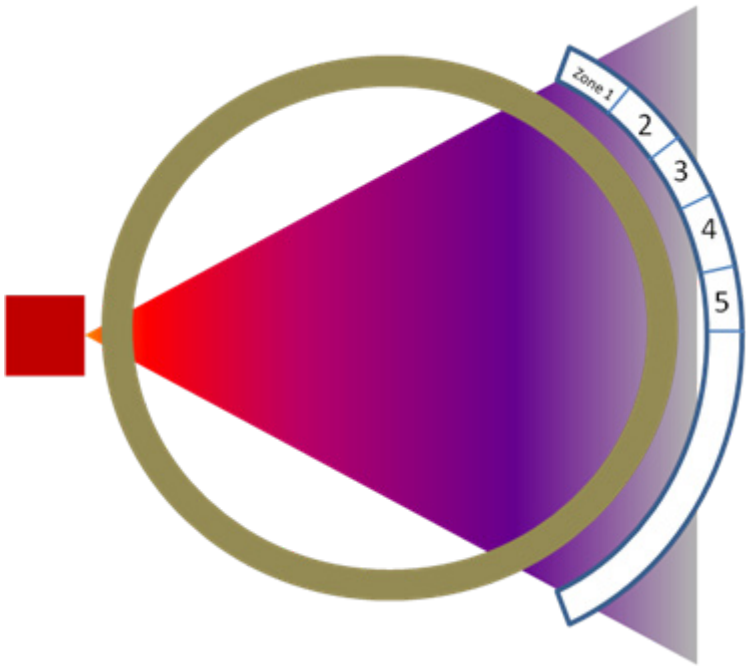

Figure 2. Example of zones for assessment of Pipe Sample 1 weld.

Table 3. Weld Defect Assessment Table

Zone	Root	Crown	Slag	Porosity	No Defect
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

For evaluating the x-ray technologies' performance in detecting the natural corrosion on Pipe Sample 1, a similar process will be used. The natural corrosion region will be divided into 10 zones. The level of corrosion will be noted by the technology operator with the qualitative terms of light, moderate, severe, or absence of defects in each zone in a tabular format (see Table 4). Both corrosion images will be assessed. These will be compared to actual corrosion depth measurements that have already been made in a previous mapping of the pipe with:

- None < 10% wall loss;
- Light 10% < depth < 25 % wall loss;
- Moderate 25% < depth < 50 % wall loss; and
- Heavy > 50 % wall loss.

Table 4. Corrosion Image Assessment Table

Zone	Corrosion Level	Actual Corrosion Depth Measurement
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

The corrosion levels found by the x-ray technology will be compared qualitatively to the levels found by the radiography camera and the actual corrosion depth measurements. The results will be discussed.

B1.1.3.2 Detection of Defects – Quantitative Results

Quantitative measures will be used to assess the performance of the x-ray technologies in measuring simulated corrosion anomalies on Pipe Sample 1. The image will be used to assess the following parameters:

1. Axial extent (length) in inches;
2. Circumferential extent (width) inches;
3. Number of pits (typically 2 or 3);
4. Axial extent of deepest pit (Pit length) in inches;
5. Circumferential extent of deepest pit (Pit width) in inches; and
6. Depth of deepest pit in inches.

The results will be tabulated for each defect (see Table 5). Actual measurements for the parameters listed in Table 5 have already been made in a previous mapping of the pipe.

Table 5. Simulated Corrosion Defect Assessment

	Radiography	X-Ray	Actual
Patch Length (inches)			
Patch Width (inches)			
Number of Pits			
Pit Length (inches)			
Pit Width (inches)			
Pit Depth (inches)			

For the drilled holes in the stainless steel Pipe Sample 2, the depth and diameter of each defect will be assessed (see Table 6). Actual measurements for the parameters listed in Table 6 will be taken using a micrometer and calipers, as discussed in Section B1.1.

A percentage error will be calculated for each measure in Tables 5 and 6. An error of +/- 10% of the wall thickness is generally accepted in the industry corrosion assessment. A percent difference will also be calculated between the results from the radiography camera and the x-ray technology for the specific corrosion and defect measurements listed in Tables 5 and 6 to compare the performance of the x-ray technology to that of the reference instrument results.

Table 6. Drill Hole Defect Assessment

	Radiography	X-Ray	Actual
Pit 1 Diameter (inches)			
Pit 1 Depth (inches)			
Pit 2 Diameter (inches)			
Pit 2 Depth (inches)			
Pit 3 Diameter (inches)			
Pit 3 Depth (inches)			

B1.1.3.3 Operational Factors

Operational factors such as maintenance needs, power needs, calibration frequency, data output, consumables used, ease of use, repair requirements, training and certification requirements, safety requirements, and image throughput will be evaluated based on testing observations and input provided from the vendor. Input will either be provided by the vendor on-site during the verification test and be recorded by Battelle staff or will be provided in documentation to the Verification Test Coordinator after completion of the verification test. To the extent possible, Battelle technical staff will also observe and record their own observations of these operational factors. Examples of information to be recorded include the daily status of diagnostic indicators for the technology, use or replacement of any consumables, use and nature of power supply needed to operate the technology, the effort or cost associated with maintenance or repair, vendor effort (e.g., time on site) for repair or maintenance, the duration and causes of any technology down time or data acquisition failure, observations about technology startup, ease of use, clarity of the user's instruction manual, user-friendliness of any needed software, overall convenience of the technologies and accessories/consumables, the safety hazard associated with the use of the technology, or the number of images that could be taken and processed per hour or per day. These observations will be summarized to aid in describing the technology performance in the verification report on each technology.

