ESTCP

TECHNICAL REPORT

ISO 14034 Verification Report and ISO 14034 Implementation Gap Analysis Report for Nanofiber-Based Low Energy Consuming HVAC Air Filters (ESTCP Project No. EW-201724)

Tim Hansen
Bill Chatterton
350Solutions, Inc.

May 2024

ESTCP Project EW20-5333

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
04-05-2024	Technical Report	Apr 2020 - Apr 2024

4. TITLE AND SUBTITLE

ISO 14034 Verification Report and ISO 14034 Implementation Gap Analysis Report for Nanofiber-Based Low Energy Consuming HVAC Air Filters (ESTCP Project No. EW201724)

5a. CONTRACT NUMBER
W912HQ20C0007

5b. GRANT NUMBER
NA

5c. PROGRAM ELEMENT NUMBER
NA

6. AUTHOR(S)
Tim Hansen, Bill Chatterton

5d. PROJECT NUMBER
EW20-5333

5e. TASK NUMBER
NA

5f. WORK UNIT NUMBER
NA

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

350Solutions, Inc.
1053 E Whitaker Mill Rd
Raleigh, NC 27604

8. PERFORMING ORGANIZATION REPORT NUMBER
EW20-5333

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of the Deputy Assistant Secretary of Defense (Energy Resilience & Optimization)
3500 Defense Pentagon, RM 5C646
Washington, DC 20301-3500

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
EW20-5333

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution Statement: Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The project was designed and executed to integrate the ISO 14034 - Environmental Technology Verification (ETV) standard into existing ESTCP processes and projects to provide an example of how the ISO standard implementation works, how it can integrate with ESTCP processes, and its potential benefits in supporting technology transition. The primary objectives of this project were to utilize the ISO 14034/17020 framework for ETV, establishing its relevance to demonstration projects within ESTCP via a gap analysis, and implementing the ISO ETV approach in initial ESTCP technology demonstrations and case studies as add-ons to two new or current ESTCP demonstration projects, and dissemination of results. ESTCP Project EW-201724, "Nanofiber-Based Low Energy Consuming HVAC Air Filters" was selected for an ISO 14034 verification under this project. Conducted by eSpin Technologies, the demonstration was completed at the Ft. Benning Military Base in Georgia and the Ft. Campbell Army Installation in Kentucky/Tennessee. At Ft. Benning, the demonstration was conducted using air handling units (AHUs) in the Martin Hospital and Starship Barracks facilities. At Ft. Campbell, AHUs within the Special Operations Building 6103 supported the demonstration. All testing and data collection methods were developed and executed by eSpin Technologies prior to selection for verification.

.

15. SUBJECT TERMS
Environmental Technology Verification, ETV, ISO 14034

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Tim Hansen
Unclass	Unclass	Unclass	Unclass	65	19b. TELEPHONE NUMBER *(include area code)* 919-536-8756

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

TABLE OF CONTENTS

Page

Acronyms and Abbreviations

acfm	actual cubic feet per minute
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating, and Air-conditioning Engineers
CFM	Cubic feet per minute
COTS	Commercial off-the-shelf
DHC	Dust holding capacity
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
dP	Differential Pressure
ESTCP	Environmental Security Technology Certification Program
HVAC	Heating Ventilation Air Conditioning
ISO	International Standards Organization
Kg/yr	Kilogram/year
KWH	Kilowatt hours
LCCA	Life Cycle Cost Analysis
MERV	Minimum Efficiency Reporting Value
NIST	National Institute of Standards and Technology
O&M	Operation and Maintenance
PI	Principal Investigator
PO	Performance Objective
RH	Relative Humidity
T	Temperature
VAV	Variable Air Volume
VFD	Variable Frequency Drive
WC	Inches of water column

ISO 14034 VERIFICATION REPORT & ISO 14034 IMPLEMENTATION GAP ANALYSIS REPORT

for

Nanofiber-Based Low Energy Consuming HVAC Air Filters (ESTCP Project No. EW201724)

ESTCP Project No. EW20-5333: *Improving ESTCP Demonstration Outcomes & Tech Transfer via Integration of Standardized Third-Party Technology Verification using ISO 14034*

1. INTRODUCTION

ESTCP Project EW20-5333 is implementing the ISO 14034 Environmental Technology Verification (ETV) standard [1] to assess and demonstrate the potential for utilizing a standardized verification process framework for technology demonstrations that is internationally accepted and potentially provides improved outcomes for demonstration programs, as well as broader acceptance of technologies to encourage their broad adoption in the market. ISO 14034-backed demonstrations can potentially address some of the barriers that currently exist between technology demonstration and broad technology acceptance and deployment by providing third party verified, high-quality data, that meets stakeholder needs.

Complete project details are provided in the ESTCP Demonstration Plan "Improving ESTCP Demonstration Outcomes & Tech Transfer via Integration of Standardized Third-Party Technology Verification using ISO 14034" [2].

The standardized verification approach used for this assessment is outlined in the international standard – ISO 14034: 2016 - Environmental Technology Verification (ETV) [2]. The approach includes the following requirements that ensure that, if implemented properly and accepted by the community, interested parties have information they need to encourage more rapid acceptance, appropriate technology transfer, and broader implementation of validated technologies. The ISO 14034 ETV process includes:

- Standardized, consistent framework for technology evaluation;
- Requirement for verification of tech performance data by a qualified independent third party;
- Requirements for quality of data provided by test labs and other data providers, including meeting data quality and quality management requirements of other international standards;
- Mechanisms for stakeholder input at planning and verification stages to ensure those in the decision chain get information they need;
- Flexible, generic approach that allows same principles to be applied for different technology categories via development of specific Verification Plans for each technology and type;
- Broad applicability to a variety of technology types, applications, and interested party needs.

ISO 14034 integrates with two additional important standards to provide assurance of high quality data and competency and independence of testing organizations and technology verifiers:

- ***ISO 17020: Conformity assessment -- Requirements for the operation of various types of bodies performing inspection*** [3], which establishes qualifications for independent entities to perform verification work.
- ***ISO 17025: General Requirements for the Competence of Testing and Calibration Laboratories*** [4], to ensure data used in evaluation of new technologies meets consistent standards and is provided by qualified entities.

The primary objectives of this project are to utilize the ISO 14034/17020 framework for ETV, establishing its relevance to demonstration projects within ESTCP via a gap analysis, implementing the ISO ETV approach in initial ESTCP technology demonstrations and evaluating implementation benefits and potential issues, and disseminating the results to the market, including relevant end users, purchasers, regulators and funders.

ESTCP Project EW-201724, "Nanofiber-Based Low Energy Consuming HVAC Air Filters" was selected for an ISO 14034 verification under this project. Conducted by eSpin Technologies, the demonstration was completed at the Ft. Benning Military Base in Georgia and the Ft. Campbell Army Installation in Kentucky/Tennessee. At Ft. Benning, the demonstration was conducted using air handling units (AHUs) in the Martin Hospital and Starship Barracks facilities. At Ft. Campbell, AHUs within the Special Operations Building 6103 supported the demonstration. All testing and data collection methods were developed and executed by eSpin Technologies prior to selection for verification.

Part I: Example Verification Statement for EW201724 - eSpin Exceed Air Filters

ISO 14034 TECHNOLOGY VERIFICATION STATEMENT

350Solutions, Inc. has verified the performance of the eSpin nanofiber-based low energy consuming air filter:

Table VS1. Technology & Company Information		
Technology Supplier	**Technology Name / Model**	**Technology Test Location**
eSpin Technologies	Exceed Air Filter (pleated) MERV 8 and 13 tested in the following sizes: 24x24x2, 20x24x2, 24x24x4 20x24x4, 20x20x2, 20x20x4 12x24x2, 26x16x2, 27x16x2	Ft. Benning, GA: Starship Barracks AHU 17, 27,18, 28 Martin Amy Hospital AHU B-2, 4-2 Ft. Campbell, KY: Special Operations Bldg 6103, 6014

350Solutions verified that the demonstration utilized appropriate equipment, procedures, and protocols to quantify performance of the Exceed air filters as compared to standard commercial off-the-shelf (COTS) filters. The verified performance of the filters is summarized below:

Table VS2. Verified Performance – eSpin Exceed Air Filters				
Criteria	**Performance Criteria**	**Reported Performance**	**Verified Performance**	**Notes**
Air Filter Life	>1.5x current baseline filters	1.6x to > 4x (MERV 8 pre-filters) Equivalent to baseline filters (Post-filters)	>2x minimum	Filter life could be significantly longer than data indicates, but test duration does not allow for accurate determination, as Exceed filters and baseline post-filters were still viable at end of test periods.
Indoor Air Quality	5% reduction in particle concentration vs. baseline	20-35% reduction in Air Quality Index	20-35% Reduction in AQI	eSpin utilized AQI instead of particle concentration as an improved indicator of air quality. Air quality studies were inconclusive in two of the three facilities
Filtration Energy Usage	2% reduction in energy required	39-61% reduction in energy	Not verified	Qualitative and quantitative indications are that energy utilization is reduced. However, due to difficulties in comparing operating conditions, results are not verifiable.
Dust Holding Capacity	Exceed filters hold 5% more dust	4 – 38% more dust capacity	Not verified	For one set of air handlers, the dust holding capacity is nearly identical, and for the other set, apparent significant changes (38%) are observed. However, this includes data for post-filters with different MERV ratings. At a second facility, pre and post-filters showed different impacts on capacity and data is not verifiable.
Solid Waste Generation	>20% reduction in kg/yer filters disposed	60-75% reduction	>50% reduction	Filter life could be significantly longer than data indicates, but test duration does not allow for accurate determination, as Exceed filters and baseline post-filters were still viable at end of test periods.
Lifecycle Cost	>5% reduction in total cost per filter Simple payback <6 months	25-70% reduction in cost; 5 mo – 3.1 yr payback	Not Verified	Although likely accurate, significant assumptions were used to calculate LCC that were not verified, including labor costs, and disposal costs. In addition, unverified energy usage values are utilized in the calculations.

The reported performance results were obtained under certain operating conditions observed during the test periods at each site. Primary operating conditions of interest are summarized below:

Table VS3. Test Period Summary & Operating Conditions		
Test Location	**Test Period**	**Data Collection Duration (includes downtime)**
Ft. Benning – Starship Barracks (FTBS)	8/28/2019 – 2/19/2021	70 weeks
Ft. Benning – Martin Army Hospital (FBMH)	1/22/2020 – 10/18/2021	56 weeks
Ft. Campbell – Special Ops Bldgs. (FCSO)	9/6/2019 – 7/18/2021	60 weeks
Test Location	**Operating Conditions**	**Value**
Ft. Benning – Starship Barracks	Air Flow Rate	~1100-1800 acfm (AHU17/27) ~2200 acfm (AHU18-Exceed) / 3200 acfm (AHU28-COTS) (1.3x air flow in COTS filters)
	Temperature	60-80°F for all units (FTBS)
	Humidity	20-90% RH for all units
	Dust Level	Dust loading was variable
Ft. Benning – Martin Army Hospital	Air Flow Rate	~23,000 cfm (Exceed) / ~28,000 cfm (COTS)
	Temperature	~55-58°F
	Humidity	~30-70% RH (consistent for all units)
	Dust Level	Dust loading was variable
Ft. Campbell – Special Ops Bldgs.	Air Flow Rate	~8000-12000 acfm (Exceed) / ~6500 acfm (COTS)
	Temperature	~60-85°F
	Humidity	~10-70% RH
	Dust Level	Dust loading was variable

The eSpin Exceed Air Filter verification:

☐Meets the requirements of ISO 14034
☒ Partially meets the requirements of ISO 14034, with the following noted exceptions
☐ Does not meet the Requirements of ISO 14034, due to the following issues

The eSpin Exceed filter verification meets most requirements of the ISO 14034 standard, including primary instrumentation, measurement, and data quality requirements. However, due to the nature of the demonstration, requiring comparison of performance between separate air handling units operating under significantly different operating conditions, some data does not allow for direct determination of Exceed filter benefits vs. current commercial filters. In addition, uncertainty and statistical analysis should be applied to determine statistical significance of variations. Finally, it is preferable that the majority of data is collected by independent test personnel. However, considering the small size of the company and the significant efforts made to utilize quality, calibrated instrumentation with cross checks, the data is acceptable.

Additional details regarding the Production Facility and Output Audits can be found in the Verification Report – eSpin Exceed Nanofiber-Based High Efficiency Air Filters (Document ID 350VR-ES2001-01).

Table VS4. Verifier Information		
Verification Body	**Lead Verifier**	**Verification ID No.**
350Solutions, Inc.	Bill Chatterton, CMVP	350VS-ES2001-01

Signed: Bill Chatterton (Lead Verifier) Tim Hansen (Peer Reviewer)

ISO 14034 TECHNOLOGY VERIFICATION STATEMENT: Additional Information

TECHNOLOGY DESCRIPTION

eSpin has designed, developed, and demonstrated the benefits of nanofiber filtration media in the automotive and commercial markets. Continuous nanofibers with very small diameters (0.1-0.3µm), are produced using eSpin's electrospinning process and are integrated with conventional large diameter fibers to form a novel air filter media. eSpin claims that its nanofiber-based air filter has a low media density that reduces air flow restriction, small interstitial spacing between the nanofibers and a high surface area, making this novel filter media capable of efficiently capturing a wide range of pollutants such as toxic industrial pollutants, hexavalent chromium dust, pollen, microorganisms, oil, smoke, paint, salt particles near coastal areas, and more.

Compared to conventional state-of-the-art large diameter fiber-based filter media, eSpin claims its filter media requires less material to achieve the same capture efficiency as a conventional filter, resulting in lower pressure drop over the life of the air filter, higher dust holding capacity, and the ability to capture smaller particles more efficiently than conventional large diameter fiber-based media. Exceed® filters are claimed to be capable of capturing more dust, last longer, and reduce the HVAC fan energy needed to operate the system.

VERIFICATION DESCRIPTION

The eSpin Exceed air filters were demonstrated in three separate test locations for over 50 weeks at each location. Test locations and conditions are summarized in Table VS3. Data was collected through continuous logging and remote monitoring of a data acquisition system that was connected to a series of instrumentation, including pressure, relative humidity, temperature sensors, particle counters, and power meters.

Verification activities were conducted by 350Solutions to independently verify the facility, equipment, filters used, operations, data, and claims. The verification was conducted following the ISO 14034 Verification Plan – Nanofiber-based Low Energy Consuming HVAC Filters v 1.4 (350Solutions). The Verification audit consisted of a site visit to Ft. Benning Starship Barracks and Martin Army Hospital in July, 2021. Output data was reviewed and verified remotely based on observation of on-site activities during the site visit.

DATA QUALITY

350Solutions is an ANAB-accredited ISO/IEC 17020:2012 independent inspection body for ISO 14034:2016 Environmental Technology Verification. 350Solutions Quality Management Plan and Quality Systems Procedures apply to activities associated with the ISO 14034 Verification. The data quality assessment includes, but is not limited to:

- Data quality assessment for the specified performance and claims;
- Assessment of ancillary data quality (operations, relevance, and representativeness);
- Performer competence (testing and analytical providers);
- Sampling and analytical procedures (repeatability, accuracy, measurement equipment calibration and quality checks); and
- Data management and processing.

