DEPARTMENT OF THE NAVY
COMMANDER
NAVY REGION HAWAII
850 TICONDEROGA ST STE 110
JBPHH, HAWAII 96860-5101

5750
Ser N4/0563
July 26, 2018

7016 0910 0001 0891 9097
Mr. Omer Shalev
U.S. Environmental Protection Agency, Region IX
75 Hawthorne Street
San Francisco, CA 94105

7016 0910 0001 0891 9103
Ms. Roxanne Kwan
State of Hawaii Department of Health
Solid and Hazardous Waste Branch
2827 Waimano Home Road
Pearl City, Hawaii 96782

Dear Mr. Shalev and Ms. Kwan:

SUBJECT: ADMINISTRATIVE ORDER ON CONSENT STATEMENT OF WORK SECTION 4.6 NEW RELEASE DETECTION ALTERNATIVE REPORT, RED HILL BULK FUEL STORAGE FACILITY (RED HILL), JOINT BASE PEARL HARBOR-HICKAM, OAHU HAWAII

The Leak Detection Evaluation for Red Hill pursuant to the Administrative Order on Consent ("AOC") Statement of Work ("SOW") Section 4.6, New Release Detection Alternatives Report is enclosed.

The U.S. Department of Navy ("Navy") and the Defense Logistics Agency ("DLA") are submitting this report in accordance with the conditional approval letter received from the U.S. Environmental Protection Agency ("EPA") and the Hawai'i Department of Health ("DOH") on July 26th, 2017.

Pursuant to satisfying condition 4 of the conditional approval, a second enclosure is included with this letter providing an initial evaluation of release responses and resultant release quantities under two different scenarios considering varying available ullage. Further evaluation of probabilities of releasing certain quantities fuel is being performed under Section 8 of the AOC/SOW, phase 1 of the QRVA. This evaluation also considers operator response and time required to drain down a tank.

If you have any questions, please contact Mr. Mark S. Manfredi, the Red Hill Regional Program Director/Project Coordinator at (808) 473-4148 at Mark.Manfredi@navy.mil.

Sincerely,

M. R. DELAO
Captain, CEC, U.S. Navy
Regional Engineer
By direction of the
Commander

Enclosure: 1. Red Hill AOC SOW Section 4.6 New Release Detection Alternative Report, July 26th, 2018
2. Red Hill Hypothetical Release Rates

Red Hill Administrative Order on Consent,
New Release Detection Alternative Report Deliverable
Red Hill Hypothetical Release Rates

Section 4.6 New Release Detection Alternative Report

In accordance with the Red Hill Administrative Order on Consent, paragraph 9, DOCUMENT CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to be the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information including the possibility of fines and imprisonment for knowing violation.

Signature: ______________________

CAPT Marc R. Delao, CEC, USN
Regional Engineer, Navy Region Hawaii

Date: 26 JUL 2018

NEW RELEASE DETECTION ALTERNATIVES REPORT

ADMINISTRATIVE ORDER ON CONSENT - SECTION 4.6

RED HILL BULK FUEL STORAGE FACILITY
JOINT BASE PEARL HARBOR-HICKAM, HAWAII

Prepared for:
Defense Logistics Agency Energy
Fort Belvoir, Virginia

Prepared under:
Naval Facilities Engineering Command Atlantic
Contract N62470-16-D-9007
Delivery Order N6247018F4014

Submitted by:
Michael Baker International
Virginia Beach, Virginia

Date:
25 July 2018

Michael Baker
INTERNATIONAL

NEW RELEASE DETECTION ALTERNATIVES REPORT
ADMINISTRATIVE ORDER ON CONSENT - SECTION 4.6

RED HILL BULK FUEL STORAGE FACILITY
JOINT BASE PEARL HARBOR-HICKAM, HAWAII

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LIST OF ABBREVIATIONS AND ACRONYMS

40 CFR 280	Title 40 Code of Federal Regulations Part 280
AFHE	Automated Fuel Handling Equipment
AOC	Administrative Order on Consent
ATG	Automatic Tank Gauging
BMP	Best Management Practice
C	Common practice
CFR	Code of Federal Regulations
CMP	Centrally Managed Program
DBB	Double-block-and-bleed
DLA	Defense Logistics Agency
DoD	Department of Defense
DOH	Department of Health
EDG	Encompass Design Group
EPA	United States Environmental Protection Agency
FLC	Fleet Logistics Center
gph	Gallon(s) per hour
GSI	Gauging Systems, Inc.
HST	Hawaii Standard Time
ILR	Induced Leak Rate
JP-5	Jet Propellant 5
KWA	Ken Wilcox Associates, Inc.
LC	Less common practice
LDS	Leak Detection System, or Release Detection System
LRDP	Low-Range Differential Pressure
MDLR	Minimum Detectable Leak Rate
Michael Baker	Michael Baker International
MTC	Mass Technology Corporation
MTG	Multifunction Tank Gauge
N/A	Not applicable
NAVFAC	Naval Facilities Engineering Command
NWGLDE	National Work Group on Leak Detection Evaluations
P_D	Probability of Detection
P_{FA}	Probability of False Alarm
PMMS	Precision Mass Measurement System
SIM	Static in-tank measurement
UC	Uncommon practice
UFM	Unscheduled fuel movement
UST	Underground storage tank
VOC	Volatile organic compounds
VPSI	Vista Precision Solutions, Incorporated

INTRODUCTION

The Defense Logistics Agency (DLA) Energy contracted Michael Baker International (Michael Baker) through Naval Facilities Engineering Command (NAVFAC) Atlantic Contract N62470-16-D-9007, Delivery Order N6247018F4014, to evaluate certain release detection methods that would be applicable for testing the eighteen (18) field-constructed underground storage tanks (USTs) at the Red Hill Bulk Fuel Storage Facility, located at Joint Base Pearl Harbor-Hickam, Hawaii. This report has been submitted to comply with the Administrative Order on Consent (AOC) Section 4.6: New Release Detection Alternatives Report. The Scope of Work and the outline for this report was submitted under Section 4.5 of the AOC and approved by AOC stakeholders (the DLA, the Navy, the United Stated Environmental Protection Agency [EPA], and the Department of Health [DOH]) in a letter dated 26 July 2017.

In 2008, the Navy and DLA conducted a Market Survey to research potential candidates for providing a leak detection system (LDS) at Red Hill. In 2009, one LDS method was selected from the candidates, and has since been in-use as the leak detection method applied to all operational USTs at Red Hill.

In 2017, under the AOC, stakeholders required a new evaluation of potential candidates for providing leak detection for the USTs at Red Hill. This evaluation would include a comparison of LDS sensitivity (minimum detectable leak rate [MDLR]) and LDS reliability (probability of detection [P_D] and probability of false alarm [P_{FA}]), as applied to the USTs at Red Hill, versus vendor claims, previous third-party evaluations, or National Work Group on Leak Detection Evaluations (NWGLDE) data. This evaluation allows for true comparative analysis of the LDS results provided by each candidate, specifically on the USTs at Red Hill. Once the effectiveness of each candidate was evaluated, a decision matrix was developed to assist in identifying the most suitable candidate to provide leak detection for the USTs at Red Hill.

This report is structured as follows:

Section 1 – Discussion of the history of the current leak detection program at Red Hill, description of how the current LDS method was selected and implemented at Red Hill, and description of the supplemental systems currently utilized at Red Hill, as a systematic approach to leak detection.

Section 2 – Review of the various forms of leak detection, both static and dynamic in nature, description of how the industry implements leak detection on USTs, and description of how candidate systems are identified for further evaluation at Red Hill.

Section 3 – Description of the candidate systems at Red Hill, identified in Section 2, and evaluated in Section 4.

Section 4 – Description of the process used during evaluation of the candidate systems at Red Hill, which represents the sensitivity results (in MDLR) of each system.

Section 5 – Compilation of evaluated data, in the form of a Decision Matrix table, to aid in the selection of a leak detection system to be implemented at Red Hill.

1.0 LEAK DETECTION PRACTICES

This section discusses existing practices for leak, or release detection, of the USTs at Red Hill. This section also describes how the current LDS by Mass Technology Corporation (MTC) was selected, how MTC testing was implemented at Red Hill, and how the MTC LDS technology was improved. In addition, this section describes the supplemental systems and operations currently utilized at Red Hill which provide a system-wide approach to leak detection.

1.1 Existing Practices: Selection of Appropriate Leak Detection

Prior to the AOC established in 2015, the Navy and DLA utilized what is considered the standard industry approach to selecting appropriate leak detection for the USTs at Red Hill. In accordance with this approach, the Navy and the DLA reviewed regulatory requirements, identified potential qualified candidates, analyzed the published performance claims, and selected the appropriate method to meet leak detection goals.

Release detection regulations in certain states include specific systems and equipment, which are approved for regulatory compliance within the state. The existing release detection regulations for the state of Hawaii do not include state-approved systems or equipment.

Also, in accordance with the standard industry approach, publications by the NWGLDE are used as guidance for selecting appropriate leak detection. The NWGLDE is a national, independent, technical work group comprised of federal and state UST regulators. The NWGLDE committees review third-party evaluations to determine if tests of the leak detection system and/or equipment were conducted in accordance with EPA test method protocols, and will meet regulatory performance standards, where applicable. The NWGLDE website provides the published listings of vetted leak detection systems and equipment, which allows operators in the industry to find appropriate leak detection solutions for each tank storage system, without commissioning individual third-party evaluations. The NWGLDE website also includes a summary of LDS 'listings', including system and equipment implementation requirements, limitations, and expected results (LDS sensitivity and LDS reliability).

1.2 Existing Practices: Selection of Current Leak Detection at Red Hill

Beginning in 2007, the DLA began searching for potential candidates to provide leak detection for the USTs at Red Hill. The selection process utilized at the time, was to initiate a Market Survey to identify appropriate LDSs for these tanks. The objective of the Market Survey was to "identify and research both commercially available and innovative technologies that may be used to solve the challenge of leak detection of the very large USTs operated by the Fleet Industrial Supply Center (now identified as the Fleet Logistics Center [FLC]) Pearl Harbor at Red Hill" (Reference 6.1). The Market Survey report, completed in 2008, is summarized in this section, and can be found in the AOC Section 4.2: Current Fuel Release Monitoring Systems Report, Appendix F;

The Market Survey effort began in 2007, with identifying regulatory release detection requirements applicable to the USTs at Red Hill at the time. An analysis of both the federal UST regulation, Title 40 Code of Federal Regulations Part 280 (40 CFR 280), and the state UST regulation, Hawaii Administrative Rules, Title 11 of the DOH Administrative Rules, Chapter 281: USTs, concluded that under both sets of regulations these field-constructed USTs were deferred from many of the regulatory requirements, including those for release detection. Neither the federal nor state UST regulations required any form of permanent or point-in-time testing, at any frequency, LDS sensitivity (measured in MDLR), or LDS reliability (measured using P_D and P_{FA}). Since there were no existing regulatory requirements for release detection, the Navy and DLA considered the implementation of release detection at Red Hill, strictly as a Best Management Practice (BMP).

The next step in the Market Survey process was to attempt to identify appropriate LDSs that could be implemented as a BMP at Red Hill. The preparers of the Market Survey initially relied on the leak detection industry information published by the NWGLDE. The preparers of the Market Survey included in their research, other forms of leak detection, not listed with the NWGLDE at the time; these included Automatic Tank Gauging (ATG) and the Automated Fuel Handling Equipment (AFHE) systems in-use at Red Hill, as well as other potential LDS candidates. Pertinent information was gathered for each potential LDS candidate, which included LDS sensitivity, LDS reliability, approach to implementation, system limitations, system restrictions, and system cost.

Seven potential LDS candidates, both listed and not-listed with the NWGLDE, were narrowed down for further evaluation, from the list of less appropriate LDS candidates. These seven LDSs were analyzed using a decision matrix, resulting in a ranked list of the best candidates for further consideration and potential implementation for the USTs at Red Hill. Ultimately, the Navy and DLA selected the MTC LDS as the best candidate for providing appropriate release detection using the established criteria. The use of the MTC LDS was implemented, in conjunction with the existing practices already in-use, to monitor for releases from the USTs at Red Hill. An update to the Market

Survey was completed in May 2014; however, no new technologies were identified that could provide either a new or a better solution than those evaluated in 2008 (Reference 6.2).

1.2.1 Red Hill Leak Detection Program: Implemented

Once the MTC LDS was selected as the candidate system for routine leak detection testing, the Navy and DLA conducted a Pilot Test to investigate potential implementation issues not foreseen during the preparation of the Market Survey. This Pilot Test was performed on Red Hill Tanks 9 and 15, from 27 February through 11 March 2008. Additionally, the measured leak rate test results were compared to a known induced leak rate (ILR), to ensure that the results measured by the LDS method were valid, compared to the NWGLDE listing. When the measured leak rate compared favorably to the ILR, the Pilot Test was deemed a success, and the Navy and DLA began a transition to full implementation of a BMP leak detection program at Red Hill.

The Navy and DLA established a leak detection program at Red Hill of biennial point-in-time testing, with LDS sensitivity of 0.7-gallons per hour (gph) MDLR, and the first round of testing was initiated in March 2009, with MTC as the LDS testing vendor. This form of testing by MTC, with notable updates to the LDS equipment technology as described in the following section, remains in-use to date on the USTs at Red Hill.

1.2.2 Red Hill Leak Detection Program: Updated

Since the start of testing, several changes have been made to the leak detection program at Red Hill. First, an update to the MTC LDS equipment technology was implemented to allow for improved testing without changes to the LDS method. The introduction of a pressure transducer which would directly measure tank pressures, was incorporated as a replacement for the bubbler system, which induced and measured nitrogen bubbles in the tank. This equipment technology update took effect in May 2009.

The MTC LDS testing undertaken prior to October 2014, included the addition of a safety factor to account for potential uncertainties based on the uniqueness of the USTs at Red Hill. This safety factor in effect, included reporting a higher MDLR of 0.7-gph, than had been calculated during the test event. After several years of successful testing of the USTs at Red Hill, the safety factor was removed, and the revised MDLR of 0.5-gph was incorporated in October 2014.

In late 2014, the frequency of leak detection testing at Red Hill was increased from biennial to annual, in anticipation of the signing of the AOC, and the expected revisions to the federal UST regulation, 40 CFR 280. In July 2015, the revised 40 CFR 280 regulations were published which, for the first time, included specific release detection requirements for the field-constructed USTs at Red Hill, which had been previously deferred from revised federal regulations. These release detection requirements are detailed in 40 CFR 280.252. By the time the revised 40 CFR 280 was published, the leak detection program at Red Hill had already incorporated the revised federal requirements, therefore the transition for the program was to record the annual testing as a regulatory requirement, instead of a BMP.

In 2016, an evaluation was conducted on two permanently installed LDSs, located in Tanks 9 and 16 at Red Hill; these two systems are manufactured by Vista Precision Solutions, Incorporated (VPSI), and identified as the Low-Range Differential Pressure (LRDP) LDS. The evaluation was initiated to determine the operability and potential for future use (Reference 6.3) of the installed equipment. The LRDP LDS was identified among the top seven best candidates in the 2008 Market Survey, therefore the Navy requested the evaluation to determine operability. Results of this 2016 evaluation showed the LRDP LDS installed in Tank 9 was operable and capable of point-in-time leak detection testing, with the addition of minimal support equipment. The LRDP equipment installed in Tank 16 was found inoperable for reasons unknown. No further efforts were made to add the sole LRDP LDS installed in Tank 9 to the leak detection program at Red Hill, nor to add the LRDP equipment to the remaining tanks.

The leak detection program at Red Hill is currently described as annual point-in-time, leak detection testing, utilizing the MTC LDS equipment with Static In-tank Measurement (SIM) capable of detecting 0.5-gph MDLR, for a P_D of 95% and a P_{FA} of 5%, in accordance with the requirements of 40 CFR 280.252(d)(1)(i).

1.3 Existing Practices: Supplemental Processes and Systems

The following subsections describe the other processes and systems in-place, which are used to supplement the point-in-time leak detection testing currently conducted at Red Hill. These processes and systems are not necessarily precision leak detection equipment for USTs but do provide overall UST assessment data.

1.3.1 GSI Multifunction Tank Gauge Automatic Tank Gauging

In 2001, the Navy installed the Multifunction Tank Gauge (MTG) ATG equipment manufactured by Gauging Systems, Inc. (GSI). This equipment was installed on all 18 serviceable USTs at Red Hill. This ATG system was identified initially as the MTG 3000, which included a sensor probe and MTG electronics. In 2009, the MTG electronics were updated with new technology, and the name of the ATG system was changed to the MTG 3012; the sensor probes have not been upgraded since the original installation. Currently, the MTG 3012 measures temperature and pressure and acts as the fluid level measuring module for the overall AFHE control system at Red Hill (described further in Section 1.3.2). In the current configuration, the MTG 3012 does not perform leak detection, but rather works in conjunction with the AFHE system to perform inventory management.

The MTG 3012 is described as a hybrid tank gauging system, which combines traditional and hydrostatic tank gauging qualities, measuring both mass and density. Each tank at the Red Hill facility is fitted with a vertical array of temperature and pressure sensors which provide the data. The system records temperature and pressure from the sensors in ATG-mode, and the software converts these readings to the data used in the tank level module of the AFHE system. The MTG 3012 ATG equipment is calibrated to a maximum tolerance of 3/16-inch, by manual tank gauging, semi-annually, and after each fuel movement.

In its current configuration the MTG 3012 system is strictly an ATG that provides data to the tank level module of the AFHE system and does not perform independent leak detection testing.

1.3.2 Automated Fuel Handling Equipment Inventory Control

The AFHE is an inventory control system, used to track the product inventory in the overall facility, in real-time. The AFHE system is monitored 24-hours a day, 7-days per week. The MTG 3012 ATG equipment installed in the USTs at Red Hill contribute to the data collected and processed by the AFHE. The AFHE is not a certified release detection system, however the AFHE does provide the level of accuracy needed for facility inventory control.

1.3.3 Combined MTG ATG and AFHE

While the previous two sections discuss the ATG equipment and the AFHE system independently, their current use as an integrated system has more interest related to release detection. The AFHE collects and processes the MTG ATG data, using a software platform by the name of Maximo. This integrated software system is used to detect unscheduled fuel movements (UFMs), including leaks. The AFHE system generates alerts of potential UFMs. The Maximo software accounts for product volumes that move through the UST systems at Red Hill using flow meters and ATG data, combined with tank strapping charts. Under static conditions, the integrated AFHE system generates a warning alarm for more than 1.0-inch of product level height discrepancy, and a critical alarm for more than 1.5-inch. The Navy investigates all UFM alarms and generates related UFM reports.

Reportedly, the AFHE at Red Hill can detect bulk inventory discrepancies across the facility and alert operators to an ‘out-of-balance’ alarm, which indicates the volume of product between the source and the destination exceeds pre-set thresholds. The AFHE alarm thresholds are set in accordance with the volumetric size of evolution, therefore with bulk volumes of product, the AFHE system reportedly conducts a static, gross form of leak detection as part of inventory control functions. These reported gross leak detection capabilities of the AFHE at Red Hill have not undergone third-party evaluation, therefore no data was available at the time of publication to validate these capabilities.

1.3.4 Environmental Sampling

Environmental sampling methods currently used at Red Hill include soil vapor monitoring, oil/water interface monitoring, and groundwater monitoring. These methods are used as indicators of possible fuel releases into the surrounding environment.

Soil Vapor Monitoring: Soil vapor monitoring is performed utilizing permanently installed vapor monitoring probes located beneath all active and accessible tanks. Soil vapor samples are collected and analyzed monthly for increased concentrations of volatile organic compound (VOC) using a photo-ionization detector. The soil vapor VOC concentration trends are monitored. Speculative causes for inconsistent trends include, but are not limited to, ongoing projects in the tunnel, groundwater level fluctuations, rainfall (or lack thereof), byproduct of biodegradation, and fuel movement in the tanks and piping.

Oil/Water Interface Monitoring: Oil/water interface monitoring is performed utilizing monitoring wells located inside the lower access tunnel. The oil/water interface is gauged and measured monthly for the presence of light non-aqueous phase liquid using an interface meter.

Groundwater Monitoring: Groundwater monitoring is performed utilizing monitoring wells located inside and outside the Lower Tunnel. Groundwater samples are collected and analyzed quarterly for petroleum products. The results are compared to site specific risk-based levels for total petroleum hydrocarbons, and to the DOH Environmental Action Levels for concentrations of contaminants.

1.4 Decommissioned Practices: Telltale Monitoring

The USTs at Red Hill were originally constructed in the 1940s with a telltale monitoring system for each tank. The telltale monitoring system included a series of riser pipes that penetrated the steel walls of the tank designed to monitor the open space between the outer steel tank wall and the adjacent concrete structure (concrete, grout, gunite, and native basalt rock). The riser pipes collected at the bottom of the tank, penetrated the tank bottom, and were accessed via the Lower Tunnel. The intent of the telltale monitoring system was to monitor for liquids, both for product being stored and groundwater, and to potentially relieve hydrostatic pressure on the outside of the tank. The telltale monitoring system was initially modified in the early 1960s to increase the riser piping diameter (to prevent clogging), and to increase the riser piping wall thickness (to prevent corrosion). The telltale monitoring system was again modified in the early 1970s to improve clogging and corrosion issues of the riser pipes. By the late 1970s, the Navy decommissioned the telltale monitoring system at Red Hill.

2.0 STATIC AND DYNAMIC LEAK DETECTION ALTERNATIVES

In an effort to arrive at the best solution for leak detection for the USTs at Red Hill, the work conducted in the 2008 Market Survey (described in Section 1.2) would be redone to identify and select the potential LDS candidates for this further evaluation at Red Hill. This section describes different LDS types, analyzes static testing versus dynamic testing, examines how industry standards treat implementation of such systems on USTs, and ultimately discusses the candidate systems selected for further evaluation and comparison at Red Hill.

One of the major discriminators in leak detection is the concept of static testing versus dynamic testing. Leak detection for single-walled tank systems is most commonly provided through static testing. Static testing involves measuring a volume of product in a tank, multiple times and determining if there is a change in the expected volume. To minimize the complexity and maximize the sensitivity of testing, measurements are taken while the product is static, meaning there is no movement of product (receipt, issue, transfer, etc.) being undertaken. Dynamic testing involves taking measurements at all times, including during the movement of product, while the product is dynamic. To further illustrate the distinction between static and dynamic, static testing monitors for leaks utilizing methods located inside the tank, and dynamic testing monitors for leaks utilizing methods located outside of the tank.