B1.2 Statistical Analysis

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

B1.2.1 Percent Error

The quantitative results will be assessed by calculating the percent error between the actual and measured defect characteristics. The pipeline industry typically normalizes the error to the wall thickness of the pipe rather than the actual reading[5]. This method is useful since small defects are not as important, but small errors on small defects can lead to large and misleading errors percentages when actual depths are used as the normalizing factor. Percent error will be calculated using the following equation:

$$\%Error = \frac{|Estimate - Actual|}{Wall\ Thickness} \times 100 \quad (1)$$

B1.2.2 Percent Difference

The quantitative results will also be assessed by calculating the percent difference between the measurements made by the x-ray technologies and the radiography camera. This evaluation, in conjunction with the qualitative parameters, will help in assessing the performance of the x-ray technology in relation to that of the reference instrument results. Percent difference will be calculated using the following:

$$\%Difference = \frac{(X\text{ - }Ray\ Technology\ Result - Radiography\ Camera\ Result)}{Radiography\ Camera\ Result} \times 100 \quad (2)$$

B1.3 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 technology's data set without reference to any other. At no time will data from different vendor's technology be compared or ranked. Following completion of the data evaluations, a draft verification report and verification statement will be prepared for each vendor's technology, stating the verification test procedures and documenting the performance observed. 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. The results of the verification test will be stated quantitatively, without comparison to any other technology tested, or comment on the acceptability of the technology's performance. Each draft verification report will be submitted for review by the respective technology vendor and by EPA and other peer reviewers. Comments on the draft report will be addressed in revisions of the report. The peer review comments and responses will be tabulated to document the peer review process. 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

Samples in the form of pipe defects in a field environment will be detected by the x-ray technologies in real time. The reference method will collect information on the same defects. All pipe defects will be analyzed on-site. No samples will be collected, stored, or shipped as part of this verification test.

B3 SAMPLE HANDLING AND CUSTODY REQUIREMENTS

No samples will be collected, stored, or shipped as part of this verification test.

B4 REFERENCE METHOD

A radiography camera will be used as the reference method for this test. The radiography camera will be used to collect images of the same pipeline defects that the x-ray technology will evaluate. This radiography camera will be part of a computed radiography system that will provide digital images to Battelle. The radiography camera will be operated by a licensed and properly certified radiographer that will meet all appropriate state safety requirements for operation of a sealed-source technology. Battelle will hire a licensed subcontractor to conduct the reference analyses with the radiography camera. It is expected that film will be used to collect the image. Efforts will be made to use plates similar to those being used by the x-ray technology.

The radiography camera operator will follow the specified operation of the particular radiography camera used per the instruction manual for that camera. Interpretations of the

images from the reference analyses will be provided to Battelle in either digital or hardcopy form. The images taken of the defects using the reference method will also be provided to Battelle by the subcontractor. The QA/QC requirements for the documentation and performance of the analytical method are described as data quality indicators (DQI) in Section B5.

B5 QUALITY CONTROL CRITERIA FOR REFERENCE METHOD MEASUREMENT DATA

Table 7 presents the DQIs and criteria for the reference method measurements. The reference method measurement quality will be assured by adherence to these DQI criteria.

Prior to starting the reference sampling, the radiography camera will be calibrated according to the manufacturer's specified procedure, if applicable. On each day of testing the device will be calibrated, if applicable.

Table 7. DQIs and Criteria of Critical Measurements for Reference Method

DQI	Method of Assessment	Frequency	Minimum Acceptance Criteria	Corrective Action
Confirmation of Detected Defects	Identification of defect in appropriate location and of appropriate size in accordance with known mapping of defect	All field test samples	N/A	Data considered suspect and reanalyzed
Image Quality	Image Quality Indicator (IQI) or comparator, as applicable	Each image	Sensitivity of 2% or 2-2T is met, the correct penetrameter hole/wire is discernable, or meets applicable and accepted IQI standards, such as ASTM E-94[3] or those specified in the radiography camera subcontractors SOP	Re-image feature

B6 INSTRUMENT/EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE

The reference equipment, micrometer, and calipers used in this test will be tested, inspected, and maintained as per the manufacturer's recommendations so as to meet the performance requirements established in this document.