In broad terms, the data provided by eSpin technologies to verify the Exceed air filter performance was found to be of high quality from a measurement and data collection standpoint. Instruments were

of required quality, calibrations were purchased, instrument cross checks completed, data collection was excellent, despite minor data drop out or instrument issues. However, issues with the test application and host site operations resulted in inability to verify specific values due to inconsistencies in operating conditions and filter specifications. Specifically:

- Testing occurred in real world applications, where air handler units in similar locations under similar operating conditions were selected to enable comparison. However, in many instances, the operating conditions ended up not being similar (i.e. air flows), resulting in significant differences. Attempts to normalize data were difficult and non-standard.
- For a portion of the test period at two locations, COTS post-filters of the correct MERV rating were not installed due to facility issues, so post-filter comparison for data collected in this period is not appropriate. Matching MERV rating filters were eventually installed, and data comparison could be done for these specific test periods only, if adequate data is available.
- At one location, testing was terminated by the facility. In addition, at this facility, the COTS filters were changed on a standard schedule, regardless of performance, and filter management was completed in such a way that consistent data collection was very difficult.

Requirements and recommendations for improvement of data quality are provided in the Verification Report. All findings of the data quality review support verification of the performance claims indicated in Table VS2 and conform to the requirements of the standards.

Part II: Technology Verification Report for EW 201724

ISO 14034 TECHNOLOGY VERIFICATION REPORT

DEMONSTRATION OF ESPIN NANOFIBER-BASED LOW ENERGY CONSUMING HVAC AIR FILTERS (ESTCP Project No. EW-201724)

1 INTRODUCTION & TECHNOLOGY DESCRIPTION

The US Department of Defense Environmental & Security Technology Certification Program (ESTCP) has sponsored the demonstration of eSpin's Exceed® air filters for heating, ventilation, and air conditioning (HVAC) systems under project number EW-201724 entitled "Nanofiber-Based Low Energy Consuming HVAC Air Filters". The objective of this demonstration is to show that the technology can lower the annual operation and maintenance (O&M) costs of heating ventilation and air-conditioning (i.e., HVAC) systems while delivering cleaner air to occupied spaces. For this demonstration, eSpin conducted operational comparisons of Exceed® filters versus commercial off-the-shelf (COTS) filters currently used at two selected test sites. The filters planned for evaluation primarily focused on pleated air filters found in many typical HVAC units.

The demonstration consisted of determination of air filtration system performance and air filter energy consumption via measurement of differential pressure across the filters, flow velocity, temperature and humidity of the air passing through the filters and the dust holding capacity of the filters. Additionally, the eSpin team measured indoor air quality and air filter efficiency via particle counters placed upstream and downstream of the filters and reported counts of particulate matter having diameters less than 10 microns and less than 2.5 microns (PM_{10} and $PM_{2.5}$, respectively) as a comparative analysis.

Complete project details are provided in the ESTCP Demonstration Plan "Nanofiber-Based Low Energy Consuming HVAC Air Filters" [5] and "Final Report: Nanofiber-Based Low Energy Consuming HVAC Filters" draft version dated June, 2022.

1.1 TECHNOLOGY OVERVIEW

eSpin has designed, developed, and successfully demonstrated the benefits of nanofiber filtration media in the automotive and commercial markets. Continuous nanofibers with very small diameters (0.1-0.3µm), are produced using eSpin's state-of-the-art electrospinning process and are integrated with conventional large diameter fibers to form a novel air filter media. eSpin claims that its nanofiber-based air filter has a low media density that reduces air flow restriction, small interstitial spacing between the nanofibers and a high surface area, making the filter media capable of efficiently capturing a wide range of pollutants such as toxic industrial pollutant-hexavalent chromium dust, pollen, microorganisms, oil, smoke, paint, and more.

Compared to conventional state-of-the-art large diameter fiber-based filter media, eSpin claims that its filter media requires less material to achieve the same capture efficiency as a conventional filter, resulting in lower pressure drop over the life of the air filter, higher dust loading capacity, and the ability to capture smaller particles more efficiently than conventional large diameter fiber-based media. Exceed® filters are claimed to be capable of capturing more dust, lasting longer, and will reducing the HVAC fan energy needed to operate the system.

The air filter media development process is key to the manufacturing and assembly of the air filters used in this demonstration. In an electrospinning process (Figure 1), electrical charge is concentrated on the surface of a dielectric liquid (i.e., a polymer solution). Under a sufficient potential difference, the liquid is ejected in the form of jets from the electrode and is attracted to a grounded target (i.e., a moving belt).

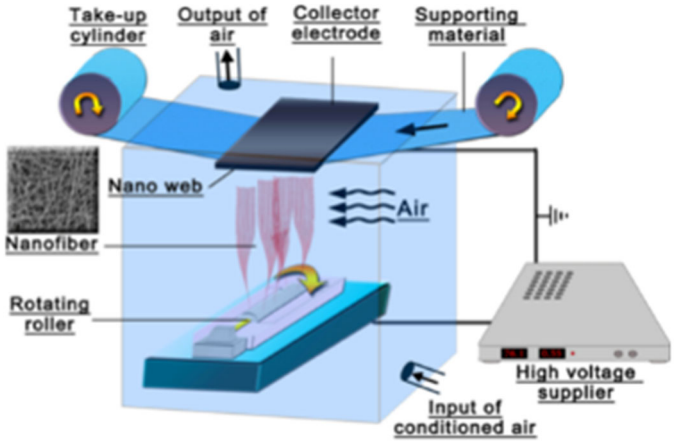

Figure 1. eSpin nanofiber filter production process

As the jet accelerates under the electrical force, the diameter reduces (i.e., the fiber elongates) in size, the jet fractures (i.e., splays) into many fine jets as a result of surface instabilities (i.e., very similar to lightning). These fine jets lose the solvent via surface evaporation, and form polymer nanofibers that are collected as nonwoven fibers on the moving belt. The diameter of individual nanofibers produced by electrospinning is typically about 1/100th of commonly used textile fibers. Filtration media is packaged in custom packaging for each specific application, and, for this demonstration, was primarily packaged as pleated filter type typically used in residential and commercial HVAC systems.

Figure 2. Example eSpin pleated filter (after use)

1.2 DEMONSTRATION OVERVIEW

1.2.1. Host Sites

The eSpin Exceed air filter demonstration was completed at three separate test locations, two located at Fort Benning, Georgia, and one located at Fort Campbell, Kentucky. With Ft. Campbell being located in ASHRAE Climate Zone 4 and Ft. Benning in ASHRAE Climate Zone 3, climatic conditions at both locations are hot and humid during the summer and cold and dry during the winter. These climate conditions affect the loading of air filters in the HVAC units serving buildings at these locations.

At the installations supporting the demonstration, 8 representative AHUs were selected for testing to assess performance over a range of applications and at two minimum efficiency rating value (MERV) ratings, as summarized in Table 1.

Table 1. Summary of Demonstration Facilities

Facility	AHU ID[1]	HVAC Application	Existing MERV rating	Verified Demonstration Period[2]
Ft Benning - Starship Barracks	17 (Exceed filters) and 27 (COTS filters)	Sleeping quarters	8 pre-filters, 13 post-filters	8/28/2019 – 2/19/2021
	18 (Exceed filters) and 28 (COTS filters)			
Ft Benning – Martin Army Hospital	AHU4-2 (Exceed filters) and AHUB-2 (COTS filters)	Outside Operating Room (OR Ring)	8 pre-filters, 13 post-filters	1/22/2020 – 10/18/2021
Ft Campbell – Special Ops Buildings	Building 6104 (Exceed filters) and Building 6103 (COTS filters)	Special operations facilities	8 pre-filters, 13 post-filters	9/6/2019 – 7/18/2021

[1] *Each AHU selected for the demonstration were variable air volume (VAV) type handlers with two stage filtration (pre- and post-filters).*

[2] *For each demonstration location, data was collected during this entire test period. However, there were instances of equipment downtime, data dropouts, and data outliers, such that data may not be representative of the entire period.*

On each of the AHUs listed, operational and performance data were collected continuously during the periods summarized in Table 1. Data was recorded at 30 second intervals and logged remotely to a dedicated server for processing at 5-minute intervals.

Additional detail regarding the host facility and specific demonstrated equipment installations is also provided in the EW-201724 Demonstration Plan and Final Technical Report.

1.3 VERIFICATION OVERVIEW

1.3.1. Verification Participants and Roles

The organizations and individuals participating in the verification are as follows:

Applicant: eSpin Technologies, Inc.
7151 Discovery Drive, Chattanooga, TN 37416
http://www.espintechnologies.com/
Lead Contact: Dr. Jayesh Doshi
jdoshi@espintechnologies.com

Verifier: 350Solutions, Inc.
1053 E Whitaker Mill Rd., Suite 115, Raleigh, NC 27604
www.350Solutions.com
Accreditation: ISO/IEC 17020:2012 and ISO 14034
ANAB Accreditation Certificate No. AI-2618
Lead Contact: Tim Hansen, PI
tim@350solutions.com

Stakeholder: ESTCP – Installation Energy and Water
4800 Mark Center Drive, Suite 16F16, Alexandria, VA 22350-3605
https://www.serdp-estcp.org/Program-Areas/Installation-Energy-and-Water
Lead Contact: Timothy Tetreault
timothy.j.tetreault.civ@mail.mil

As the technology developer, eSpin identified the technology and operational applications and conditions under which performance verification was conducted, as well as performance claims to be verified. eSpin provided design, operational, and performance specifications and data to support the verification.

350Solutions: As the accredited verifier, 350Solutions designed and conducted all verification activities including the following:

- Review of verification application (waived for this demonstration);
- Initial request for additional information required for application completeness and verification planning;
- Review of applicant performance claims and verifiability,
- Development of verification objectives and plan,
- Verification of applicant submitted performance data and supporting data quality,
- Completeness assessment with respect to performance claims and objectives, determination of need for additional data or testing,
- Final performance claims verification,
- Preparation and submittal of Verification Report and Statement, and

The lead verifier was Bill Chatterton, with overview and document review conducted by Tim Hansen, PI and CEO of 350Solutions. Mr. Chatterton was responsible for executing the verification approaches and procedures specified in this Verification Plan.

2 VERIFICATION OBJECTIVES AND PROCESS

The primary objectives of this project were to apply the ISO 14034/17020 framework for ETV to representative ESTCP demonstration projects to facilitate:

- Examination of a standardized approach to verification of performance of technology categories;
- Broader acceptance and dissemination of ESTCP demonstration results in the market, including relevant end users, purchasers, regulators and funders;
- A gap analysis identifying differences between the requirement of the ESTCP demonstration program and the ISO Standard, and the potential impact of these gaps.

Note: This verification was not anticipated to be fully ISO 14034 compliant. A significant goal of this verification was to determine the differences and gaps between the existing ESTCP Demonstration Program requirements and the ISO 14034 standard requirements, which can inform future ESTCP program guidelines and protocols to enable future compliance with ISO 14034.

This Verification Report should not be considered a final ISO 14034 verification, but an example of a verification and a tool that is utilized to determine future ESTCP process improvements and potential for integration of ISO 14034 and other standards in test and demonstration guidelines.

The verification process used here was based on 350Solutions' Standard Operating Procedure (SOP) QSP-350-223-02: "ISO 14034 Environmental Technology Verification" [6], and the ISO Technical Committee 207 draft guidance document "*Environmental technology verification — E.T.V — Guidance to implement ISO 14034*" [7]. The objectives and approaches used for this verification are designed to apply these principles and processes to verification of eSpin's performance claims with respect to the ESTCP demonstration, and to facilitate the resulting gap analysis.

2.1 VERIFICATION OBJECTIVES

The primary objectives of the verification were:

- To verify key quantitative performance claims made by eSpin as represented by the performance objective success criteria defined for the ESTCP demonstration with respect to the ETV requirements of the ISO 14034 Standard; and,
- To assess the gaps between the verification requirements of the ISO Standard and the requirements of demonstrations under the ESTCP program.

The demonstration was designed to show that eSpin's Exceed® filters with nanofibers can lower the annual operation and maintenance (O&M) costs of heating ventilation and air-conditioning

(i.e., HVAC) systems while delivering cleaner air to occupied spaces. For this demonstration eSpin conducted operational comparisons of Exceed® filters versus COTS filters currently used at two selected test sites, at three total facilities. The filters to be evaluated primarily included pleated filters found in many HVAC units.

Table 2 below lists the performance objectives and the metrics by which the performance objectives were measured and evaluated.

Table 2. Performance and Verification Objectives

Quantitative Performance Objectives				
Performance Objective		**Metric (Units)**	**Data Requirements**	**Success Criteria**
1	Life Cycle Cost (LCC)	Operational costs of the filters in tested HVAC units over their useful life **($)**	Initial filter costs, energy consumption costs, labor costs, maintenance costs, solid waste disposal costs	>5% reduction in total costs per filter SPP target: 6 months
2	Air Filter life (AFL)	Length of time filters retain their useful life without exceeding the manufacturer's threshold pressure drop **(Days)**	# of Days Exceed® filter outlasts current filters	Exceed® filter life > 1.5x current filters
3	Indoor Air Quality (IAQ)	Particle counts reported in (**µg/m³**)	Particle counts of air upstream and downstream of the filters	5% µg/m³ particle concentration reduction compared to conventional air filters
4	Filter Energy	Energy consumed by air filters due to flow work (**kWh)**	Differential pressure (dP) across filters and air flow through filters	2% reduction in filter energy compared with COTS filters
5	Dust Holding Capacity (DHC)	Difference in the mass of the filters before and after the test (**g**)	Mass of the filters in grams	Exceed® filters hold 5% more dust by mass
6	Solid Waste (SW)	Non-hazardous solid waste sent to landfill (**Kg/yr**)	Solid waste disposal data based on # of filters changed per cycle	>20% reduction in kg/yr of filters disposed of compared to current amounts

During the demonstration period, eSpin assessed air filtration system performance and air filter energy consumption by measuring:

- differential pressure across the filters,
- supply air flow velocity,
- supply air temperature and humidity
- supply air and post-filtration air particulate count (PM-2.5 and PM-10)
- filter weights (for filter dust holding capacity determination).

The design for these tests was that of a side-by-side comparison (or short-term sequential test) of Exceed® and COTS filters. Use of COTS filters and their associated costs and performance

represents the demonstration baseline. Full details regarding the demonstration's conceptual test design, characterization of the baseline approach used to assess technology performance, design and layout of system components, operational testing, and sampling protocols is provided in the Demonstration Plan "Nanofiber-Based Low Energy Consuming HVAC Air Filters".

2.2 VERIFICATION DATA AND PARAMETERS

Verification data and parameters used to evaluate technology performance with respect to the performance objectives were assessed quantitively using data generated during the ESTCP demonstration. Table 3 summarizes the measurement approach used for the demonstration. Details of specific verification activities are provided in Section 2.5.

