# Field Testing with Unattended Environmental Sampling Devices

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**Abstract**

Researchers at Savannah River National Laboratory (SRNL) and Oak Ridge National Laboratory (ORNL) have been developing a tamper resistant/tamper indicating aerosol contaminant extractor (TRI-ACE) to be used for unattended environmental sampling in support of safeguards applications. Environmental sampling has become a key component of International Atomic Energy Agency (IAEA) safeguards approaches by supporting conclusions concerning the absence of undeclared nuclear material or nuclear activities in a State. Swipe sampling is the most commonly used method for the collection of environmental samples from bulk handling facilities. However, augmenting swipe samples with an air monitoring system, which could continuously draw samples from the environment of bulk handling facilities, could improve the possibility of the detection of undeclared activities. Continuous, unattended sampling offers the possibility to collect airborne materials before they settle on surfaces which can be decontaminated, taken into existing duct work, filtered by plant ventilation, or escape via alternate pathways (i.e. drains, doors). The TRI-ACE system will allow for such collection in a manner that ensures sample integrity. The TRI-ACE prototype, which was completed in early 2013, has many features which could indicate possible tampering events that may have occurred during unattended collection. Some of these features include a particle counter, air flow monitor, proximity detectors, temperature and humidity detectors, accelerometers, etc. All of these components can be used to establish normal, baseline facility operating parameters and then send out an alert when conditions deviate from normal. With the completion of the prototype, the next step in the development of the TRI-ACE is to conduct field trials in relevant environments. To date, the instrument has been laboratory tested and subjected to several blind tampering scenarios. Additional international field trial demonstrations with the instrument are currently being pursued. In this paper we will present testing preparation, testing scenarios, sample plan development, key findings, and field trial preparations for the TRI-ACE.

**Introduction**

The tamper resistant/indicating aerosol contaminant extractor (TRI-ACE) is an electrostatic particle collector that has been developed for use as an unattended environmental sampling system at uranium bulk-handling facilities. The conceptual design for the TRI-ACE prototype (Figure 1) began in 2011, and is based off of a standard ACE design which is shown in Figure 2. The ACE collector pulls air (aerosol) and the particles suspended (contaminants) in the air through a non-metallic flow tube via a muffin fan and electrostatically deposits particles on collection plates. The TRI-ACE utilizes the electrostatic collection system of the standard ACE but has been redesigned to include several tamper indicating and tamper resistant components such as a particle counter, air flow monitor, proximity detectors, temperature and humidity detectors, accelerometers, etc. All of these components can be used to establish normal, baseline facility operating parameters and then send out an alert when conditions deviate from normal.

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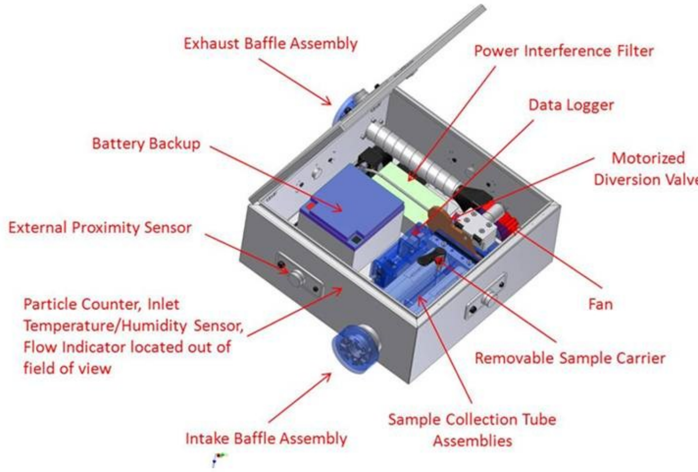


***Figure 1.*** *Conceptual design of the TRI-ACE.*

***Figure 2.*** *ACE sampler.*

The TRI-ACE collection system provides an air monitoring approach that may complement current environmental sampling protocols for IAEA-safeguarded uranium or plutonium bulk-handling facilities. Additionally, this method offers timely collection of airborne materials before they settle on surfaces (that can be decontaminated prior to collection), taken into existing duct work (that can be filtered by plant ventilation), or escape via alternate pathways (i.e. drains, doors). Augmenting swipe samples with an aerosol collection system such as the TRI-ACE, which could operate in a mode to collect discrete, timed samples or continuously draw samples from the atmosphere of uranium handling areas of bulk facilities, could improve the probability of detecting undeclared activities.

