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INNOVATIVE TECHNOLOGY
Summary Report

Airborne Laser Induced Fluorescence Imaging

Characterization, Monitoring, and Sensor Technology Crosscut Program and Deactivation and Decommissioning Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

Airborne Laser Induced Fluorescence Imaging

OST Reference #78

Characterization, Monitoring, and Sensor Technology Crosscut Program and Deactivation and Decommissioning Focus Area

Demonstrated at
Fernald Environmental Management Project Plant 1
Fernald, Ohio

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://OST.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

Technology Description

Laser-Induced Fluorescence (LIF) was demonstrated as part of the Fernald Environmental Management Project (FEMP) Plant 1 Large Scale Demonstration and Deployment Project (LSDDP) sponsored by the U.S. Department of Energy (DOE) Office of Science and Technology, Deactivation and Decommissioning Focus Area located at the Federal Energy Technology Center (FETC) in Morgantown, West Virginia. The demonstration took place on November 19, 1996.

LIF works by using laser light to cause an excitation of the uranium oxide molecules that may be present as a surface contaminant. Energy is then released from the molecules in the form of fluorescence that is then detected using a close-coupled device (CCD) camera (i.e., video camera) and displayed on a monitor attached to the laser. The LIF system consists of two major components: the component comprised of both the laser cooling and laser control subsystems, and the component consisting of the laser, CCD camera, and monitor which were mounted on a tripod.

In order to allow the contaminated buildings undergoing deactivation and decommissioning (D&D) to be opened to the atmosphere, radiological surveys of floors, walls and ceilings must take place. After successful completion of the radiological clearance survey, demolition of the building can continue. Currently, this process is performed by collecting and analyzing swipe samples for radiological analysis. Two methods are used to analyze the swipe samples: hand-held frisker and laboratory analysis. For the purpose of this demonstration, the least expensive method, swipe samples analyzed by hand-held frisker, is the baseline technology. The objective of the technology demonstration was to determine if the baseline technology could be replaced using LIF.

Based on the LIF demonstration at the FEMP Plant 1, the Laser-Induced Fluorescence (LIF) technology:

can be an effective screening tool for uranium oxide contamination over large areas;

can be moved in a panning effect to survey large areas quickly, or can be used to survey discreet 2 ft × 2 ft areas at a time;

can be performed up to 20 ft away from the surface being surveyed;

can improve safety by eliminating the need to climb scaffolding to obtain swipe samples from vertical or overhead surfaces.

The comparative net unit costs are dependent on the quantity of D&D work. For quantities of D&D greater than 29,000 square feet (SF), the LIF system has the potential if fully developed and calibrated, to be more cost effective than the baseline method. For example, a project requiring 40,000 SF of survey area would cost $13,000 with the baseline technology and $10,000 using LIF.

Technology Status

The LIF system was developed by the DOE's Special Technologies Laboratory at Santa Barbara, CA.

The demonstration was performed in FEMP Plant 1 (Building 1A) after interior cleaning activities were completed.

LIF was compared to radiological clearance surveys required to open the Plant 1 structure to the atmosphere by removing the external transite panels.

Since the D&D contractor opted not to powerwash but vacuum clean the building for final clean up, a random sample of swipe collections was used by Radiological Control Technicians to determine if final cleanup levels were met.

All surveying operations, both baseline and LIF, were performed by Fluor Daniel Fernald (FDF) personnel.

Key Results

The key results of the LIF demonstration include the following:

- The LIF system, if fully developed and calibrated, has the potential to offer a significant cost benefit over current baseline technology when performing large area surveys over 29,000 SF.

  The LIF system was used to screen various surfaces including steel beams, concrete walls, and scabbled surfaces. In each of these cases, surface uranium contamination was readily detected.

- The LIF technology proved to be fairly simple to use once several initial difficulties were corrected including problems with connections and portability of the system.

  Instant feedback was received from the LIF system which displayed contamination data on the color monitor.

  While the LIF system can not replace the baseline technology as a regulatory-approved measurement device, it offers advantages when used as a screening tool to identify areas of potential uranium contamination to help define boundaries of contaminated areas, track the progress of decontamination efforts and guide waste management strategies.