Table 3. Summary of Verification Parameters

Verification Parameters	Performance Criteria	Data Types	Data Source(s)
Life Cycle Cost (LCC) Air Filter life (AFL)	>5% reduction in total costs per filter SPP target: 6 months	Initial filter costs, energy consumption costs, labor costs, maintenance costs, solid waste disposal costs	Procurement records, host facility labor and maintenance records, facility disposal records
Indoor Air Quality (IAQ) Filter Energy	Exceed® filter life > 1.5x current filters	# of Days Exceed® filter outlasts current filters	Host facility maintenance records, AHU air flow, differential pressure, and energy consumption field data
Dust Holding Capacity (DHC)	5% µg/m³ particle concentration reduction compared to conventional air filters	Particle counts of air upstream and downstream of the filters	Host facility maintenance records, AHU air flow and particle counter field data
Solid Waste (SW)	2% reduction in filter energy compared with COTS filters	dP across filters and air flow through filters	Air flow, differential pressure, and AHU power use field data
Life Cycle Cost (LCC)	Exceed® filters hold 5% more dust by mass	Mass of the filters in grams	Host facility maintenance records, AHU air flow and particle counter field data
Air Filter life (AFL)	>20% reduction in kg/yr of filters disposed of compared to current amounts	Solid waste disposal data based on # of filters changed per cycle	host facility maintenance records, facility disposal records

2.3 VERIFICATION PROCESS

For the purpose of ETV under ISO 14034, verification is defined as confirmation through the provision of objective evidence that the environmental technology performs as claimed under specified conditions, taking into consideration any measurement uncertainty and relevant assumptions. When performing this verification, verifiers assessed the conditions under which the technology performance demonstration was conducted, data quality, data management, and the overall ability to make definitive statements regarding the established verification

parameters. This approach allows the verifiers to:

- Assess the applicability and relevance of the existing test data for verification;
- Conduct a gap analysis with respect to activities conducted under the ESTCP demonstration and the requirements of the ISO standard;
- Make decisions on the need to generate new test data;
- Define measures and requirements to assure the quality of the test data;
- Verify technology performance with respect to the performance claims.

Verification checklist templates based on the requirements of the appropriate standards are used to guide the verification activities and assessment of the demonstration. A separate checklist shown in Appendix B summarizes the gap analysis by comparing the verification findings with the requirements of the ISO standards.

2.4 VERIFICATION ACTIVITIES

The verification included three primary tasks including development of verification objectives and plans, verification of technology performance claims and reporting, and an ISO 14034 conformity gap analysis. Since the demonstration data collection period was near completion at the time of verification planning, performance verification was limited to data generated by the demonstrating party (eSpin). Using data determined to be relevant to the performance claims and of sufficient quality to support verification, verifiers assessed the verifiability of the claims.

Prior to the end of the demonstration period, verifiers conducted on-site observations of measurement equipment and operation at the Ft. Benning demonstration site on July 14, 2021. Specifically, verifiers conducted:

- Interviews with base Energy Managers to verify satisfaction with demonstration activities, technical and economic performance of the filters, and technology operability.
- Observations of AHUs used for demonstration activities, location and use of critical demonstration measurement instrumentation.
- Observations of data generation and collection, and traceability of raw data to performance calculations.

Field verification included but was not limited to a detailed audit of critical measurements and associated instrumentation, as well as data produced by such instrumentation and their use in calculation of team performance and competition Verification Parameters. A critical measurement is defined as a specific input into the calculation of a performance claim and would include, for example, measurements leading to values for filter life, energy savings, or dust capacity.

Specific verification activities conducted, and technology performance information verified, are detailed in a series of Verification Activities and Checklists. These checklists guide the

verification and, when executed following the Verification Plan, result in independent and defensible verification data with respect to technology performance.

A summary of activities is provided below:

Table 4. Verification Activities

Date(s)	Verification Activity	Verification Tasks
Jan - June, 2021	Preparatory Discussions, Demonstration Plan review, Verification Plan development	- eSpin ESTCP Demonstration Plan review - Verification Plan development and review - Review of documents, drawings, and equipment/instrument specifications - Review of equipment, calibrations, and measurements details - Review of performance objectives, critical measurements, instrumentation - Review of data analysis and validation procedures
7/14/2021	Site visit – Fort Benning	- Opening meeting and process walk through - Witness of operations, measurement points, and instrumentation – Fort Benning Starship Barracks and Martin Army Hospital - Verify critical measurements and performance parameters - Review of equipment, calibrations, and measurements details - Review of data collection and calculation of parameters
7/14/2021 – 8/30/2022	Review of final submitted data and supporting documentation	- Review of data collection and calculation of parameters - Review traceability from raw data through data collection, processing/reduction, validation, analysis and reporting steps - Review and verification of Final Technical Report and final performance objective / verification performance parameter values submitted by eSpin - Final review of data quality and completeness - Preparation of verification report and statement

2.4.1.Verification of Existing Performance Data

Following the General Review Checklist**,** verification activities included full review of a representative set of demonstration data to confirm the adequacy and relevance of the testing and results with respect to assessment of the performance claims. Verifiers reviewed and documented essential requirements of verification data to enable assessment and completion of the verification process. The following specific verification activities were conducted:

A summary of primary activities conducted during each phase during the testing and demonstration period is provided below to document primary activities that occurred during the test period and on-site visits.

Large amounts of measurement data and operational records were compiled during the ESTCP demonstration of the eSpin technology. Verifiers reviewed the available volume of data collected, test periods, logging frequency, number of units tested, etc. Subsets of these data (a full data analysis spreadsheet for the entire demonstration period at one of the monitoring sites (Ft Campbell)) were reviewed to verify the following characterizations:

- Relevance: Review of the specifications and operations of the units used for the demonstration to verify representativeness and relevance, variability in operations, completeness of data collection for supporting field measurements during the period, and variability in performance;
- Level of consistency between installation and operations of AHUs equipped with Exceed and COTS (baseline) filters;
- Quality control and assurance activities and documentation; and
- Conformance to ASHRAE 52.2 procedures for determination of particle removal efficiency.

Upon data validation and following the Data Analysis and Interpretation and Data Quality review Checklists, the verifier then reviewed the technology performance data to determine whether the data meet the objectives of the verification process. The data related to the technology must be of sufficient quality and quantity to permit statistical analysis of the data in relation to the performance claim. The result of the verification represents a confirmation of the performance of the technology.

Specifically, verifiers:

- To the extent possible, the calculations used to transform raw field data to performance metrics were verified (the complex nature of much of the calculations - completed using custom program eSpin programming - precluded full verification of all data and calculations);
- To the extent possible, partially verified the calculations used to determine test results with respect to the performance claims;
- Conducted statistical analyses of results to evaluate results uncertainties with respect to performance claims.
- Examined baseline performance data and relevance with respect to operations and operational conditions;
- Reviewed and assessed AHU monitoring and data generation and records;
- Reviewed data collection, validation, and management procedures;
- Reviewed assessment of performance parameters using data generated during the demonstration;
- Reviewed instrument specifications, including accuracy and calibration and impacts on data quality.

2.4.2.Data Analysis

To the extent possible, given the level of information made available to verifiers, the verification included a representative assessment of data analysis to verify demonstration findings with respect to the Performance Claims are supported by valid field measurements generated during the demonstration period. Verifiers:

- Reviewed traceability from raw data through data collection, processing/reduction, validation, analysis and reporting steps.
- Validated that all relevant data is properly validated, stored, and utilized for required calculations.
- Reviewed that the impact on data quality of any noted calibration, QA/QC, or process deviations is properly accounted for and reflected in reported results.
- Reviewed demonstration procedures in place to ensure impact on data quality of deviations is assessed and addressed
- Reviewed that reported results are based on valid data that is representative of actual process performance.

2.4.3.Assessment of Data Quality

To verify validity of field data collected during the demonstration, verifiers attempted to review instrument specifications, data analysis procedures, testing procedures and personnel qualifications, and data validation process to ensure impacts on final results and data quality are understood and documented.

Where available, verifiers reviewed operational and accuracy specifications of measurement instrumentation and sensors used for critical measurements used to assess the performance objectives and metrics of the demonstration. This review included:

- Review of critical equipment and sensor list and specifications,
- Locations of critical measurements in AHU systems,
- Documentation of equipment rated accuracy and calibration processes before or during use in the demonstration.

Where available, verifiers reviewed data collection procedures and data validation processes to ensure only representative data was used in final analyses, and outliers were eliminated where possible, and that data subsets were not selected to provide only selective results.

Where available, verifiers reviewed the execution and results of statistical analyses planned for the demonstration including those specified in the EW-201724 Demonstration Plan.

2.4.1. ISO 14034 Conformance

Following ISO 14034 guidance, data supporting the verification of the technology performance was examined to determine if it was of sufficient quality such that the verified results meet the decision-making needs of all parties with an interest in the technology. In conformance with ISO 14034 requirements, test data generated during the demonstration are deemed acceptable for the verification if they meet the following requirements:

- Are relevant for the performance to be verified,
- Are produced and reported according to the requirements of ISO/IEC 17025, and
- Meet the requirements specified in the verification plan.

Key review components and corresponding ISO 14034 section references that were reviewed during this verification include the following:

Requirements relevant to the organizations that conducted the testing:

4.1 Impartiality – assessment of verifier and test body impartiality with respect to the technology.

6.2 Personnel – procedures for or documentation of personnel competencies.

8 Management requirements – certification of ISO 9001 accreditation or equivalent management practices.

Requirements relevant to the data supporting this verification:

6.6 Metrological traceability:

6.6.1 sample chain of custody records for off-site analyses or transport of collected samples.

6.6.2 traceability to NIST, or other appropriate reference standards.

7.2 Verification or validation of methods used – Citation to reference methods or demonstration of method validation.

7.3.4 Records of relevant test or sample data where applicable (sample ID, dates received/analyzed, relevant environmental conditions, etc.).

7.4 Documentation of processes for procurement and management of calibration standards.

7.5 Technical records – traceability records from sample receipt through analysis and reporting.

7.6 Measurement uncertainty – processes and records for evaluation of uncertainty for equipment calibrations and analytical results.

7.8 Quality of results – procedures or processes for monitoring of the validity and quality of results:

- Equipment maintenance plans and routine functionality checks,
- Regular use of calibration standards and metrological traceability,
- Quality control procedures: Instrument calibrations, blank and blind sample challenges.

7.9 Reporting of results – complete testing and analytical reports:

- identifies client, sample ID, dates, method citations, parameters, results, other pertinent information,
- references to QA/QC procedures and calibration standards and procedures,
- includes or cites availability of standards and calibration certifications.

Verifiers also verified test results using these approaches:

1) Validation of field measurements via assessment of method conformance and equipment calibrations,
2) Review of data collection, recording, and management processes,
3) Audit of calculation of test parameter results (i.e., reconcile reported test results with field measurements),

3 VERIFICATION RESULTS

Verification of the performance objectives was conducted after completion of field-testing activities and submittal of the demonstration draft Final Technical Report by eSpin.

Note that, because demonstration performers (eSpin) had not planned to undergo ISO 14034 verification when initiating the project, some requested data, documentation, or information was not available without significant additional effort to the team, which impacts compliance with ISO 14034 requirements.

3.1 VERIFIED OPERATIONAL PERIOD & OPERATING CONDITIONS

The eSpin filter testing occurred over a significant testing period, with a large amount of data collected, including data from multiple different heating and cooling seasons. The demonstration periods are summarized below:

Table 5. Verified Demonstration Period and Test Locations

Test Period Summary & Operating Conditions		
Test Location	**Test Period**	**Data Collection Duration (includes downtime)**
Ft. Benning – Starship Barracks (FTBS)	8/28/2019 – 2/19/2021	70 weeks
Ft. Benning – Martin Army Hospital (FBMH)	1/22/2020 – 10/18/2021	56 weeks
Ft. Campbell – Special Ops Bldgs. (FCSO)	9/6/2019 – 7/18/2021	60 weeks

Note that although operating and collecting data throughout these test periods, there are periods of facility or equipment shutdown, instrument malfunction, communications malfunctions, or other non-operational periods, for which data was appropriately removed from calculations and analyses.

The eSpin Exceed filter was demonstrated at three facilities, as summarized in Table 1. The specific range of operating conditions during which filter testing occurred at each facility are summarized below.

Table 6. Operating conditions during demonstration

Test Period Summary & Operating Conditions		
Test Location	**Operating Conditions**	**Value**
Ft. Benning – Starship Barracks	Air Flow Rate	~1100-1800 acfm (AHU17/27) ~2200 acfm (AHU18-Exceed) / 3200 acfm (AHU28-COTS) (1.3x air flow in COTS filters)
	Temperature	60-80°F for all units (FTBS)
	Humidity	20-90% RH for all units
	Dust Level	Dust loading was variable
Ft. Benning – Martin Army Hospital	Air Flow Rate	~23,000 cfm (Exceed) / ~28,000 cfm (COTS)
	Temperature	~55-58°F
	Humidity	~30-70% RH (consistent for all units)
	Dust Level	Dust loading was variable
Ft. Campbell – Special Ops Bldgs.	Air Flow Rate	~8000-12000 acfm (Exceed) / ~6500 acfm (COTS)
	Temperature	~60-85°F
	Humidity	~10-70% RH
	Dust Level	Dust loading was variable

It should be noted that the operating conditions were not similar in all cases for units that were to be used to compare Exceed filters to COTS filters. For example, air flow in AHUs at Fort Benning Starship Barracks had 1.3 times the air flow for AHU 28 compared to 18. This results in significant pressure drop differences, which impact dust loading and energy efficiency data comparison. Attempts to normalize for air flow were completed, but the normalization procedures were non-standard and questionable, as indicated by eSpin in its report.

3.2 VERIFIED PERFORMANCE METRICS

Verification of performance with respect to demonstration Performance Claims are summarized in Table 3-2. As shown, the data and information available for verification at the time of this report support verification of a subset of the demonstration Performance Objectives. Further, the verified performance values shown in Table 3-2 for those objectives are based on a partial set of data collection within the full demonstration period. The data collection periods and operational conditions during those periods are discussed in further detail in Section 3.1.1 below. The operational conditions present during periods of verified performance are considered boundaries around the verified performance values.

Table 7. Verified Performance Objectives

Verified Performance – eSpin Exceed Air Filters				
Criteria	**Performance Criteria**	**Reported Performance**	**Verified Performance**	**Notes**
Air Filter Life	>1.5x current baseline filters	1.6x to > 4x (MERV 8 pre-filters) Equivalent to baseline filters (Post-filters)	>2x minimum	Filter life could be significantly longer than data indicates, but test duration does not allow for accurate determination, as Exceed filters and baseline post-filters were still viable at end of test periods.

Indoor Air Quality	5% reduction in particle concentration vs. baseline	20-35% reduction in Air Quality Index	20-35% Reduction in AQI	eSpin utilized AQI instead of particle concentration as an improved indicator of air quality. Air quality studies were inconclusive in two of the three facilities
Filtration Energy Usage	2% reduction in energy required	39-61% reduction in energy	Not verified	Qualitative and quantitative indications are that energy utilization is reduced. However, due to difficulties in comparing operating conditions, results are not verifiable.
Dust Holding Capacity	Exceed filters hold 5% more dust	4 – 38% more dust capacity	Not verified	For one set of air handlers, the dust holding capacity is nearly identical, and for the other set, apparent significant changes (38%) are observed. However, this includes data for post-filters with different MERV ratings. At a second facility, pre and post-filters showed different impacts on capacity and data is not verifiable.
Solid Waste Generation	>20% reduction in kg/yer filters disposed	60-75% reduction	>50% reduction	Filter life could be significantly longer than data indicates, but test duration does not allow for accurate determination, as Exceed filters and baseline post-filters were still viable at end of test periods.
Lifecycle Cost	>5% reduction in total cost per filter Simple payback <6 months	25-70% reduction in cost; 5 mo – 3.1 yr payback	Not Verified	Although likely accurate, significant assumptions were used to calculate LCC that were not verified, including labor costs, and disposal costs. In addition, unverified energy usage values are utilized in the calculations.

Specific verification activities and technology performance information verified are detailed in a series of Verification Activities and Checklists, provided here as Part II - Appendix A, Verification Review Forms and Findings. These checklists guide the verification process and, when executed following the verification plan, result in independent and defensible verification data with respect to technology performance.