2.1 Static Leak Detection Systems

The following subsections provide information regarding the most typical static leak detection approach, in accordance with the requirements of 40 CFR 280, and utilizing equipment located inside the tank.

2.1.1 Inventory Control for Leak Detection

Inventory control for leak detection in accordance with 40 CFR 280, is a basic approach to testing a tank system for leaks by manually measuring a starting volume, and subtracting an ending volume, as the product remains undisturbed during the test period. In accordance with regulation, inventory control must be performed for a maximum of 10 years after the tank installation date, after which time annual tank tightness testing (described in Section 2.1.4) must be included.

2.1.2 Manual Gauging for Leak Detection

Manual gauging for leak detection in accordance with 40 CFR 280, is a basic approach to testing small tanks (maximum of 2,000-gallons), and is performed by manually measuring, or sticking, the tank to obtain the daily starting volume, and subtracting the daily ending volume for comparison. The measured volume changes are compared to known transfer volumes, either into or out of the tank, and should equal the net amount of transfers. From the regulatory perspective, manual gauging for leak detection is allowed only for small USTs.

2.1.3 Automatic Tank Gauging/Continuous In-Tank Leak Detection

The Automatic Tank Gauging (ATG)/Continuous in-tank leak detection in accordance with 40 CFR 280, is an improved approach to manual gauging (described in Section 2.1.2) which uses permanently installed equipment. This approach is similar to manual gauging, but with the volume, or product level, being measured by the ATG, the ATG/continuous in-tank leak detection allows for increased testing frequency and improved accuracy above manual gauging of the tank. The numerous tank level measurements are used to determine an inventory result accurate enough for leak detection measurements of 0.1-gph. This is a common approach to leak detection for small USTs (below 50,000-gallons) found in typical service station facilities (or retail gas stations) but is not typically applied to bulk USTs (above 50,000-gallons).

2.1.4 Tank Tightness Testing

There are numerous approaches to tank tightness testing for leak detection in accordance with 40 CFR 280, which include a range of formats, from creating a vacuum in a UST to listen for air leaks and bubbles, to introducing pressure sensing units to read changes in mass over time. The distinguishing feature for these tank tightness testing systems, is that they are not permanently installed; they are utilized for point-in-time leak detection testing and then removed upon test completion. The majority of USTs are small shop-fabricated USTs (below 50,000-gallons) found in typical service station facilities (or retail gas stations) and utilize permanently installed monitoring systems. The leak detection requirements for bulk USTs (above 50,000-gallons) differ however, and for these bulk UST applications, tank tightness testing is a common approach.

2.1.5 Statistical Inventory Reconciliation

Statistical inventory reconciliation in accordance with 40 CFR 280, is an improved approach to inventory control for leak detection (described in Section 2.1.1). This approach involves trained professionals utilizing specialized software to analyze inventory data, and thus determine the existence of a leak. Since the installation of ATG equipment is economical, and often assists in meeting other regulatory requirements, statistical inventory reconciliation for leak detection is not often utilized but can be found in some Department of Defense (DoD) applications, for small USTs (below 50,000-gallons).

2.2 Dynamic Leak Detection Systems

The following subsections provide information regarding the most typical dynamic leak detection approach, in accordance with the requirements of 40 CFR 280, and utilizing equipment located outside the tank.

2.2.1 Interstitial Monitoring

Interstitial monitoring for leak detection in accordance with 40 CFR 280, is one of the most widely-used dynamic leak detection methods. In addition to being capable of identifying a leak, even in non-static conditions, this approach to leak detection has the additional benefit of containing a product release before impact to the environment. Interstitial monitoring includes specified containment systems installed around tanks and tank system components, such as piping and product dispensers. Such secondary containment can be considered a tank contained within a second tank, and piping contained within a second pipe. The closed interstitial space, or the space between the walls of the various structures, is monitored for potential leak of product.

A less common type of interstitial monitoring includes the use of a secondary barrier. The secondary barrier membrane installed around or beneath a single-walled UST, consists of specified thick and impermeable engineered material, which requires proper installation and impermeability to create an open interstitial space designed to be monitored for potential leak of product. The open interstitial space also gathers water and other liquids which require periodic removal.

2.2.2 Tracer Testing

Tracer testing for leak detection in accordance with 40 CFR 280, is a unique form of point-in-time leak detection testing that works while the system is in either a static or a dynamic state, but only for the duration of the test, and not continuously. The test works by injecting a marker chemical, or "tracer" into the product stored in the UST system. The UST system is then operated normally to ensure that the tracer is mixed in all portions of the tank and associated piping. An array of small monitoring wells and sensor probes are installed into specified points in the soils directly surrounding the walls of the UST, such that the outer walls of the subject tank or pipe lie within the specified area of sampling influence. Gas samples from the atmosphere of the soils are then extracted from the array of wells and probes and analyzed in laboratory equipment. If any tracer chemical is found in the soils outside the subject tank or piping, then the test indicates a leak. A typical single tracer testing event is one to two weeks in duration.

2.2.3 Vapor/Groundwater Monitoring

Vapor or groundwater monitoring for leak detection in accordance with 40 CFR 280, is a dynamic form of leak detection that relies on the use of wells installed in specified points around the UST system, similar to tracer testing. These wells are outfitted with electronic petroleum sensors, which provide data to a control panel for monitoring. The panel alarms if petroleum products are detected either in or on the groundwater in the well, or if petroleum vapors are sensed inside the well, above the liquid level. Vapor or groundwater monitoring is commonly used as leak detection on single-walled UST systems, to monitor the sections of associated piping in a UST system. Leak detection for the tanks in single-walled USTs systems is more commonly conducted using in-tank ATG monitoring.

2.3 Leak Detection for USTs: Industry Standards

In order to discuss the standard industry approach to leak detection, it is important to discuss another discriminator relative to UST leak detection, which is the concept of shop-fabricated versus field-constructed USTs. The large majority of UST systems are shop-fabricated and can be found at typical service station facilities (or retail gas stations). These tanks are manufactured in a factory and transported to a site for installation. The construction of shop-fabricated USTs is limited by the size of the trucks used to transport the USTs for installation. In practicality, the maximum size of a shop-fabricated UST is limited to 50,000-gallons.

2.3.1 Shop-Fabricated USTs

As described in Sections 2.1 and 2.2, there are several leak detection options for shop-fabricated USTs. Due to the many designs of shop-fabricated USTs, there are various leak detection options available. Depending on state regulations, USTs constructed prior to 16 April 2016, could be either single-walled or double-walled construction. The tank construction material varies from welded steel to fiberglass-reinforced plastic. Although the USTs at Red Hill are not shop-fabricated, the methods of leak detection for small UST systems (below 50,000-gallons) were identified as potentially capable of meeting regulatory leak detection requirements.

Table 2-1 includes applied leak detection methods based on shop-fabricated UST construction.

Table 2-1: Leak Detection for Shop-Fabricated USTs

UST Construction	Inventory Control	Manual Tank Gauging	Tank Tightness Testing	Automatic Tank Gauging	Statistical Inventory Reconciliation	Interstitial Monitoring	Tracer Testing	Vapor/ Groundwater Monitoring
Single-walled	UC	UC	UC	C	UC	N/A	UC	LC
Double-walled	UC	UC	UC	C	UC	C	N/A	N/A

Notes, Table 2-1:
1. C – Common practice
2. LC – Less common practice
3. UC – Uncommon practice
4. N/A – Not applicable

2.3.2 Field-Constructed USTs

Field-constructed USTs are typically single-walled, vertical cylinders of 50,000-gallons capacity or greater, and almost exclusively used by the Department of Defense. Due to field-constructed USTs being previously deferred from the 40 CFR 280 regulation, there are a limited number of leak detection systems available in the market for consideration.

Table 2-2 includes applied leak detection methods based on field-constructed UST construction. Note that double-walled field-constructed USTs are rare, especially in the United States, and as such the leak detection methods for these tanks are categorized as either “uncommon practice” (UC) or “not applicable” (N/A); there are no “common practice” leak detection methods for double-walled field-constructed USTs.

Table 2-2: Leak Detection for Field-Constructed USTs

UST Construction	Inventory Control	Manual Tank Gauging	Tank Tightness Testing	Automatic Tank Gauging	Statistical Inventory Reconciliation	Interstitial Monitoring	Tracer Testing	Vapor/ Groundwater Monitoring
Single-walled	N/A	N/A	C	LC	UC	N/A	LC	LC
Double-walled	N/A	N/A	UC	UC	UC	UC	N/A	N/A

Notes, Table 2-2:
1. C – Common practice
2. LC – Less common practice
3. UC – Uncommon practice
4. N/A – Not applicable

2.4 Red Hill: Challenges and Limitations of Construction and Operations

The USTs at Red Hill pose challenges due to size, geometry, construction, and throughput that must be considered when evaluating and selecting an appropriate LDS. Specific challenges relative to selecting a LDS for potential implementation at Red Hill include:

- The size of each UST at Red Hill is approximately 100-feet diameter by 250-feet height (12,500,000-gallons nominal volume). Tank sizes for common field-constructed USTs range in size from 42-feet diameter by 10-feet height (100,000-gallons nominal volume) to 120-feet diameter by 25-feet height (2,100,000-gallons nominal volume).

- The tank geometry of each UST at Red Hill is that of a vertical capsule (dome-shaped top and bottom). The geometry of common field-constructed USTs are vertical cylinders (flat top and bottom).

- The tank construction of each UST at Red Hill includes outer tank walls of welded steel plate, and the adjacent concrete structure (concrete, grout, gunite and native basalt rock). Construction of common field-constructed USTs includes welded steel plates laid upon reinforced concrete in-contact with specified backfill.

- The throughput of the USTs at Red Hill is infrequent, as the tanks are operated as reserve storage. The throughput for common field-constructed USTs is more frequent as the tanks are operated as bulk or operating storage.

Information published on the NWGLDE website was not solely used to determine if a leak detection method was worthy of further consideration; this reference was used to identify applicable, existing limitations that would be of use in further evaluations of potential leak detection systems.

The USTs at Red Hill represent only a small population of tanks that the industry supports with leak detection. Due to the small demand, the industry has not widely-developed readily available leak detection systems to support such tanks.

2.5 Leak Detection Options Selected for Further Evaluation

Both static testing and dynamic testing options for shop-fabricated and for field-constructed USTs were considered for the USTs at Red Hill.

2.5.1 Static Leak Detection Options

Inventory Control Methods. This form of leak detection was not considered as it does not meet the minimum requirements to comply with 40 CFR 280.

Manual Tank Gauging. This form of leak detection was not considered as it does not meet the minimum requirements to comply with 40 CFR 280.

Automatic Tank Gauging. Given the challenges and limitations presented by the construction of the USTs at Red Hill, no form of existing, commercially available ATG LDS in compliance with 40 CFR 280 was identified for further consideration. The existing ATG installed in the USTs at Red Hill, the MTG 3012 by GSI, does not include the analytical components necessary to conduct leak detection. The MTG ATG, combined with the appropriate external leak detection computation system applied at Tank 9, was considered as a potential LDS for further consideration in this evaluation (described in Section 2.6).

Tank Tightness Testing. This method of leak detection is commonly used for leak detection of field-constructed USTs and was considered for further evaluation for this report. Three potential vendors were identified that met the unique initial requirements for conducting leak detection in accordance with 40 CFR 280, on the USTs at Red Hill. These were as follows:

- Gauging Systems, Inc., or GSI, was considered because they are the vendor of the current tank gauging system at Red Hill; it was plausible that their equipment could meet release detection requirements when combined with additional computational analysis.

- Mass Technology Corporation, or MTC, was considered because they are the vendor currently used to conduct annual tank tightness testing, utilizing their mobile LDS equipment; it was plausible that their LDS equipment could be permanently installed.

- Vista Precision Solutions, Inc., or VPSI, was considered because they are the vendor that previously developed their LDS on one of the USTs at Red Hill, and it was plausible that their equipment could meet release detection requirements.

Statistical Inventory Reconciliation. This form of leak detection was not considered as it does not meet the minimum requirements to comply with 40 CFR 280.

2.5.2 Dynamic Leak Detection Options

Interstitial Monitoring. This form of leak detection was not considered as it does not meet the minimum requirements to comply with 40 CFR 280. In addition, due to the construction and design of the existing USTs at Red Hill, there are no secondary tanks or secondary barriers – including the former telltale monitoring system at Red Hill – which would form the interstitial spaces, or possess the impermeability required, for interstitial monitoring.

Tracer Testing. This form of leak detection was not considered as it does not meet the minimum requirements to comply with 40 CFR 280. In addition, due to the construction and size of the existing USTs at Red Hill, the specified locations for the monitoring wells and sensor probes could not be installed properly outside the tank walls, and would not provide a reliable method for detecting tracer compound and potential leaks.

Vapor/Groundwater Monitoring. This form of leak detection was not considered as it does not meet the minimum requirements to comply with 40 CFR 280. In addition, due to the construction of the USTs at Red Hill, the geologic conditions at the site would not allow for a reliable method of leak detection. The vapor or groundwater monitoring currently performed on the USTs at Red Hill is a form of environmental sampling, and not a form of leak detection in accordance with 40 CFR 280.

2.6 Red Hill: LDSs for Further Evaluation

After careful consideration of the challenges and limitations posed by the USTs at Red Hill versus known leak detection systems, three potential LDSs were proposed for further consideration in this evaluation. These systems are:

- Gauging Systems, Inc. – MTG ATG with external leak detection computation system
- Mass Technology Corporation – Precision Mass Measurement System
- Vista Precision Solutions, Inc. – Low Range Differential Pressure system

The selection of these three potential LDSs for further evaluation at Red Hill were proposed for discussion among the AOC Stakeholders, and the AOC Stakeholders agreed that these three LDSs should be the final candidates for further evaluation under the AOC Section 4.6: New Release Detection Alternatives Report.

3.0 TANK TIGHTNESS TESTING ALTERNATIVES

Three leak detection system vendors were selected to participate in the evaluation testing at Red Hill, each providing their own proprietary static leak detection systems for consideration as tank tightness testing alternatives. Each system under evaluation at Red Hill is mass-based, utilizing hydrostatic sensors and a computer system to continuously log sensor data for computation of a leak rate.

3.1 <u>LDS by Gauging Systems, Inc.</u>

The GSI equipment currently installed in all tanks at Red Hill, is known as the MTG 3012 ATG. This equipment includes a liquid probe, identified as the MTG-L, which provides ATG inventory management data to the AFHE system. The MTG-L consists of an array of thirty pressure and temperature sensors on a rigid vertical probe; this equipment, as installed at Red Hill, does not provide leak detection. In order to develop an alternate technology approach for evaluation testing at Red Hill, GSI installed a second temporary vertical probe, in Tank 9 only, to collect additional data required for leak detection. The second probe consists of an array of ten vapor sensors and is known as the MTG-VU or vapor unit probe. Prior to testing, the temporary vapor probe of rigid vertical design and approximately 12-feet length, was lowered into the vapor space of Tank 9, and affixed to the access port of the manway.

Figure 3-1 includes a diagrammatic representation of the GSI equipment utilized for evaluation testing at Tank 9.

<u>Equipment</u>: The existing liquid probe and the temporary vapor probe in Tank 9 were wired to a local GSI computer, located in the Upper Tunnel. Data from both probes was logged continuously in the GSI computer, collected by a technician after each test, and processed using proprietary software developed by GSI.

Data collected from the liquid and the vapor probe was analyzed using two proprietary math models named A and B, which reportedly utilize different weighting factors to evaluate the data. Both A and B were applied to data gathered from, either the liquid and vapor probes together, or the liquid probe alone. The result of the equipment and math model combinations are four GSI LDS Alternative Technologies, identified and described as:

- GSI 1 – model A, liquid probe data and vapor probe data
- GSI 2 – model A, liquid probe data
- GSI 3 – model B, liquid probe data and vapor probe data
- GSI 4 – model B, liquid probe data

Vendor Claims: GSI acknowledged the currently-installed MTG-L liquid probe was not designed to provide the quality of data required for precision leak detection, and therefore proposed the addition of the temporary vapor probe. Reportedly, the addition of the vapor probe was introduced to provide a higher sensitivity of data for leak detection than the liquid probe alone could provide. GSI also introduced two math models to provide four approaches to the computation of a leak rate, with the data gathered from the liquid probe, and from both probes simultaneously. GSI did not provide performance claims for either of the four alternative LDS approaches utilized during evaluation testing; details of the third-party evaluation GSI was a participant in, are discussed in the following segment.

Third-party Evaluation: In April 2002, GSI participated in a third-party evaluation by Ken Wilcox Associates, Inc. (KWA) featuring a leak detection system manufactured by Encompass Design Group (EDG). The EDG system included a vertical array of mass-based sensors manufactured by GSI, identified as the MTG 300M probe, which provided ATG inventory management data. According to GSI, the probes utilized in the EDG system are similar, older versions of their current MTG probe design. A series of 12, 48-hour simulated leak tests were conducted per United States Environmental Protection Agency (EPA) protocols, using the EDG system with the MTG 300M probe, on a field-constructed UST of 2,100,000-gallons nominal capacity located at a Navy fueling facility in Manchester, Washington. For a P_D of 95% and a P_{FA} of 5%, the evaluation results stated the MDLR was 1.11-gph. This 2002 third-party evaluation of the EDG system with the GSI-manufactured MTG 300M probe has not been published by the NWGLDE to date, therefore review or evaluation by the NWGLDE is not known.

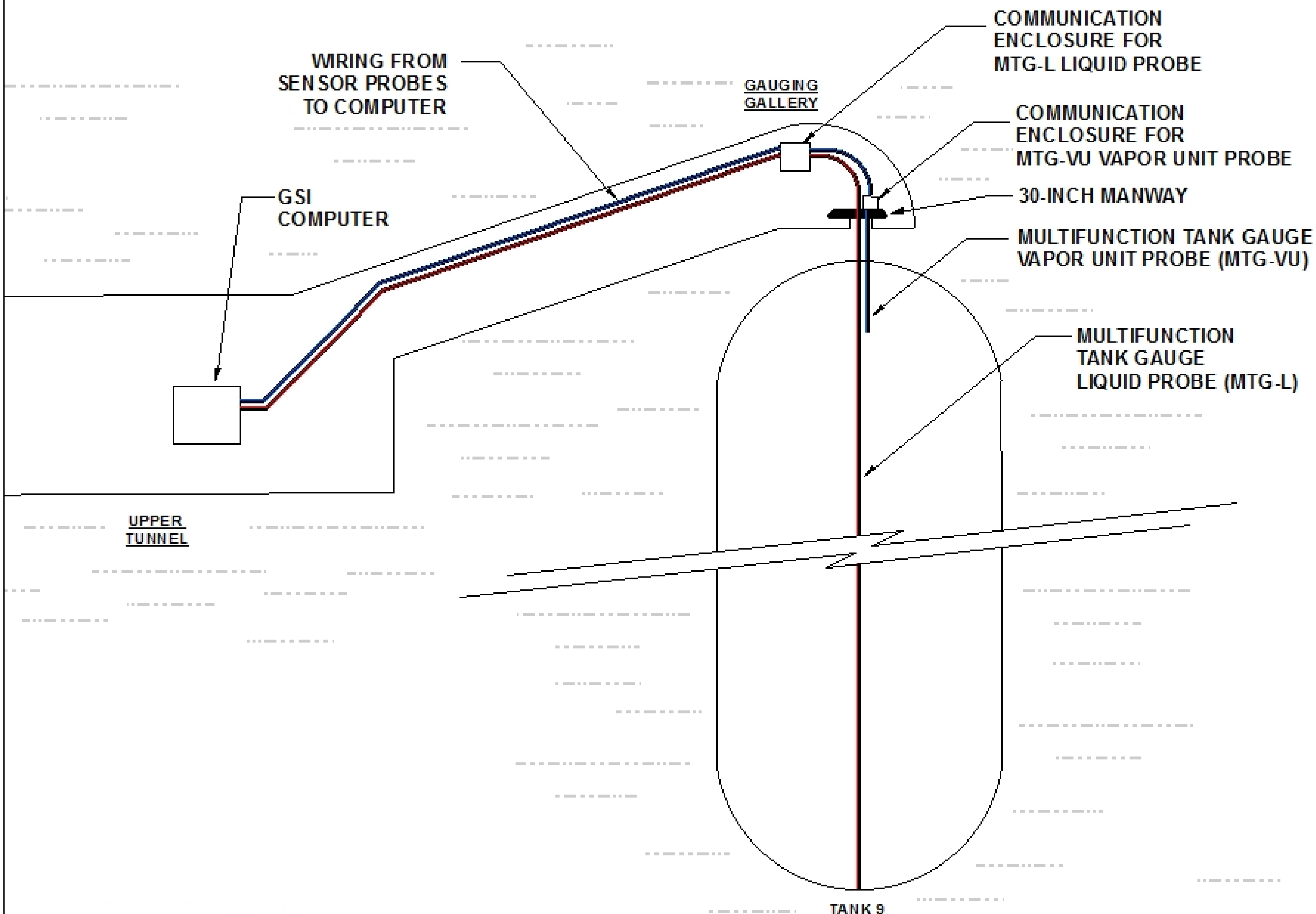
The four GSI LDS Alternative Technologies, were developed and manufactured specifically for this evaluation, and therefore have not been previously tested per EPA protocols, nor have they undergone previous third-party review. The evaluation at Red Hill marks the first time these components have been assembled for use in leak detection.

The potential leak detection capability of any the four GSI LDS Alternative Technologies would need to be proven as meeting or exceeding the regulatory requirement for leak detection testing of USTs, per 40 CFR 280, with MDLR of 0.5-gph.

NWGLDE Listing: Currently, GSI has no listing with the NWGLDE.

Maintenance: Long-term maintenance of a GSI LDS would include calibrating sensors and replacing non-functional sensors on either the liquid probe or the vapor probe, or both. Calibration of sensors can reportedly be conducted without technician activity onsite. Replacement of non-functional sensors would require lifting, clamping and disassembling the rigid vertical probe assembly in pieces, out of the top of the tank in the Gauging Gallery, to access and replace the subject sensor(s). For sensors located in the lower hemisphere of the tanks at Red Hill, replacement would require lifting and disassembling more than 200-feet of the vertical probe assembly. GSI reported that for the currently installed MTG-L probe, a single non-functional sensor out of the 30 sensors installed along the length of the probe would not affect capability; in the event that two or more proximate non-functional sensors were found, the sensors' position on the probe would require analysis of the impact to the flow of data generated by the equipment. Possible effects of non-functional sensors in the temporary vapor probe were not evaluated.