Contacts

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SECTION 2

TECHNOLOGY DESCRIPTION

Technology Schematic

- LIF works by using laser light to cause an excitation of the uranium oxide molecules that may be present as a surface contaminant. Energy is then released from the molecules in the form of fluorescence, which is then detected using a CCD camera, and displayed on a monitor attached to the laser.
- The LIF system demonstrated at the FEMP consisted of two major components (Figure 1).
  - The first component was comprised of both the laser cooling and laser control subsystems.

    The second component consisted of the laser, CCD camera, and monitor that were mounted on a tripod.

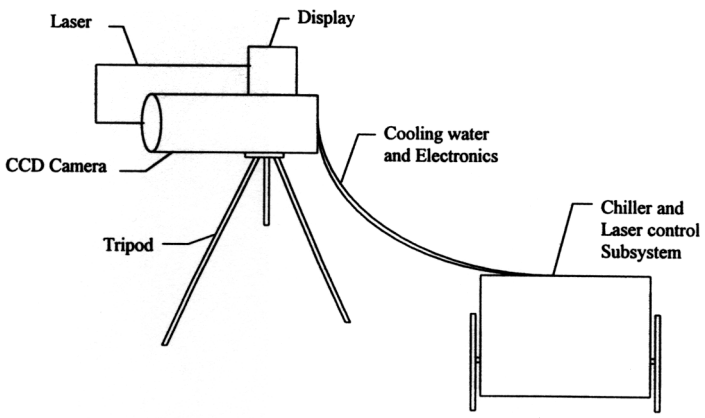

Figure 1. Laser-induced fluorescence system components.

- The LIF system can be used in one of two applications. First, the laser/CCD/monitor can be moved in a panning motion to survey large areas quickly. Secondly, the system can be used to survey discreet 2 ft x 2 ft areas. In both cases, uranium oxide detection is performed virtually instantaneously.

System Operations

An onboard battery powers the system. The battery can be effectively recharged overnight and has an operational lifetime of 2 to 4 hours depending upon the usage of the LIF instrumentation. As an alternative to the onboard battery, a standard 120 V power supply can be plugged into the LIF system allowing for extended usage.

Operational parameters:

The camera F-stop is adjusted manually each time the system is used to minimize the entry of excess solar energy into the LIF detection system.

An abundance of solar light can overwhelm the detection system and effectively mask any uranium fluorescence.

- Laser lamp energy is adjusted at the beginning of the work shift prior to turning on the laser.

- All technicians that operate the equipment must undergo laser training to apprise them of the hazards involved in operating this equipment and ensure maximum performance of the instrumentation.
- An advantage of this system is the lack of any waste streams as a byproduct of the analyses.
- Transport issues:

  The CCD camera, laser, and monitor were mounted on a tripod that needed to be manually carried. The other component containing the laser control and cooling systems was mounted on wheels allowing for easier transport.

  The short length of the connecting water (laser cooling) line and electronics cables made it difficult to move both components in tandem resulting in the bending and breaking of cable pins and water connections.

SECTION 3

PERFORMANCE

Demonstration Overview

The demonstration was performed within the Plant 1 building on surface contaminated transite after interior cleaning activities had been completed. Vacuuming was used as a cleaning technology to perform the final cleaning. Radiological clearance surveys of random locations were performed at the discretion of the radiological control technicians.

- The LIF system was compared to the radiological clearance surveys that were previously performed. The system was operated in both a discreet survey mode (2 ft x 2 ft areas) and panning motion to survey large surface areas.

  All LIF measurements and hand-held frisker results were evaluated for comparable readings. The LIF data were acquired at various standoff distances from the surface being surveyed.

- The field demonstration of the LIF was performed during off-shift hours.

- The timing of the demonstration tested the LIF system under less than ideal conditions since ambient temperatures were at or below freezing during the entire demonstration.

Technology Performance

The current configuration of the system made it very difficult to move from location to location and caused the problems with the cabling and water cooling lines. The developer, based on the input received from FDF technicians, is redesigning the system packaging to make it field portable and durable. The new configuration is expected to be a backpack with the total weight of the system being 50 lbs. or less.

For periods when the LIF system was operational, technicians were able to stand 8 - 10 ft away from the surfaces being surveyed while acquiring data. The increased distance could bring about improvements in safety by eliminating the need for ladders and lifts for survey areas at heights.

The LIF was used half the time in the panning mode and half the time in the discrete mode. In the panning mode a fast screening is done, which identifies contamination as fast as the LIF can be panned by an operator. In the discrete mode, where the LIF is allowed to dwell, the contamination can be identified more precisely (i.e., more distinct coloration).