3.3 VERIFICATION FINDINGS & DATA QUALITY

350 Solutions, acting as an accredited ISO 14034 Type A independent verifier, has verified the performance claims summarized in Section 2.1. In broad terms, the data provided by eSpin to verify performance with respect to the performance claims were found to be compliant with ISO 14034 standards for 3 of the 6 original demonstration performance objectives. For other performance metrics, although instrumentation and measurements typically met requirements, site operating condition variations or test implementation issues prevented full verification at this time.

Verifiability of the performance claims was assessed as follows:

- Verifier observations of field instrumentation, measurements, and data generation and processing indicated that the demonstration was conducted by qualified test personnel, at an acceptable level of data quality and representativeness; Test personnel were not independent, however.
- Relevant HVAC AHU applications and operations were used to demonstrate the basis of the performance claims, using real-world applications of the filters in operating HVAC AHUS; and,
- Data presentation and documentation of quality control procedures are generally acceptable or justified in cases where documentation of these activities was missing or incomplete.

Table 8 summarizes the verification review activities and findings.

Table 8. Summary of Verification Review Activities and Findings

Relevant ETV Requirements		Standard Requirements	Evidence Reviewed	Verifier Findings
ETV eligibility	Legal qualification	ISO 14034 (5.2)	ESTCP proposal (ETV application)	Exclusive commercial rights to the technology for sale and use
	Technology added value	ISO 14034 (5.3)	ESTCP proposal, technology description	Positive environmental and efficiency impacts
	Potential adverse impacts			None identified. Full lifecycle analysis not presented.
	Technology readiness	ISO 14034 (5.2)	ESTCP proposal, existing performance data	Commercial and in use, demonstrated ability to meet performance claims
	Quality of performance claims	ISO 14034 (5.3)	ESTCP proposal, Demonstration Plan and Progress Reports	Market relevant and measurable
Verification of demonstration performance data	Relevance	ISO 14034 (5.4.2)	ESTCP proposal, existing performance data	Verified ISO 14034 compliant for support of three performance claims.
	ISO 17025 conformant		Demonstration Plan, on-site observations of SOPs, methods, and procedures	Insufficient information to verify conformance to all requirements of ISO 17025. Additional information needed. Prefer independent test bodies.
	Verification plan conformant		methods and procedures, performance data and statistical analyses conform to Demonstration Plan	Verified acceptable to support certain performance claims
Laboratory qualifications	Impartiality	ISO 17025 (4.1)	ESTCP Proposal and Demonstration Plan	Non-conformant to standard

	Structural requirements	ISO 17025 (5)		Reported legal entity (eSpin) with documented structural management and operations
	Personnel	ISO 17025 (6.2)	DP-1.01, B-2.14, on-site observations	On-site observations & follow-up discussions indicate personnel are qualified.
	Facilities and equipment	ISO 17025 (6.3, 6.4)	Demonstration Plan, On-site observations	Verified acceptable, support performance claims
	QA/QC procedures	ISO 17025 (6.6, 7)	Demonstration Plan, On-site observations	Not independently verified

[a] *Test body defined as the demonstrating body (eSpin).*

3.3.1.Critical Measurements

350Solutions identified the following measurements as the critical measurements for determination of all Verification Parameters and Performance Objectives. All measurements were collected by eSpin using instrumentation specified in Section 3.3.2.

Table 9. Critical Measurements

Critical Measurement	Required Measurement	Instrument	Units of Measure	Verification Parameter Supported
Filter ΔP (Prefilter, postfilter, all filters)	Pressure	Pressure Gauges (Veris)	In H2O	Filter Life, LCC, Energy Usage, Solid Waste Generation
Air flow rate (supply air)	Volumetric flow rate	Ebtron flow sensor, JC orifice plate	acfm	Operating condition validation for comparison
Temperature	Temperature	Type 2 Thermistor	°F	Operating condition validation for comparison, air flow rate
Relative Humidity	Humidity	Capacitive sensor	%	Operating condition validation for comparison, air flow rate
Electric Power Consumption (fan/system)	Flow Rate	Dent power meter	Kwh	Energy Savings
Particulate Concentration (upstream / downstream)	Particle concentration	PurpleAir particle sensor	µg/m^3	Air quality
Filter weight	Mass	Weigh scale	kg	Dust holding capacity

3.3.2.Instrumentation

Table 10 summarizes equipment specifications for measurements conducted throughout the demonstration periods that were considered critical to assessment of the performance objectives and metrics.

Table 10. Verified Equipment for Critical Measurements

Measured Parameters	Equipment /sensor	Operational Range	Accuracy Specification	Calibration
Real power (kW)	Dent, PowerScout 3037, 200A Current Transformers	Variable: 208 or 480v, single or three phase selectable CT	± 0.2% reading	Certified revenue grade, not independently verified
Air flow	Ebtron Advantage GTx116e-PC*	0 – 5,000 fpm	± 2% reading	NIST traceable accuracy spec., not independently verified
Differential pressure	Veris PX3PLX02 PX3UXX05	2.5 inches H2O	± 1.0% FS	Factory accuracy specification, not independently verified
Relative Humidity	Campbell Scientific CS215-L	0 – 100%	± 2% reading (10-90%)	NIST traceable accuracy spec., not independently verified
Temperature		-40 to +70°C	± 0.4°C (5-40°C)	
Particulate Concentration	PurpleAir particle counter, 2CP PAII-SD	0-500 µg/m^3	±10% (100-500 µg/m^3) ±10 µg/m^3 (0-100µg/m^3)	Factory accuracy specification, not independently verified
Filter weight	NA	NA	NA	Not verified

**At Ft. Benning Martin Hospital, the internal Johnson Controls air flow sensor was utilized, with output provided to eSpin datalogger and required calculations completed by eSPin.*

The accuracy specifications of these instruments are consistent with what is typically expected by stakeholders interested in energy technology (revenue grade power meter, NIST traceable temperature sensors, etc.). eSpin states that the differential pressure sensor, temperature, RH, power meter, and particle sensor had NIST traceable factory calibrations. Due to resource limitations and the verification being conducted after completion of the demonstration, actual equipment calibration certificates were not reviewed.

The instrument cabinet and datalogger are shown in Figure 3.

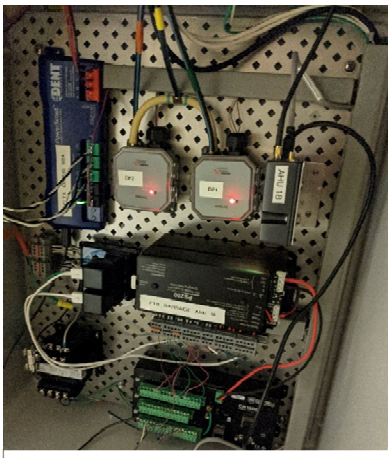

Figure 3. Instrument cabinet with power meter, pressure sensors, data logger located at Ft. Benning Starship Barracks

In addition to the equipment specified above, the eSpin team performed numerous cross checks and equipment calibrations on site as well as during setup and programming of the data acquisition system. In summary, eSpin has performed the following additional field checks:

- Periodic check of differential pressure using Hobo, Dwyer, or TSI pressure gauges;

- In-house verification of differential pressure sensor using manual readings of water column height in tubing;
- Testo air flow meter for checking air flow sensor calibration and accuracy;
- Cross check of power meter vs. handheld meter;
- In-house checks of particle sensors using size specific test dust and TSI laboratory particle counters;
- In-house cross-comparison of four particle sensors against each other;
- Power analysis for each datalogger installation to ensure instruments and logger receive adequate power from power source;
- Sending Veris pressure transducers to manufacturer for recalibration as necessary;

The efforts provided by eSpin and regular checks against handheld meters or other equipment indicate a significant effort to ensure measurements and instrumentation provided high quality data and consistent accuracy within instrument specification. ***350Solutions can verify that the data produced by the eSpin instrumentation is generally of acceptable quality to meet ISO 14034 requirements.***

3.3.3.Test & Operational Procedures

The Exceed air filter demonstration test procedures were intended to ensure adequate data was obtained for comparison of the Exceed filter vs. air filters currently used by the host facility (COTS filters). This approach requires two primary conditions to ensure data can be compared and appropriate conclusions drawn regarding filter performance:

- air handling unit at each location are tested under similar operating conditions (flow rate, temperature, humidity, particle loading)
- the same efficiency level (MERV rating) air filters are utilized in the same locations in the paired air handlers (i.e. MERV 8 prefilters and MERV 13 post filters) based on manufacturer specifications.

Based on these requirements, eSPin and the host sites identified AHUs at three locations that were estimated to provide similar operating conditions. In addition, it was determined that the manufacturer specification for each AHU included use of MERV 8 prefilters and MERV 13 or 14 post filters. The following table summarizes the filter requirements for each location.

Table 11. Air handling unit filter requirements

Location	Size	Type	MERV Rating	Quantity
Fort Benning Barrack AHU-17	24x24x2	Pleated-Prefilters	8	1
Fort Benning Barrack AHU-17	20x24x2	Pleated- Prefilters	8	1
Fort Benning Barrack AHU-17	24x24x4	Pleated-Postfilters	13	1
Fort Benning Barrack AHU-17	20x24x4	Pleated-Postfilters	13	1
Fort Benning Barrack AHU-18	20x20x2	Pleated-Prefilters	8	2
Fort Benning Barrack AHU-18	20x20x4	Pleated-Postfilters	13	2
Fort Benning Hospital AHU-B2/B4	12x24x2	Pleated-Prefilters	8	4
Fort Benning Hospital AHU- B2/B4	24x12x2	Pleated- Prefilters	8	4

Fort Benning Hospital AHU- B2/B4	24x24x2	Pleated-Postfilters	8	16
Fort Benning Hospital AHU- B2/B4	12x24x12	Aluminum Separator Postfilter	14	4
Fort Benning Hospital AHU- B2/B4	24x12x12	Aluminum Separator Postfilter	14	4
Fort Benning Hospital AHU- B2/B4	24x24x12	Aluminum Separator Postfilter	14	16
Fort Campbell Special Ops Bldg 6103 AHU 1-1	16x20x2	Pleated- Prefilters	8	8
Fort Campbell Special Ops Bldg 6103 AHU 1-1	20x20x2	Pleated- Prefilters	8	4
Fort Campbell Special Ops Bldg 6103 AHU 1-1	16x20x4	Pleated-Postfilters	13	8
Fort Campbell Special Ops Bldg 6103 AHU 1-1	20x20x4	Pleated-Postfilters	13	4
Fort Campbell Special Ops Bldg 6104 AHU 1-1	25x16x2	Pleated- Prefilters	8	12
Fort Campbell Special Ops Bldg 6104 AHU 1-1	27x16x2	Pleated- Prefilters	8	4
Fort Campbell Special Ops Bldg 6104 AHU 1-1	25x16x2	Pleated-Postfilters	13	12
Fort Campbell Special Ops Bldg 6104 AHU 1-1	27x16x2	Pleated-Postfilters	13	4

Several issues were identified during verification and by eSpin during testing that impact data utilization for certain verification parameters:

- Although initially specified properly, Fort Benning installation facilities management contractors did not have MERV 13 filters available, so MERV 8 COTS filters were installed at the Starship Barracks. The AHUs operated for several months with MERV 8 COTS post filters in one AHU and MERV 13 Exceed post-filters in the other AHU. The MERV rating makes it very difficult to compare filter performance, as the filter pressure drop, efficiency and dust holding capacity are directly impacted by MERV rating.
- filter size and quantity at the Fort Campbell facility were significantly different, which prevents direct comparison between the COTS and Exceed filters for most parameters at Fort Campbell, as COTS filters were used in Building 6103 and Exceed filters in building 6104.
- observed flow rates in the AHU-B2 and AHU B4 varied significantly, which made comparison difficult
- observed flow rates in AHU 18 and AHU 28 were significantly different, with approximately 1.3 times flow observed in AHU 28 vs. 18.

Because of the differences between the filter MERV ratings and the operating conditions (flow rates), it is suggested that caution is used for certain comparisons.

Data for the AHU 17 vs AHU 27 operations at the Ft. Benning Starship Barracks from June 2020 until end of testing is the most complete and comparable data set and could be utilized for all comparisons.

3.3.4.Analytical testing

ASHRAE 52.2 testing was completed by eSpin at its facility to determine the MERV rating for each filter type produced. Records of ASHRAE testing and compliance with the standard are maintained by eSpin. Test reports and MERV rating reports were provided by eSpin in the Final Technical Report.

Although insufficient data was available to fully verify eSPin compliance with the ASHRAE standard, the data is likely available from eSpin and initial review of documents provided indicates that eSpin appears to perform high-quality testing, with proper documentation, and little reason to question results of testing.

3.3.5.Uncertainty Analysis

Uncertainty analysis and calculation of 95% confidence intervals for all performance parameters was not provided as part of the Final Technical Report nor any data reported to 350Solutions.

Without proper uncertainty analysis, it becomes difficult to establish, with certainty, that observed differences are statistically significant with any confidence. Therefore, certain performance parameters may not be verified due to lack of statistical analysis of differences.

It should be noted that, due to the very large amount of data in the data sets, and the relatively stable operations and values for many of the measured parameters, it is likely that the primary uncertainty observed will be based on measurement uncertainties from instrumentation utilized, as opposed to process variability, with the primary exception of pressure drop for COTS filters. Based on instrument specifications and preliminary calculations, the majority of uncertainties will likely be less than 5% for each performance parameter (i.e. propagated uncertainty in the measurements, for example calculation of normalized power consumption (per unit flow) was ± 2.7%).

3.3.6.Deviations from Test Plan

Several deviations from the Demonstration Plan were identified that potentially impact data quality and utility. These include the following:

- Utilization of MERV 8 COTS postfilters at Fort Benning Starship Barracks for first half of test. AS a result, any data comparing post-filters here prior to the replacement with MERV 13 filters should be ignored and only considered qualitatively, if at all;
- Ft. Benning facilities management changed the hospital air filters (COTS) on a regular 3-month schedule, regardless of pressure drop or performance level, in part due to hospital air quality requirements and COVID-related concerns. This reduces utility of data from the hospital units.
- eSpin utilized the US EPA Indoor Air Quality Index method to calculate change in air quality instead of the proposed calculation of the change in concentrations only. This is an acceptable deviation.

    - However, note that eSpin noted several challenges in the AQI index calculation and comparisons, including significant variations in particle concentrations from day to day and upstream and downstream in some cases; selection of data subsets to utilize for calculation without bias; and lack of comparability between Exceed and COTS inlet particle concentrations.
- Due to variability in air flow between two AHUs that are being compared, eSPin attempted to apply a normalization procedure when calculating energy consumption changes. Although this is a logical approach, it is not a standard normalization process, and, as eSpin indicates, the normalization method can be questioned based on the significant impact it had in some applications.
- Analysis of dust holding capacity for Fort Campbell applications was reported based on combined dust holding of pre and post filters. The capacities should be reported separately, and are likely not comparable, as filter sizes flow rates in the two buildings are significantly different.

4 RECOMMENDATIONS FOR IMPROVEMENTS

To improve the ability to utilize the data collected by eSPin, 350Solutions recommends the following be completed and values for performance parameters be updated wherever possible:

- For all analyses where post filters of MERV8 were compared to post filters of MERV 13, remove that data from calculation of performance parameters (i.e. dust loading). Data from the period after June 2020, when COTS post filters were changed to MERV 13 should be utilized for all such calculations.
- Complete an uncertainty analysis for each parameter, indicating the 95% confidence interval on the parameter and report all performance parameters as the value +- the 95% confidence interval.