Figure 3-1: GSI Leak Detection Systems, Numbered 1 through 4



Figures are Diagrammatic Representations.

DATE: MAY 2018 SCALE: NTS DGN / DWN / CHK BY: KLM / JES / KLM JOB: 164378 TASK: 4.0	Michael Baker INTERNATIONAL Michael Baker International Virginia Beach, Virginia	FIGURE 3-1 NEW RELEASE DETECTION ALTERNATIVES REPORT DRAFT GSI LEAK DETECTION SYSTEMS, NUMBERED 1 THROUGH 4 RED HILL BULK FUEL STORAGE FACILITY JOINT BASE PEARL HARBOR-HICKAM, HAWAII

3.2 LDS by Mass Technology Corporation

The MTC Precision Mass Measurement System (PMMS) LDS, with Static In-Tank Measurement (SIM) SIM-1000, was utilized for evaluation testing at Red Hill. The MTC LDS is currently in-use for annual tank tightness testing conducted in accordance with 40 CFR 280, on all operational tanks at Red Hill. Figure 3-2 includes a diagrammatic representation of the MTC equipment utilized for evaluation testing at Tank 9.

Equipment: The MTC LDS is a mass-based leak detection and monitoring system that utilizes a pressure transducer placed at the bottom of the tank, and a separate array of temperature sensors located in the lower hemisphere of the tank. The transducer and the sensor array are each connected by cable to the local MTC computer located in the Upper Tunnel area, where leak detection data points are continuously logged at set intervals. In preparation for testing, both equipment cables are lowered through the tank access port at the Gauging Gallery, above the tank dome. Test data is analyzed using proprietary software developed by MTC.

Vendor Claims: MTC has stated that by applying the standard industry approach to averaging and scaling, their LDS can meet or exceed the regulatory requirement for leak detection testing of USTs, per 40 CFR 280, with MDLR of 0.5-gph. The MTC LDS is a field-proven and third-party certified leak detection technology.

MTC also states the flexibility of their LDS design allows for potential implementation options at Red Hill which range from, maintaining the current annual point-in-time testing, utilizing the current mobile MTC LDS testing equipment, through to permanent in-tank installations of the MTC LDS equipment across all operational tanks at Red Hill.

Potential optimization for the point-in-time testing approach utilizing the MTC LDS design, would include the installation of a stilling well in each UST to provide an uninterrupted vertical path from the tank access port to the lower hemisphere. Stilling wells are typically installed to provide a chamber of minimized disruption inside a tank. The USTs at Red Hill include permanent equipment installed along the center structure of each tank. The addition of a stilling well in each UST at Red Hill although not required, would facilitate unfettered access to the lower hemisphere for testing purposes, without grazing or disrupting existing equipment. The addition of a stilling well would also protect testing equipment from turbulence during fuel receipt and issue.

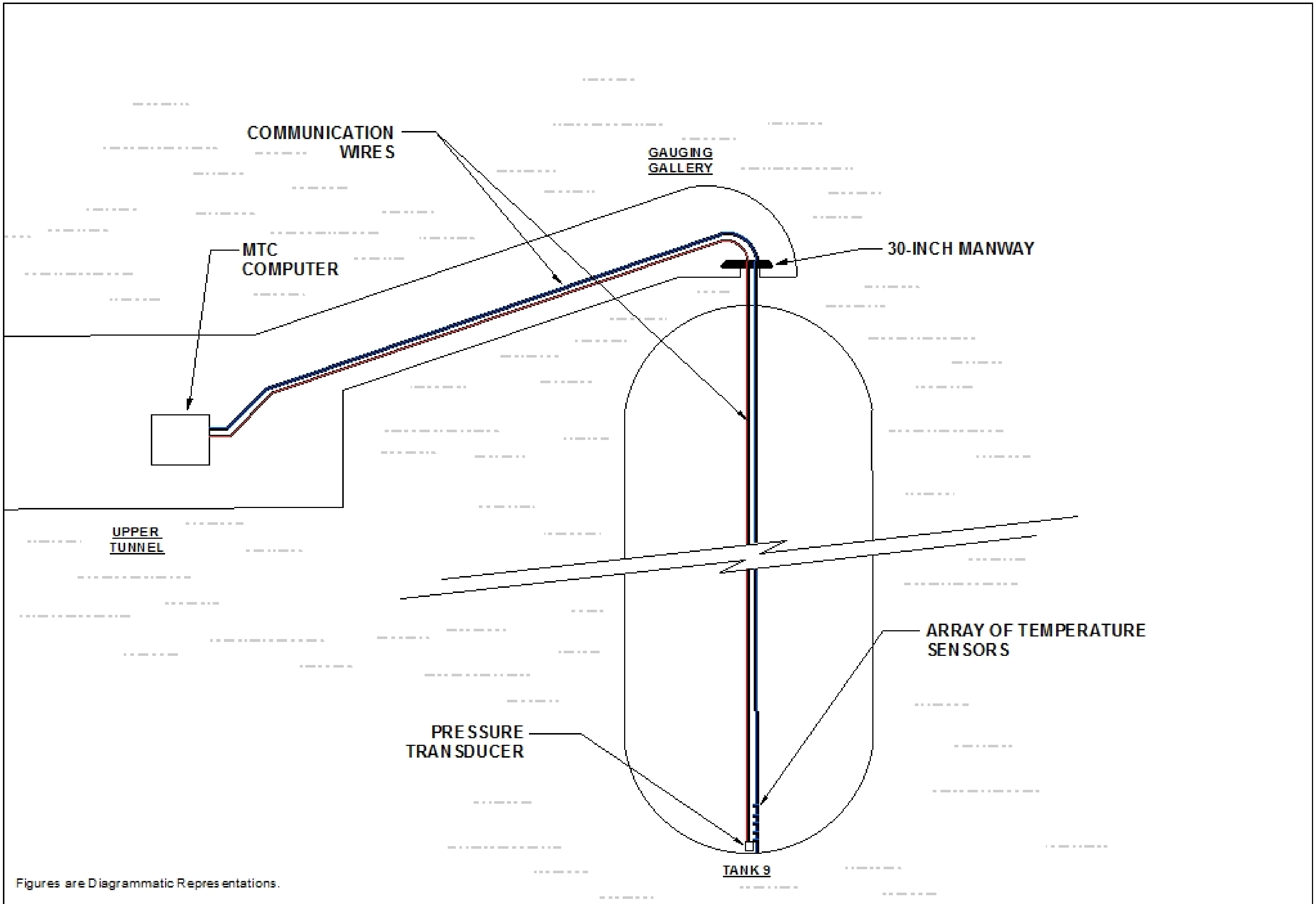
Third-party Evaluation: In March 1998, the MTC LDS underwent an initial third-party evaluation by KWA. At the time, the MTC LDS included a bubbler unit as part of the system components which generated a controlled flow of inert gas pressure corresponding to the differential pressure of the fluid mass. A series of 12, 72-hour simulated leak tests were conducted per EPA protocols, on a field-constructed UST of 2,000,000-gallons nominal capacity located at a Navy fueling facility in San Pedro, California. For a P_D of 95% and a P_{FA} of 5%, the evaluation results stated the MDLR was 0.638-gph. The testing protocol used in the 1998 third-party evaluation included product levels of 90% full or greater and average settling time duration after product delivery of approximately 1-hour. Scaling of the MTC LDS was stated in the third-party evaluation to expand to tanks with diameter up to 205-feet, provided that adjustments are made in accordance with compared ratios of tank surface area.

In May 2009, the MTC LDS was upgraded to newer technology, the bubbler unit was removed, and an additional third-party evaluation was conducted by KWA at Red Hill. A 5-day simulated leak test was induced, followed by two 50-gallons product draws, to provide exploratory development data on the capability of the current generation of MTC LDS, identified as the SIM-1000. Testing was conducted on Tank 6 at Red Hill, a field-constructed UST of 12,500,000-gallons nominal capacity. The test results measured by the SIM-1000 were compared to the induced leak rate, and the evaluation concluded that the upgraded LDS performance was consistent with the third-party evaluation conducted in 1998.

NWGLDE Listing: In August 1999, the MTC LDS obtained the NWGLDE listing as a certified field-constructed UST leak detection method, for bulk tanks of 50,000-gallons capacity or greater. The MTC LDS listing was revised in 2011 to include the pressure transducer technology upgrade, in addition to the previous generation of MTC LDS which included the use of a bubbler unit.

Maintenance: Maintaining the MTC LDS would require calibration of equipment sensors and replacement of non-functional components. Due to the design, accessing the testing equipment for maintenance could be achieved by lifting the flexible testing unit out through the tank access port in the Gauging Gallery.

Figure 3-2: MTC Leak Detection System



DATE: MAY 2018
SCALE: NTS
DGN / DWN / CHK BY:
KLM / JES / KLM
JOB: 164378
TASK: 4.0

Michael Baker INTERNATIONAL

Michael Baker International
Virginia Beach, Virginia

FIGURE 3-2
MTC LEAK DETECTION SYSTEM
NEW RELEASE DETECTION ALTERNATIVES REPORT DRAFT
RED HILL BULK FUEL STORAGE FACILITY
JOINT BASE PEARL HARBOR-HICKAM, HAWAII

3.3 LDS by Vista Precision Solutions Inc.

The LRDP LDS, manufactured by VPSI, was installed in Tank 9 at Red Hill in 2001. A second LRDP was installed in Tank 16 at Red Hill during this time but is not part of this evaluation. At the current time, only the LRDP installed in Tank 9 is operational. Figure 3-3 includes a diagrammatic representation of the VPSI equipment utilized for evaluation testing at Tank 9.

Equipment: The LRDP is a mass-based LDS that utilizes a vertical reference tube which spans the full usable height of the tank and is shaped to match the geometry of the upper and lower hemispheres of the tank. The reference tube inside the tank is attached to the center structure of Tank 9 and is constructed from a series of 8-feet to 20-feet sections bolted together with flanges, that are welded to the tube. At the bottom of the reference tube is a differential pressure sensor and a pneumatically-operated valve used to isolate a column of fluid inside the reference tube. Proprietary software monitors the changes in differential pressure over time. The design of the two LRDP systems installed in Tanks 9 and 16 differ; in Tank 9, the sensor and valve assembly are located inside the tank, and in Tank 16, the sensor and valve assembly are located outside, in the Lower Tunnel area of the tank.

Vendor Claims: The single test performance of the LRDP installed in Tank 9, over a 24-hour test duration, is a MDLR of 0.586-gph, with P_D of 95% and P_{FA} of 5%. VPSI has stated that the LRDP test performance, for two single 24-hour tests averaged together, meets the regulatory requirement per 40 CFR 280, of MDLR of 0.5-gph for field-constructed USTs. VPSI has stated that with the continuous logging of tank data, the LRDP could conduct trending analysis in conjunction with precision testing. The VPSI LRDP LDS technology is a field-proven and third-party certified leak detection technology.

VPSI has stated that potential implementation options at Red Hill would include designing uniform reference tubes for installation inside each UST, as well as designing uniform system components installed on the outside of each tank, in a design configuration similar to the Tank 16 system.

Third-party Evaluation: Since initial development, the LRDP system technology has undergone several third-party evaluations conducted by KWA in the years 1998-2002, on bulk field-constructed USTs of 50,000-gallons or greater nominal capacity. These evaluations tests were each conducted in accordance with EPA protocols, and include variations on test duration times, subject tank size, geometry, and capacity.

In August 2001, the LRDP installed in Tank 9 was third-party evaluated by KWA. The testing protocol used was the EPA, "Alternative Test Procedures, Bulk Field-Constructed Tank, Mass-Based Leak Detection Method" which is an approved modification of the EPA, "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods" (Reference 6.4). The alternative test procedure did not evaluate the temperature differential and minimum stabilization time limitations. This 2001 evaluation of the LRDP was specific to the tanks at Red Hill and is not listed with the NWGLDE.

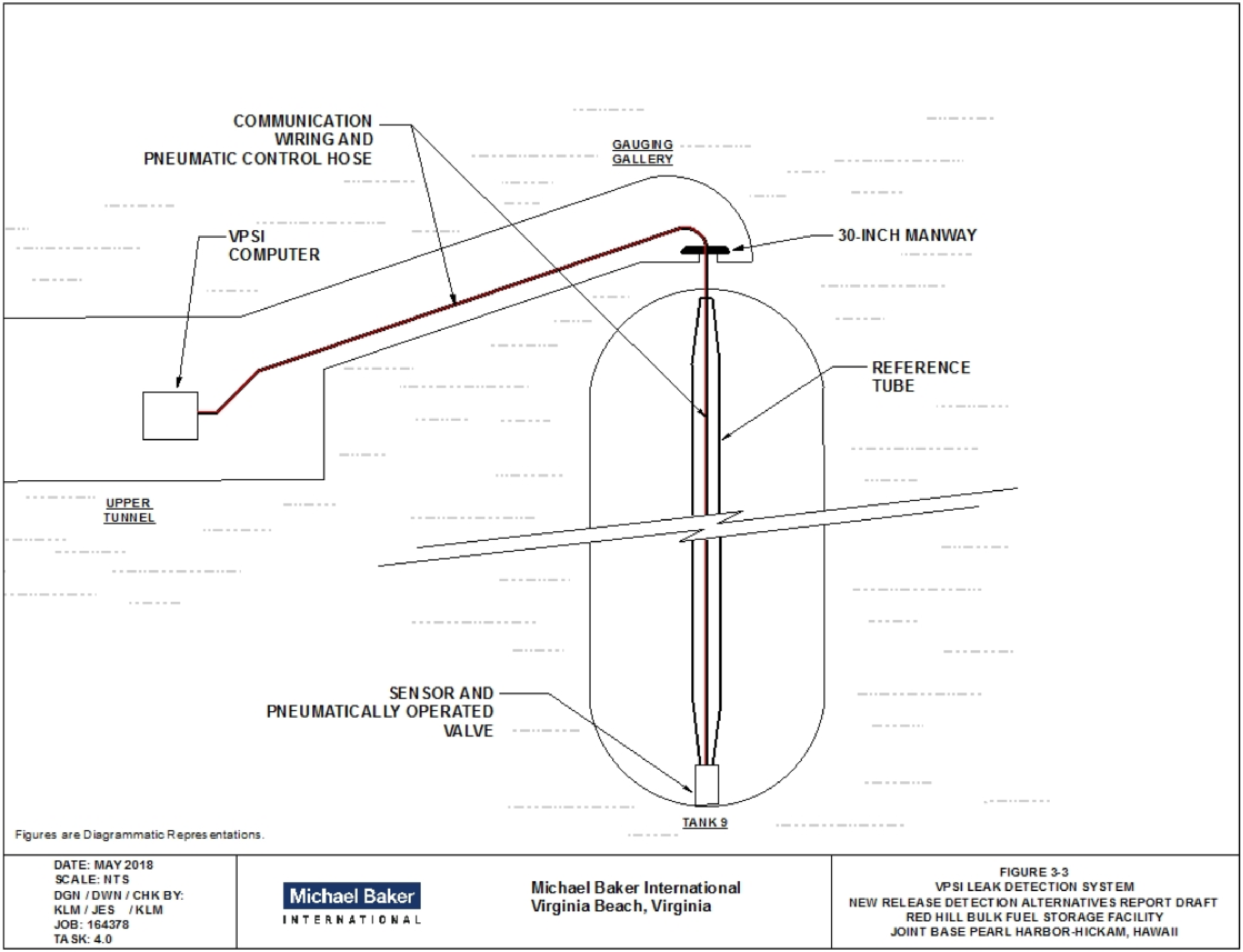
In 2016, an evaluation was conducted on the two LRDP systems installed in Tanks 9 and 16 to determine operational status and potential for future use. The LRDP accuracy was not evaluated. During this evaluation, only the LRDP installed in Tank 9 was found operational and capable of performing a leak detection test; the LRDP installed in Tank 16 was found inoperable for reasons unknown. Reported speculation for the inoperable Tank 16 system included possible third-party induced damages to the equipment, or possible questions of long-term reliability.

NWGLDE Listing: In August 1999, the LRDP technology obtained multiple NWGLDE listings, including 24-hour and 48-hour testing duration times, tank size, geometry and capacity variations. Each of the four current LRDP technology NWGLDE listings are certified field-constructed UST leak detection methods, for bulk tanks of 50,000-gallons capacity or greater.

Prototype: The LRDP systems installed at Red Hill are considered prototypes and have never been implemented for use as leak detection. Prior to the year 2008, the Navy reported the VPSI LRDP as operationally prohibitive and cost prohibitive for implementation as leak detection. After 2008, the DLA had not implemented the VPSI LRDP systems as leak detection due to significant construction and cost challenges associated with installing the VPSI LRDP reference tube in all operational tanks at Red Hill.

Maintenance: Maintaining the VPSI LDS, as installed in Tank 9 at Red Hill, would require repair or replacement of the components inside the tank. Accessing the inside of the tank would require draining the tank, moving the product elsewhere for storage, and cleaning the tank. For a potential LRDP installation that included exterior LDS components, as seen in the Tank 16 installation, maintenance of the sensor and valve assembly would be accessible in the Lower Tunnel of each tank. Access to the internal reference tube of either of the two existing LRDP configurations, would also entail draining and cleaning the tank.

Figure 3-3: VPSI Leak Detection System



3.4 Other Market Technologies

At the current time, there are no other appropriate market technologies available for conducting release detection on the USTs at Red Hill. Should any viable release detection technologies become available in the future, review of the vendor's performance claims and an evaluation of applicability to Red Hill should be conducted. In addition to preliminary vetting of such research technologies, a third-party evaluation should be commissioned to ensure adherence to EPA requirements.

4.0 EFFECTIVENESS OF EXISTING AND ALTERNATIVE TECHNOLOGIES

4.1 Evaluation Testing

Beginning in January 2018, a series of evaluation tests were conducted on Tank 9 at Red Hill. The three leak detection system vendors selected for participation were: GSI, MTC and VPSI. Each vendor contributed either an existing technology or an alternative technology leak detection system for evaluation at Red Hill. An existing technology would be either previously utilized or currently available in the LDS market; an alternative technology would be in-development, and not previously utilized nor currently available in the LDS market. The structure of the evaluation testing was provided to AOC Stakeholders via the Draft Test Plan dated 2 November 2017 (Reference 6.5), based on the existing EPA protocol, "Standard Test Procedures for Evaluating Leak Detection Methods, Volumetric Tank Tightness Testing Methods" dated March 1990. The Draft Test Plan was developed, reviewed and finalized over a series of telephone and email communications with AOC stakeholders in September and October 2017, in preparation for the planned start of testing in January 2018. The updated version, identified as the Executed Test Plan, is included in Appendix B of this report.

The general approach for evaluation testing was to have an independent third-party testing company induce a series of continuous leaks (magnitude at or near 0.5-gph) at Tank 9, of alternating values unknown to the vendors, have the three vendors utilize their release detection equipment simultaneously to measure the induced leaks, and have the vendors report their measured test results. The third-party testing company would provide an evaluation report with a comparison of the induced leak rates to the measured test results. The breadth of evaluation testing activities included staging of vendor/evaluator equipment, evaluation testing in accordance with the Test Plan, and demobilization of vendor/evaluator equipment.

Through discussion and approval by the AOC stakeholders, KWA was selected as the independent third-party testing company. Together with Michael Baker International (Michael Baker), KWA worked to develop logistics in accordance with the Test Plan, prior to the start of testing. The general schedule of evaluation testing was as follows:

- Staging – Conducted from 18 December through 21 December 2017, and from 8 January through 12 January 2018. Staging activities included obtaining access to the Tank 9 area, mobilizing vendor equipment to the Upper Tunnel area, setting-up of equipment in a vendor-dedicated area of the Upper Tunnel, adding a modified manway cover for Tank 9 manufactured and installed by MTC, and each vendor conducting operational tests of their equipment.

- Evaluation testing – Conducted from 16 January through 31 March 2018. Evaluation testing activities are further described in Section 4.2 of this report.
- Demobilization – Conducted from 2 April through 5 April 2018. Demobilization activities included removal of equipment, tear-down of vendor-dedicated area of the Upper Tunnel, and clean-up activities.

4.2 Test Plan

Development: The three vendors conducted testing simultaneously. In accordance with the Test Plan, a total of 15 tests were conducted at Tank 9, which contained Jet Propellant 5 (JP-5) fuel, which included; one trial run test known to the vendors as a no-leak condition test, and four evaluation tests with induced leak rates, blind to the vendors, at each of the three tank product levels. Operational requirements at Red Hill dictated a modification to the tank product levels tested, and the final product levels utilized for testing, were in the following order: 190-feet for Block 1, 160-feet for Block 2, and 125-feet for Block 3.

Evaluation test durations at Red Hill were set to 48-hours for all tests, in accordance with the Test Plan. The possible scaling of release detection test durations can be further explored and may assist in minimizing disruptions to facility operations due to the required periods of tank quiet time, however test duration scaling was not evaluated, and is out of the scope of this report.

The Executed Test Plan, dated 16 May 2018, includes the updates summarized below:

1. GSI provided four alternative technology test results using combinations of two pieces of leak detection equipment, and two mathematical models for calculating MDLR.
2. Statistical analysis of the results will be applied using the calculations referred to in, “Standard Test Procedures For Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods”, dated March 1990 (Reference 6.4).
3. Leaks induced at a constant rate and held continuously for the full length of each test duration.
4. The three trial run tests were known to the vendors, the 12 evaluation tests were blind to the vendors; the total number of tests was 15.

5. The order of induced leak rates applied during evaluation testing was randomized by the evaluator.
6. Test 6 (trial run), Test 7, Test 8 were repeated and replaced with Retest 6 (trial run), Retest 7, Retest 8 respectively, due to unconfirmed tightness of a tank isolation valve.
7. The order of the block product levels was determined by operational requirements at the facility.
8. The three tank product levels were determined by operational requirements at the facility; Block 1 at 190-feet, Block 2 at 160-feet, Block 3 at 125-feet, nominal.

Logistics: Representatives from Michael Baker, KWA, MTC, and VPSI were present daily at Red Hill for each stage of evaluation testing activity. Representatives from GSI were onsite for the staging and demobilization phases only. During evaluation testing, GSI data was collected at the end of each test by a representative from ENGlobal, subcontracted by GSI for data collection purposes. ENGlobal currently provides services at Red Hill, related to the GSI ATG components currently installed.

In preparation for evaluation testing, MTC manufactured a custom tank manway cover for Tank 9, to include three access ports designed to facilitate testing by two vendors simultaneously. Both MTC and GSI used the access ports to lower their LDS equipment into the tank for testing activities. During staging activities at Tank 9, with the support of facility operators at Red Hill, MTC successfully installed the manway cover.