Incorporation of tamper resistant and tamper indicating technologies into the ACE system will allow continuous collection of samples at bulk-handling facilities in a manner that ensures sample integrity. Tamper resistant/indicating components could deter attempts to alter the samples by the operator and indicate if any such tampering has taken place. A TRI-ACE would be an important addition to the international nuclear safeguards inspector's toolkit when developing advanced safeguards approaches for the IAEA. In addition, a TRI-ACE could be utilized by domestic regulatory authorities to confirm the declared enrichment values at gas centrifuge enrichment plants (GCEPs) and verify the absence of undeclared production.

The TRI-ACE prototype (Figure 3) was completed in early 2013 and has been laboratory tested and subjected to several blind tampering scenarios. The prototype has also undergone a series of field tests at a U.S. uranium bulk-handling facility. Field testing was conducted at Paducah Gaseous Diffusion Plant in April-May of 2013. Additional international field trial demonstrations with the instrument are also currently being pursued. This paper will discuss the preparation, logistics, and lessons learned from testing demonstrations performed with the TRI-ACE prototype.

***Figure 3.*** *(Left) TRI-ACE prototype outer enclosure. (Right) Components inside the TRI-ACE prototype.*

**Field Trial Deployment Case Study – Paducah Gaseous Diffusion Plant**

**Field Trial Planning**

After completion of the TRI-ACE prototype, SRNL, ORNL and DOE NA-241 sponsors conceived plans to conduct initial field trial demonstrations with the system. Preliminary planning for the field trail deployment included developing a goals statement, selecting a facility and performing negotiations with the facility.

*Field Trial Goals*

The goal for the initial test effort was to evaluate the operation of a standard ACE and TRI-ACE in an operating uranium enrichment facility. During Phase 1 of the testing, we wanted to evaluate the effectiveness of the ACE/TRI-ACE system in unattended monitoring of airborne particulate, particularly:

Perform a side-by-side comparison of the TRI-ACE and standard ACE systems.
Ascertain the relative effectiveness of ACE and TRI-ACE collection versus swipe collection in environments with relatively high uranium air loading (i.e., environments applicable to the interior of operating facilities rather than remote from such facilities).

During Phase 2 of the testing, we wanted to evaluate the effectiveness of the tamper resistant features of the TRI-ACE system, and determine the resistance of the system to “spoofing”.

*Facility Selection*

SRNL, ORNL and DOE NA-241 sponsors initially discussed all available options for locations where field trial demonstrations of the TRI-ACE could be conducted to achieve the goals set forth for the deployment. A target facility, Paducah Gaseous Diffusion Plant, was chosen based on previous working relationships with ORNL and SRNL researchers.

*Facility Negotiations*

ORNL made the initial request to allow for the testing to occur at the facility. The ORNL TRI-ACE team members had strong ties to the selected facility and therefore led all negotiations for performing testing at the location. Before agreeing to the demonstration the facility had several questions regarding the instrumentation, planned activities, and cost that had to be addressed. A series of conference calls were held between all of the parties to answers questions and address issues. Fact sheets were also issued to the facility disclosing all of the components and operational principles of the TRI-ACE and ACE systems. Cost estimates for supporting the testing were also provided by the facility during the negotiation process. This process resulted with ORNL establishing a formal contract with the facility to allow for testing.

**Field Trial Preparation**

After the facility agreed to host SRNL and ORNL for the field demonstration, the team began preparing for the deployment. Pre-deployment preparation included performing instrument checks, developing a deployment plan and pre-deployment checklist, and creating a team schedule.

*Instrument Checks*

Several laboratory checks were run on the TRI-ACE prior to deployment to test the function and response of the tamper indicating features. These checks included blocking the intake and exhaust on the system and inducing an increased particle count scenario. Temperature sensors and proximity gauges were also checked for functionality. The collection efficiency of the TRI-ACE was testing with salt particles in a particle collection chamber at SRNL. Several ACE units were also being deployed so these too were checked prior to deployment to ensure they were operational. The fan speed on all instruments was also set to approximately the same flow rate (~300 L/min) prior to deployment.