To improve data quality in future testing applications, we recommend the following:

- Ensure all measurement instrumentation is purchased with a NIST Traceable calibration and that any regular calibrations are completed as required. Although it appears eSPin did this, it has not been independently verified.
- Consider the addition of a controlled test as a first phase of testing, if possible, to allow for a more accurate determination of the impacts of the filter changes on energy consumption, dust loading, filter life (dP) under comparable operating conditions.
- Alternatively, focus initial site selection on ensuring that comparable AHUs are utilized (nearly identical operating conditions and identical filter requirements). This could also be evaluated by completing a baseline monitoring period on AHU operation using a reduced suite of instruments prior to full installation and long-term monitoring.
- Utilize a higher quality particle measurement instrument, or, at a minimum, complete additional regular testing using a high-quality instrument to compare to the lower cost sensors
- For energy savings calculations, wherever possible, use direct measurement of system energy consumption (via power meter), and ensure that all operating conditions are comparable, as this may significantly impact energy usage.

To enable compliance with the ISO 14034 standard and verification, we recommend:

- Complete all uncertainty analyses and indicate statistical significance and 95% confidence interval of performance parameters;
- Provide documentation of all instrument calibrations traced to NIST standards;
- Do not report data for data sets where proper comparisons cannot be made due to different filter ratings or two significantly different operating conditions. Only report data for comparable operations;
- Preferably have testing completed, where possible, by qualified independent test bodies, such as outside laboratories or contractors. It is understood that this can add significant expense, so testing performed by the technology supplier can be acceptable, as long as instrument and data quality requirements are met. It is also recommended that the test body, if the technology developer itself, have documented quality management programs, trained and qualified staff, and documented standard operating procedures for testing, data validation, and data analysis.

Part II - APPENDIX A: Select Excerpts from Data Quality Review Forms and Verifier Notes:

eSpin Exceed Air Filter Verification - review of existing performance data from ESTCP demonstration
General review checklist

Review Criteria:
Test data necessary to verify the performance claims was provided to permit implementation of a specific test or set of tests providing statistically relevant data.

Findings: Examples of relevant raw data used to support assessment of performance were observed, provided and reviewed. Calculations of performance metrics including AHU air flows, filter pressure differentials, and AHU power consumption were reviewed and verified. Equipment specifications and locations for critical measurements were observed and reviewed.

Review Criteria:
Testing was conducted by expert(s) with specialized and documented training and capabilities relevant to technology evaluation.

Findings: Acceptable. The credentials and expertise of lead performer eSpin are well established in the industry. Industry standard approaches and procedures used to conduct the demonstration and modeling effort are detailed in the Demonstration Plan.

Review Criteria:
The testing was suitable for generating sufficient data to perform statistical analysis and meets the requirements related to test data specified in the verification plan.

Findings: Acceptable. Baseline and technology data collection occurred over full calendar years at two relevant installations, with millions of data points collected and analyzed under a wide range of environmental conditions, as was specified in the ESTCP approved Demonstration Plan.

Review Criteria:
The technical and operational details specified in the report are suitable to document quality assured data according to requirements of ISO/IEC 14034 and the requirements specified in the verification plan. The testing was suitable for measuring appropriate parameters specific to the technology and performance claim. Note: It is essential that all parameters that could affect the performance evaluation are either restricted to pre- specified operating conditions or are measured. The testing was suitable for obtaining test data representative of process characteristics at specified.

Findings: Partially acceptable. The technical and operational details of the demonstration conform to the Demonstration Plan and are sufficient to form relevant performance conclusions toward the technology

performance objectives. Gaps in the technical and operational details with respect to the ISO Standard revolve around the lack of impartiality and metrological traceability of the critical field measurements.

Data quality checklist

Review Criteria:

Appropriate sampling and analytical methods were used to generate performance data

Findings: Acceptable. Industry standard approaches and procedures were followed to design and conduct the demonstration efforts. Appropriate field-testing procedures conformed to the Demonstration Plan approved by ESTCP.

Review Criteria:

The apparatus and facilities used for performance testing were adequate for generation of relevant data (i.e., testing was performed at a location and under operating conditions and environmental conditions for which the performance claim has been defined).

Findings: Acceptable. As evidenced by the facilities used to support the demonstration (AHUs at the Ft Benning and Ft Campbell facilities), and rational used to demonstrate facilities environmental relevance and operational adequacy of these facilities to support performance objectives.

Review Criteria:

Information and data on operating conditions and measuring equipment measurements and calibrations are available to the verifier.

Findings: Partially acceptable. Examples of relevant raw data used to support assessment of performance, including operating and environmental conditions evident during the demonstration, were provided and reviewed. Equipment specifications and locations for critical measurements were observed and reviewed. Calibration and metrological traceability of the critical field measurements were not verified.

Review Criteria:

Quality assurance/ quality control (QA/QC) procedures were followed during sample collection in conformance with methods cited. Information and data on operating conditions and measuring equipment measurements and calibrations were provided to the verifier Quality assurance procedures were applied throughout data generation and collection.

Findings: Partially acceptable. As evidenced by the approaches, methods, and standards forming the design and execution of the demonstration referenced in the Demonstration Plan. Detailed QA/QC procedures and findings, including calibration and metrological traceability of the critical field measurements were not verified.

Review Criteria:

Acceptable methods, procedures and protocols were used for sample collection, preservation and transport where applicable.

Findings: See above, verified acceptable.

Review Criteria:
Samples were analyzed using approved analytical methods, procedures, and protocols.

Findings: See above, verified acceptable.

Review Criteria:
The performance test data are acceptable (i.e., the quality of the data submitted is accepted based on the best professional judgment of the verifier).

Findings: Acceptable. Data sets complete with respect to application relevance (relevant AHU demonstration facilities), completeness (robust coverage of operating conditions), key measurements (instrumental systems and sensor locations), methodologies (ESTCP pre-approved and ASHRAE standard approaches for particle loading), and determination of performance metrics (traceability of raw data through calculation of key performance metrics). Metrological traceability of key instrumentation not independently verified.

Verification review of existing performance data - Data analysis and Interpretation
Review Criteria:
The performance data are statistically and operationally significant. The verifier has confirmed the assumptions and the applicability of the statistical tools used. This validates the use of the test and related inferences.

Findings: Partially acceptable. Verified acceptable based on measurement frequency and instrument accuracy (propagated field measurement uncertainty for key performance objectives). The volume of data generated at both facilities over extended demonstration periods with baseline and Exceed filters (30-second readings of key measurements logged as 5-minute averages over the periods) is evidence of statistically significant representation of test conditions and operational performance. A full statistical evaluation of the field data and uncertainty analysis was not provided nor verified.

In addition, issues with comparability of data due to variation in operational conditions or differences in filter MERV rating between COTS and Exceed filters limited ability to provide comparisons.

Review Criteria:
The performance tests are sufficient to support the claim being made.

Findings: Verified partially acceptable. Data is of high quality and meets criteria.
Inconsistencies in operating conditions prevent full analysis of all claims.

Review Criteria:
Statistical evaluation of the claims put forward by the applicant should be carried out for each claim when appropriate. Statistical evaluation assumptions must be clearly described.
Raw Data - A description is provided on how the raw data is presented.
Assessing Normality Assumptions - This determines if the data variability is normally distributed or log-normally distributed.
Testing if the mean is equal to the specified value - This determines at a level of 95 % confidence that the mean is not equal to a pre-specified value.

Findings: Uncertainty analysis not completed nor documented in Final Technical Report and performance parameter results. Not independently verified, see above.

Review Criteria:
The data analysis and interpretation are presented in a defensible manner.

Findings: Reviewed and verified, see results narrative in Section 3 of this report and comments above re: partial verification due to operating conditions and other issues.

Test body and/or laboratory conformance to requirements of ISO17025
Not applicable, no analytical testing was used to support the demonstration. However, ASHRAE 52.2 testing was completed by eSpin. Although documented results and information provided indicates quality testing was done by eSpin, insufficient documentation was provided to fully assess the method performed vs. requirements of ISO 17025. Also, as the testing was performed by eSpin personnel, who are not managed independently from those implementing the demonstration program. It is preferred that testing be implemented by independent test bodies, where possible.

PART III: ISO 14034 IMPLEMENTATION GAP ANALYSIS & CASE STUDY

Improving ESTCP Demonstration Outcomes & Tech Transfer via Integration of Standardized Third-Party Technology Verification using ISO 14034

Example Implementation for ESTCP Project EW201724: Nanofiber Based Low Energy Consuming HVAC Air Filters

1 Introduction

DoD's Environmental Security Technology Certification Program (ESTCP) was established to promote the transfer of innovative technologies that have successfully established proof of concept to field or production use. ESTCP demonstrations collect cost and performance data to overcome the barriers to employ an innovative technology because of concerns regarding technical or programmatic risk, the period in technology commercialization known as the so-called "Valley of Death". The Program's goal is to identify and demonstrate the most promising innovative and cost-effective technologies that address DoD's high-priority environmental requirements. Projects conduct formal demonstrations at DoD facilities and sites in operational settings to document and validate improved performance and cost savings. To ensure the demonstrated technologies have a real impact, ESTCP collaborates with end-users and regulators throughout the development and execution of each demonstration. Challenges to implementation of new technologies are overcome with rigorous and well-documented demonstrations that provide the information needed by all stakeholders for acceptance of the technology.

However, the transfer of technologies and market uptake is still limited, and challenges remain. In many markets, including the Department of Defense, transfer of knowledge to end users, purchasers, regulators, and others is often done in an ad hoc, inconsistent manner, which can result in critical stakeholders having to repeatedly compare options, review barriers, assess performance, and estimate impact on their own, relying on information from various resources.

One approach to reducing barriers to entry and reducing risk associated with implementation of innovative technologies is to provide credible, independently verified, high-quality data that directly addresses stakeholder information needs. This approach to technology demonstration and validation has been standardized via ISO Standard 14034: Environmental Technology Verification [2] – establishing a scalable, unified framework for technology validation and incorporating qualification requirements for independent verifiers as well as data quality assurance requirements for test and calibration labs and data providers.

This project examines integration of the ISO 14034 – Environmental Technology Verification (ETV) standard into existing ESTCP processes and projects to provide an example of how the ISO standard implementation can work, how it can integrate with existing ESTCP processes, identification of gaps and barriers to implementation, and the potential benefits in supporting technology transition.

Integration of ISO or other consensus international standards into the ESTCP process can enable improved technology demonstration and tech transfer, and ultimately technology deployment through the following potential benefits:

- Development of a unified testing protocol for specific technology categories that can be applied to all future projects in those areas;
- Integration of stakeholder needs and input in the protocol to ensure needed data and information is obtained during demonstrations for each specific technology type;
- Implementation of third-party verification of data and information to ensure high data quality and consistency across demonstration programs;

- More rapid acceptance of technologies due to the inclusion of interested parties input as well as use of an internationally accepted standard;

Often, data and information from technology demonstration programs is collected, evaluated, submitted, and published by the technology developers themselves regarding the performance of the technology. This is an inherently biased approach, which can result in decreased certainty regarding technology performance. In some cases, selective or low-quality data may be used to justify performance, while in others, developers may provide a very accurate picture of technology performance using high quality data. Independent verification can help sort through the information provided by vendors and provide a validated set of performance data to guide decision-making.

2 The ISO 14034 Standard

ISO Standard 14034: Environmental Technology Verification [2] – establishes a scalable, unified framework for technology evaluation that addresses issues of data quality, stakeholder needs, publication of information, and information validity, all independently verified by a qualified third party. ISO 14034 also integrates with two additional important standards to ensure data quality and competency of independent verifiers and test bodies:

- ***ISO 17020: Conformity assessment -- Requirements for the operation of various types of bodies performing inspection***[3]***,*** which establishes qualifications for independent entities to perform verification work.
- ***ISO 17025: General Requirements for the Competence of Testing and Calibration Laboratories***[4] to ensure data used in evaluation of new technologies meets consistent standards and is provided by qualified entities.

ISO 14034 reflects an international consensus that standardization of the performance verification process, with data quality requirements, independent verification, and detailed documentation is an effective way of establishing the global credibility of innovative solutions,
addressing one of the critical barriers to market acceptance of innovations. The standard provides transparent and robust procedures and specifies the highest levels of quality assurance via ISO 17020 and ISO 17025.

With proof of performance under well-defined operating conditions credibly assured through an ISO 14034 verification, innovations can expect improved market access, because technological risk is reduced for technology purchasers. Additionally, with ISO 14034, standardization of the ETV process will facilitate global market access for verified technologies. Broader market access typically enables more rapid growth and ease of access or transition within sub-markets, such as DoD.

3 ISO 14034 and ESTCP

3.1 Alignment

The ISO 14034 standard aligns well with ESTCP programmatic objectives, as both address evaluation of technologies that:

- are ready for market or already available;
- are innovative compared to current technologies;
- may not have existing product certification standards;
- demonstrate environmental added value or measure parameters that indicate environmental impacts.

ETV provides third party evidence that a specific environmental technology achieves a declared performance (technical/functional) and resulting environmental benefits for a specific application, under specific operational conditions, and taking into account all measurement uncertainties and other assumptions. Unlike in standardized certification or labeling programs, parameters for verification are not predetermined, but developed to reflect user needs and focused on specific aspects of the technological innovation.

The overall ISO ETV approach is summarized in Figure 4, which also depicts the alignment of the ISO 14034 standard and verification process with the existing ESTCP Demonstration Program approach.

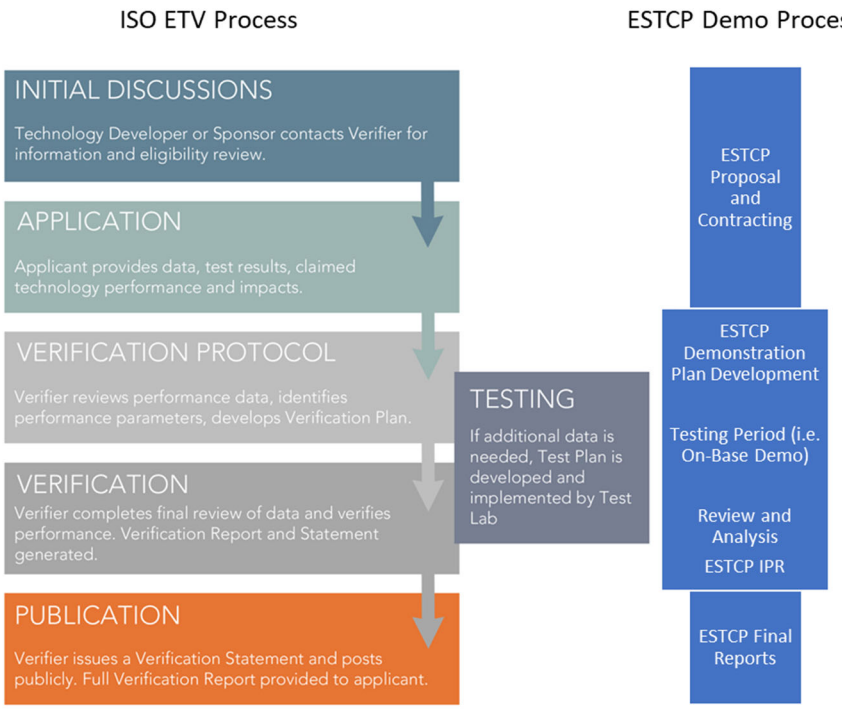

Figure 4. the ISO 14034 ETV Process & ESTCP Process Comparison

As discussed, there are many potential barriers to technology deployment and transfer that are encountered within the ESTCP portfolio and follow-on attempts to transition technologies to the DoD market. Table 12 illustrates some potential barrier categories translated to specific example issues associated with transition of ESTCP validated technologies to broad deployment within DoD markets.