Prior to the evaluation testing kick-off, Michael Baker reviewed safety precautions and provided a site-specific Health and Safety Plan (HASP) (Reference 6.6) for parties onsite. The Upper Tunnel and Lower Tunnel areas of Tank 9 were cordoned off, and informational signs were posted on vendor and evaluator equipment to request that the leak detection equipment not be disturbed. A sign-in sheet was posted at the Tank 9 Upper Tunnel area, and lock-out/tag-out procedures were secured with facility operators.

Once evaluation testing had begun, Michael Baker coordinated each onsite visit at Red Hill with the vendors and evaluator, to enter and exit the facility simultaneously, as a group. During testing, vendor access was restricted to the Upper Tunnel of Tank 9 only; this included the data gathering by ENGlobal on behalf of GSI. Only the evaluator was granted access to the Lower Tunnel of Tank

9, where evaluation testing leaks were induced, blind to the vendors. A representative of Michael Baker was in attendance for the full length of each onsite visit conducted.

Prior to testing at each block level, the movement of product was coordinated with the facility operations team. Once the product level had been adjusted to the nominal height specified in the Test Plan, facility operators conducted a manual tank gauge reading of the product level. The manual reading was compared to the ATG reading to verify tolerance within 3/16-inch maximum. For out-of-tolerance readings, re-calibration of the ATG would have been required, however the ATG and manual readings were within tolerance for each of the three product level heights achieved during evaluation testing.

Michael Baker visually confirmed the product level height reading from the ATG display, and the vendors were informed that the 4-day product settling time was initiated. Following the end of product settling time, a 24-hour test setup time was planned; during which vendors confirmed equipment functionality in preparation for testing. As part of test preparation, the 4-day minimum product settling time and 1-day test setup time were to follow each product level change only. The test setup time between each test within a block, was initially set to 24-hours. As Block 1 testing proceeded, Michael Baker consulted with the evaluator and the three vendors to optimize the test setup time, and all parties agreed that a 4-hour test setup time would suffice. During Blocks 2 and 3, the test setup time was updated to 4-hours.

In conjunction with facility operators, Michael Baker confirmed the isolation of Tank 9 following each product level movement. Currently, there are two (2) operational isolation valves in the Lower Tunnel of Tank 9 which are utilized for issue, receipt, and tank maintenance procedures. Both tank isolation valves are of double-block-and-bleed (DBB) design. Prior to the start of each block of testing, the effectiveness of the DBBs which provide tank isolation were verified. In addition, each block of testing was initiated with a 48-hour trial run, no-leak condition test, known to the vendors, so that each vendor could review their data and confirm the isolation of Tank 9. During Block 2 testing, after Test 6 (no-leak condition), Test 7, and Test 8 were completed, multiple vendors raised concerns about tank isolation after finding slight anomalies, or background noise, in their readings. The decision was made to discard the results for Block 2 Tests 6, 7, and 8, and replace them with retests of each, after tank isolation could again be confirmed. Tank 9 isolation was confirmed, Block 2 Retest 6 (no-leak condition), Retest 7, and Retest 8 were conducted, and the retest results were submitted to replace the three anomalous tests.

At the completion of every trial run and evaluation test, results were submitted by each vendor to Michael Baker within 24-hours of test completion. The evaluator requested that each vendor provide their LDS equipment resultant MDLR in gph, in the form of a plus or minus value, to indicate product inflow or outflow, respectively.

Observations:

Observations made during evaluation testing included the following:

- The air pressure inside the tunnels at Red Hill varied enough to require manual force to control the initial push or pull of the door at the adit entrance point.

- Between January and March 2018, the local weather in the Red Hill area was observed to fluctuate within a given day, in multiple bursts of rainfall, changing temperatures and changing windspeed.

- GSI Alternative Technology LDS 1, 2, 3, 4 – GSI was not present during daily onsite data gathering. The data was gathered at the end of each test by a subcontracted onsite representative from ENGlobal. GSI reported their equipment registered anomalies and background noise during every evaluation test conducted. According to GSI, lower product level heights resulted in larger registered anomalies. GSI requested the ventilation system at Tank 9 not be used during testing. GSI requested access to the Gauging Gallery at Tank 9 be prohibited during testing. The ventilation system distributes forced air into the Gauging Gallery space and is activated to provide improved breathable air for personnel accessing the Gauging Gallery.

    - The ventilation system at Tank 9 was activated during evaluation testing, to accommodate a technical visit to the Gauging Gallery at Tank 9, by AOC stakeholders on 20 February 2018. Onsite records logged by Michael Baker representatives indicate that this was an isolated incident, of approximately 30-minute duration.

- MTC PMMS LDS – Testing operators were onsite daily for data gathering. MTC reported the LDS equipment provided consistent data throughout evaluation testing.

- VPSI LRDP LDS – Testing operators were onsite daily for data gathering. VPSI reported the LDS equipment was registering background noise during initial Block 1 testing. During later testing of Block 1, then during Blocks 2 and 3, VPSI reported the background noise diminished incrementally with each test.

Evaluation Testing Data: The following tables summarize the Evaluation Testing data:

Table 4-1 includes the product level height of each block of testing, the block number, the time stamp for the start of each 48-hour test, the test number, and the ILR as induced by the third-party evaluator onsite.

Table 4-2 includes the summary of Evaluation Testing results reported for each LDS evaluated, as well as the ILR, induced by the third-party evaluator for each test conducted.

Table 4-3 includes the summary of Evaluation Testing results, showing the MDLR of each LDS evaluated, ranked in the statistically-determined order of leak rate sensitivity. The statistical analysis of data is based on a P_D of 95%, and a P_{FA} of 5%, and utilizes a two-sided test analysis approach, which allows for liquid incursion into the tank, as well as for a leak or loss of product from the tank.

Table 4-1: Summary of Evaluation Testing Conducted

Product Level Height	Block Number	Test Start Time Stamp [1]	Test Number	Induced Leak Rate (gph) [2]
Nominal 190-feet Actual 189-feet 10-inch 4/16-inch	Block 1	19 Jan 2018 at 1200 HST [3]	Test 1 Trial Run [4]	No-leak condition
		24 Jan 2018 at 0900 HST	Test 2	1.035
		27 Jan 2018 at 0900 HST	Test 3	0.446
		30 Jan 2018 at 0900 HST	Test 4	0.216
		2 Feb 2018 at 0900 HST	Test 5	0.000
Nominal 160-feet Actual 159-feet 11-inch 2/16-inch	Block 2	1 Mar 2018 at 0700 HST	Retest 6 Trial Run [4, 5]	No-leak condition
		3 Mar 2018 at 1100 HST	Retest 7 [5]	0.628
		5 Mar 2018 at 1500 HST	Retest 8 [5]	0.307
		8 Mar 2018 at 0700 HST	Test 9	0.000
		10 Mar 2018 at 1100 HST	Test 10	1.017
Nominal 125-feet Actual 125-feet 0-inch 1/16-inch	Block 3	20 Mar 2018 at 0700 HST	Test 11 Trial Run [4]	No-leak condition
		22 Mar 2018 at 1100 HST	Test 12	0.255
		24 Mar 2018 at 1500 HST	Test 13	0.994
		27 Mar 2018 at 0700 HST	Test 14	0.596
		29 Mar 2018 at 0700 HST	Test 15	0.000

Notes, Table 4-1:

1. All tests are 48-hour duration;
2. Gallons per hour - gph;
3. Hawaii Standard Time - HST;
4. Test 1, Retest 6, and Test 11 were initial tests or trial run tests, conducted under no-leak conditions to confirm tank and equipment functionality in accordance with the Test Plan;
5. Test 6, Test 7 and Test 8 were repeated and replaced with Retest 6, Retest 7 and Retest 8, respectively, due to unconfirmed tightness of the tank isolation valve.

Table 4-2: Summary of Evaluation Testing Results

Test Name	ILR [1] (gph)	GSI 1 Result [2] (gph)	GSI 2 Result [2] (gph)	GSI 3 Result [2] (gph)	GSI 4 Result [2] (gph)	MTC Result [2] (gph)	VPSI Result [2] (gph)
Block 1 Test 2	1.035	0.757	0.643	0.640	0.619	0.845	1.016
Block 1 Test 3	0.446	0.477	0.443	0.360	0.396	0.464	0.594
Block 1 Test 4	0.216	0.495	0.514	0.611	0.569	0.182	0.155
Block 1 Test 5	0.000	-0.050		-0.135		-0.009	0.003
Block 2 Retest 7	0.628	0.761	0.598	0.466	0.469	0.664	0.596
		-0.006		-0.075			
Block 2 Retest 8	0.307	0.265	0.383	0.511	0.369	0.291	0.240
Block 2 Test 9	0.000	-0.059	0.080	-0.015	0.116	0.054	
Block 2 Test 10	1.017	1.219	1.260	1.206	1.227	1.054	1.074
						-0.082	
Block 3 Test 12	0.255	0.002	0.054	-0.108	-0.007	0.254	0.099
Block 3 Test 13	0.994	1.316	1.057	1.472	1.178	0.973	0.932
Block 3 Test 14	0.596	0.668	0.937	0.817	1.076	0.501	0.585
Block 3 Test 15	0.000	0.391	0.274	0.324	0.168	0.004	-0.051

Notes, Table 4-2:

1. Induced leak rate - ILR;
2. Positive leak rate values indicate product outflow from the tank; negative leak rate values indicate product inflow to the tank.

Table 4-3: Summary of MDLR Sensitivity Ranking

Leak Rate Sensitivity	Vendor LDS	MDLR (gph)
1st	MTC	0.294
2nd	VPSI	0.333
3rd	GSI 1	0.940
4th	GSI 2	0.943
5th	GSI 4	1.128
6th	GSI 3	1.273

Notes, Table 4-3:

1. The statistical analysis of data is based on a P_D of 95%, and a P_{FA} of 5%, and utilizes a two-sided test analysis approach, which allows for liquid incursion into the tank, as well as for a leak or loss of product from the tank.

5.0 DECISION MATRIX

The decision matrix developed in Table 5-1 was populated with information acquired during the development of this evaluation report. The decision matrix was reviewed during the "Decision Matrix Meeting", held at the EPA Region 9 offices in San Francisco, California on 26 April 2018. During this meeting, the main components of the decision matrix were discussed and agreed upon by the AOC stakeholders.

The statistical analysis of data, as presented in Table 4-3 of this report, utilizes a two-sided approach, which allows for liquid incursion into the tank, as well as for a leak or loss of product from the tank. The evaluation results presented in draft format during the Decision Matrix Meeting on 26 April 2018, were analyzed by KWA using a one-sided approach. After the Meeting concluded, the evaluation results were updated to include possible liquid incursion from the water table.

The decision matrix is designed to be used in conjunction with a scoring system, to assist in the selection of a release detection method for use at the Red Hill Bulk Fuel Storage Facility. The scoring system and selection of a release detection method are not the subject of this report.

Table 5-1: Decision Matrix

Release Detection System Attribute Definitions and Rating System Matrix Red Hill Bulk Fuel Storage Facility – New Release Detection Alternatives Report									
Attribute	**Attribute Definition (Criteria for Evaluation)**	**Rating System**	**Release Detection Method**						
			GSI 1	**GSI 2**	**GSI 3**	**GSI 4**	**MTC**	**VPSI**
1. Release Detection	Release detection system should meet current MDLR (in gph) requirements of 40 CFR 280 for field-constructed USTs (0.5-gph with 95% Probability of Detection and 5% Probability of False Alarm).	Exceeds Criteria: MDLR < 0.5-gph[1]					0.294	0.333
		Meets Criteria: MDLR = 0.5-gph[1]						
		Does Not Meet Criteria: MDLR > 0.5-gph[1]	0.940	0.943	1.273	1.128		
2a. Undetected Release: 7-day	This is the quantity (in gallons) of fuel that may be released from the tank undetected by release detection system; if one test was conducted every 7-days[2].	Exceeds Criteria: < 2,448-gal[3]	158	158	214	189	49	56
		Meets Criteria: 2,448-gal[3]						
		Does Not Meet Criteria: > 2,448-gal[3]						
2b. Undetected Release: 30-day	This is the quantity (in gallons) of fuel that may be released from the tank undetected by release detection system; if one test was conducted every 30-days[2].	Exceeds Criteria: < 2,448-gal[3]	676	678	916	811	211	239
		Meets Criteria: 2,448-gal[3]						
		Does Not Meet Criteria: > 2,448-gal[3]						
2c. Undetected Release: 90-day	This is the quantity (in gallons) of fuel that may be released from the tank undetected by release detection system; if one test was conducted every 90-days[2].	Exceeds Criteria: < 2,448-gal[3]	2,028	2,034		2,434	633	717
		Meets Criteria: 2,448-gal[3]						
		Does Not Meet Criteria: > 2,448-gal[3]			2,748			
2d. Undetected Release: 365-day	This is the quantity (in gallons) of fuel that may be released from the tank undetected by release detection system; if one test was conducted every 365-days[2].	Exceeds Criteria: < 2,448-gal[3]						
		Meets Criteria: 2,448-gal[3]						
		Does Not Meet Criteria: > 2,448-gal[3]	8,226	8,252	11,143	9,873	2,567	2,908

Notes, Table 5-1:

1. Minimum detectable leak rate (MDLR) based on leak detection evaluation in this report, conducted per the Test Plan, 48-hr test duration, utilizing the statistical evaluation of data by the EPA, Standard Test Procedures (Reference 6.4);
2. The calculation for quantity of fuel is: Volume (in gallons) = (x-days) *(24-hours) *(MDLR - 0.001);
3. The reported current alarm set point for the unscheduled fuel movement (UFM) alarm (in gallons).

Table 5-1: Decision Matrix (Continued)

Release Detection System Attribute Definitions and Rating System Matrix Red Hill Bulk Fuel Storage Facility – New Release Detection Alternatives Report								
Attribute	**Attribute Definition (Criteria for Evaluation)**	**Rating System**	**Release Detection Method**					
			GSI 1	**GSI 2**	**GSI 3**	**GSI 4**	**MTC**	**VPSI**
3a. Constructible: Inside Tank	Release detection system requires sensors to be located inside the tank; logistics could include: draining the tank, ventilating, and working inside the tank.	Exceeds Criteria: Does not require working inside the tank					x	
		Meets Criteria: Requires working inside the tank	x	x	x	x		x
3b. Constructible: Outside Tank	Release detection system requires computer to be located outside the tank and incorporated into secure data network. Note: 1. Incorporation into the secure data network requires additional investigation through various DoD agencies, which is outside the scope of this report.	Exceeds Criteria: Currently installed						
		Meets Criteria: Could be installed	x	x	x	x	x	x
3c. Constructible: Schedule	The amount of time to install release detection systems in all operational tanks. Note: 1. Schedule is driven by the availability of requiring the tank to be empty to complete installation. 2. Schedule does not account for any tank improvements that are indirect to the release detection system (i.e. replacement of tank isolation valves).	Exceeds Criteria: < 1-year					x	
		Meets Criteria: 1-year						
		Somewhat Meets Criteria: > 1-year	x	x	x	x		x
3d. Constructible: Cost	The cost to install release detection system. Note: 1. Various configurations for release detection system installation and operation are possible. The determination of release detection system configuration and operation are outside the scope of this report. Further investigation is required.	Not Evaluated: But should be considered when selecting a release detection system	Not Rated					

Table 5-1: Decision Matrix (Continued)

<table>
<tr><th colspan="10">Release Detection System Attribute Definitions and Rating System Matrix
Red Hill Bulk Fuel Storage Facility – New Release Detection Alternatives Report</th></tr>
<tr><th rowspan="2">Attribute</th><th rowspan="2">Attribute Definition
(Criteria for Evaluation)</th><th rowspan="2">Rating System</th><th colspan="6">Release Detection Method</th></tr>
<tr><th>GSI 1</th><th>GSI 2</th><th>GSI 3</th><th>GSI 4</th><th>MTC</th><th>VPSI</th></tr>
<tr><td rowspan="2">4a.
Operable:
Data</td><td rowspan="2">Release detection system requires that onsite data processing be evaluated by manufacturer technician.
Notes:
1. Data processing times were not evaluated.
2. Test results were typically provided 24-hrs after test conclusion.</td><td>Exceeds Criteria:
Does not require leak detection technician</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Meets Criteria:
Requires leak detection technician</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td rowspan="2">4b.
Operable:
Static</td><td rowspan="2">Release detection testing can be completed while the tank is isolated.
Notes:
1. The product settling times were uniform for all evaluation testing (4-days minimum, after product level change, and 4-hours minimum, between tests conducted at each product level height).
2. The test duration times were uniform for all evaluation testing (48-hours).
3. Product settling times and test duration times were not evaluated. Factors to be considered for scaling include variations due to fuel type, fuel batch, product level, flow rate of receipt, flow rate of issue, and tank internal configuration. Further investigation is required for scaling.</td><td>Meets Criteria</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Does Not Meet Criteria</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4c.
Operable:
Dynamic</td><td>Release detection testing can be completed while the tank is not isolated.</td><td>Not Evaluated: Probably not possible for single-walled USTs</td><td colspan="6">Not Rated</td></tr>
</table>

Table 5-1: Decision Matrix (Continued)

Release Detection System Attribute Definitions and Rating System Matrix Red Hill Bulk Fuel Storage Facility – New Release Detection Alternatives Report								
Attribute	**Attribute Definition (Criteria for Evaluation)**	**Rating System**	**Release Detection Method**					
			GSI 1	**GSI 2**	**GSI 3**	**GSI 4**	**MTC**	**VPSI**
4d. Operable: Monitoring	Release detection system can monitor product level in the tank and detect an UFM of less than 2,448-gal when the tank is isolated. Note: 1. Additional consideration could be given to scaling leak detection test durations and/or product settling times, further investigation is required. 2. Increased test durations could be averaged to achieve improved MDLRs, further investigation is required. The lower limit of the MDLR also requires further investigation.	Not Evaluated: Probably possible	Not Rated					
5a. Reliable At Product Level Heights, As Evaluated	Reliable at product level heights, as evaluated, range between 125-feet and 190-feet (located within the vertical barrel section of the tank).	Meets Criteria	x	x	x	x	x	x
		Does Not Meet Criteria						
5b. Reliable At Other Product Level Heights	Reliable at product level heights, outside of the evaluated range and in accordance with facility operations. Note: 1. Navy personnel reported that product level heights for facility operational storage are within the vertical barrel section of the tank.	Not Evaluated: Probably possible. Product level heights outside of the evaluated range, between 125-feet and 190-feet, require further investigation.	Not Rated					

Table 5-1: Decision Matrix (Continued)

Release Detection System Attribute Definitions and Rating System Matrix Red Hill Bulk Fuel Storage Facility – New Release Detection Alternatives Report									
Attribute	**Attribute Definition (Criteria for Evaluation)**	**Rating System**	**Release Detection Method**						
			GSI 1	**GSI 2**	**GSI 3**	**GSI 4**	**MTC**	**VPSI**
6. Serviceable: Inside Tank	Repair / replacement of release detection system components located inside the tank.	Exceeds Criteria: Does not require working inside the tank					x	
		Meets Criteria: Requires working inside the tank	x	x	x	x		x
7. Other Installations	Release detection system in-use elsewhere.	Meets Criteria					x	x
		Does Not Meet Criteria						
		Unknown	x	x	x	x		

6.0 REFERENCES

6.1 *Market Survey of Leak Detection Systems for the Red Hill Fuel Storage Facility, Fleet Industrial Supply Center, Pearl Harbor*; Prepared for: Defense Energy Support Center; Prepared Under: AFCEE Contract FA8903-04-D-8684-0008; Prepared by: Michael Baker Jr., Inc., Virginia Beach, Virginia; Date: 3 July 2008.

6.2 *Addendum 1 to the Market Survey of Leak Detection Systems for the Red Hill Fuel Storage Facility, Fleet Industrial Supply Center, Pearl Harbor*; Prepared by: Michael Baker Jr., Inc., Virginia Beach, Virginia; Date: 19 May 2014.

6.3 *Final 2016 Leak Detection System Evaluation at Red Hill Underground Fuel Storage Complex, Joint Base Pearl Harbor-Hickam, Hawaii*; Prepared for: Defense Logistics Agency Energy, Fort Belvoir, Virginia; Prepared Under: NAVFAC Atlantic Contract N62470-10-D-3000-0048; Prepared by: Michael Baker International, Virginia Beach, Virginia; Date: 25 March 2016.

6.4 *Standard Test Procedures For Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods*; Published by: United States Environmental Protection Agency Office of Underground Storage Tanks; Date: March 1990.

6.5 *Draft Test Plan for Evaluating Leak Detection Methods at the Red Hill Fuel Storage Complex, Joint Base Pearl Harbor-Hickam, Hawaii*; Prepared for: Defense Logistics Agency Energy, Fort Belvoir, Virginia; Prepared Under: Naval Facilities Engineering Command Atlantic Contract N62470-10-D-3000-0048; Prepared by: Michael Baker International, Virginia Beach, Virginia; Date: 2 November 2017.

6.6 *Site Specific Health and Safety Plan, Joint Base Pearl Harbor-Hickam, Hawaii*; Prepared for: Defense Logistics Agency Energy, Fort Belvoir, Virginia; Prepared Under: Naval Facilities Engineering Command Atlantic Contract N62470-10-D-9007-N6247018F4014; Prepared by: Michael Baker International, Virginia Beach, Virginia; Date: January 2018.

APPENDIX A

KEN WILCOX ASSOCIATES, INC.

EVALUATION RESULTS

Results of the Evaluation of GSI 1 Leak Detection Method On Red Hill Tank 9 at Joint Base Pearl Harbor-Hickam

Final Report

PREPARED FOR:

Michael Baker International

June 20, 2018

Ken Wilcox Associates, Inc**.**

1125 Valley Ridge Drive, Grain Valley, MO 64029, USA

Phone (816) 443-2494, Fax (816) 443-2495

E-mail cwilcox@kwaleak.com, Web http://www.kwaleak.com

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PREFACE

This report was prepared by Ken Wilcox Associates, Inc., for Michael Baker International. The purpose of this report is to present the results of the testing of the Gauging Systems, Inc. (GSI), Leak Detection System (LDS) number 1, identified as the GSI 1 LDS, on the Bulk Field-Constructed Tank 9 at the Red Hill Bulk Fuel Storage Facility, located at Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The testing was conducted in a tank 250-feet tall with a diameter of 100-feet with a nominal capacity of 12,500,000-gallons. All evaluation testing was conducted at the Red Hill Bulk Fuel Storage Facility at JBPHH. The leak simulations, data collection, data analysis, and reporting were conducted by Ken Wilcox Associates, Inc. This report was prepared by Craig D. Wilcox and Jairus D. Flora, Jr., Ph.D.