B7 INSTRUMENT CALIBRATION AND FREQUENCY

Prior to start of the reference sampling, the radiography camera, micrometer, and calipers will be calibrated according to the manufacturer's specified procedure, as applicable. The micrometer and calipers are generally calibrated at least annually. Prior calibration within a year before testing will satisfy the calibration requirement for these instruments. The participating x-ray technology will be calibrated by the operator or vendor according to the technology's specified procedures. If possible, this calibration will be performed on-site prior to testing.

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, or the vendor.

B9 NON-DIRECT MEASUREMENTS

No non-direct measurements will be used during this verification test.

B10 DATA MANAGEMENT

Various types of data will be acquired and recorded electronically or manually by Battelle during the verification test. Table 2 summarizes the types of data to be recorded. All maintenance activities, repairs, calibrations, and operator observations relevant to the technology operation will be documented by technical staff in LRBs or on data sheets. Results from the reference method, including raw data, analyses, and final results, will be compiled by Battelle.

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 designated person by adding his/her initials and date to the hard copy of the record being reviewed. A technical review of 100% of the test and reference data produced will be conducted. In addition, any calculations performed by technical staff will be 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. Results for technologies from different vendors will not be compared with each other.

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 QA Manager (or his designee) of at least 25% of the test data. During the course of any such audit, the Battelle QA Manager will inform the technical staff of any findings and any need for immediate corrective action. If serious data quality problems exist, the Battelle QA 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 QA Manager will ensure that a follow-up corrective action has been taken.

Data obtained during the verification test will be maintained confidentially at Battelle, and used only for purposes of the technology verification. Data reporting in the final report will consist of tabular results of the calculations in Section B.

It is anticipated that testing of an x-ray technology will take place in one day. As such, Battelle will provide technology test data and associated reference data (including records; data sheets; notebook records) within 2 weeks of generation to EPA. The goal of this data delivery schedule is prompt identification and resolution of any data collection or recording issues.

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 QA 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.

Any changes to the approved test/QA plan must be reported within 24 hours and documented in a formal deviation submitted to the Battelle AMS Center Manager, EPA AMS Center Project Officer, and EPA AMS Center Quality Manager. If approval by EPA or its designee is not received within 24 hours of notification, testing will be halted until a suitable resolution has been achieved.

C1.1 Performance Evaluation Audits

Because of the nature of the samples to be evaluated in this verification test (i.e., defects on a pipe), a Performance Evaluation (PE) audit will not be conducted as PE audit samples are not available.

C1.2 Technical Systems Audits

The Battelle QA 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] this test/QA plan, and any Standard Operating Procedures (SOPs) used by Battelle. In the TSA, the Battelle QA Manager or a designee may review the reference method used, compare actual test procedures to those specified or referenced in this plan, and review data acquisition and handling procedures. The Battelle QA Manager will tour the test site, observe and review the test procedures, and review record books. He will also check calibration certifications for test measurement devices. A draft TSA will be prepared within 2 weeks of performance of the TSA and sent to EPA. The final TSA report will be prepared, include a statement of findings and the actions taken to address any adverse findings. 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 QA Manager will audit at least 25% of the verification data acquired in the verification test. The Battelle QA 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 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 audits (both TSA and ADQ) will be submitted to EPA. Audit reports may include the following:

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

C2 REPORTS TO MANAGEMENT

The Battelle QA Manager, during the course of any 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 QA Manager is authorized to request that Battelle's AMS Center Manager issue a stop work order. Once the audit 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 QA Manager will ensure that follow-up corrective action has been taken. The test/QA plan and final report are reviewed by EPA AMS Center QA staff and EPA AMS Center program management staff. 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 two 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.

The data validation requirements for this test involve a data quality audit relative to the DQIs and audit acceptance criteria specified for this test. The DQIs listed in Section B5 will be used to validate the data quality. The QA audits described within Section C of this document, including the performance evaluation audit and data quality audit, are designed to validate the data quality.

D2 VALIDATION AND VERIFICATION METHODS

As part of the normal data and report review process the US EPA 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 (i.e., for analytical instrumentation) 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 TSA as described in Section C. The data from this test will be evaluated relative to the measurement DQIs described in Section A4 and B5 of this test/QA plan. Data failing to meet these criteria will be flagged in the data set and not used for evaluation of the technologies, unless these deviations are accompanied by descriptions of their potential impacts on the data quality.

A data quality audit will be conducted by the Battelle QA 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 technologies which detect defects in pipelines used in the oil and gas industry in a simulated field environment. This test evaluates the non-radioactive source x-ray technology capabilities. This evaluation will include comparisons of the results from the technologies to results from the standard reference technique, radiography cameras. To meet the requirements of the user community, 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 participating 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. Environmental Technology Verification Program Quality Management Plan, EPA/600/R-08/009, U.S. Environmental Protection Agency, Cincinnati, Ohio, January 2008.

3. ASTM Standard E-94, "Standard Practice for Radiographic Testing", ASTM International, West Conshohocken, PA, 2009.

4. American Petroleum Institute Standard 1163, "In-line Inspection Systems Qualification Standard, Edition 5", API Publications, Englewood, CO, August 2005.