Table 12. Barriers to Transition of Innovative Technologies to DoD and Impacts of ISO 14034 verification.

Barrier Category	ESTCP-specific examples	How ISO 14034 Can Address
Policy / Regulatory	New technologies not incorporated in Unified Facility Criteria due to lack of data or knowledge. Regulatory approvals (DoD, EPA) difficult due to lack of data or knowledge.	Incorporate UFC and regulatory stakeholders at beginning to define data needs. Provide quality, reliable data to reduce risk of technology, and enable incorporation in UFC and regulatory approval.

Administrative	Complicated DoD procurement process and difficult to include new techs due to lack of specifications for new technologies;	Verification Results for a technology category can be used to develop valid procurement specification; Incorporating procurement reps in front end processes ensures appropriate info verified.
Technical	Low acceptance rate of new techs and projects by DoD Energy Managers; Lack of options for new technologies.	ETV provides independent data to validate technical performance and that it meets user specified needs or criteria. Improves user acceptance. Standardized approach results in multiple technologies evaluated the same way in single category.
Financial	Difficult to finance new technologies due to perceived risk or project economics; DoD preferred 3rd party financers reluctant to include newer technologies due to risk.	Verification provides required data to reduce risk to financers, including economic performance. Including appropriate stakeholders
Environmental	Unknown environmental risks of new technologies and adherence to Fed, State, Local, DoD requirements.	ETV requires evaluation of environmental benefits and impacts. Includes need to evaluate secondary impacts and other concerns vendor may not include. Specific environmental policy/regulatory issues can be incorporated in ETV approach.

3.2 Gaps

350Solutions performed a detailed gap analysis [8] to evaluate the areas in ESTCP processes where process modifications or guideline requirements may be needed to ensure compliance with the ISO 14034 standard, when implemented. Table 13 provides a summary of the gap analysis review at a high level. Based on this review, many of the requirements of the ISO standards are already addressed in the ESTCP guidance and procedural processes and, as such, much of the current ESTCP program processes are conformant with these standards. In some cases, opportunities for improvement are identified where additional requirements within ESTCP processes could improve consistency, quality, and demonstration outcomes via improved compliance with the ISO standards.

Table 13. Summary of ISO 14034 comparison vs. ESTCP Processes

ISO 14034 Standard Section	Principle Requirement of ISO Standards	Relevant ESTCP Process or Requirement Demonstrating Compliance
1. **Scope**	Focus on the evaluation of innovative environmental technologies, including their benefits and performance	ESTCP Program focus on innovative environmental technologies as applied to Defense Installations
2, 3. References and Definitions	NA	NA
4. General Principles & Requirements	General principles of credible, impartial evaluation, Factual approach, Transparency and Credibility, Flexibility.	All principles are, in general, adhered to via ESTCP programs, except for requirement for third party verification. Opportunities for improvement exist regarding

		independent or impartial evaluation, input of stakeholders, and improved data quality standards.
5. Application Requirements & Review	Requirements for technology details, justification of its impact and performance claims, and initial approach for verification	ESTCP Proposal process requires significant technology details and justification, as well as supporting information for performance and impact claims. ESTCP Technical review and proposal selection evaluates most relevant information to ensure technologies are beneficial and ready for demonstration.
5. Verification Planning	Specification of Verification Parameters, test methods, operating conditions, for verification. Input of interested stakeholders is obtained. Consistent evaluation approaches across similar technologies are used. Data quality specifications are established.	ESTCP Demonstration Planning requires significant aspects of ISO verification planning, including specification of performance parameters, site conditions, operation. However, Demonstration plans do not require input of outside stakeholders, uniform approaches for similar techs, specific data quality requirements. Independent verification not required.
5. Verification Reporting & Publication	Requires specific information to be included regarding the technology and verified data. Verification information must be published.	ESTCP reporting requirements are thorough and match well with ISO requirements, except for the reporting being completed or verified by an independent entity.

The key difference between existing ESTCP guidance and policies is the utilization of a qualified independent verifier to evaluate and verify the performance data and results provided by the technology developer. This is a key requirement that adds credibility and ensures quality of results. In some ways, the ESTCP Technical Review Panel, and the outputs of the ESTCP In-Progress Review (IPR) meetings can partially serve the role of independent verifier. But, to be compliant with the ISO standards, a more detailed process would need to be established, or qualified verifier participate.

4 Project/Case Study Objectives

To further evaluate the potential benefits of implementing ISO 14034 requirements in the ESTCP program, full verifications were completed for two projects. These implementation case studies were completed to evaluate the ease of implementation and identify specific real-world examples of issues and potential challenges to adoption of the ISO standard for ESTCP.

Of primary interest in completing the real-world ISO 14034 verifications of ESTCP projects is determining answers to the following questions:

- **What are the gaps in project implementation vs. ISO 14034**
- **What does it take to implement ISO 14034 verification vs. a typical ESTCP project?**
    - **What extra costs?**
    - **What extra effort by the project team?**

- **What are the issues in implementation of ISO 14034?**
    - **Are there major barriers?**
    - **What can be done to overcome these barriers?**
- **What are benefits of implementation of ISO 14034 at the project level and for end users?**

5 Case Study Approach

To evaluate the potential implementation of ISO 14034 in ESTCP projects, 350Solutions served as an independent 3rd party verifier for the evaluation of the technology being demonstrated in a currently active ESTCP project. This attempt at verification provided direct in sight into potential issues in application of the ISO standard, while also serving to identify potential areas where the current demonstration meets ISO14034-level requirements, but also where improvements to demonstration could be implemented in the future.

It should be noted that the selected projects were ongoing, in-process demonstrations, with instrumentation, Demonstration Plans, and data analysis already occurring. Participating project teams agreed to support 350Solutions verification activities, including site visits, provision of documentation, and reviews of data and data analysis. Teams performed these activities voluntarily, in addition to their contract activities. As a result, it was not anticipated that the teams would fully meet the ISO 14034 requirements, enabling full verification. ***Therefore, any performance criteria that were not fully verifiable in accordance with ISO 14034 requirements are not a reflection on the performance of the technology, but a result of applying ISO 14034 after the demonstration plan had been established and testing initiated.***

5.1 eSpin Exceed Air Filter Technology

The US Department of Defense Environmental & Security Technology Certification Program (ESTCP) has sponsored the demonstration of eSpin's Exceed® air filters for heating, ventilation, and air conditioning (HVAC) systems under project number EW-201724 entitled "Nanofiber-Based Low Energy Consuming HVAC Air Filters". The objective of this demonstration is to show that the technology can lower the annual operation and maintenance (O&M) costs of heating ventilation and air-conditioning (i.e., HVAC) systems while delivering cleaner air to occupied spaces. For this demonstration, eSpin conducted operational comparisons of Exceed® filters versus commercial off-the-shelf (COTS) filters currently used at two selected test sites. The filters planned for evaluation primarily focused on pleated air filters found in many typical HVAC units.

The demonstration consisted of determination of air filtration system performance and air filter energy consumption via measurement of differential pressure across the filters, flow velocity, temperature and humidity of the air passing through the filters and the dust holding capacity of the filters. Additionally, the eSpin team measured indoor air quality and air filter efficiency via particle counters placed upstream and downstream of the filters and reported counts of particulate matter having diameters less than 10 microns and less than 2.5 microns (PM_{10} and $PM_{2.5}$, respectively) as a comparative analysis.

Complete project details are provided in the ESTCP Demonstration Plan "Nanofiber-Based Low Energy Consuming HVAC Air Filters" [5] and "Final Report: Nanofiber-Based Low Energy Consuming HVAC Filters" draft version dated June, 2022.

5.2 Technology Overview

eSpin has designed, developed, and demonstrated the benefits of nanofiber filtration media in the automotive and commercial markets. Continuous nanofibers with very small diameters (0.1-0.3µm), are produced using eSpin's electrospinning process and are integrated with conventional large diameter fibers to form a novel air filter media. eSpin claims that its nanofiber-based air filter has a low media density that reduces air flow restriction, small interstitial spacing between the nanofibers and a high surface area, making the filter media capable of efficiently capturing a wide range of pollutants such as toxic industrial pollutant-hexavalent chromium dust, pollen, microorganisms, oil, smoke, paint, and more.

Compared to conventional state-of-the-art large diameter fiber-based filter media, eSpin claims that its filter media requires less material to achieve the same capture efficiency as a conventional filter, resulting in lower pressure drop over the life of the air filter, higher dust loading capacity, and the ability to capture smaller particles more efficiently than conventional large diameter fiber-based media. Exceed® filters are claimed to be capable of capturing more dust, lasting longer, and will reducing the HVAC fan energy needed to operate the system.

5.3 Demonstration Approach

The demonstration consisted of installation of the Exceed air filters and COTS filters in a variety of air handler units (AHUs) at three locations at two installations. At the installations supporting the demonstration, 8 representative AHUs were selected for testing to assess performance over a range of applications and at two filter minimum efficiency rating value (MERV) ratings, as summarized in Table 14. HVAC systems and AHUs at all facilities were operated in normal operating conditions at all times, for test periods of over a year in at least one facility. Data on system operating conditions and filter performance was collected continuously during the demonstration period.

Table 14. Summary of Demonstration Facilities

Facility	AHU ID[1]	HVAC Application	Existing MERV rating	Verified Demonstration Period[2]
Ft Benning - Starship Barracks	17 (Exceed filters) and 27 (COTS filters)	Sleeping quarters	8 pre-filters, 13 post-filters	8/28/2019 – 2/19/2021
	18 (Exceed filters) and 28 (COTS filters)			
Ft Benning – Martin Army Hospital	AHU4-2 (Exceed filters) and AHUB-2 (COTS filters)	Outside Operating Room (OR Ring)	8 pre-filters, 13 post-filters	1/22/2020 – 10/18/2021
Ft Campbell – Special Ops Buildings	Building 6104 (Exceed filters) and Building 6103 (COTS filters)	Special operations facilities	8 pre-filters, 13 post-filters	9/6/2019 – 7/18/2021

[1] *Each AHU selected for the demonstration were variable air volume (VAV) type handlers with two stage filtration (pre- and post-filters).*

[2] *For each demonstration location, data was collected during this entire test period. However, there were instances of equipment downtime, data dropouts, and data outliers, such that data may not be representative of the entire period.*

5.4 ISO 14034 Verification Approach

Verification data and parameters used to evaluate technology performance with respect to the

performance objectives were assessed quantitively using data generated during the ESTCP demonstration. Table 15 summarizes the measurement approach used for the demonstration. Details of specific verification activities are provided in 5.5.

Table 15. Summary of Verification Parameters

Verification Parameters	Performance Criteria	Data Types	Data Source(s)
Life Cycle Cost (LCC) Air Filter life (AFL)	>5% reduction in total costs per filter SPP target: 6 months	Initial filter costs, energy consumption costs, labor costs, maintenance costs, solid waste disposal costs	Procurement records, host facility labor and maintenance records, facility disposal records
Indoor Air Quality (IAQ) Filter Energy	Exceed® filter life > 1.5x current filters	# of Days Exceed® filter outlasts current filters	Host facility maintenance records, AHU air flow, differential pressure, and energy consumption field data
Dust Holding Capacity (DHC)	5% µg/m³ particle concentration reduction compared to conventional air filters	Particle counts of air upstream and downstream of the filters	Host facility maintenance records, AHU air flow and particle counter field data
Solid Waste (SW)	2% reduction in filter energy compared with COTS filters	dP across filters and air flow through filters	Air flow, differential pressure, and AHU power use field data
Life Cycle Cost (LCC)	Exceed® filters hold 5% more dust by mass	Mass of the filters in grams	Host facility maintenance records, AHU air flow and particle counter field data
Air Filter life (AFL)	>20% reduction in kg/yr of filters disposed of compared to current amounts	Solid waste disposal data based on # of filters changed per cycle	host facility maintenance records, facility disposal records

5.5 Verification Process

For the purpose of ETV under ISO 14034, verification is defined as confirmation through the provision of objective evidence that the environmental technology performs as claimed under specified conditions, taking into consideration any measurement uncertainty and relevant assumptions. When performing this verification, verifiers assessed the conditions under which the technology performance demonstration was conducted, data quality, data management, and the overall ability to make definitive statements regarding the established verification parameters. Verifiers conducted on-site observations of measurement equipment and operation at the Ft. Benning demonstration site on July 14, 2021. Specifically, verifiers conducted:

- Interviews with base Energy Managers to verify satisfaction with demonstration activities, technical and economic performance of the filters, and technology operability.
- Observations of AHUs used for demonstration activities, location and use of critical demonstration measurement instrumentation.
- Observations of data generation and collection, and traceability of raw data to performance calculations.

Field verification included but was not limited to a detailed audit of critical measurements and associated instrumentation, as well as data produced by such instrumentation and their use in calculation of team performance and competition Verification Parameters.

A summary of verification activities is provided below:

Table 16. Verification Activities

Date(s)	Verification Activity	Verification Tasks
Jan - June, 2021	Preparatory Discussions, Demonstration Plan review, Verification Plan development	- eSpin ESTCP Demonstration Plan review - Verification Plan development and review - Review of documents, drawings, and equipment/instrument specifications - Review of equipment, calibrations, and measurements details - Review of performance objectives, critical measurements, instrumentation - Review of data analysis and validation procedures
7/14/2021	Site visit – Fort Benning	- Opening meeting and process walk through - Witness of operations, measurement points, and instrumentation – Fort Benning Starship Barracks and Martin Army Hospital - Verify critical measurements and performance parameters - Review of equipment, calibrations, and measurements details - Review of data collection and calculation of parameters
7/14/2021 – 8/30/2022	Review of final submitted data and supporting documentation	- Review of data collection and calculation of parameters - Review traceability from raw data through data collection, processing/reduction, validation, analysis and reporting steps - Review and verification of Final Technical Report and final performance objective / verification performance parameter values submitted by eSpin - Final review of data quality and completeness - Preparation of verification report and statement

6 Results & Discussion

6.1 Verification Results

The operating conditions during which filter testing occurred at each facility were documented to provide the context of the testing that was completed. For all parameters evaluated and verified, the verified performance can be assumed to only apply under similar operating conditions and for similar equipment. Observed operating conditions are summarized below.

Table 17. Operating conditions during demonstration

Test Period Summary & Operating Conditions		
Test Location	**Operating Conditions**	**Value**
Ft. Benning – Starship Barracks	Air Flow Rate Temperature Humidity Dust Level	~1100-1800 acfm (AHU17/27) ~2200 acfm (AHU18-Exceed) / 3200 acfm (AHU28-COTS) (1.3x air flow in COTS filters) 60-80°F for all units (FTBS) 20-90% RH for all units Dust loading was variable
Ft. Benning – Martin Army Hospital	Air Flow Rate Temperature Humidity Dust Level	~23,000 cfm (Exceed) / ~28,000 cfm (COTS) ~55-58°F ~30-70% RH (consistent for all units) Dust loading was variable
Ft. Campbell – Special Ops Bldgs.	Air Flow Rate Temperature Humidity Dust Level	~8000-12000 acfm (Exceed) / ~6500 acfm (COTS) ~60-85°F ~10-70% RH Dust loading was variable

6.1 Verified Performance Metrics

Verification of performance with respect to demonstration Performance Objectives are summarized in Table 18. As shown, the data and information evaluated support verification of a subset of the demonstration Performance Objectives.