This report presents the results of testing of the GSI 1 Leak Detection System (LDS) evaluated at Red Hill.

KEN WILCOX ASSOCIATES, INC.

Craig D. Wilcox, President	Jairus D. Flora, Jr., Ph.D.
June 20, 2018	June 20, 2018

1.0 INTRODUCTION

Gauging Systems, Incorporated (GSI) developed the GSI 1 Leak Detection System (LDS) specifically for this project. Ken Wilcox Associates, Inc. (KWA) conducted an independent third-party evaluation of this leak detection system following a procedure that meets the requirements of the evaluation protocol drafted specifically for this project. Testing was conducted in a nominal 12,500,000-gallon underground bulk, field-constructed tank with a diameter of approximately 100-feet and a height of 250-feet.

The United States Environmental Protection Agency (EPA) requires that all tank testing equipment be tested to define the equipment's performance parameters. The equipment must be capable of detecting leaks at a rate defined by the regulating agencies with a probability of detection of 95% or greater. At the same time, the method must not produce false alarms (declaring a leak when the tank is tight) more than 5% of the time.

The evaluation test plan was developed based on the existing protocol, "Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods", United States EPA, March 1990. The evaluation test plan was developed, reviewed and finalized over communications with the project stakeholders. The EPA protocol specified that a minimum of 12 tests would be conducted for the bulk field-constructed tank leak detection evaluation. The evaluation test plan included testing in three different test blocks, at three different product levels. There were a total of 4 evaluation tests performed for each block, with Block 1 product level at 189-feet 10-inches; Block 2 at 159-feet 11-inches; and Block 3 at 125-feet 0-inches.

The evaluation test plan specified that leak rates should be induced equivalent to multiples of the target threshold: zero, half the target threshold, the target threshold, and two times the target threshold. The target threshold was 0.50 gallons per hour (gph). The 4 nominal induced leak rates that were used during the evaluation were 0.00-gph, 0.25-gph, 0.50-gph and 1.00-gph. The induced leak rates were kept blind to the vendor during the entire evaluation. The GSI 1 LDS leak rates were reported to Michael Baker International within 24 hours after each test was concluded.

2.0 DESCRIPTION OF TESTING LOCATION

The GSI 1 LDS was tested at the Red Hill Bulk Fuel Storage Facility, on Tank 9 Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The Red Hill Bulk Fuel Storage Facility includes a number of bulk field-constructed tanks and a bulk pipeline system at JBPHH. The test tank was a field-constructed tank with a nominal capacity of 12,500,000-gallons. The test tank nominal dimensions are 250-feet tall with a diameter of 100-feet. Tank 9 is a field constructed vertical underground storage tank, shaped like a capsule, with domed top and domed bottom, that was constructed inside the mountain at Red Hill.

In order to lower the product level in the test tank, fuel transfers were conducted through a bulk pipeline that supplies fuel to JBPHH.

The GSI 1 LDS equipment was installed through a manway at the top of the test tank. The GSI 1 LDS main console was located in the upper tunnel next to Tank 9. The KWA evaluation equipment was located in the lower tunnel with the leak simulation equipment installed on a small diameter pipeline manifold that was attached to the bottom of the tank. The test tank was nominally made available to KWA staff 24-hours a day for the duration of the evaluation. Leak simulations were induced by KWA staff, Craig Wilcox, who was present for the duration of the evaluation.

3.0 OVERVIEW OF EVALUATION

Table 1 contains the test schedule, test duration, product level and the order the leaks were induced during the evaluation. Table 2 summarizes the GSI 1 LDS reported leak rate, the induced leak rate and the difference between the reported and induced leak rate that were achieved during the evaluation.

The GSI 1 LDS was installed in the test tank by the vendor. Testing was carried out using the vendor's normal test routine. Leak simulations were induced through a 1-inch diameter pipeline that was connected directly into Tank 9 at approximately 10-feet from the bottom. All leaks induced were kept blind to the vendor for the duration of the evaluation. The leak rate reported by the GSI 1 LDS was compared to the actual volume of product removed from the tank. A statistical analysis of the data was used to determine the performance characteristics of the test method.

In this report, leak rates are reported as positive numbers—the rate in gallons per hour of product removed from the tank. Any result reported as a negative number is considered as being reported as a liquid inflow into the tank. The leak rates were induced or simulated by removing product from the tank at various constant rates. There were twelve (12) tests conducted. Nine of the tests had leaks simulated and three (3) tests used a zero leak rate, representing a tight or non-leaking tank. Tests were conducted in three blocks with each block, containing 4 official evaluation tests, corresponding to a different level or depth of product in the tank. Block 1 was 189-feet 10-inches; Block 2 was 159-feet 11-inches; and Block 3 was 125-feet 0-inches. There was a product level drop performed before each block of tests began. This was to verify the performance of the leak detection system at different product levels. After a product level drop, there was a minimum 96-hour product settling time to let the product stabilize. After the 96-hour product settling time, the vendor was given a 24-hour setup period to verify that their system was functioning properly. After the 24-hour setup period, the vendor performed a 48-hour preliminary test to ensure the tank was tight before the first official evaluation test began for each block. During this preliminary 48-hour test, the vendor was aware that the tank did not have a leak induced, so these preliminary results are not considered

during the statistical analysis of the results. After the preliminary test was completed, the first official tests were performed at approximately 168-hours after the fuel drop was completed.

During the evaluation, the vendor reported the estimated leak rate within 24-hours of the completion of each test. For analysis, the induced leak rate was subtracted from the reported leak rate and these differences were analyzed. The method of analysis used was that found in the quantitative EPA leak detection protocols. The EPA procedure first estimates the probability of false alarm and the probability of detecting a leak rate of the size specified in the EPA regulations for the particular type of leak detection. The requirement for an annual tank tightness test for release detection of field-constructed tanks is 0.5-gph leak rate. The analysis estimates the threshold or criterion for declaring a leak that would give a 5% probability of false alarm (PFA). The analysis also determines the corresponding leak rate that is detectable with a probability of detection (PD) of at least 95%. See specifically Section 7.5.1 of the “Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods”, United States EPA, March 1990, which gives the procedure for calculating a threshold for determining a significant leak rate with a 5% PFA and Section 7.5.2, which gives the procedure for determining the 95% MDL.

Test times were 48-hours (two days) for each of the 12 tests. Leak simulations were controlled and monitored by KWA throughout the duration of the testing. Product level, volume, temperature and leak rates were recorded by KWA throughout the evaluation.

Leak simulations were conducted by utilizing a variable valve precision flow meter connected to a small diameter pipeline located 10-feet off the bottom of the tank. The head pressure from the fuel allowed for fuel to flow at a constant rate through the flow meter during the duration each test. Nominal leak rates of zero gph, 0.25-gph, 0.50-gph and 1.00-gph were randomly induced during the evaluation. Leak rates were calculated from the total mass of product removed from the tank during the test time and the density of the product. The mass of the product removed was measured by flowing product through the precision flow meter into a 55-gallon barrel that was placed onto a precision

scale to measure the mass of the product. Leak rates were also verified by KWA staff periodically during each test by measuring the flow rate with a graduated cylinder and a stop watch. Product level, temperature, and specific gravity readings were recorded throughout the evaluation from the automatic tank gauge (ATG) located at the upper tunnel of Tank 9.

Table 3 - Test Schedule for GSI 1 LDS Evaluation

Task Name	Scheduled Duration	Nominal Induced Leak Rate
Level Change	level drop down to 189' 10"	
Product Settling Time	96 hours	
Block 1: Test 1 Trial Run Setup		
Block 1: Test 1 Trial Run	48 hours	No Leak
Block 1: Test 2 Setup		
Block 1: Test 2	48 hours	LR4
Block 1: Test 3 Setup		
Block 1: Test 3	48 hours	LR3
Block 1: Test 4 Setup		
Block 1: Test 4	48 hours	LR2
Block 1: Test 5 Setup		
Block 1: Test 5	48 hours	LR1
Level Change	level drop down to 159' 11"	
Product Settling Time	96 hours	
Block 2: Retest 6 Trial Run Setup		
Block 2: Retest 6 Trial Run	48 hours	No Leak
Block 2: Retest 7 Setup		
Block 2: Retest 7	48 hours	LR3
Block 2: Retest 8 Setup		
Block 2: Retest 8	48 hours	LR2
Block 2: Test 9 Setup		
Block 2: Test 9	48 hours	LR1
Block 2: Test 10 Setup		
Block 2: Test 10	48 hours	LR4
Level Change	level drop down to 125' 0"	
Product Settling Time	96 hours	
Block 3: Test 11 Trial Run Setup		
Block 3: Test 11 Trial Run	48 hours	No Leak
Block 3: Test 12 Setup		
Block 3: Test 12	48 hours	LR2
Block 3: Test 13 Setup		
Block 3: Test 13	48 hours	LR4
Block 3: Test 14 Setup		
Block 3: Test 14	48 hours	LR3
Block 3: Test 15 Setup		
Block 3: Test 15	48 hours	LR1

LR1: 0-gph, LR2: 0.25-gph nominal, LR3: 0.5-gph nominal, LR4:1.0-gph nominal

4.0 DESCRIPTION OF THE GSI 1 LDS

The GSI 1 LDS is a mass-based system which includes a currently-installed liquid probe and a temporary vapor probe installed for evaluation testing; these probes contain pressure and temperature sensors. The sensors provide data, logged continuously at set intervals, to a local computer for computation of leak rate analyzed using proprietary software. The GSI 1 LDS includes mathematical model A, applied to data gathered from the liquid probe and the vapor probe.

5.0 TEST RESULTS AND DISCUSSION

5.1 GSI 1 Leak Detection System Results

Using the data in table 2, the mean difference between the GSI 1 LDS measured leak rates and the induced leak rates was 0.062-gph, with the positive sign indicating that on the average, the GSI 1 LDS measured leak rates were larger than the induced leak rates. The standard deviation of these differences was 0.213-gph. A t-statistic was calculated to test whether the mean difference was statistically significantly different from zero. A mean difference that was significantly different from zero would represent a bias in estimating the leak rate by that method. The calculated value of the t-statistic was 1.012 (with 11 degrees of freedom). The two-sided significance level (sometimes referred to as the P-value) was 0.333, or 33.3%, showing that the difference was not significantly different from zero at the 5% level. Thus, there was no significant bias in the method.

Table 2 contains the data from the GSI 1 LDS tests. For each of the 12 tests, the table contains the test number, the block and test name, the vendor's measured leak rate in gallons per hour (gph), the leak rate induced by removing product from the tank, collecting and measuring it in gph, and the difference between the measured and induced leak rates, found by subtracting the induced leak rate from the measured leak rate.

Table 5 - GSI 1 LDS Results

Test Number	Block and Test Name	GSI 1 LDS Method Result (gph)	Induced Leak (gph)	Difference (gph)
1	Block 1, Test 2	0.757	1.035	-0.278
2	Block 1, Test 3	0.477	0.446	0.031
3	Block 1, Test 4	0.495	0.216	0.279
4	Block 1, Test 5	-0.050	0	-0.050
5	Block 2, Retest 7	0.761	0.628	0.133
6	Block 2, Retest 8	0.265	0.307	-0.042
7	Block 2, Test 9	-0.059	0	-0.059
8	Block 2, Test 10	1.219	1.017	0.202
9	Block 3 Test12	0.002	0.255	-0.253
10	Block 3 Test 13	1.316	0.994	0.322
11	Block 3 Test 14	0.668	0.596	0.072
12	Block 3 Test 15	0.391	0	0.391

There were two evaluation tests that were re-run during Block 2 due to the uncertainty of the tightness of a valve from the transfer pipeline. The new evaluation tests are labeled as Retest 7 and Retest 8.

The results can be used to calculate a threshold value for determining whether a measured leak rate is significantly different from zero, indicating a potential leak, or is only minimally different from zero, indicating only measurement error. A two-sided test analysis approach has been used in this evaluation, meaning that the method would test for liquid incursion into the tank as well as for a leak or loss of product from the tank.

When there is no leak, it is possible that a leak detection system might produce a negative estimate, indicating an inflow into the tank. Such a finding could indicate a leak, if, for example, part of the tank was below the water table, which might produce an inward pressure at some points in the tank. Some leak detection methods may guard against that possibility.

Considering this, a two-sided threshold was used for this evaluation. This is calculated by using a two-sided t-value (with 11 degrees of freedom here) to multiply the standard deviation, with a leak being declared if the estimated leak rate fell outside the resulting interval. In this case, the t-value is 2.201 and the threshold is ±0.470. Then a leak would be declared if the measured leak rate were less than –0.470 or greater than +0.470. This would result in a 5% chance of error when the tank was tight. Note that the standard deviation is used in this calculation (not the standard error of the mean) because the standard deviation is an estimate of the error associated with a single leak rate measurement, whereas the standard error of the mean is the error associated with estimating the mean of several leak measurements (12 in this case). Generally, a tank test only measures a single leak rate.

5.2 Test for the Effect of Product Level

These tests were conducted in three blocks, corresponding to three different levels or depths of product. The data can also be used to test whether the different product levels affected the leak detection method significantly. To do this the induced leak rate was subtracted from the measured leak rate and the differences were analyzed using a one-way or one-factor analysis of variance (ANOVA). Table 2 indicates the blocks or different product levels where the evaluation tests were performed. For GSI 1 LDS, the mean differences were found: Block 1 averaged –0.005, Block 2 averaged 0.059, and Block 3 averaged 0.133. The analysis of variance gave an F-statistic of 0.368 with 2 and 9 degrees of freedom, corresponding to a P-value of 0.702, which was not statistically significant at the 5% level. The critical value for F was 4.256. Thus, it is reasonable to conclude that the different product depths did not affect the GSI 1 LDS method.

Table 3 is a summary of the findings of the data analysis.

Table 3 - Summary of the Test Results for the GSI 1 LDS

Required Test Time	48-hours
Required Product Level in Tank	Between 125-feet and 190-feet
Maximum Size of Tank (evaluation only applicable to Red Hill)	Red Hill Tanks with nominal volume of 12,500,000-gallons
Maximum Temperature Difference (between product delivered and product in the tank)	Not Evaluated
Required Product Settling Time After Delivery or Fueling Operations	Not Evaluated for product delivery, Minimum wait period of 168-hrs, after product level drop
Standard Deviation of the Test Data	0.213-gph
Threshold	0.470-gph
Bias (not statistically significant at 5% level)	0.062 (not significant)
Minimum Threshold for a 5% P_{FA}	0.470-gph
Minimum Detectable Leak Rate for 95% P_D (when the minimum threshold is used)	0.940-gph

5.3 Test Times

Each of the 12 tests conducted in this evaluation had a duration of exactly 48-hours. This test duration time was established in the evaluation test plan. Alternate test duration times were not evaluated.

5.4 Product Levels

For this evaluation, per the test plan, testing was conducted with tank product levels at 189-feet 10-inch, 159-feet 11-inch and 125-feet 0-inch. The results of this evaluation indicate that tank product levels at Red Hill between 125-feet and 190-feet nominal product level height are acceptable for conducting leak detection tests. Product level heights outside of this range were not evaluated.

5.5 Size of Tank

The volume of Tank 9 at Red Hill is nominally 12,500,000-gallons. For leak detection systems, the performance can be affected by the size and geometry of the tank. For most mass-based technologies, performance is related to the surface area of the fuel in the tank (but not the depth of the tank); for some systems, performance is a function of both volume and surface area. The GSI 1 LDS is a mass-based technology.

The evaluation test plan specifies that the results of this evaluation are applicable to the tanks at Red Hill. This is due to the test plan being developed specifically for this unique installation and the environment where the tanks are installed. The possibility of scaling the Red Hill evaluation test results was not evaluated.

5.6 Temperature Differences and Waiting Time After Product Deliveries and Drops

As part of the evaluation test plan, differences in product temperature were not evaluated. During the evaluation, after a product level drop, there was a minimum 168-hour wait period before the official first test on each block began.

6.0 CONCLUSIONS

The following conclusions and recommendations are based on the results of the testing described in this report.

1. For the GSI 1 LDS, the Probability of Detection (P_D) of a 0.940-gph leak (or water incursion) is 95.0% when the threshold is set at ±0.470-gph. The corresponding Probability of False Alarm (P_{FA}) is 5.0% when the threshold is set at ±0.470-gph.

2. The minimum test duration time evaluated for a leak detection test to be valid, is 48-hours.

3. The Red Hill tank must be between 125-feet and 190-feet nominal product level height before conducting a valid leak detection test.

4. As specified by the evaluation test plan, the results of this evaluation are valid only for the tanks with nominal volume of 12,500,000-gallons at the Red Hill Fuel Storage Complex. The installation and location of the fuel storage tanks at the Red Hill Fuel Storage Complex provide a very stable environment for leak detection that is not typically found at other fuel storage facilities. Therefore the results of this evaluation of the GSI 1 LDS should only be considered applicable to the fuel storage tanks at the Red Hill Fuel Storage Complex.

5. Product delivery was not a part of this evaluation, therefore, product settling time for conducting leak detection testing after product delivery was not determined.

6. Leak detection tests may be initiated 168-hours (minimum) following a product level drop, provided a minimum of 48-hours of quality data are collected and analyzed.

7. Scaling was not included in this evaluation. If scaling is to be considered at a facility other than the Red Hill Fuel Storage Complex, additional evaluation tests should be performed in order to verify the application of scaling the evaluation results. Several other factors may need to be considered including test duration times, tank size, tank installation/location, and product settling time after fuel transfers.

ATTACHMENT A

EPA Forms for the GSI 1 LDS

Results of U.S. EPA Standard Evaluation

Volumetric Tank Tightness Testing Method

This form tells whether the tank tightness testing method described below complies with the performance requirements of the federal underground storage tank regulation. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods." The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name	Gauging Systems, Incorporated		
Version number	GSI 1 LDS		
Vendor	Gauging Systems, Incorporated		
(street address)	910A Industrial Boulevard		
	Sugarland	Texas	77478
(phone)	(281) 980-3999		

Evaluation Results

This method, which declares a tank to be leaking when the measured leak rate exceeds the threshold of 0.470 gallon per hour, has a probability of false alarms [P(FA)] of 5 %.

The corresponding probability of detection [P(D)] of a 0.500 gallon per hour leak is 55.50 %.

Therefore, this method ☐ does **X** does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency (0.500 gallon per hour at P(D) of 95% and P(FA) of 5%).

Test Conditions During Evaluation

The evaluation testing was conducted in a 12,500,000 gallon **X** steel ☐ fiberglass tank that was 100 foot in diameter and 250 foot tall.

The tests were conducted with the tank product level between 125 and 190 foot.

The temperature difference between product added to fill the tank and product already in the tank ranged from not evaluated °F to not evaluated °F, with a standard deviation of not evaluated °F.

The product used in the evaluation was JP-5 .

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for using the method are followed.
- The tank is no larger than not included in this evaluation gallons.
- The tank contains a product identified on the method description form.
- The tank product level height is between 125 and 190 foot.
- The waiting time after adding any substantial amount of product to the tank is at least not included in this evaluation hours.
- The temperature of the added product does not differ more than not included in this evaluation degrees Fahrenheit from that already in the tank.
- The waiting time between the end of "topping off," if any, and the start of the test data collection is at least not included in this evaluation hours.
- The total data collection time for the test is at least 48 hours.
- This method **X** can ☐ cannot be used if the ground-water level is above the bottom of the tank.
- Other limitations specified by the vendor or determined during testing: After a fuel drop, there was a minimum 168-hour product settling time before any test began during the evaluation.

> **Safety disclaimer: This test procedure only addresses the issue of the Leak Detection Method's ability to detect leaks. It does not test the equipment for safety hazards.**

Certification of Results

I certify that the Leak Detection Method was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation.

Craig D. Wilcox President
(printed name)

[signature]
(signature)

Ken Wilcox Associates, Inc.
(organization performing evaluation)

Grain Valley, Missouri 64029
(city, state, zip)

Jairus Flora, Jr., Ph.D.
(printed name)

[signature]
(signature)

June 20, 2018
(date)

(816) 443-2494

Results of the Evaluation of GSI 2 Leak Detection Method On Red Hill Tank 9 at Joint Base Pearl Harbor-Hickam

Final Report

PREPARED FOR:

Michael Baker International

June 20, 2018

Ken Wilcox Associates, Inc**.**

1125 Valley Ridge Drive, Grain Valley, MO 64029, USA

Phone (816) 443-2494, Fax (816) 443-2495

E-mail cwilcox@kwaleak.com, Web http://www.kwaleak.com

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PREFACE

This report was prepared by Ken Wilcox Associates, Inc., for Michael Baker International. The purpose of this report is to present the results of the testing of the Gauging Systems, Inc. (GSI), Leak Detection System (LDS) number 2, identified as the GSI 2 LDS, on the Bulk Field-Constructed Tank 9 at the Red Hill Bulk Fuel Storage Facility, located at Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The testing was conducted in a tank 250-feet tall with a diameter of 100-feet with a nominal capacity of 12,500,000-gallons. All evaluation testing was conducted at the Red Hill Bulk Fuel Storage Facility at JBPHH. The leak simulations, data collection, data analysis, and reporting were conducted by Ken Wilcox Associates, Inc. This report was prepared by Craig D. Wilcox and Jairus D. Flora, Jr., Ph.D.

This report presents the results of testing of the GSI 2 Leak Detection System (LDS) evaluated at Red Hill.

KEN WILCOX ASSOCIATES, INC.

Craig D. Wilcox, President

June 20, 2018

Jairus D. Flora, Jr., Ph.D.

June 20, 2018

1.0 INTRODUCTION

Gauging Systems, Incorporated (GSI) developed the GSI 2 Leak Detection System (LDS) specifically for this project. Ken Wilcox Associates, Inc. (KWA) conducted an independent third-party evaluation of this leak detection system following a procedure that meets the requirements of the evaluation protocol drafted specifically for this project. Testing was conducted in a nominal 12,500,000-gallon underground bulk, field-constructed tank with a diameter of approximately 100-feet and a height of 250-feet.

The United States Environmental Protection Agency (EPA) requires that all tank testing equipment be tested to define the equipment's performance parameters. The equipment must be capable of detecting leaks at a rate defined by the regulating agencies with a probability of detection of 95% or greater. At the same time, the method must not produce false alarms (declaring a leak when the tank is tight) more than 5% of the time.