The LIF based on this demonstration had an estimated threshold limit of 3000 dpm at a stand off distance of 8 - 10 feet. The hand-held frisker also had an approximate limit of 3000 dpm due to background activity levels.

The LIF system will only "excite" molecules on the surface. This proves advantageous in some situations since those molecules on the surface are the potentially removable contaminants while those covered by paint would be considered fixed and undetectable by this method.

The technology is limited in that it cannot be used in bright sunlight. Performance of the LIF diminishes as the level/intensity of light increases. For this reason, the LIF was used only at night within Plant 1. Another limitation is that at this point in its development, the LIF can only be used for the detection of uranium.

Technology developers feel that it is possible to develop a correlation between color observed and activity (dpm/area) at a given measurement distance.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

Technology Applicability

In order to allow buildings to be opened to the atmosphere, radiological surveys of floors, walls, and ceilings must take place. The radiological clearance surveys must demonstrate that removable contamination levels are < 5000 dpm alpha and < 5000 dpm beta/gamma.

The LIF technology can be an effective screening tool for detecting uranium oxide contamination over large areas.

- If calibrated, the technology could serve to perform the routine surveys required during the D&D process as well as clearance surveys for tools and equipment.

If calibrated and integrated into standard radiological control practices, the LIF technology could have a significant positive impact on all radiological control monitoring practices.

The technology was fully developed for identification of contamination and had undergone limited field testing prior to arrival at the FEMP.

This was the first opportunity for the technology developer to have an end user employ their technology. This allowed the technology developer to have input from end users on the positive and negative aspects of their technology.

A dialogue on how to package the technology, and how to make the technology more user friendly took place. It is anticipated that the technology will be redesigned and reconfigured into its final packaging within the next year.

Competing Technologies

Radiological clearance surveys and general surveys are performed in one of two ways.

Hand-held friskers, which can be specific to alpha, beta, and gamma detection, are typically used. Hand-held friskers are used to measure contamination directly, which measures both removable and fixed contamination; and to measure contamination on swipe samples which measures the removable contamination. Despite being relatively inexpensive to use, the technology is limited in that direct contact with the surface being measured must be maintained, surveys of large areas take considerable time to perform, and hand-held devices are subject to interferences from background radiation.

- The second method, swipe collection with laboratory counting, is also inexpensive and relatively easy to perform. Yet, it has limitations as well: direct contact with the surface is required, swipe analysis generates waste and can require up to 24 hours to perform.

Patents/Commercialization/Sponsor

The LIF technology was developed by the Special Technologies Laboratory with sponsorship by the DOE Office of Science and Technology Characterization, Monitoring, and Sensor Technology Crosscutting Program. The LIF is a DOE developed technology which was developed in conjunction with a DOE sponsored Management and Integration (M&I) contractor, currently Bechtel Nevada, which has the first right of refusal on a patent for the technology. The technology developer is currently seeking private commercial partners.

SECTION 5

COST

Introduction

In the cost analysis, an innovative Laser-Induced Fluorescence characterization system was compared to the baseline technology, i.e., swipe samples with hand-held frisker analyses. The hand-held frisker was owned by FDF, and the LIF system was supplied by the vendor for the duration of the demonstration.

Data collected during the demonstration included:

activity duration
work crew composition
equipment used to perform the activity
supplies used, including parts for equipment and utilities
training required
quantification of activities

Cost for the innovative technology was based on actual demonstration data. Costs for the baseline technology were based on historical performance data at FEMP. Additional data were provided by the Integrating Contractor Team (ICT) members. Videotapes were also made of the demonstration.

The cost drivers being analyzed were taken from the 2nd level of the Hazardous, Toxic and Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary (HTRW RA WBS), US Army Corps of Engineers, February 1996. Cost estimates for this analysis were prepared using MCACES Gold cost estimating software.

Some costs are omitted from this analysis so that it is easier to understand and to facilitate comparison with costs for each individual DOE site. These omitted costs are overhead costs that are applied at the same rate for both technologies, these would be indirect costs such as: sales tax, standard training, site services and other costs of this nature that would vary on a site to site basis.

Basic assumptions:

Costs for mobilization, site work, and demobilization are fixed and independent of the time the equipment is used on the site.

- Equipment hourly rates for the hand-held frisker device were based on the amortized purchase price and maintenance cost of the equipment as reported by FDF personnel and calculated using the MCACES Gold Equipment Database.