Table 18. Verified Performance Objectives

Verified Performance – eSpin Exceed Air Filters				
Criteria	**Performance Criteria**	**Reported Performance**	**Verified Performance**	**Notes**
Air Filter Life	>1.5x current baseline filters	1.6x to > 4x (MERV 8 pre-filters) Equivalent to baseline filters (Post-filters)	>2x minimum	Filter life could be significantly longer than data indicates, but test duration does not allow for accurate determination, as Exceed filters and baseline post-filters were still viable at end of test periods.
Indoor Air Quality	5% reduction in particle concentration vs. baseline	20-35% reduction in Air Quality Index	20-35% Reduction in AQI	eSpin utilized AQI instead of particle concentration as an improved indicator of air quality. Air quality studies were inconclusive in two of the three facilities
Filtration Energy Usage	2% reduction in energy required	39-61% reduction in energy	Not verified	Qualitative and quantitative indications are that energy utilization is reduced. However, due to difficulties in

				comparing operating conditions, results are not verifiable.
Dust Holding Capacity	Exceed filters hold 5% more dust	4 – 38% more dust capacity	Not verified	For one set of air handlers, the dust holding capacity is nearly identical, and for the other set, apparent significant changes (38%) are observed. However, this includes data for post-filters with different MERV ratings. At a second facility, pre and post-filters showed different impacts on capacity and data is not verifiable.
Solid Waste Generation	>20% reduction in kg/yer filters disposed	60-75% reduction	>50% reduction	Filter life could be significantly longer than data indicates, but test duration does not allow for accurate determination, as Exceed filters and baseline post-filters were still viable at end of test periods.
Lifecycle Cost	>5% reduction in total cost per filter Simple payback <6 months	25-70% reduction in cost; 5 mo – 3.1 yr payback	Not Verified	Although likely accurate, significant assumptions were used to calculate LCC that were not verified, including labor costs, and disposal costs. In addition, unverified energy usage values are utilized in the calculations.

6.2 Compliance with ISO 14034 Verification Requirements

Overall, when considering that ISO 14034 verification was not designed into the Demonstration Plan for the eSpin Exceed demonstration, there were many areas which complied with the ISO standard requirements, indicating that (1) the ESTCP guidelines are inherently partially compliant with ISO 14034 in current form, and that (2) eSpin pursued rigorous approaches to testing and instrumentation that met ISO 14034 requirements without issue. In fact, the majority of instrumentation used, and the data collection approach, were excellent and would be considered generally compliant with ISO 14034.

A gap analysis specific to the eSpin project was completed using information provided by eSpin, existing performance data generated during the demonstration period, and other verifiable information from the demo (instrument specifications, demonstration conditions, data quality assessment), and assessing this with respect to the relevant requirements of the ISO standards. This analysis is detailed in the gap analysis tables in Appendix B and summarized below.

A summary of critical compliance successes is provided below.

Table 19. eSpin ESTCP Demonstration compliance with ISO 14034

ISO 14034 ETV Requirement	Meets ISO 14034 requirements?	Notes
Eligibility for ETV: *legal entity, environmental benefits, commercial ready, relevant and thorough performance claims*	Y	The ESTCP program requirements ensure that the technology evaluated meets all administrative eligibility requirements. eSpin's demonstration meets these. In addition, the Demonstration Plan provides a list of market relevant performance parameters and objectives that ensure data from demonstration will aid in future decision-making.
Demonstration Performance data quality: Appropriate, quality instruments, proper calibrations, data validation and analysis	Y	The instrumentation used for data collection by eSpin generally provided high quality data and was appropriate for parameters measured. Instrumentation was properly calibrated and maintained (although calibration documentation was not fully provided). Data was properly collected, handled, validated, and analyzed.
Test / Demonstration Approach: Market relevant test design, representative host sites	Y	Demonstration utilized multiple real-world systems operating in market relevant conditions. Planned approach is relevant and appropriate.

Generally, because of the compliance with the established requirements of the ESTCP program, many of the basic requirements of ISO 14034 were met by eSpin during the demonstration. Overall, data quality level was acceptable and mostly compliant with ISO 14034 standards, with some key exceptions. Test design was also relevant and appropriate for demonstration of key performance objectives in an operational setting.

6.3 Gaps in Compliance with ISO 14034 Verification Requirements

Although data produced during testing was of high quality, with proper instrumentation utilized by eSpin, there remained significant gaps in compliance with ISO 14034 that prevent a full verification of all performance objectives. In addition, there were some identified test design and execution issues that prevented full verification. Table 20 summarizes identified issues and gaps in compliance with ISO 14034.

Table 20. eSpin ESTCP Demonstration important gaps in compliance with ISO 14034

ISO 14034 ETV Requirement	Meets ISO 14034 requirements?	Notes
Demonstration Performance data quality: compliance with ISO 17025, proper calibration	Partially	ISO 14034 requires that data collected for verification purposes meet the requirements of ISO 17025, which includes rigorous testing organization quality management requirements and documentation. In addition, it is generally preferred that testing and data collection is done by independent test bodies. Although, properly qualified testing staff supported by an independent

		observation and qualification or review may be considered adequate. A full review of testing staff and eSpin testing quality management programs would be required.
Test / Demonstration Approach: Utilization of Accepted Standards, Proper Test Design, proper data analysis	Partially	Although eSpin did perform ASHRAE 52.2 testing to establish filter MERV rating in their lab, additional ASHRAE, ASTM, or other standards were not applied in the field evaluation of the Exceed air filters, nor additional lab tests utilized. Also, indoor air quality testing approaches were acceptable, but could have utilized established EPA or OSHA test procedures for greater acceptance. Due to significant differences in observed operating conditions, it is difficult to draw verifiable conclusions from data regarding certain performance objectives Initial test periods at Fort Benning, for which much of the reported data analysis is provided, included a period where post-filters were of different MERV ratings, yet were still compared. For one test location, testing plans were not followed and filters changed on regular schedules due to facility requirements. This prevents that data from being used, for determination of filter life, and should be reported as such.
Data Analysis & Reporting	Partially	Uncertainty analyses were not completed to fully demonstrate the statistical significance of changes in performance between COTS filters and Exceed filters. Performance parameters should always, when possible, be presented along with uncertainty, represented by the 95% confidence interval on the value.

Overall, the eSpin verification utilized generally acceptable approaches to demonstration. However, some of the test program implementation issues prevent the full verification of data and performance parameters due to lack of comparability between baseline (COTS) and candidate (Exceed) filters. Although data can be used to provide insight into these performance parameters with validity, they cannot be considered compliant with ISO 14034.

In addition, some minor issues with reporting and data analysis identified above are present, but these can easily be addressed with additional data analysis efforts (i.e. uncertainty analysis).

Finally, to fully verify all values to ISO 14034 compliant levels, a more thorough review of eSpin data quality management procedures and staff qualifications would be required to ensure compliance of testing and data collection with ISO 17025.

It should also be noted that an independent 3rd party verification was not included in the original eSpin demonstration plan, which is a requirement of ISO 14034, and that the current project (EW20-5333) was implemented to provide that capability and compliance with ISO 14034.

6.4 ISO 14034 Implementation Issues

The implementation of the ISO 14034 verification for the eSpin Exceed filter demonstration was straightforward, with a few key exceptions. A summary of the implementation process for the eSpin verification is provided in Figure 5.

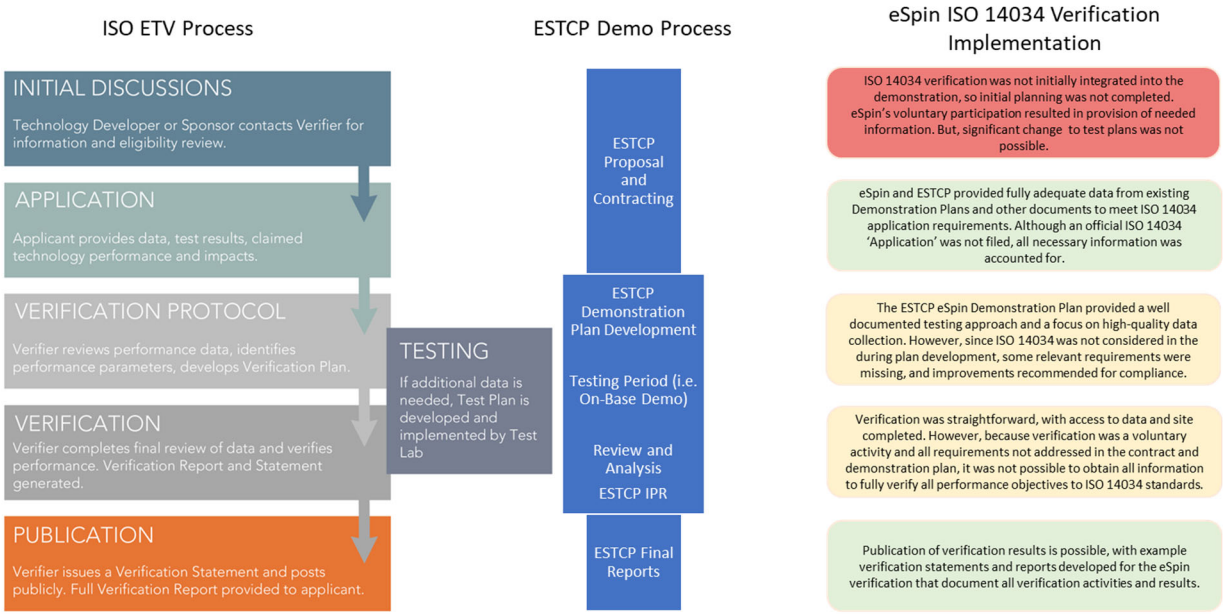

Figure 5. ISO 14034 Verification Process implementation issues for eSpin ESTCP Demonstration. Red = Not completed, Yellow = Issues identified, Green = little to no implementation issues

The primary issues associated with implementation of ISO 14034 Verification for the eSpin Exceed air filters included the following:

- **Lack of integration of ISO 14034 in planning activities**: Because this verification was added onto the eSpin demonstration after testing was initiated, it was not possible to ensure demonstration plans and test approaches would meet ISO 14034 requirements. Future demonstrations should identify ISO 14034 verification as a requirement and use modified ESTCP guidelines that provide required information to enable verification success.
- **Improvement in testing approach and utilization of testing standards and practices:** Although eSpin utilized quality instruments and data collection procedures, additional test design considerations that incorporate accepted standards or protocols, and addition of controlled lab testing in addition to field testing could provide better outcomes and consistency or comparability across different projects.
- **Independent testing:** As verification was not originally planned for this demonstration, Demonstration Plans did not account for use of independent test bodies to collect data, where possible (such as ASHRAE 52.2 testing), which is preferred.
- **Provisions for independent verification, including data and document access:** Because verification was not originally planned, full data access for verification was not integrated into plans, and was difficult due to the large quantity of data collected, as well as the custom programming required for data processing and analysis. Verification was based on sample data sets obtained and reviewed, which provided a snapshot for auditing. This approach is acceptable, but not preferred. In addition,

some quality related documents were not readily available, such as original calibration certificates for instruments in some cases.

6.5 Additional Requirements and Costs of Verification

Integrating ISO 14034 verification inherently adds additional costs to a project. The primary cost is the addition of an independent verifier to the project to provide the third party verification.

Additional costs can arise due to additional requirements imposed to ensure compliance with ISO 14034. Potential cost additions include:

- **Independent verifier costs:** Costs to cover labor and site visit travel for a qualified third party verifier. These include verifier participation in development and review of ISO 14034 compliant Demonstration Plan, site visit during verification, verification activities, including all data and document review, and reporting.
- **Additional Project Team labor costs:** It is likely that project team members will incur some additional costs associated with managing verification activities, including packaging and provision of data for verifier, preliminary planning and discussions with verifier, site visit for verification, and review of verification reports.
- **Additional testing costs:** In certain verification programs, where analytical testing is being completed by the project team, independent samples may be collected and submitted to independent ISO 17025 accredited laboratories for comparative analyses. These will typically be limited samples and will be costed based on the analytical requirement.
- **Additional calibration costs:** There is a potential for incurring additional costs for calibrated equipment in compliance with ISO 14034. If project teams are not already specifying purchasing instruments with NIST-traceable calibrations, those calibrations should be obtained. The most cost-effective means is to do this with original purchase. Costs are on the order of $130-300 for each instrument for temperature, pressure, humidity, flow, and other common sensors (for example, $186 cost for pressure transducers and $291 for gas flow meters when purchased from Cole-Parmer via Innocal).

A summary of the estimated additional costs to support independent verification is provided in Figure 6. Note that these costs are estimated for typical projects based on experience from numerous verifications completed for similar technologies. For eSpin, no additional calibration costs or analytical costs were required. However, estimates below include costs for calibration of 14 instruments (to address most instruments at the eSpin Fort Benning Starship Barracks facility), and include estimated costs for an outside laboratory to complete ASHRAE 52.2 MERV rating tests for four filter sizes or types.

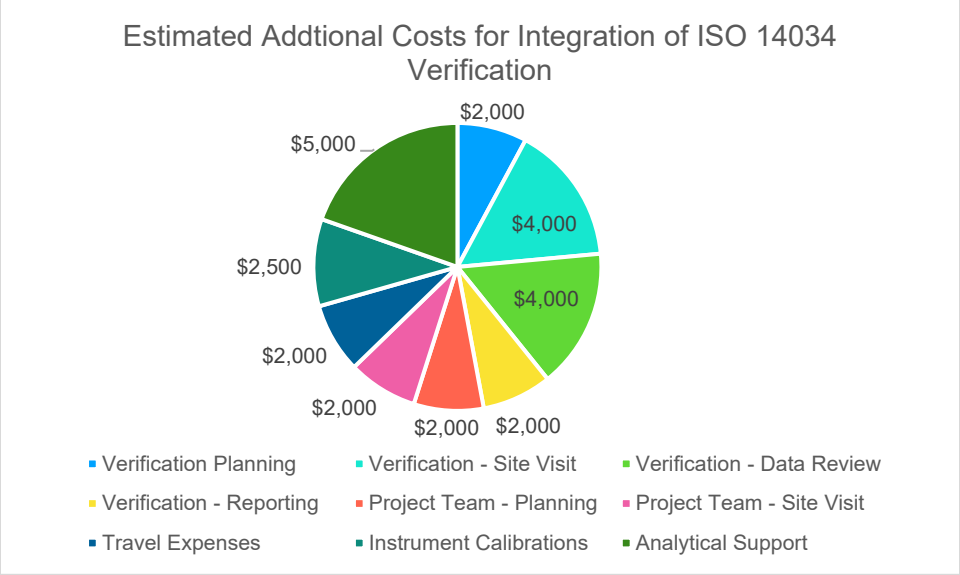

Figure 6. Estimated additional costs of ISO 14034 Verification for ESTCP Demonstrations

7 Benefits of Verification

Although the ISO 14034 verification of the eSpin Exceed air filters was an add-on task to an existing project, the evaluation of the implementation of the independent verification and the ISO 14034 requirements indicates some significant potential benefits. Some of the benefits result from independent verifiers identifying potential issues in data analysis and reporting of results, whereas other benefits potentially result from identification of improvements in test design, planning, and execution that can inform future studies and improve outcomes and consistency.