The evaluation test plan was developed based on the existing protocol, "Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods", United States EPA, March 1990. The evaluation test plan was developed, reviewed and finalized over communications with the project stakeholders. The EPA protocol specified that a minimum of 12 tests would be conducted for the bulk field-constructed tank leak detection evaluation. The evaluation test plan included testing in three different test blocks, at three different product levels. There were a total of 4 evaluation tests performed for each block, with Block 1 product level at 189-feet 10-inches; Block 2 at 159-feet 11-inches; and Block 3 at 125-feet 0-inches.

The evaluation test plan specified that leak rates should be induced equivalent to multiples of the target threshold: zero, half the target threshold, the target threshold, and two times the target threshold. The target threshold was 0.50 gallons per hour (gph). The 4 nominal induced leak rates that were used during the evaluation were 0.00-gph, 0.25-gph, 0.50-gph and 1.00-gph. The induced leak rates were kept blind to the vendor during the entire evaluation. The GSI 2 LDS leak rates were reported to Michael Baker International within 24 hours after each test was concluded.

2.0 DESCRIPTION OF TESTING LOCATION

The GSI 2 LDS was tested at the Red Hill Bulk Fuel Storage Facility, on Tank 9 Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The Red Hill Bulk Fuel Storage Facility includes a number of bulk field-constructed tanks and a bulk pipeline system at JBPHH. The test tank was a field-constructed tank with a nominal capacity of 12,500,000-gallons. The test tank nominal dimensions are 250-feet tall with a diameter of 100-feet. Tank 9 is a field constructed vertical underground storage tank, shaped like a capsule, with domed top and domed bottom, that was constructed inside the mountain at Red Hill.

In order to lower the product level in the test tank, fuel transfers were conducted through a bulk pipeline that supplies fuel to JBPHH.

The GSI 2 LDS equipment was installed through a manway at the top of the test tank. The GSI 2 LDS main console was located in the upper tunnel next to Tank 9. The KWA evaluation equipment was located in the lower tunnel with the leak simulation equipment installed on a small diameter pipeline manifold that was attached to the bottom of the tank. The test tank was nominally made available to KWA staff 24-hours a day for the duration of the evaluation. Leak simulations were induced by KWA staff, Craig Wilcox, who was present for the duration of the evaluation.

3.0 OVERVIEW OF EVALUATION

Table 1 contains the test schedule, test duration, product level and the order the leaks were induced during the evaluation. Table 2 summarizes the GSI 2 LDS reported leak rate, the induced leak rate and the difference between the reported and induced leak rate that were achieved during the evaluation.

The GSI 2 LDS was installed in the test tank by the vendor. Testing was carried out using the vendor's normal test routine. Leak simulations were induced through a 1-inch diameter pipeline that was connected directly into Tank 9 at approximately 10-feet from the bottom. All leaks induced were kept blind to the vendor for the duration of the evaluation. The leak rate reported by the GSI 2 LDS was compared to the actual volume of product removed from the tank. A statistical analysis of the data was used to determine the performance characteristics of the test method.

In this report, leak rates are reported as positive numbers—the rate in gallons per hour of product removed from the tank. Any result reported as a negative number is considered as being reported as a liquid inflow into the tank. The leak rates were induced or simulated by removing product from the tank at various constant rates. There were twelve (12) tests conducted. Nine of the tests had leaks simulated and three (3) tests used a zero leak rate, representing a tight or non-leaking tank. Tests were conducted in three blocks with each block, containing 4 official evaluation tests, corresponding to a different level or depth of product in the tank. Block 1 was 189-feet 10-inches; Block 2 was 159-feet 11-inches; and Block 3 was 125-feet 0-inches. There was a product level drop performed before each block of tests began. This was to verify the performance of the leak detection system at different product levels. After a product level drop, there was a minimum 96-hour product settling time to let the product stabilize. After the 96-hour product settling time, the vendor was given a 24-hour setup period to verify that their system was functioning properly. After the 24-hour setup period, the vendor performed a 48-hour preliminary test to ensure the tank was tight before the first official evaluation test began for each block. During this preliminary 48-hour test, the vendor was aware that the tank did not have a leak induced, so these preliminary results are not considered

during the statistical analysis of the results. After the preliminary test was completed, the first official tests were performed at approximately 168-hours after the fuel drop was completed.

During the evaluation, the vendor reported the estimated leak rate within 24-hours of the completion of each test. For analysis, the induced leak rate was subtracted from the reported leak rate and these differences were analyzed. The method of analysis used was that found in the quantitative EPA leak detection protocols. The EPA procedure first estimates the probability of false alarm and the probability of detecting a leak rate of the size specified in the EPA regulations for the particular type of leak detection. The requirement for an annual tank tightness test for release detection of field-constructed tanks is 0.5-gph leak rate. The analysis estimates the threshold or criterion for declaring a leak that would give a 5% probability of false alarm (PFA). The analysis also determines the corresponding leak rate that is detectable with a probability of detection (PD) of at least 95%. See specifically Section 7.5.1 of the "Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods", United States EPA, March 1990, which gives the procedure for calculating a threshold for determining a significant leak rate with a 5% PFA and Section 7.5.2, which gives the procedure for determining the 95% MDL.

Test times were 48-hours (two days) for each of the 12 tests. Leak simulations were controlled and monitored by KWA throughout the duration of the testing. Product level, volume, temperature and leak rates were recorded by KWA throughout the evaluation.

Leak simulations were conducted by utilizing a variable valve precision flow meter connected to a small diameter pipeline located 10-feet off the bottom of the tank. The head pressure from the fuel allowed for fuel to flow at a constant rate through the flow meter during the duration each test. Nominal leak rates of zero gph, 0.25-gph, 0.50-gph and 1.00-gph were randomly induced during the evaluation. Leak rates were calculated from the total mass of product removed from the tank during the test time and the density of the product. The mass of the product removed was measured by flowing product through the precision flow meter into a 55-gallon barrel that was placed onto a precision

scale to measure the mass of the product. Leak rates were also verified by KWA staff periodically during each test by measuring the flow rate with a graduated cylinder and a stop watch. Product level, temperature, and specific gravity readings were recorded throughout the evaluation from the automatic tank gauge (ATG) located at the upper tunnel of Tank 9.

Table 3 - Test Schedule for GSI 2 LDS Evaluation

Task Name	Scheduled Duration	Nominal Induced Leak Rate
Level Change	level drop down to 189' 10"	
Product Settling Time	96 hours	
Block 1: Test 1 Trial Run Setup		
Block 1: Test 1 Trial Run	48 hours	No Leak
Block 1: Test 2 Setup		
Block 1: Test 2	48 hours	LR4
Block 1: Test 3 Setup		
Block 1: Test 3	48 hours	LR3
Block 1: Test 4 Setup		
Block 1: Test 4	48 hours	LR2
Block 1: Test 5 Setup		
Block 1: Test 5	48 hours	LR1
Level Change	level drop down to 159' 11"	
Product Settling Time	96 hours	
Block 2: Retest 6 Trial Run Setup		
Block 2: Retest 6 Trial Run	48 hours	No Leak
Block 2: Retest 7 Setup		
Block 2: Retest 7	48 hours	LR3
Block 2: Retest 8 Setup		
Block 2: Retest 8	48 hours	LR2
Block 2: Test 9 Setup		
Block 2: Test 9	48 hours	LR1
Block 2: Test 10 Setup		
Block 2: Test 10	48 hours	LR4
Level Change	level drop down to 125' 0"	
Product Settling Time	96 hours	
Block 3: Test 11 Trial Run Setup		
Block 3: Test 11 Trial Run	48 hours	No Leak
Block 3: Test 12 Setup		
Block 3: Test 12	48 hours	LR2
Block 3: Test 13 Setup		
Block 3: Test 13	48 hours	LR4
Block 3: Test 14 Setup		
Block 3: Test 14	48 hours	LR3
Block 3: Test 15 Setup		
Block 3: Test 15	48 hours	LR1

LR1: 0-gph, LR2: 0.25-gph nominal, LR3: 0.5-gph nominal, LR4:1.0-gph nominal

4.0 DESCRIPTION OF THE GSI 2 LDS

The GSI 2 LDS is a mass-based system which includes a currently-installed liquid probe containing pressure and temperature sensors. The sensors provide data, logged continuously at set intervals, to a local computer for computation of leak rate analyzed using proprietary software. The GSI 2 LDS includes mathematical model A, applied to data gathered from the liquid probe.

5.0 TEST RESULTS AND DISCUSSION

5.1 GSI 2 Leak Detection System Results

Using the data in table 2, the mean difference between the GSI 2 LDS measured leak rates and the induced leak rates was 0.062-gph, with the positive sign indicating that on the average, the GSI 2 LDS measured leak rates were larger than the induced leak rates. The standard deviation of these differences was 0.214-gph. A t-statistic was calculated to test whether the mean difference was statistically significantly different from zero. A mean difference that was significantly different from zero would represent a bias in estimating the leak rate by that method. The calculated value of the t-statistic was 1.002 (with 11 degrees of freedom). The two-sided significance level (sometimes referred to as the P-value) was 0.338, or 33.8%, showing that the difference was not significantly different from zero at the 5% level. Thus, there was no significant bias in the method.

Table 2 contains the data from the GSI 2 LDS tests. For each of the 12 tests, the table contains the test number, the block and test name, the vendor's measured leak rate in gallons per hour (gph), the leak rate induced by removing product from the tank, collecting and measuring it in gph, and the difference between the measured and induced leak rates, found by subtracting the induced leak rate from the measured leak rate.

Table 5 - GSI 2 LDS Results

Test Number	Block and Test Name	GSI 2 LDS Method Result (gph)	Induced Leak (gph)	Difference (gph)
1	Block 1, Test 2	0.643	1.035	-0.392
2	Block 1, Test 3	0.443	0.446	-0.003
3	Block 1, Test 4	0.514	0.216	0.298
4	Block 1, Test 5	-0.006	0	-0.006
5	Block 2, Retest 7	0.598	0.628	-0.030
6	Block 2, Retest 8	0.383	0.307	0.076
7	Block 2, Test 9	0.080	0	0.080
8	Block 2, Test 10	1.260	1.017	0.243
9	Block 3 Test12	0.054	0.255	-0.201
10	Block 3 Test 13	1.057	0.994	0.063
11	Block 3 Test 14	0.937	0.596	0.341
12	Block 3 Test 15	0.274	0	0.274

There were two evaluation tests that were re-run during Block 2 due to the uncertainty of the tightness of a valve from the transfer pipeline. The new evaluation tests are labeled as Retest 7 and Retest 8.

The results can be used to calculate a threshold value for determining whether a measured leak rate is significantly different from zero, indicating a potential leak, or is only minimally different from zero, indicating only measurement error. A two-sided test analysis approach has been used in this evaluation, meaning that the method would test for liquid incursion into the tank as well as for a leak or loss of product from the tank.

When there is no leak, it is possible that a leak detection system might produce a negative estimate, indicating an inflow into the tank. Such a finding could indicate a leak, if, for example, part of the tank was below the water table, which might produce an inward pressure at some points in the tank. Some leak detection methods may guard against that possibility.

Considering this, a two-sided threshold was used for this evaluation. This is calculated by using a two-sided t-value (with 11 degrees of freedom here) to multiply the standard deviation, with a leak being declared if the estimated leak rate fell outside the resulting interval. In this case, the t-value is 2.201 and the threshold is ±0.471. Then a leak would be declared if the measured leak rate were less than –0.471 or greater than +0.471. This would result in a 5% chance of error when the tank was tight. Note that the standard deviation is used in this calculation (not the standard error of the mean) because the standard deviation is an estimate of the error associated with a single leak rate measurement, whereas the standard error of the mean is the error associated with estimating the mean of several leak measurements (12 in this case). Generally, a tank test only measures a single leak rate.

5.2 Test for the Effect of Product Level

These tests were conducted in three blocks, corresponding to three different levels or depths of product. The data can also be used to test whether the different product levels affected the leak detection method significantly. To do this the induced leak rate was subtracted from the measured leak rate and the differences were analyzed using a one-way or one-factor analysis of variance (ANOVA). Table 2 indicates the blocks or different product levels where the evaluation tests were performed. For GSI 2 LDS, the mean differences were found: Block 1 averaged –0.026, Block 2 averaged 0.092, and Block 3 averaged 0.119. The analysis of variance gave an F-statistic of 0.469 with 2 and 9 degrees of freedom, corresponding to a P-value of 0.640, which was not statistically significant at the 5% level. The critical value for F was 4.256. Thus, it is reasonable to conclude that the different product depths did not affect the GSI 2 LDS method.

Table 3 is a summary of the findings of the data analysis.

Table 3 - Summary of the Test Results for the GSI 2 LDS

Required Test Time	48-hours
Required Product Level in Tank	Between 125-feet and 190-feet
Maximum Size of Tank (evaluation only applicable to Red Hill)	Red Hill Tanks with nominal volume of 12,500,000-gallons
Maximum Temperature Difference (between product delivered and product in the tank)	Not Evaluated
Required Product Settling Time After Delivery or Fueling Operations	Not Evaluated for product delivery, Minimum wait period of 168-hrs, after product level drop
Standard Deviation of the Test Data	0.214-gph
Threshold	0.471-gph
Bias (not statistically significant at 5% level)	0.062 (not significant)
Minimum Threshold for a 5% P_{FA}	0.471-gph
Minimum Detectable Leak Rate for 95% P_D (when the minimum threshold is used)	0.943-gph

5.3 Test Times

Each of the 12 tests conducted in this evaluation had a duration of exactly 48-hours. This test duration time was established in the evaluation test plan. Alternate test duration times were not evaluated.

5.4 Product Levels

For this evaluation, per the test plan, testing was conducted with tank product levels at 189-feet 10-inch, 159-feet 11-inch and 125-feet 0-inch. The results of this evaluation indicate that tank product levels at Red Hill between 125-feet and 190-feet nominal product level height are acceptable for conducting leak detection tests. Product level heights outside of this range were not evaluated.

5.5 Size of Tank

The volume of Tank 9 at Red Hill is nominally 12,500,000-gallons. For leak detection systems, the performance can be affected by the size and geometry of the tank. For most mass-based technologies, performance is related to the surface area of the fuel in the tank (but not the depth of the tank); for some systems, performance is a function of both volume and surface area. The GSI 2 LDS is a mass-based technology.

The evaluation test plan specifies that the results of this evaluation are applicable to the tanks at Red Hill. This is due to the test plan being developed specifically for this unique installation and the environment where the tanks are installed. The possibility of scaling the Red Hill evaluation test results was not evaluated.

5.6 Temperature Differences and Waiting Time After Product Deliveries and Drops

As part of the evaluation test plan, differences in product temperature were not evaluated. During the evaluation, after a product level drop, there was a minimum 168-hour wait period before the official first test on each block began.

6.0 CONCLUSIONS

The following conclusions and recommendations are based on the results of the testing described in this report.

1. For the GSI 2 LDS, the Probability of Detection (P_D) of a 0.943-gph leak (or water incursion) is 95.0% when the threshold is set at ±0.471-gph. The corresponding Probability of False Alarm (P_{FA}) is 5.0% when the threshold is set at ±0.471-gph.

2. The minimum test duration time evaluated for a leak detection test to be valid, is 48-hours.

3. The Red Hill tank must be between 125-feet and 190-feet nominal product level height before conducting a valid leak detection test.

4. As specified by the evaluation test plan, the results of this evaluation are valid only for the tanks with nominal volume of 12,500,000-gallons at the Red Hill Fuel Storage Complex. The installation and location of the fuel storage tanks at the Red Hill Fuel Storage Complex provide a very stable environment for leak detection that is not typically found at other fuel storage facilities. Therefore the results of this evaluation of the GSI 2 LDS should only be considered applicable to the fuel storage tanks at the Red Hill Fuel Storage Complex.

5. Product delivery was not a part of this evaluation, therefore, product settling time for conducting leak detection testing after product delivery was not determined.

6. Leak detection tests may be initiated 168-hours (minimum) following a product level drop, provided a minimum of 48-hours of quality data are collected and analyzed.

7. Scaling was not included in this evaluation. If scaling is to be considered at a facility other than the Red Hill Fuel Storage Complex, additional evaluation tests should be performed in order to verify the application of scaling the evaluation results. Several other factors may need to be considered including test duration times, tank size, tank installation/location, and product settling time after fuel transfers.

ATTACHMENT A

EPA Forms for the GSI 2 LDS

Results of U.S. EPA Standard Evaluation

Volumetric Tank Tightness Testing Method

This form tells whether the tank tightness testing method described below complies with the performance requirements of the federal underground storage tank regulation. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods." The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name	Gauging Systems, Incorporated		
Version number	GSI 2 LDS		
Vendor	Gauging Systems, Incorporated		
(street address)	910A Industrial Boulevard		
	Sugarland	Texas	77478
(phone)	(281) 980-3999		

Evaluation Results

This method, which declares a tank to be leaking when the measured leak rate exceeds the threshold of 0.471 gallon per hour, has a probability of false alarms [P(FA)] of 5 %.

The corresponding probability of detection [P(D)] of a 0.500 gallon per hour leak is 55.23 %.

Therefore, this method ☐ does **X** does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency (0.500 gallon per hour at P(D) of 95% and P(FA) of 5%).

Test Conditions During Evaluation

The evaluation testing was conducted in a 12,500,000 gallon **X** steel ☐ fiberglass tank that was 100 foot in diameter and 250 foot tall.

The tests were conducted with the tank product level between 125 and 190 foot.

The temperature difference between product added to fill the tank and product already in the tank ranged from not evaluated °F to not evaluated °F, with a standard deviation of not evaluated °F.

The product used in the evaluation was JP-5 .

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for using the method are followed.
- The tank is no larger than _not included in this evaluation_ gallons.
- The tank contains a product identified on the method description form.
- The tank product level height is between 125 and 190 foot.
- The waiting time after adding any substantial amount of product to the tank is at least _not included in this evaluation_ hours.
- The temperature of the added product does not differ more than _not included in this evaluation_ degrees Fahrenheit from that already in the tank.
- The waiting time between the end of "topping off," if any, and the start of the test data collection is at least _not included in this evaluation_ hours.
- The total data collection time for the test is at least _48_ hours.
- This method **X** can ☐ cannot be used if the ground-water level is above the bottom of the tank.
- Other limitations specified by the vendor or determined during testing: After a fuel drop, there was a minimum 168-hour product settling time before any test began during the evaluation.

> **Safety disclaimer: This test procedure only addresses the issue of the Leak Detection Method's ability to detect leaks. It does not test the equipment for safety hazards.**

Certification of Results

I certify that the Leak Detection Method was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation.

Craig D. Wilcox President
(printed name)

(signature)

Jairus Flora, Jr., Ph.D.
(printed name)

(signature)

Ken Wilcox Associates, Inc.
(organization performing evaluation)

Grain Valley, Missouri 64029
(city, state, zip)

June 20, 2018
(date)

(816) 443-2494

Results of the Evaluation of GSI 3 Leak Detection Method On Red Hill Tank 9 at Joint Base Pearl Harbor-Hickam

Final Report

PREPARED FOR:

Michael Baker International

June 20, 2018

Ken Wilcox Associates, Inc.

1125 Valley Ridge Drive, Grain Valley, MO 64029, USA

Phone (816) 443-2494, Fax (816) 443-2495

E-mail cwilcox@kwaleak.com, Web http://www.kwaleak.com

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PREFACE

This report was prepared by Ken Wilcox Associates, Inc., for Michael Baker International. The purpose of this report is to present the results of the testing of the Gauging Systems, Inc. (GSI), Leak Detection System (LDS) number 3, identified as the GSI 3 LDS, on the Bulk Field-Constructed Tank 9 at the Red Hill Bulk Fuel Storage Facility, located at Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The testing was conducted in a tank 250-feet tall with a diameter of 100-feet with a nominal capacity of 12,500,000-gallons. All evaluation testing was conducted at the Red Hill Bulk Fuel Storage Facility at JBPHH. The leak simulations, data collection, data analysis, and reporting were conducted by Ken Wilcox Associates, Inc. This report was prepared by Craig D. Wilcox and Jairus D. Flora, Jr., Ph.D.

This report presents the results of testing of the GSI 3 Leak Detection System (LDS) evaluated at Red Hill.

KEN WILCOX ASSOCIATES, INC.

Craig D. Wilcox, President

June 20, 2018

Jairus D. Flora, Jr., Ph.D.

June 20, 2018

1.0 INTRODUCTION

Gauging Systems, Incorporated (GSI) developed the GSI 3 Leak Detection System (LDS) specifically for this project. Ken Wilcox Associates, Inc. (KWA) conducted an independent third-party evaluation of this leak detection system following a procedure that meets the requirements of the evaluation protocol drafted specifically for this project. Testing was conducted in a nominal 12,500,000-gallon underground bulk, field-constructed tank with a diameter of approximately 100-feet and a height of 250-feet.

The United States Environmental Protection Agency (EPA) requires that all tank testing equipment be tested to define the equipment's performance parameters. The equipment must be capable of detecting leaks at a rate defined by the regulating agencies with a probability of detection of 95% or greater. At the same time, the method must not produce false alarms (declaring a leak when the tank is tight) more than 5% of the time.

The evaluation test plan was developed based on the existing protocol, "Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods", United States EPA, March 1990. The evaluation test plan was developed, reviewed and finalized over communications with the project stakeholders. The EPA protocol specified that a minimum of 12 tests would be conducted for the bulk field-constructed tank leak detection evaluation. The evaluation test plan included testing in three different test blocks, at three different product levels. There were a total of 4 evaluation tests performed for each block, with Block 1 product level at 189-feet 10-inches; Block 2 at 159-feet 11-inches; and Block 3 at 125-feet 0-inches.

The evaluation test plan specified that leak rates should be induced equivalent to multiples of the target threshold: zero, half the target threshold, the target threshold, and two times the target threshold. The target threshold was 0.50 gallons per hour (gph). The 4 nominal induced leak rates that were used during the evaluation were 0.00-gph, 0.25-gph, 0.50-gph and 1.00-gph. The induced leak rates were kept blind to the vendor during the entire evaluation. The GSI 3 LDS leak rates were reported to Michael Baker International within 24 hours after each test was concluded.