- Equipment costs for the Laser-Induced Fluorescence System were based on the estimated cost of ownership.

Production rates were based on actual times recorded for characterization.

Labor rates established for the FEMP were used in the analysis. All demonstration work was performed by FDF personnel.

- Crews were created for the cost estimate based on the labor crafts and technology equipment reported from the demonstrations by the Demonstration Project Engineer.

Costs for materials and supplies used during the technology demonstrations were provided by the Demonstration Project Engineer.

Personal protective equipment (PPE) costs were based on four changes of reusable PPE items per crew member per day. Data was not collected on costs for laundering reusable PPE items. PPE costs for disposable items were based on four changes per crew member per day. Costs for individual PPE items were provided by the Demonstration Project Engineer.

Cost Comparison

Baseline Cost

Costs for demonstration are based on using swipe sample collection and hand-held frisker analyses at a designated sampling area within Plant 1 to ascertain contamination levels. The baseline technology costs include monitoring, sampling, testing, and personal protective equipment.

The baseline method had a capital cost of $1,000 for equipment and no fixed costs (mobilization, demobilization, and sitework).

LIF System

Costs for demonstration are based on using the LIF system at a designated sampling area within Plant 1 to ascertain contamination levels. The innovative technology costs include mobilization, site work, monitoring, sampling, testing, waste disposal, demobilization, and personal protective equipment.

- The LIF system had capital and fixed costs totaling $87,507 for equipment, mobilization, and demobilization.

Comparison

- In comparison, the baseline had low equipment cost but had a higher characterization cost, and a higher PPE cost. The LIF was more costly for equipment, mobilization, and demobilization.

Table 1. Cost comparison

Cost Factor/Variable	Swipe/Hand-Held Frisker (Baseline)	Laser-Induced Fluorescence (Innovative)
Scope of Work		
Quantity (surface area) of material characterized	800 SF Estimated	800 SF
Characterization methodology	Survey area with swipes and Hand-held frisker	Portable LIF on tripod to survey without manual grid survey methodology
Work Performance		
Crew size	2	2
Personal protective equipment	Double Anti-Cs with Saranex suit outer layer + respirators*** (Level C)	Double Anti-Cs with Saranex suit outer layer (Level C)
Ambient temperature (°F)*	N/A	N/A
Level of work effort**	Light work	Light work
Production rates	60 SF/hr	720 SF/hr
Other		
Capital cost of equipment	$1,000	$86,000
Technology equipment decon	0 man-hours	2 man-hours

* Assumed, not measured.
** As defined in the Productivity Study for Hazardous, Toxic, and Radioactive Waste (HTRW) Remedial Action Projects, US Army Corps of Engineers, October 1994.
*** Respirators were not required for the LIF due to the fact that airborne monitoring was performed for the demonstration and it indicated that respirators were not required. This was not due to the use of the LIF itself. Similarly, respirators are not needed for using the baseline technology and are not included in the summary costs for the 800 SF demonstration baseline technology cost of $3.22/SF.

Cost Summary

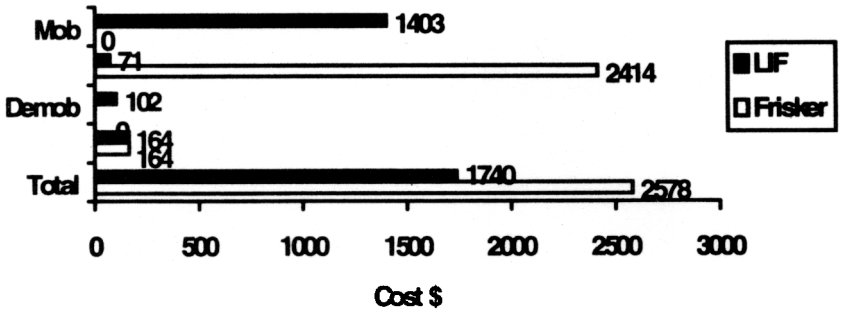

Figure 2. Summary cost comparison.

The comparative total unit costs (without capital equipment costs) for the two technologies for the demonstrated application are:

- $3.22/SF - Swipes/Hand-Held Frisker
- $2.18/SF - Laser-Induced Fluorescence

The LIF system offered no cost savings over the baseline alternative for the 800 SF of D&D work performed during the demonstration when capital cost of equipment is taken into consideration. The break-even cost is provided in Figure 3. The break-even cost does include the capital equipment cost.