*Deployment Plan Development*

A day-by-day deployment plan was developed to guide the field testing. The deployment plan first listed equipment and supplies that would be needed and which party would supply them. Potential testing locations were then identified, and daily procedures were developed for phase I and phase II of the testing.

Phase I of the testing (i.e., side-by-side performance testing of the ACE and TRI-ACE) was scheduled for week 1, while phase II of the testing (i.e., initial spoofing attempts on the TRI-ACE) was scheduled for week 2. An abbreviated version of the deployment plan is shown below:

**Phase 1 Performance Testing of ACE/TRI-ACE Equipment**

*Day 1:*

Organization and coordination meeting.

Transfer equipment into facility and set up the test units (10 ACE units and 1 TRI-ACE unit) at the ten test locations.

Insert new sample collection plate into each ACE and TRI-ACE unit.

Start the ACE and TRI-ACE units.

Collect 1 environmental swipe samples at each location.

Make sketches and take photos of each test location.

*Day 2:*

At each of the test locations, perform the following steps:

Check the ACE and/or TRI-ACE units and ensure they are operating properly.

Collect 1 environmental swipe samples at each location.

Package the environmental sample in SRNL-supplied Mylar bag with desiccant and store awaiting shipment to the ORNL analytical lab at the end of the testing.

Remove the sample collection plate from each ACE and TRI-ACE unit and package it in a Mylar bag with desiccant.

Install a new sample collection plate in each ACE and TRI-ACE unit.

*Days 3-5 repeat above*

**Phase 2 Tamper-Indicating and "Spoofing" Tests of TRI-ACE Equipment**
One of the ACE units will be a "control" unit that will be left alone by the Red Team. The other ACE unit is to be "spoofed" in the same manner as the TRI-ACE unit.

*Day 1*

Blue Team:
At each of the test locations, perform the following steps:

Check the ACE and/or TRI-ACE units and ensure they are operating properly.

Change out the data logger from the TRI-ACE unit, and look for indications of "spoofing" before completing the next day's rounds.

Collect 1 environmental swipe samples at each location.

Package the environmental sample in SRNL-supplied Mylar bag with desiccant and store awaiting shipment to the ORNL analytical lab at the end of the testing.

Remove the sample collection plate from each ACE and TRI-ACE unit and package it in a Mylar bag with desiccant.

Install a new sample collection plate in each ACE and TRI-ACE unit.

Red Team:
This activity is to be performed after the Blue Team has completed their daily rounds.

By the close of business, implement an action at the TRI-ACE test locations that will "spoof" the readings collected by the TRI-ACE unit and the test ACE unit. The team should then remove the "spoof" prior to the blue team making their rounds the following day.
The spoof will be conducted in such a way so that the Blue Team does not know when it was applied or removed, or have any knowledge of the nature of the spoof.

*Repeat for Days 2-4*

*Final Day*

Remove equipment from testing locations

Perform radiological survey of the ACE and TRI-ACE units. Disassemble the units as needed to check for potential internal contamination. If internal contamination is found (or if it is not possible to verify that contamination is not present due to lack of access to wetted internals), remove and dispose of materials.

Perform radiological checks and other checks as needed to prepare for shipment of collection plates to ORNL. Package the collection plates in the Mylar bags with desiccant provided by SRNL. Double bag and wrap the Mylar bags for shipment.

Remove the ACE and TRI-ACE units, and supporting equipment and load into DOE van for return to SRNL.

*Pre-deployment Checklist*
An equipment and materials list was prepared outlining specific hardware, software, testing supplies and tools that would be needed during the field trials. The parties involved were assigned materials and equipment to bring.

Facility Equipment & Material Needed

- Vehicle to transport equipment and personnel
- Location to stage equipment
- Digital camera
- 10 test locations, each with:
- Electrical power nearby (110 VAC, 15 A)
- 1 Small table/work surface for TRI-ACE unit

SRNL Supplied Equipment & Material Needed

- 1 TRI-ACE field deployable system
- 10 ACE field deployable systems.
- Sample collection plates for ACE & TRI-ACE units (110+ plates)
- Mylar bags and desiccant for packaging sample collection plates and environmental samples (310+ bags)
- Portable label maker or Sharpie pen for labeling packaged samples and sample collection plates

- Extension cords for powering equipment
- Computer
- Equipment List

ORNL Supplied Equipment & Material Needed

- Environmental swipe sample collection supplies

In addition to the list above, a more detailed equipment list was created. This list included component manufacturers and model numbers, as well as software information. The list also outlined various test equipment and tools that would be brought for any troubleshooting work that would need to be done in the field. The equipment list was provided to the facility in order to prepare approval paperwork for the electronics.