2.0 DESCRIPTION OF TESTING LOCATION

The GSI 3 LDS was tested at the Red Hill Bulk Fuel Storage Facility, on Tank 9 Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The Red Hill Bulk Fuel Storage Facility includes a number of bulk field-constructed tanks and a bulk pipeline system at JBPHH. The test tank was a field-constructed tank with a nominal capacity of 12,500,000-gallons. The test tank nominal dimensions are 250-feet tall with a diameter of 100-feet. Tank 9 is a field constructed vertical underground storage tank, shaped like a capsule, with domed top and domed bottom, that was constructed inside the mountain at Red Hill.

In order to lower the product level in the test tank, fuel transfers were conducted through a bulk pipeline that supplies fuel to JBPHH.

The GSI 3 LDS equipment was installed through a manway at the top of the test tank. The GSI 3 LDS main console was located in the upper tunnel next to Tank 9. The KWA evaluation equipment was located in the lower tunnel with the leak simulation equipment installed on a small diameter pipeline manifold that was attached to the bottom of the tank. The test tank was nominally made available to KWA staff 24-hours a day for the duration of the evaluation. Leak simulations were induced by KWA staff, Craig Wilcox, who was present for the duration of the evaluation.

3.0 OVERVIEW OF EVALUATION

Table 1 contains the test schedule, test duration, product level and the order the leaks were induced during the evaluation. Table 2 summarizes the GSI 3 LDS reported leak rate, the induced leak rate and the difference between the reported and induced leak rate that were achieved during the evaluation.

The GSI 3 LDS was installed in the test tank by the vendor. Testing was carried out using the vendor's normal test routine. Leak simulations were induced through a 1-inch diameter pipeline that was connected directly into Tank 9 at approximately 10-feet from the bottom. All leaks induced were kept blind to the vendor for the duration of the evaluation. The leak rate reported by the GSI 3 LDS was compared to the actual volume of product removed from the tank. A statistical analysis of the data was used to determine the performance characteristics of the test method.

In this report, leak rates are reported as positive numbers—the rate in gallons per hour of product removed from the tank. Any result reported as a negative number is considered as being reported as a liquid inflow into the tank. The leak rates were induced or simulated by removing product from the tank at various constant rates. There were twelve (12) tests conducted. Nine of the tests had leaks simulated and three (3) tests used a zero leak rate, representing a tight or non-leaking tank. Tests were conducted in three blocks with each block, containing 4 official evaluation tests, corresponding to a different level or depth of product in the tank. Block 1 was 189-feet 10-inches; Block 2 was 159-feet 11-inches; and Block 3 was 125-feet 0-inches. There was a product level drop performed before each block of tests began. This was to verify the performance of the leak detection system at different product levels. After a product level drop, there was a minimum 96-hour product settling time to let the product stabilize. After the 96-hour product settling time, the vendor was given a 24-hour setup period to verify that their system was functioning properly. After the 24-hour setup period, the vendor performed a 48-hour preliminary test to ensure the tank was tight before the first official evaluation test began for each block. During this preliminary 48-hour test, the vendor was aware that the tank did not have a leak induced, so these preliminary results are not considered

during the statistical analysis of the results. After the preliminary test was completed, the first official tests were performed at approximately 168-hours after the fuel drop was completed.

During the evaluation, the vendor reported the estimated leak rate within 24-hours of the completion of each test. For analysis, the induced leak rate was subtracted from the reported leak rate and these differences were analyzed. The method of analysis used was that found in the quantitative EPA leak detection protocols. The EPA procedure first estimates the probability of false alarm and the probability of detecting a leak rate of the size specified in the EPA regulations for the particular type of leak detection. The requirement for an annual tank tightness test for release detection of field-constructed tanks is 0.5-gph leak rate. The analysis estimates the threshold or criterion for declaring a leak that would give a 5% probability of false alarm (PFA). The analysis also determines the corresponding leak rate that is detectable with a probability of detection (PD) of at least 95%. See specifically Section 7.5.1 of the "Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods", United States EPA, March 1990, which gives the procedure for calculating a threshold for determining a significant leak rate with a 5% PFA and Section 7.5.2, which gives the procedure for determining the 95% MDL.

Test times were 48-hours (two days) for each of the 12 tests. Leak simulations were controlled and monitored by KWA throughout the duration of the testing. Product level, volume, temperature and leak rates were recorded by KWA throughout the evaluation.

Leak simulations were conducted by utilizing a variable valve precision flow meter connected to a small diameter pipeline located 10-feet off the bottom of the tank. The head pressure from the fuel allowed for fuel to flow at a constant rate through the flow meter during the duration each test. Nominal leak rates of zero gph, 0.25-gph, 0.50-gph and 1.00-gph were randomly induced during the evaluation. Leak rates were calculated from the total mass of product removed from the tank during the test time and the density of the product. The mass of the product removed was measured by flowing product through the precision flow meter into a 55-gallon barrel that was placed onto a precision

scale to measure the mass of the product. Leak rates were also verified by KWA staff periodically during each test by measuring the flow rate with a graduated cylinder and a stop watch. Product level, temperature, and specific gravity readings were recorded throughout the evaluation from the automatic tank gauge (ATG) located at the upper tunnel of Tank 9.

Table 3 - Test Schedule for GSI 3 LDS Evaluation

Task Name	Scheduled Duration	Nominal Induced Leak Rate
Level Change	level drop down to 189' 10"	
Product Settling Time	96 hours	
Block 1: Test 1 Trial Run Setup		
Block 1: Test 1 Trial Run	48 hours	No Leak
Block 1: Test 2 Setup		
Block 1: Test 2	48 hours	LR4
Block 1: Test 3 Setup		
Block 1: Test 3	48 hours	LR3
Block 1: Test 4 Setup		
Block 1: Test 4	48 hours	LR2
Block 1: Test 5 Setup		
Block 1: Test 5	48 hours	LR1
Level Change	level drop down to 159' 11"	
Product Settling Time	96 hours	
Block 2: Retest 6 Trial Run Setup		
Block 2: Retest 6 Trial Run	48 hours	No Leak
Block 2: Retest 7 Setup		
Block 2: Retest 7	48 hours	LR3
Block 2: Retest 8 Setup		
Block 2: Retest 8	48 hours	LR2
Block 2: Test 9 Setup		
Block 2: Test 9	48 hours	LR1
Block 2: Test 10 Setup		
Block 2: Test 10	48 hours	LR4
Level Change	level drop down to 125' 0"	
Product Settling Time	96 hours	
Block 3: Test 11 Trial Run Setup		
Block 3: Test 11 Trial Run	48 hours	No Leak
Block 3: Test 12 Setup		
Block 3: Test 12	48 hours	LR2
Block 3: Test 13 Setup		
Block 3: Test 13	48 hours	LR4
Block 3: Test 14 Setup		
Block 3: Test 14	48 hours	LR3
Block 3: Test 15 Setup		
Block 3: Test 15	48 hours	LR1

LR1: 0-gph, LR2: 0.25-gph nominal, LR3: 0.5-gph nominal, LR4:1.0-gph nominal

4.0 DESCRIPTION OF THE GSI 3 LDS

The GSI 3 LDS is a mass-based system which includes a currently-installed liquid probe and a temporary vapor probe installed for evaluation testing; these probes contain pressure and temperature sensors. The sensors provide data, logged continuously at set intervals, to a local computer for computation of leak rate analyzed using proprietary software. The GSI 3 LDS includes mathematical model B, applied to data gathered from the liquid probe and the vapor probe.

5.0 TEST RESULTS AND DISCUSSION

5.1 GSI 3 Leak Detection System Results

Using the data in table 2, the mean difference between the GSI 3 LDS measured leak rates and the induced leak rates was 0.055-gph, with the positive sign indicating that on the average, the GSI 3 LDS measured leak rates were larger than the induced leak rates. The standard deviation of these differences was 0.289-gph. A t-statistic was calculated to test whether the mean difference was statistically significantly different from zero. A mean difference that was significantly different from zero would represent a bias in estimating the leak rate by that method. The calculated value of the t-statistic was 0.654 (with 11 degrees of freedom). The two-sided significance level (sometimes referred to as the P-value) was 0.526, or 52.6%, showing that the difference was not significantly different from zero at the 5% level. Thus, there was no significant bias in the method.

Table 2 contains the data from the GSI 3 LDS tests. For each of the 12 tests, the table contains the test number, the block and test name, the vendor's measured leak rate in gallons per hour (gph), the leak rate induced by removing product from the tank, collecting and measuring it in gph, and the difference between the measured and induced leak rates, found by subtracting the induced leak rate from the measured leak rate.

Table 5 - GSI 3 LDS Results

Test Number	Block and Test Name	GSI 3 LDS Method Result (gph)	Induced Leak (gph)	Difference (gph)
1	Block 1, Test 2	0.640	1.035	-0.395
2	Block 1, Test 3	0.360	0.446	-0.086
3	Block 1, Test 4	0.611	0.216	0.395
4	Block 1, Test 5	-0.135	0	-0.135
5	Block 2, Retest 7	0.466	0.628	-0.162
6	Block 2, Retest 8	0.511	0.307	0.204
7	Block 2, Test 9	-0.015	0	-0.015
8	Block 2, Test 10	1.206	1.017	0.189
9	Block 3 Test12	-0.108	0.255	-0.363
10	Block 3 Test 13	1.472	0.994	0.478
11	Block 3 Test 14	0.817	0.596	0.221
12	Block 3 Test 15	0.324	0	0.324

There were two evaluation tests that were re-run during Block 2 due to the uncertainty of the tightness of a valve from the transfer pipeline. The new evaluation tests are labeled as Retest 7 and Retest 8.

The results can be used to calculate a threshold value for determining whether a measured leak rate is significantly different from zero, indicating a potential leak, or is only minimally different from zero, indicating only measurement error. A two-sided test analysis approach has been used in this evaluation, meaning that the method would test for liquid incursion into the tank as well as for a leak or loss of product from the tank.

When there is no leak, it is possible that a leak detection system might produce a negative estimate, indicating an inflow into the tank. Such a finding could indicate a leak, if, for example, part of the tank was below the water table, which might produce an inward pressure at some points in the tank. Some leak detection methods may guard against that possibility.

Considering this, a two-sided threshold was used for this evaluation. This is calculated by using a two-sided t-value (with 11 degrees of freedom here) to multiply the standard deviation, with a leak being declared if the estimated leak rate fell outside the resulting interval. In this case, the t-value is 2.201 and the threshold is ±0.636. Then a leak would be declared if the measured leak rate were less than –0.636 or greater than +0.636. This would result in a 5% chance of error when the tank was tight. Note that the standard deviation is used in this calculation (not the standard error of the mean) because the standard deviation is an estimate of the error associated with a single leak rate measurement, whereas the standard error of the mean is the error associated with estimating the mean of several leak measurements (12 in this case). Generally, a tank test only measures a single leak rate.

5.2 <u>Test for the Effect of Product Level</u>

These tests were conducted in three blocks, corresponding to three different levels or depths of product. The data can also be used to test whether the different product levels affected the leak detection method significantly. To do this the induced leak rate was subtracted from the measured leak rate and the differences were analyzed using a one-way or one-factor analysis of variance (ANOVA). Table 2 indicates the blocks or different product levels where the evaluation tests were performed. For GSI 3 LDS, the mean differences were found: Block 1 averaged –0.055, Block 2 averaged 0.054, and Block 3 averaged 0.165. The analysis of variance gave an F-statistic of 0.531 with 2 and 9 degrees of freedom, corresponding to a P-value of 0.605, which was not statistically significant at the 5% level. The critical value for F was 4.256. Thus, it is reasonable to conclude that the different product depths did not affect the GSI 3 LDS method.

Table 3 is a summary of the findings of the data analysis.

Table 3 - Summary of the Test Results for the GSI 3 LDS

Required Test Time	48-hours
Required Product Level in Tank	Between 125-feet and 190-feet
Maximum Size of Tank (evaluation only applicable to Red Hill)	Red Hill Tanks with nominal volume of 12,500,000-gallons
Maximum Temperature Difference (between product delivered and product in the tank)	Not Evaluated
Required Product Settling Time After Delivery or Fueling Operations	Not Evaluated for product delivery, Minimum wait period of 168-hrs, after product level drop
Standard Deviation of the Test Data	0.289-gph
Threshold	0.636-gph
Bias (not statistically significant at 5% level)	0.055 (not significant)
Minimum Threshold for a 5% P_{FA}	0.636-gph
Minimum Detectable Leak Rate for 95% P_D (when the minimum threshold is used)	1.273-gph

5.3 Test Times

Each of the 12 tests conducted in this evaluation had a duration of exactly 48-hours. This test duration time was established in the evaluation test plan. Alternate test duration times were not evaluated.

5.4 Product Levels

For this evaluation, per the test plan, testing was conducted with tank product levels at 189-feet 10-inch, 159-feet 11-inch and 125-feet 0-inch. The results of this evaluation indicate that tank product levels at Red Hill between 125-feet and 190-feet nominal product level height are acceptable for conducting leak detection tests. Product level heights outside of this range were not evaluated.

5.5 Size of Tank

The volume of Tank 9 at Red Hill is nominally 12,500,000-gallons. For leak detection systems, the performance can be affected by the size and geometry of the tank. For most mass-based technologies, performance is related to the surface area of the fuel in the tank (but not the depth of the tank); for some systems, performance is a function of both volume and surface area. The GSI 3 LDS is a mass-based technology.

The evaluation test plan specifies that the results of this evaluation are applicable to the tanks at Red Hill. This is due to the test plan being developed specifically for this unique installation and the environment where the tanks are installed. The possibility of scaling the Red Hill evaluation test results was not evaluated.

5.6 Temperature Differences and Waiting Time After Product Deliveries and Drops

As part of the evaluation test plan, differences in product temperature were not evaluated. During the evaluation, after a product level drop, there was a minimum 168-hour wait period before the official first test on each block began.

6.0 CONCLUSIONS

The following conclusions and recommendations are based on the results of the testing described in this report.

1. For the GSI 3 LDS, the Probability of Detection (P_D) of a 1.273-gph leak (or water incursion) is 95.0% when the threshold is set at ±0.636-gph. The corresponding Probability of False Alarm (P_{FA}) is 5.0% when the threshold is set at ±0.636-gph.

2. The minimum test duration time evaluated for a leak detection test to be valid, is 48-hours.

3. The Red Hill tank must be between 125-feet and 190-feet nominal product level height before conducting a valid leak detection test.

4. As specified by the evaluation test plan, the results of this evaluation are valid only for the tanks with nominal volume of 12,500,000-gallons at the Red Hill Fuel Storage Complex. The installation and location of the fuel storage tanks at the Red Hill Fuel Storage Complex provide a very stable environment for leak detection that is not typically found at other fuel storage facilities. Therefore the results of this evaluation of the GSI 3 LDS should only be considered applicable to the fuel storage tanks at the Red Hill Fuel Storage Complex.

5. Product delivery was not a part of this evaluation, therefore, product settling time for conducting leak detection testing after product delivery was not determined.

6. Leak detection tests may be initiated 168-hours (minimum) following a product level drop, provided a minimum of 48-hours of quality data are collected and analyzed.

7. Scaling was not included in this evaluation. If scaling is to be considered at a facility other than the Red Hill Fuel Storage Complex, additional evaluation tests should be performed in order to verify the application of scaling the evaluation results. Several other factors may need to be considered including test duration times, tank size, tank installation/location, and product settling time after fuel transfers.

ATTACHMENT A

EPA Forms for the GSI 3 LDS

Results of U.S. EPA Standard Evaluation

Volumetric Tank Tightness Testing Method

This form tells whether the tank tightness testing method described below complies with the performance requirements of the federal underground storage tank regulation. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods." The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name	Gauging Systems, Incorporated		
Version number	GSI 3 LDS		
Vendor	Gauging Systems, Incorporated		
(street address)	910A Industrial Boulevard		
	Sugarland	Texas	77478
(phone)	(281) 980-3999		

Evaluation Results

This method, which declares a tank to be leaking when the measured leak rate exceeds the threshold of 0.636 gallon per hour, has a probability of false alarms [P(FA)] of 5 %.

The corresponding probability of detection [P(D)] of a 0.500 gallon per hour leak is 32.44 %.

Therefore, this method ☐ does **X** does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency (0.500 gallon per hour at P(D) of 95% and P(FA) of 5%).

Test Conditions During Evaluation

The evaluation testing was conducted in a 12,500,000 gallon **X** steel ☐ fiberglass tank that was 100 foot in diameter and 250 foot tall.

The tests were conducted with the tank product level between 125 and 190 foot.

The temperature difference between product added to fill the tank and product already in the tank ranged from not evaluated °F to not evaluated °F, with a standard deviation of not evaluated °F.

The product used in the evaluation was JP-5 .

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for using the method are followed.
- The tank is no larger than _not included in this evaluation_ gallons.
- The tank contains a product identified on the method description form.
- The tank product level height is between 125 and 190 foot.
- The waiting time after adding any substantial amount of product to the tank is at least _not included in this evaluation_ hours.
- The temperature of the added product does not differ more than _not included in this evaluation_ degrees Fahrenheit from that already in the tank.
- The waiting time between the end of "topping off," if any, and the start of the test data collection is at least _not included in this evaluation_ hours.
- The total data collection time for the test is at least _48_ hours.
- This method **X** can ☐ cannot be used if the ground-water level is above the bottom of the tank.
- Other limitations specified by the vendor or determined during testing: After a fuel drop, there was a minimum 168-hour product settling time before any test began during the evaluation.

> **Safety disclaimer: This test procedure only addresses the issue of the Leak Detection Method's ability to detect leaks. It does not test the equipment for safety hazards.**

Certification of Results

I certify that the Leak Detection Method was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation.

Craig D. Wilcox President
(printed name)

Ken Wilcox Associates, Inc.
(organization performing evaluation)

(signature)

Grain Valley, Missouri 64029
(city, state, zip)

Jairus Flora, Jr., Ph.D.
(printed name)

June 20, 2018
(date)

(signature)

(816) 443-2494

Results of the Evaluation of GSI 4 Leak Detection Method On Red Hill Tank 9 at Joint Base Pearl Harbor-Hickam

Final Report

PREPARED FOR:

Michael Baker International

June 20, 2018

Ken Wilcox Associates, Inc**.**

1125 Valley Ridge Drive, Grain Valley, MO 64029, USA

Phone (816) 443-2494, Fax (816) 443-2495

E-mail cwilcox@kwaleak.com, Web http://www.kwaleak.com

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PREFACE

This report was prepared by Ken Wilcox Associates, Inc., for Michael Baker International. The purpose of this report is to present the results of the testing of the Gauging Systems, Inc. (GSI), Leak Detection System (LDS) number 4, identified as the GSI 4 LDS, on the Bulk Field-Constructed Tank 9 at the Red Hill Bulk Fuel Storage Facility, located at Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The testing was conducted in a tank 250-feet tall with a diameter of 100-feet with a nominal capacity of 12,500,000-gallons. All evaluation testing was conducted at the Red Hill Bulk Fuel Storage Facility at JBPHH. The leak simulations, data collection, data analysis, and reporting were conducted by Ken Wilcox Associates, Inc. This report was prepared by Craig D. Wilcox and Jairus D. Flora, Jr., Ph.D.

This report presents the results of testing of the GSI 4 Leak Detection System (LDS) evaluated at Red Hill.

KEN WILCOX ASSOCIATES, INC.

Craig D. Wilcox, President

June 20, 2018

Jairus D. Flora, Jr., Ph.D.

June 20, 2018

1.0 INTRODUCTION

Gauging Systems, Incorporated (GSI) developed the GSI 4 Leak Detection System (LDS) specifically for this project. Ken Wilcox Associates, Inc. (KWA) conducted an independent third-party evaluation of this leak detection system following a procedure that meets the requirements of the evaluation protocol drafted specifically for this project. Testing was conducted in a nominal 12,500,000-gallon underground bulk, field-constructed tank with a diameter of approximately 100-feet and a height of 250-feet.

The United States Environmental Protection Agency (EPA) requires that all tank testing equipment be tested to define the equipment's performance parameters. The equipment must be capable of detecting leaks at a rate defined by the regulating agencies with a probability of detection of 95% or greater. At the same time, the method must not produce false alarms (declaring a leak when the tank is tight) more than 5% of the time.

The evaluation test plan was developed based on the existing protocol, "Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods", United States EPA, March 1990. The evaluation test plan was developed, reviewed and finalized over communications with the project stakeholders. The EPA protocol specified that a minimum of 12 tests would be conducted for the bulk field-constructed tank leak detection evaluation. The evaluation test plan included testing in three different test blocks, at three different product levels. There were a total of 4 evaluation tests performed for each block, with Block 1 product level at 189-feet 10-inches; Block 2 at 159-feet 11-inches; and Block 3 at 125-feet 0-inches.

The evaluation test plan specified that leak rates should be induced equivalent to multiples of the target threshold: zero, half the target threshold, the target threshold, and two times the target threshold. The target threshold was 0.50 gallons per hour (gph). The 4 nominal induced leak rates that were used during the evaluation were 0.00-gph, 0.25-gph, 0.50-gph and 1.00-gph. The induced leak rates were kept blind to the vendor during the entire evaluation. The GSI 4 LDS leak rates were reported to Michael Baker International within 24 hours after each test was concluded.

2.0 DESCRIPTION OF TESTING LOCATION

The GSI 4 LDS was tested at the Red Hill Bulk Fuel Storage Facility, on Tank 9 Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The Red Hill Bulk Fuel Storage Facility includes a number of bulk field-constructed tanks and a bulk pipeline system at JBPHH. The test tank was a field-constructed tank with a nominal capacity of 12,500,000-gallons. The test tank nominal dimensions are 250-feet tall with a diameter of 100-feet. Tank 9 is a field constructed vertical underground storage tank, shaped like a capsule, with domed top and domed bottom, that was constructed inside the mountain at Red Hill.

In order to lower the product level in the test tank, fuel transfers were conducted through a bulk pipeline that supplies fuel to JBPHH.

The GSI 4 LDS equipment was installed through a manway at the top of the test tank. The GSI 4 LDS main console was located in the upper tunnel next to Tank 9. The KWA evaluation equipment was located in the lower tunnel with the leak simulation equipment installed on a small diameter pipeline manifold that was attached to the bottom of the tank. The test tank was nominally made available to KWA staff 24-hours a day for the duration of the evaluation. Leak simulations were induced by KWA staff, Craig Wilcox, who was present for the duration of the evaluation.

3.0 OVERVIEW OF EVALUATION

Table 1 contains the test schedule, test duration, product level and the order the leaks were induced during the evaluation. Table 2 summarizes the GSI 4 LDS reported leak rate, the induced leak rate and the difference between the reported and induced leak rate that were achieved during the evaluation.