While there is no direct comparison as a measurement tool, as a screening tool the LIF will be more cost effective than the baseline method for quantities of work greater than 29,000 SF. This is illustrated by Figure 2 using the formula:

$$y = mx+b$$

where:
y = total cost of D&D work
m = variable costs or those costs based only on the quantity of D&D work performed
x = quantity of D&D work
b = total fixed costs(costs included mob., demob. and equipment)

For the LIF:

m = ($71+$164)/800 SF = 0.29. This is the unit cost for PPE and characterization, i.e. variable cost

b = $87,505 (fixed cost) of which $86,000 is the cost of the LIF equipment plus mob. costs of $1403 and demob. costs of $102.

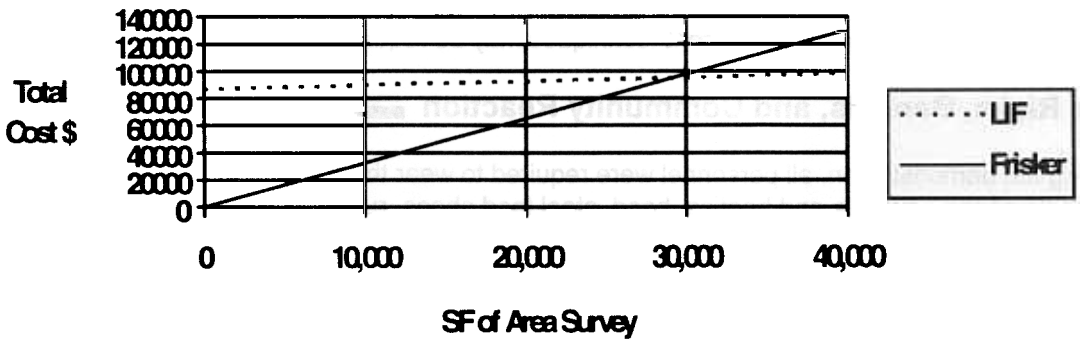

Figure 3. Break-even point analysis.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

- No special regulatory considerations were required to demonstrate this technology. However, prior to the implementation of the technology, the use of the LIF system must have an approved written procedure in compliance with 10CFR835.

  All work was conducted under existing Radiological Work Permits (RWPs) and existing Health & Safety Plans.

  No special permits or plans were required for the demonstration, nor are any special plans or permits anticipated should this technology be deployed for baseline operations.

  No secondary waste streams were generated as a byproduct of the technology or the demonstration.

- All PPE was managed through existing Plant 1 mechanisms.

- Comparability to existing measurement techniques may be required for utilization of this technology.

Safety, Risks, Benefits, and Community Reaction

- During the demonstration, all personnel were required to wear the following PPE to perform work: reusable cotton coveralls and booties, hood, steel toed shoes, rubber shoe covers, hardhat, and safety glasses. Additionally, 25% of all personnel were required to wear breathing zone monitors (BZs) for air monitoring purposes.

  For the Plant 1 building, the primary isotope of concern was Uranium-238. If the Derived Air Concentrations (DAC) levels for such isotope are exceeded, additional radiological controls such as extra dosimetry (urinalysis, bioassay) or respiratory protection are required. If the LIF system is used routinely, it is not anticipated that any increase in airborne concentration levels would occur due to the non-destructive nature of the analysis technique.

  No significant concerns are associated with any community safety issues or environmental impact.

  A protocol must be written, approved and implemented, to assure safe use of the laser.

SECTION 7

LESSONS LEARNED

Implementation Considerations

This technology appears to have its best application as a screening tool in areas where large surfaces need to be assessed and where access to certain areas is difficult due to height or limited access issues.

- The LIF technology has the potential if fully developed and calibrated, to offer significant improvement over currently accepted surveying techniques by providing instantaneous surveys over significantly larger areas than traditional methodologies.
- The LIF system performs best in areas where solar light is minimal; operations during periods of low light are recommended for well-lit areas.

Technology Limitations/Needs for Future Development

Limitations

- The current configuration of the system is somewhat bulky and difficult to transport.
- This system is limited to the detection of uranium ores, oxides, and other molecular forms of uranium. The system will have extreme difficulty in detecting U_3O_8 (Black Oxide) because of the absorptive nature of black compounds.

  The system can be easily overwhelmed by solar light. Precautions must be taken to ensure that sunlight is minimized.
- The system detects but does not measure uranium activity.