*Team Schedule*

The field trial team consisted of 4 personnel from SRNL and 3 personnel from ORNL. Essential personnel participated in the field trial for the entire duration, however, since the field trial was scheduled for two weeks certain team members rotated during the demonstration. The team schedule was set several weeks before the field trials commenced.

**Field Trial Deployment**

*Equipment Transport and Set-up*

The field trial deployment took place in the spring of 2013, after approximately 6 months of preparation. The ACE and TRI-ACE systems were transported to the test facility from SRNL by vehicle because the TRI-ACE prototype had not been secured for shipping. Once at the facility the SRNL/ORNL team members met with facility escorts at the barricade to complete the facility entrance training and badging. The equipment was inspected at the barricade by protective force personnel and approved for entrance into the facility. The SRNL/ORNL team members were then escorted in with the equipment and issued all required radiation protection badging and facility approved work clothes. The facility provided the team with a staging location for the instrumentation and an area to hold meetings. Before deploying the equipment, s pre-deployment meeting was held with SRNL/ORNL team members and all facility stakeholders to discuss the implementation plan, job hazards, facility entry requirements, etc. After approval of the work plan, equipment, and testing methods, the SRNL/ORNL team dressed out and prepared the equipment for deployment. The team completed the initial deployment of the equipment to all 10 sampling locations on the first day.

*Sampling Plan Implementation and Troubleshooting*

For the majority of the two week field trials the deployment implementation went according to plan. The daily procedures were followed and it took the majority of the day to change out the ACE and TRI-ACE collection plates and collect environmental swipe samples at the 10 locations. The rest of the testing days were normally spent examining data collected from the TRI-ACE sensors and preparing labels for the collections the following day.

There were, however, a few issues that had to be solved in the field during the demonstration. On the second day a couple of problems were noticed with the TRI-ACE system. The first issue was that the TRI-ACE was not collecting particles. The device was switched over to operation on the back-up collection tube and began operating normally. It was believed that there was a problem with the high voltage power supply to the primary collection tube. With the back-up collection tube operational this did not affect the implementation of the sampling plan. When the TRI-ACE was set up at the facility 2 of the 6 proximity sensors were not functioning. This issue could not be resolved in the field and the demonstration had to be conducted with the two sensors not operating. The final issue that arose on the second to last day was the number of remaining collection plates was not going to be enough to collect samples at all locations the following day. Therefore, changes were quickly made to the sampling plan to obtain samples at the most important locations.

*Closeout*

On the final day of the field trial demonstration, the facilities radiological protection personnel escorted the team to each of the 10 locations to collect the instrumentation. The instruments were surveyed for contamination prior to removal and then transported back to the staging area. Once all equipment was collected it was packaged and loaded into a vehicle to return to SRNL. The samples collected were packaged and surveyed and shipped to ORNL for analysis.

**Key Findings**

During the phase II, tamper indicating and spoofing testing, the TRI-ACE was subjected to 4 spoofing scenarios by the red team (see *deployment plan* above). During the spoofing scenarios the blue team was unaware of any activities being conducted by the red team. After completion of the testing the blue team analyzed the data from the TRI-ACE tamper indicating sensors.

As an example, data collected during one such test is shown below. During this particular scenario the red team obstructed the intake manifold of the TRI-ACE. Figure 4 shows background data from the flow sensors and main airflow fan current, while Figure 5 shows data collected from the same sensors during the spoofing scenario. A noticeable change is seen with the flow sensor (Figure 5) as a sharp decrease in flow from ~9m/s to 2m/s. This indicates that there has been a major restriction to the flow path of the TRI-ACE during this time period. Also shown in Figure 5 is the main airflow fan current draw. The current decreases during the same time period as the flow, which would support the indication of a reduced air flow. The fan is moving less air thus doing less work hence the reduced current draw. This data set shows that a tampering scenario could be easily detected with the TRI-ACE tamper indicating components.