Observed benefits of independent verification of the eSpin Exceed air filter demonstration include:

- Identification of testing issues including variable operating conditions and differing filter specifications, which impact analysis and reporting of results. Identification of these issues resulted in improved and clarified reporting of results;
- Independent validation and documentation of high-quality data and instrumentation to provide additional credibility to reported results;
- Identification of potential improvements to future testing such that improved outcomes can be achieved;
- Verification that specific reported values for three performance objectives generally meet the criteria of ISO 14034;

In addition to observed technical benefits, 350Solutions received feedback from on-site energy managers as well as the eSpin PI that indicate the detailed and rigorous independent review of the filter demonstration provided value to them as well. Although anecdotal, the site facilities manager indicated that the additional oversight and independent review and confirmation of results would reduce the perceived risk to him of ordering significant quantities of filters in the future and would provide additional supporting justification for procurement officials for sign-off.

The eSpin PI also indicated that he is continuing to pursue additional demonstrations and that the recommendations for improvements to his demonstration approach will significantly improve outcomes and reduce potential for not achieving demonstration objectives. He has also indicated that he plans to

utilize the reports and statements provided from the draft verification as additional material to provide to potential DoD clients to reduce the perceived risks and concerns regarding implementation of the air filters at their facilities.

8 Lessons Learned & Recommendations for Improved Alignment of ESTCP Demonstrations with ISO 14034

This case study implementation of ISO 14034 requirements on top of the existing ESTCP Demonstration Guidelines identified issues with implementation of the standard, gaps between ESTCP and ISO 14034 requirements, and potential means of addressing these issues. Significant lessons learned and recommendations include:

Plan for ISO 14034 verification from the beginning: To ensure compliance with the ISO 14034 requirements, specifications that are critical to achieving verification should be included in ESTCP guidance from the full proposal stage forward, with clear requirements identified in the Demonstration Plan guidance. When these requirements are clearly identified up front, the likelihood of successful verification increases significantly.

Implement requirements on quality of instrumentation and analytical testing, including:

- Specification of high-quality instrumentation with certain accuracy requirements for specific types of instruments
- Requirement to purchase NIST-traceable calibrations when purchasing instrumentation and maintain documentation of all calibration and QA/QC data for instruments, including logs of ongoing calibrations and instrument cross checks.
- Require, at a minimum, analytical testing to meet ISO 17025 requirements, or at a minimum, include ISO 17025 compliant confirmational testing by independent accredited labs to cross check regular analytical testing by project teams

Statistical analyses matter: During review of data, especially when comparing two values, such as a candidate technology versus a baseline technology, it can seem as if one technology performs better than the other, but without statistical analyses, it is difficult to determine if that is truly the case. Require uncertainty analysis and reporting of results with 95% confidence interval as standard in all performance objective reporting. ISO 14034 and 17025 recommend this approach. Various potential guidelines can be referenced which describe approaches to uncertainty analysis, such as ISO Guide 98 and NIST TN 1297.

Real world demonstrations are great, but sometimes controlled testing is needed too: real-world demonstrations are the most relevant to energy managers, facility operators, and other critical stakeholders, as they demonstrate how a technology will work in a truly relevant operational space. However, as witnessed in the eSpin demonstration, because these are operational facilities, it is difficult, if not impossible, to control the operations of relevant equipment and facilities to ensure you can collect data that allows for the analysis desired. Because of the real-world variability and lack of control, test programs can benefit from designing controlled tests that ensure that some relevant comparison can be made, with real world data supplementing the controlled results.

Using standardized testing approaches has benefits: The eSpin demonstration consisted of appropriate test design with approaches that enabled collection of high-quality data as well as relevant analyses of comparisons between filters. However, additional benefit could be obtained by implementing use of some standard methods and protocols, such that direct comparison to other filters tested in similar manner is allowable. Examples of potentially applicable standards would include Eurovent 4/10 Standard for In Situ Evaluation of Fractional Efficiency for General ventilation Filters, and ISO 29462: Field Testing of General Ventilation Filtration Devices. Additional general-purpose standards such as

those focused on determination of outliers for data validation purposes (ASTM E178) or uncertainty analysis referenced about are also applicable. ISO 14034 provides accepted framework to ensure a demonstration is of very high-quality and that it is independently verified by qualified verifiers. But, detailed test procedures using accepted standards provide another layer of certainty and consistency in analysis.

Improved quality costs money: The case study of applying the ISO 14034 verification approach to the ESTCP demonstration program for the eSpin Exceed air filter demonstrates the potential value of implementing such approaches and standardization, in general. However, there are additional costs associated with the improved data quality and credibility. This results in the need to complete a cost benefit analysis for relevant projects to determine if the benefit of the additional work associated with verification and data quality improvements is worthwhile. This may need to include assessment of total project costs and additional costs specific to verification for each type of project. For low-cost projects (<$250k), the added costs may be prohibitive, as they are potentially greater than 10% of project cost (considering that typical cost of verification is roughly $25k. For larger projects, the cost of verification would likely be proportionally lower. It should be noted that, if requirements for improved instrumentation, analytical methods, or application of testing standards are implemented during the project proposal stage, those costs would already be accounted for, and any additional costs would be primarily for the verification, which would typically be in the range of $25k. In any event, projects funded under the ESTCP program that include ISO 14034 independent verification can expect an increased overall cost on the order of $25k.

APPENDIX B: ISO 14023 and 17025 Gap Analysis Review Forms

EW-201724_ESTCP ISO 14034 Gap analysis		ISO Conformance			
ISO 14034 Citations	**Requirement**	**Conforms**	**Partial conform**	**Non conform (gaps)**	**Comments**
4 - General Principles and Requirements					
4.1.1 - General	Provide a credible and impartial account of the performance of technologies. ETV is based on a number of principles to ensure that verifications are performed and reported accurately, clearly, unambiguously and objectively.		x		Performance demonstration is credible and representative, but not fully impartial. That is, field testing was self-performed, but managed under the review of ESTCP program.
4.1.2 - Factual approach	Verification statements are based on factual and relevant evidence confirming objectively the performance of technologies.	x			Evaluation of primary performance objectives was conducted in relevant setting and conditions, and according to industry standards: (ASHRAE 52.2)
4.1.3 - Sustainability	Povides credible information on the performance of technologies	x			
4.1.4 - Transparency and credibility	Demonstration is based on reliable test results and robust procedures. The process is facilitated such that, to the greatest extent possible, methods and data are fully disclosed and reports are clear, complete, objective and useful to the interested parties.	x			
4.2 - Requirements	When verifying the performance of technologies, the requirements of ISO/IEC 14034 and 17020:2012 shall be applied and demonstrated.		x		Conducted under the requirements of the ESTCP program, the demonstration partially conformed to the ISO standards, as noted in the gap analysis

EW-201724_ESTCP ISO 14034 Gap analysis (Con't.)		ISO Conformance			
ISO 14034 Citations	**Requirement**	**Conforms**	**Partial conform**	**Non conform (gaps)**	**Comments**
5 - Environmental Technology Verification					
5.2.1 - Application requirements	Information about the technology vendor/developer, including its name and address(es) of its physical location(s).	x			The technology demonstration application and selection process executed under the ESTCP Program sufficiently conforms to the application requirements as stated in the standard
	Description of the technology	x			
	Information about the intended application of the technology	x			
	Operation and performance of the technology	x			
	Development status of the technology proposed for verification and its readiness for market	x			
	Information on relevant alternative of the technology; including its relevant performance and impacts	x			
	Information on significant impacts of the technology proposed for verification and its added value	x			
	Performance claim including a proposed set of performance parameters and their numerical values to be verified	x			
	Installation and operating requirements and conditions	x			
	Service and maintenance requirements	x			
	Expected length of time for which a technology functions under normal operating conditions	x			
	Any applicable safety requirements and considerations	x			
	Relevant existing test data and methods for acquiring these data that were applied to support the performance claim				
5.3.1 - Specification of performance claims	Are relevant and sufficient for the verification of the performance of the technology, and its added value	x			The technology demonstration performance objectives and test design developed and executed under the ESTCP Program sufficiently conforms to the requirements of the standard
	Correspond in full to the needs of the interested parties	x			
	Can be quantitatively verified through testing	x			
	Can be verified under set operating conditions	x			
5.3.2 - Verification planning	The verification plan shall detail the verification procedure specific to the technology and the performance to be verified.	x			
5.4.1 - General	Verification organization - acceptance of existing data, need for additional data, confirmation of performance		x		Partial conformance to the standard using the data generated under the ESTCP demonstration program
5.4.2 - Acceptance of existing test data	Relevant for the performance to be verified	x			
	Produced and reported according to the requirements of ISO/IEC 17025		x		See ISO 17025 conformance checklist
	Meet the requirements specified in the demonstration plan	x			
5.5 - Verification Report and Statement	A verification report shall be developed. It shall adhere to the verification plan and shall include at a minimum the list of required elements in standard.	x			
5.6.1 - Publication	At a minimum, the verification statement shall be made publicly available. The publication shall be included in a publicly available directory (e.g. website).	x			
5.6.2 - Validity of verification report/statement	The applicant shall: a) ensure that the technology for which performance has been verified is conforming to the conditions as per its verification, published verification statement and report, if relevant; b) inform the verifier, in writing, of any changes that have been made to the technology.	x			

EW-201724_ESTCP ISO 17025 Gap analysis	Note: References to "laboratories" supporting ESTCP demonstrations are assumed to include any body performing measurements or analytical support of demonstrations	ISO Conformance			
ISO 17025 Citations	**Requirement**	**Conforms**	**Partial conform**	**Non conform (gaps)**	**Notes**
4 - General requirements					
4.1	Testing and laboratory activities shall be undertaken impartially			x	The ESTCP demonstration program does not require that testing and laboratory activities be impartial to the technology under demonstration, as is the case for this project.
4.2	The test body shall ensure the protection of confidential information and proprietary rights, including protecting the electronic storage and transmission of results	x			
5 - Structural Requirements					
6 - Resource Requirements					
6.1 - General	Test body will employ, or have contracts with, a sufficient number of persons with the required competencies, including, where needed, the ability to make professional judgements, to perform the type, range and volume of its inspection activities	x			
6.2 - Personnel	The test body shall manage the risk to impartiality arising from over-familiarity between its personnel and the customer.			x	See 4.1 above, testing was not performed by impartial test body.
6.3 - Laboratory facilities	The facilities conditions shall be suitable to realize the testing activities and do not adversely affect the validity of results.	x			The facilities and test conditions, selection and use of critical measurements equipment, and data collection and handling were verified as suitable with regard to the demonstration objectives, and to conform to requirements and guidance of the ESTCP demonstration program.
6.4 - Equipment	6.4.1 The test body shall have access to all equipment required for the correct performance of the laboratory activities. Equipment shall include software, measurement standards, reference materials, reagents and consumables or auxiliary apparatus or combination thereof necessary to realize a measurement process and which may influence the measurement result.	x			
	6.4.3. The test body shall have documented processes for appropriate handling, transport, storage, use and planned maintenance of equipment to ensure proper functioning and in order to prevent contamination or deterioration.		x		Equipment utilized to monitor critical measurements supporting the demonstration were identified along with sensor specifications and stated accuracies. Equipment calibration procedures and supporting reference materials were not independently verified.
	6.4.5. The test body shall identify equipment used for measurements and capable of achieving the accuracy required and complying with the specifications relevant to the activities concerned. It shall establish a documented calibration program for such equipment to ensure metrological traceability of the measurement results.		x		
	6.4.6. All equipment requiring calibration shall be labelled, coded or otherwise identified to allow the user of the equipment to readily identify the status of calibration		x		
	6.4.12. The test body shall select and use reference materials that are fit for the specific purpose in the measurement process.		x		

EW-201724_ESTCP ISO 17025 Gap analysis	Note: References to "laboratories" supporting ESTCP demonstrations are assumed to include any body performing measurements or analytical support of demonstrations	ISO Conformance			
ISO 17025 Citations	**Requirement**	**Conforms**	**Partial conform**	**Non conform (gaps)**	**Notes**
6.6 - Metrological traceability	6.6.1. The test body shall establish and maintain metrological traceability of its measurement results by means of a documented unbroken chain of calibrations or comparisons each contributing to the measurement uncertainty, linking them to an appropriate reference.		x		Test body provided sensor specifications and stated factory traceable accuracies for all critical measurements supporting the demonstration. The procedures and traceability of factory or other equipment calibrations were not available for independent verification.
	6.6.2. Where it is technically possible, the test body shall demonstrate that the appropriate reference is a direct realization of, or traceable to the International System of Units (SI) . The link to SI units shall be achieved by comparison or reference to national or international measurement standards or certified reference materials with stated metrological traceability to the SI.		x		
	6.6.4. Metrological traceability of measurement results shall be assured through calibrations by laboratories that can demonstrate competence, measurement capability and traceability.		x		
7.0 - Process requirements	7.2.1.1 The test body shall use appropriate methods and procedures for all tests and/or calibrations. These include procedures for sampling, handling, transport, storage and preparation of items to be tested and/or calibrated, and, where appropriate, for evaluation of the measurement uncertainty as well as statistical techniques for analysis of test and/or calibration data.	x			Conforms to requirements and guidance of ESTCP demonstration program
	7.3.1 The sampling process shall address the factors to be controlled to ensure the validity of results. The test body shall have a sampling plan and procedures for sampling when it carries out sampling of substances, materials or products for subsequent testing or calibration. The sampling plan and procedures shall be available at the site where sampling is undertaken. Sampling plans shall, whenever reasonable, be based on appropriate statistical methods.	x			
	7.3.4 The test body shall have procedures for recording relevant data and operations relating to sampling that forms part of the testing or calibration that is undertaken.	x			
	7.5.1 The test body shall ensure that records for testing activity contain the report or certificate and sufficient information to facilitate, if possible, identification of factors affecting the uncertainty and enable the activity to be repeated under conditions as close as possible to the original.	x			
	7.6.1 A test body performing calibrations, including of its own equipment, shall apply procedures to evaluate the uncertainty of measurement for all calibrations.		x		Verifiers estimated overall uncertainty in normalized power consumption at approximately +/- 2.7% by propagating the rated accuracy of the critical field measurements.
	7.6.2 A test body performing testing activities shall apply procedures for evaluating uncertainty of measurement.		x		

REFERENCES

[1]. SERDP/ESTCP Project #EW20-5333, Demonstration Plan "Improving ESTCP Demonstration Outcomes & Tech Transfer via Integration of Standardized Third-Party Technology Verification using ISO 14034, Version 3.1", January 14, 2021, https://www.serdp-estcp.org/Program-Areas/Installation-Energy-and-Water/Energy/Conservation-and-Efficiency/EW20-5333.

[2]. ISO 14034:2016 Environmental Management – Environmental Technology Verification (ETV), International Organization for Standardization. November 2016.

[3] ISO 17020 :2012 Conformity Assessment – Requirements for the Operation of Various Types of Bodies Performing Inspection, International Organization for Standardization. March 2012.

[4] ISO/IEC 17025:2017 – General Requirements for the Competence of Testing and Calibration Laboratories. International Organization for Standardization. March 2018.

[5]. SERDP/ESTCP Project #EW-201724, Demonstration Plan "Nanofiber Based Low Energy Consuming HVAC Air Filters", January 2018, https://www.serdp-estcp.org/projects/details/12480881-4c09-4157-90d8-c3487b41241b/ew-201724-project-overview .

[6]. 350Solutions, QSP-350-223-02, "ISO 14034 Environmental Technology *Verification Standard Operating Procedure",* 350Solutions internal document, January 2020.

[7]. International Standards Organization (ISO), Technical Committee 207, *Draft Environmental Technology Verification – Guidance to Implement ISO 14034*, ISO/PDTR WD1:2017(E), 10-16-2017.

[8] 350Solutions, Inc. "*ESTCP / ISO 14034 Gap Analysis Report v 1.2"*. August, 2020.