Need for Future Development

The new system, currently under design at the Special Technologies Laboratory, should eliminate the difficulties with transport by combining the system into a backpack, weighing approximately 50 lbs., which would allow one person to transport and operate the system.

Technology Selection Considerations

- While the LIF system can not replace the baseline technology as a measurement device, it offers advantages when used as a screening tool to identify areas of potential uranium contamination, to help define boundaries of contaminated areas, to track the progress of decontamination efforts and to guide waste management strategies.
- The technology's ability to scan areas, while eliminating the need to be in direct contact with the surface being screened, makes the technique highly desirable for both productivity and safety improvements.

APPENDIX A

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APPENDIX B

ACRONYMS AND ABBREVIATIONS

BZs	breathing zone monitors
CCD	Charge-Coupled Device
DAC	Derived Air Concentrations
D&D	Deactivation and decommissioning
DOE	U.S. Department of Energy
demob	Demobilization
dpm	Disintegrations per minute
FEMP	Fernald Environmental Management Project
FETC	Federal Energy Technology Center
FDF	Fluor Daniel Fernald
F-stop	The focal distance divided by the effective diameter of the lens aperture; a numerical indication of the relative exposure required by a lens.
ft	feet (foot)
hr.	Hour
HTRW	hazardous, toxic and radioactive waste
ICT	Integrating Contractor Team
LIF	Laser-induced Fluorescence
LSDDP	Large Scale Demonstration and Deployment Project
M&I	Management and Integration
mob	mobilization
PPE	Personal protective equipment
RA	remedial action
RWPs	Radiological Work Permits
SF	Square Feet (Foot)
WBS	work breakdown structure

APPENDIX C

SUMMARY OF COST ELEMENTS

Table C-1. Breakdown of major cost elements

Fixed Costs

Description	Quantity	Unit	Man Hours	Labor	Equipment	Materials	Other	Total
LIF(Innovative)	800	ft^2						
Mobilization	800	ft^2	8	$203	$0	$0	$1,200	$1,403
Demobilization	800	ft^2	4	$102	$0	$0	$0	$102
Total LIF	800	ft^2	12	$305	$0	$0	$1,200[A]	$1,505
Frisker (Baseline)	800	ft^2						
Mobilization	0	ft^2						
Demobilization	0	ft^2						
Total Frisker	0	ft^2	0	$0	$0	$0	$0	$0

A = Travel and per diem for 2 technology providers for 5 days

Variable Costs

Description	Quantity	Unit	Man Hours	Labor	Equipment	Materials	Other	Total	Unit Cost
LIF (Innovative)	800	ft^2							
Surveying	800	ft^2	2	$56	$15	$0	$0	$71	$0.09
PPE	800	ft^2	0	$0	$0	$164	$0	$164	$0.20
Total LIF	800	ft^2	2	$56	$15	$164	$0	$235	$0.29
Frisker (Baseline)	800	ft^2							
Surveying	800	ft^2	27	$679	$5	$0	$1,730[B]	$2,414	$3.02
PPE	800	ft^2	0	$0	$0	$164	$0	$164	$0.20
Total Frisker	800	ft^2	27	$679	$5	$164	$1,730	$2,578	$3.22

B = Cost for collection and laboratory analysis of swipes

Total Costs

Description	Quantity	Unit	Man Hours	Labor	Equipment	Materials	Other	Total	Unit Cost
LIF (Innovative)	800	ft^2							
Mobilization	800	ft^2	8	$203	$0	$0	$1,200	$1,403	$1.75
Surveying	800	ft^2	2	$56	$15	$0	$0	$71	$0.09
Demobilization	800	ft^2	4	$102	$0	$0	$0	$102	$0.13
PPE	800	ft^2	0	$0	$0	$164	$0	$164	$0.20
Total LIF	800	ft^2	14	$361	$15	$164	$1,200	$1,740	$2.18
Frisker (Baseline)	800	ft^2							
Mobilization	800	ft^2	0	$0	$0	$0	$0	$0	$0
Surveying	800	ft^2	27	$679	$5	$0	$1,730	$2,414	$3.02
Demobilization	800	ft^2	0	$0	$0	$0	$0	$0	$0
PPE	800	ft^2	0	$0	$0	$164	$0	$164	$0.20
Total Frisker	800	ft^2	27	$679	$5	$164	$1,730	$2,578	$3.22