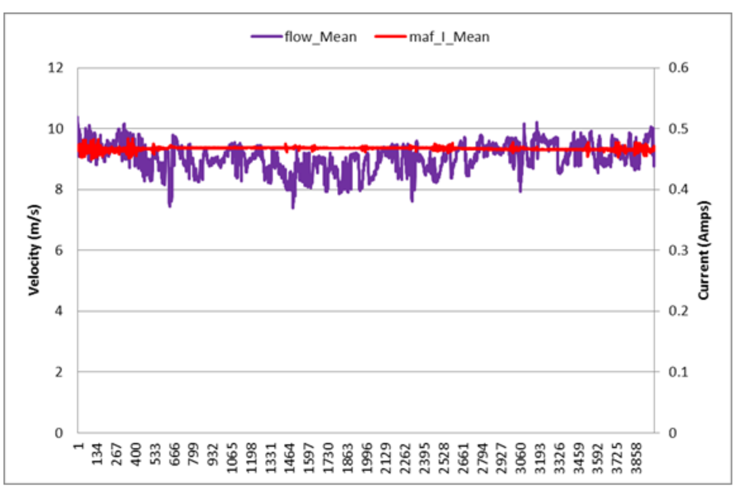


**Figure 4.** Facility baseline of flow velocity and current draw from the fan vs. time.

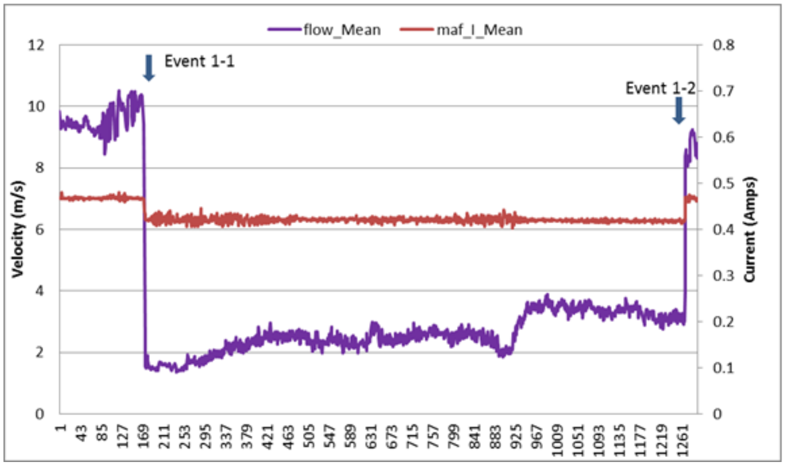


**Figure 5.** Flow velocity and current draw from the fan vs. time during spoof day 1.

**Lessons Learned**

The TRI-ACE field trial demonstration produced a list of lessons learned regarding conducting instrument field trial:

- It helps to have someone on the team that has previous experience with field trials
- Take pictures and make sketches of the set-up
- Generate a daily report and sample manifest that is shared with team members not participating in the deployment
- Be flexible and be prepared for something to break
- Bring more supplies than you think you'll need
- Have a post deployment meeting/plan
- Establish a draft sample analysis plan prior to deployment
- Consider an onsite meeting prior to deployment to allow for scoping of electrical and sample locations

**Future Field Trials**

During the U.S. field trails the TRI-ACE was subjected to three tampering scenarios and operated as expected. However, a full vulnerability analysis of the instrument has not been conducted. The TRI-ACE research team is currently seeking out opportunities to conduct international field trials with the system to demonstrate the full functionality and operability of the system.

**Conclusions**

During the two week field trial many lessons were learned about the operation of the TRI-ACE. Overall, the TRI-ACE spoof testing conducted at the Paducah Gaseous Diffusion Plant was very successful, showing that the design concept was functional. The TRI-ACE successfully collected samples and recorded data from the tamper indicating components with a few exceptions (i.e., 2 malfunctioning proximity detectors). Data from the sensors was used to determine off-normal events caused both by human interaction and environmental transients.

Field testing has proven to be a critical component of the instrument development. Testing in the field has provided valuable information that cannot be learned in a laboratory setting. Having a well thought out plan and a good team allowed for the TRI-ACE demonstrations to run smoothly and provide important information about the system.