The GSI 4 LDS was installed in the test tank by the vendor. Testing was carried out using the vendor's normal test routine. Leak simulations were induced through a 1-inch diameter pipeline that was connected directly into Tank 9 at approximately 10-feet from the bottom. All leaks induced were kept blind to the vendor for the duration of the evaluation. The leak rate reported by the GSI 4 LDS was compared to the actual volume of product removed from the tank. A statistical analysis of the data was used to determine the performance characteristics of the test method.

In this report, leak rates are reported as positive numbers—the rate in gallons per hour of product removed from the tank. Any result reported as a negative number is considered as being reported as a liquid inflow into the tank. The leak rates were induced or simulated by removing product from the tank at various constant rates. There were twelve (12) tests conducted. Nine of the tests had leaks simulated and three (3) tests used a zero leak rate, representing a tight or non-leaking tank. Tests were conducted in three blocks with each block, containing 4 official evaluation tests, corresponding to a different level or depth of product in the tank. Block 1 was 189-feet 10-inches; Block 2 was 159-feet 11-inches; and Block 3 was 125-feet 0-inches. There was a product level drop performed before each block of tests began. This was to verify the performance of the leak detection system at different product levels. After a product level drop, there was a minimum 96-hour product settling time to let the product stabilize. After the 96-hour product settling time, the vendor was given a 24-hour setup period to verify that their system was functioning properly. After the 24-hour setup period, the vendor performed a 48-hour preliminary test to ensure the tank was tight before the first official evaluation test began for each block. During this preliminary 48-hour test, the vendor was aware that the tank did not have a leak induced, so these preliminary results are not considered

during the statistical analysis of the results. After the preliminary test was completed, the first official tests were performed at approximately 168-hours after the fuel drop was completed.

During the evaluation, the vendor reported the estimated leak rate within 24-hours of the completion of each test. For analysis, the induced leak rate was subtracted from the reported leak rate and these differences were analyzed. The method of analysis used was that found in the quantitative EPA leak detection protocols. The EPA procedure first estimates the probability of false alarm and the probability of detecting a leak rate of the size specified in the EPA regulations for the particular type of leak detection. The requirement for an annual tank tightness test for release detection of field-constructed tanks is 0.5-gph leak rate. The analysis estimates the threshold or criterion for declaring a leak that would give a 5% probability of false alarm (PFA). The analysis also determines the corresponding leak rate that is detectable with a probability of detection (PD) of at least 95%. See specifically Section 7.5.1 of the "Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods", United States EPA, March 1990, which gives the procedure for calculating a threshold for determining a significant leak rate with a 5% PFA and Section 7.5.2, which gives the procedure for determining the 95% MDL.

Test times were 48-hours (two days) for each of the 12 tests. Leak simulations were controlled and monitored by KWA throughout the duration of the testing. Product level, volume, temperature and leak rates were recorded by KWA throughout the evaluation.

Leak simulations were conducted by utilizing a variable valve precision flow meter connected to a small diameter pipeline located 10-feet off the bottom of the tank. The head pressure from the fuel allowed for fuel to flow at a constant rate through the flow meter during the duration each test. Nominal leak rates of zero gph, 0.25-gph, 0.50-gph and 1.00-gph were randomly induced during the evaluation. Leak rates were calculated from the total mass of product removed from the tank during the test time and the density of the product. The mass of the product removed was measured by flowing product through the precision flow meter into a 55-gallon barrel that was placed onto a precision

scale to measure the mass of the product. Leak rates were also verified by KWA staff periodically during each test by measuring the flow rate with a graduated cylinder and a stop watch. Product level, temperature, and specific gravity readings were recorded throughout the evaluation from the automatic tank gauge (ATG) located at the upper tunnel of Tank 9.

Table 3 - Test Schedule for GSI 4 LDS Evaluation

Task Name	Scheduled Duration	Nominal Induced Leak Rate
Level Change	level drop down to 189' 10"	
Product Settling Time	96 hours	
Block 1: Test 1 Trial Run Setup		
Block 1: Test 1 Trial Run	48 hours	No Leak
Block 1: Test 2 Setup		
Block 1: Test 2	48 hours	LR4
Block 1: Test 3 Setup		
Block 1: Test 3	48 hours	LR3
Block 1: Test 4 Setup		
Block 1: Test 4	48 hours	LR2
Block 1: Test 5 Setup		
Block 1: Test 5	48 hours	LR1
Level Change	level drop down to 159' 11"	
Product Settling Time	96 hours	
Block 2: Retest 6 Trial Run Setup		
Block 2: Retest 6 Trial Run	48 hours	No Leak
Block 2: Retest 7 Setup		
Block 2: Retest 7	48 hours	LR3
Block 2: Retest 8 Setup		
Block 2: Retest 8	48 hours	LR2
Block 2: Test 9 Setup		
Block 2: Test 9	48 hours	LR1
Block 2: Test 10 Setup		
Block 2: Test 10	48 hours	LR4
Level Change	level drop down to 125' 0"	
Product Settling Time	96 hours	
Block 3: Test 11 Trial Run Setup		
Block 3: Test 11 Trial Run	48 hours	No Leak
Block 3: Test 12 Setup		
Block 3: Test 12	48 hours	LR2
Block 3: Test 13 Setup		
Block 3: Test 13	48 hours	LR4
Block 3: Test 14 Setup		
Block 3: Test 14	48 hours	LR3
Block 3: Test 15 Setup		
Block 3: Test 15	48 hours	LR1

LR1: 0-gph, LR2: 0.25-gph nominal, LR3: 0.5-gph nominal, LR4:1.0-gph nominal

4.0 DESCRIPTION OF THE GSI 4 LDS

The GSI 4 LDS is a mass-based system which includes a currently-installed liquid probe containing pressure and temperature sensors. The sensors provide data, logged continuously at set intervals, to a local computer for computation of leak rate analyzed using proprietary software. The GSI 4 LDS includes mathematical model B, applied to data gathered from the liquid probe.

5.0 TEST RESULTS AND DISCUSSION

5.1 GSI 4 Leak Detection System Results

Using the data in table 2, the mean difference between the GSI 4 LDS measured leak rates and the induced leak rates was 0.051-gph, with the positive sign indicating that on the average, the GSI 4 LDS measured leak rates were larger than the induced leak rates. The standard deviation of these differences was 0.256-gph. A t-statistic was calculated to test whether the mean difference was statistically significantly different from zero. A mean difference that was significantly different from zero would represent a bias in estimating the leak rate by that method. The calculated value of the t-statistic was 0.689 (with 11 degrees of freedom). The two-sided significance level (sometimes referred to as the P-value) was 0.505, or 50.5%, showing that the difference was not significantly different from zero at the 5% level. Thus, there was no significant bias in the method.

Table 2 contains the data from the GSI 4 LDS tests. For each of the 12 tests, the table contains the test number, the block and test name, the vendor's measured leak rate in gallons per hour (gph), the leak rate induced by removing product from the tank, collecting and measuring it in gph, and the difference between the measured and induced leak rates, found by subtracting the induced leak rate from the measured leak rate.

Table 5 - GSI 4 LDS Results

Test Number	Block and Test Name	GSI 4 LDS Method Result (gph)	Induced Leak (gph)	Difference (gph)
1	Block 1, Test 2	0.619	1.035	-0.416
2	Block 1, Test 3	0.396	0.446	-0.050
3	Block 1, Test 4	0.569	0.216	0.353
4	Block 1, Test 5	-0.075	0	-0.075
5	Block 2, Retest 7	0.469	0.628	-0.159
6	Block 2, Retest 8	0.369	0.307	0.062
7	Block 2, Test 9	0.116	0	0.116
8	Block 2, Test 10	1.227	1.017	0.210
9	Block 3 Test12	-0.007	0.255	-0.262
10	Block 3 Test 13	1.178	0.994	0.184
11	Block 3 Test 14	1.076	0.596	0.480
12	Block 3 Test 15	0.168	0	0.168

There were two evaluation tests that were re-run during Block 2 due to the uncertainty of the tightness of a valve from the transfer pipeline. The new evaluation tests are labeled as Retest 7 and Retest 8.

The results can be used to calculate a threshold value for determining whether a measured leak rate is significantly different from zero, indicating a potential leak, or is only minimally different from zero, indicating only measurement error. A two-sided test analysis approach has been used in this evaluation, meaning that the method would test for liquid incursion into the tank as well as for a leak or loss of product from the tank.

When there is no leak, it is possible that a leak detection system might produce a negative estimate, indicating an inflow into the tank. Such a finding could indicate a leak, if, for example, part of the tank was below the water table, which might produce an inward pressure at some points in the tank. Some leak detection methods may guard against that possibility.

Considering this, a two-sided threshold was used for this evaluation. This is calculated by using a two-sided t-value (with 11 degrees of freedom here) to multiply the standard deviation, with a leak being declared if the estimated leak rate fell outside the resulting interval. In this case, the t-value is 2.201 and the threshold is ±0.564. Then a leak would be declared if the measured leak rate were less than –0.564 or greater than +0.564. This would result in a 5% chance of error when the tank was tight. Note that the standard deviation is used in this calculation (not the standard error of the mean) because the standard deviation is an estimate of the error associated with a single leak rate measurement, whereas the standard error of the mean is the error associated with estimating the mean of several leak measurements (12 in this case). Generally, a tank test only measures a single leak rate.

5.2 Test for the Effect of Product Level

These tests were conducted in three blocks, corresponding to three different levels or depths of product. The data can also be used to test whether the different product levels affected the leak detection method significantly. To do this the induced leak rate was subtracted from the measured leak rate and the differences were analyzed using a one-way or one-factor analysis of variance (ANOVA). Table 2 indicates the blocks or different product levels where the evaluation tests were performed. For GSI 4 LDS, the mean differences were found: Block 1 averaged –0.047, Block 2 averaged 0.057, and Block 3 averaged 0.143. The analysis of variance gave an F-statistic of 0.499 with 2 and 9 degrees of freedom, corresponding to a P-value of 0.702, which was not statistically significant at the 5% level. The critical value for F was 4.256. Thus, it is reasonable to conclude that the different product depths did not affect the GSI 4 LDS method.

Table 3 is a summary of the findings of the data analysis.

Table 3 - Summary of the Test Results for the GSI 4 LDS

Required Test Time	48-hours
Required Product Level in Tank	Between 125-feet and 190-feet
Maximum Size of Tank (evaluation only applicable to Red Hill)	Red Hill Tanks with nominal volume of 12,500,000-gallons
Maximum Temperature Difference (between product delivered and product in the tank)	Not Evaluated
Required Product Settling Time After Delivery or Fueling Operations	Not Evaluated for product delivery, Minimum wait period of 168-hrs, after product level drop
Standard Deviation of the Test Data	0.256-gph
Threshold	0.564-gph
Bias (not statistically significant at 5% level)	0.051 (not significant)
Minimum Threshold for a 5% P_{FA}	0.564-gph
Minimum Detectable Leak Rate for 95% P_D (when the minimum threshold is used)	1.128 -gph

5.3 Test Times

Each of the 12 tests conducted in this evaluation had a duration of exactly 48-hours. This test duration time was established in the evaluation test plan. Alternate test duration times were not evaluated.

5.4 Product Levels

For this evaluation, per the test plan, testing was conducted with tank product levels at 189-feet 10-inch, 159-feet 11-inch and 125-feet 0-inch. The results of this evaluation indicate that tank product levels at Red Hill between 125-feet and 190-feet nominal product level height are acceptable for conducting leak detection tests. Product level heights outside of this range were not evaluated.

5.5 Size of Tank

The volume of Tank 9 at Red Hill is nominally 12,500,000-gallons. For leak detection systems, the performance can be affected by the size and geometry of the tank. For most mass-based technologies, performance is related to the surface area of the fuel in the tank (but not the depth of the tank); for some systems, performance is a function of both volume and surface area. The GSI 4 LDS is a mass-based technology.

The evaluation test plan specifies that the results of this evaluation are applicable to the tanks at Red Hill. This is due to the test plan being developed specifically for this unique installation and the environment where the tanks are installed. The possibility of scaling the Red Hill evaluation test results was not evaluated.

5.6 Temperature Differences and Waiting Time After Product Deliveries and Drops

As part of the evaluation test plan, differences in product temperature were not evaluated. During the evaluation, after a product level drop, there was a minimum 168-hour wait period before the official first test on each block began.

6.0 CONCLUSIONS

The following conclusions and recommendations are based on the results of the testing described in this report.

1. For the GSI 4 LDS, the Probability of Detection (P_D) of a 1.128-gph leak (or water incursion) is 95.0% when the threshold is set at ±0.564-gph. The corresponding Probability of False Alarm (P_{FA}) is 5.0% when the threshold is set at ±0.564-gph.

2. The minimum test duration time evaluated for a leak detection test to be valid, is 48-hours.

3. The Red Hill tank must be between 125-feet and 190-feet nominal product level height before conducting a valid leak detection test.

4. As specified by the evaluation test plan, the results of this evaluation are valid only for the tanks with nominal volume of 12,500,000-gallons at the Red Hill Fuel Storage Complex. The installation and location of the fuel storage tanks at the Red Hill Fuel Storage Complex provide a very stable environment for leak detection that is not typically found at other fuel storage facilities. Therefore the results of this evaluation of the GSI 4 LDS should only be considered applicable to the fuel storage tanks at the Red Hill Fuel Storage Complex.

5. Product delivery was not a part of this evaluation, therefore, product settling time for conducting leak detection testing after product delivery was not determined.

6. Leak detection tests may be initiated 168-hours (minimum) following a product level drop, provided a minimum of 48-hours of quality data are collected and analyzed.

7. Scaling was not included in this evaluation. If scaling is to be considered at a facility other than the Red Hill Fuel Storage Complex, additional evaluation tests should be performed in order to verify the application of scaling the evaluation results. Several other factors may need to be considered including test duration times, tank size, tank installation/location, and product settling time after fuel transfers.

ATTACHMENT A

EPA Forms for the GSI 4 LDS

Results of U.S. EPA Standard Evaluation

Volumetric Tank Tightness Testing Method

This form tells whether the tank tightness testing method described below complies with the performance requirements of the federal underground storage tank regulation. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods." The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name	Gauging Systems, Incorporated		
Version number	GSI 4 LDS		
Vendor	Gauging Systems, Incorporated		
(street address)	910A Industrial Boulevard		
	Sugarland	Texas	77478
(phone)	(281) 980-3999		

Evaluation Results

This method, which declares a tank to be leaking when the measured leak rate exceeds the threshold of 0.564 gallon per hour, has a probability of false alarms [P(FA)] of 5 %.

The corresponding probability of detection [P(D)] of a 0.500 gallon per hour leak is 40.43 %.

Therefore, this method ☐ does **X** does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency (0.500 gallon per hour at P(D) of 95% and P(FA) of 5%).

Test Conditions During Evaluation

The evaluation testing was conducted in a 12,500,000 gallon **X** steel ☐ fiberglass tank that was 100 foot in diameter and 250 foot tall.

The tests were conducted with the tank product level between 125 and 190 foot.

The temperature difference between product added to fill the tank and product already in the tank ranged from not evaluated °F to not evaluated °F, with a standard deviation of not evaluated °F.

The product used in the evaluation was JP-5 .

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for using the method are followed.
- The tank is no larger than not included in this evaluation gallons.
- The tank contains a product identified on the method description form.
- The tank product level height is between 125 and 190 foot.
- The waiting time after adding any substantial amount of product to the tank is at least not included in this evaluation hours.
- The temperature of the added product does not differ more than not included in this evaluation degrees Fahrenheit from that already in the tank.
- The waiting time between the end of "topping off," if any, and the start of the test data collection is at least not included in this evaluation hours.
- The total data collection time for the test is at least 48 hours.
- This method **X** can ☐ cannot be used if the ground-water level is above the bottom of the tank.
- Other limitations specified by the vendor or determined during testing: After a fuel drop, there was a minimum 168-hour product settling time before any test began during the evaluation.

> **Safety disclaimer: This test procedure only addresses the issue of the Leak Detection Method's ability to detect leaks. It does not test the equipment for safety hazards.**

Certification of Results

I certify that the Leak Detection Method was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation.

Craig D. Wilcox President
(printed name)

(signature)

Ken Wilcox Associates, Inc.
(organization performing evaluation)

Grain Valley, Missouri 64029
(city, state, zip)

Jairus Flora, Jr., Ph.D.
(printed name)

(signature)

June 20, 2018
(date)

(816) 443-2494

Results of the Evaluation of MTC Leak Detection Method On Red Hill Tank 9 at Joint Base Pearl Harbor-Hickam

Final Report

PREPARED FOR:

Michael Baker International

June 20, 2018

Ken Wilcox Associates, Inc.

1125 Valley Ridge Drive, Grain Valley, MO 64029, USA

Phone (816) 443-2494, Fax (816) 443-2495

E-mail cwilcox@kwaleak.com, Web http://www.kwaleak.com

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PREFACE

This report was prepared by Ken Wilcox Associates, Inc., for Michael Baker International. The purpose of this report is to present the results of the testing of the Mass Technology Corporation (MTC), Leak Detection System (LDS), identified as the MTC LDS, on the Bulk Field-Constructed Tank 9 at the Red Hill Bulk Fuel Storage Facility, located at Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The testing was conducted in a tank 250-feet tall with a diameter of 100-feet with a nominal capacity of 12,500,000-gallons. All evaluation testing was conducted at the Red Hill Bulk Fuel Storage Facility at JBPHH. The leak simulations, data collection, data analysis, and reporting were conducted by Ken Wilcox Associates, Inc. This report was prepared by Craig D. Wilcox and Jairus D. Flora, Jr., Ph.D.

This report presents the results of testing of the MTC Leak Detection System (LDS) evaluated at Red Hill.

KEN WILCOX ASSOCIATES, INC.

Craig D. Wilcox, President

June 20, 2018

Jairus D. Flora, Jr., Ph.D.

June 20, 2018

1.0 INTRODUCTION

Mass Technology Corporation (MTC) developed the MTC Leak Detection System (LDS) specifically for this project. Ken Wilcox Associates, Inc. (KWA) conducted an independent third-party evaluation of this leak detection system following a procedure that meets the requirements of the evaluation protocol drafted specifically for this project. Testing was conducted in a nominal 12,500,000-gallon underground bulk, field-constructed tank with a diameter of approximately 100-feet and a height of 250-feet.

The United States Environmental Protection Agency (EPA) requires that all tank testing equipment be tested to define the equipment's performance parameters. The equipment must be capable of detecting leaks at a rate defined by the regulating agencies with a probability of detection of 95% or greater. At the same time, the method must not produce false alarms (declaring a leak when the tank is tight) more than 5% of the time.

The evaluation test plan was developed based on the existing protocol, "Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods", United States EPA, March 1990. The evaluation test plan was developed, reviewed and finalized over communications with the project stakeholders. The EPA protocol specified that a minimum of 12 tests would be conducted for the bulk field-constructed tank leak detection evaluation. The evaluation test plan included testing in three different test blocks, at three different product levels. There were a total of 4 evaluation tests performed for each block, with Block 1 product level at 189-feet 10-inches; Block 2 at 159-feet 11-inches; and Block 3 at 125-feet 0-inches.

The evaluation test plan specified that leak rates should be induced equivalent to multiples of the target threshold: zero, half the target threshold, the target threshold, and two times the target threshold. The target threshold was 0.50 gallons per hour (gph). The 4 nominal induced leak rates that were used during the evaluation were 0.00-gph, 0.25-gph, 0.50-gph and 1.00-gph. The induced leak rates were kept blind to the vendor during the entire evaluation. The MTC LDS leak rates were reported to Michael Baker International within 24 hours after each test was concluded.

2.0 DESCRIPTION OF TESTING LOCATION

The MTC LDS was tested at the Red Hill Bulk Fuel Storage Facility, on Tank 9 Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The Red Hill Bulk Fuel Storage Facility includes a number of bulk field-constructed tanks and a bulk pipeline system at JBPHH. The test tank was a field-constructed tank with a nominal capacity of 12,500,000-gallons. The test tank nominal dimensions are 250-feet tall with a diameter of 100-feet. Tank 9 is a field constructed vertical underground storage tank, shaped like a capsule, with domed top and domed bottom, that was constructed inside the mountain at Red Hill.

In order to lower the product level in the test tank, fuel transfers were conducted through a bulk pipeline that supplies fuel to JBPHH.

The MTC LDS equipment was installed through a manway at the top of the test tank. The MTC LDS main console was located in the upper tunnel next to Tank 9. The KWA evaluation equipment was located in the lower tunnel with the leak simulation equipment installed on a small diameter pipeline manifold that was attached to the bottom of the tank. The test tank was nominally made available to KWA staff 24-hours a day for the duration of the evaluation. Leak simulations were induced by KWA staff, Craig Wilcox, who was present for the duration of the evaluation.

3.0 OVERVIEW OF EVALUATION

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Block 3: Test 14	48 hours	LR3
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LR1: 0-gph, LR2: 0.25-gph nominal, LR3: 0.5-gph nominal, LR4:1.0-gph nominal

4.0 DESCRIPTION OF THE MTC LDS

The MTC LDS is a mass-based system which includes pressure and temperature sensors lowered into the tank through the tank manway. The sensors provide data, logged continuously at set intervals, to a local computer for computation of leak rate analyzed using proprietary software.

5.0 TEST RESULTS AND DISCUSSION

5.1 MTC Leak Detection System Results

Using the data in table 2, the mean difference between the MTC LDS measured leak rates and the induced leak rates was -0.018-gph, with the negative sign indicating that on the average, the MTC LDS measured leak rates were smaller than the induced leak rates. The standard deviation of these differences was 0.067-gph. A t-statistic was calculated to test whether the mean difference was statistically significantly different from zero. A mean difference that was significantly different from zero would represent a bias in estimating the leak rate by that method. The calculated value of the t-statistic was -0.9363 (with 11 degrees of freedom). The two-sided significance level (sometimes referred to as the P-value) was 0.369, or 36.9%, showing that the difference was not significantly different from zero at the 5% level. Thus, there was no significant bias in the method.

Table 2 contains the data from the MTC LDS tests. For each of the 12 tests, the table contains the test number, the block and test name, the vendor's measured leak rate in gallons per hour (gph), the leak rate induced by removing product from the tank, collecting and measuring it in gph, and the difference between the measured and induced leak rates, found by subtracting the induced leak rate from the measured leak rate.

Table 5 - MTC LDS Results

Test Number	Block and Test Name	MTC LDS Method Result (gph)	Induced Leak (gph)	Difference (gph)
1	Block 1, Test 2	0.845	1.035	-0.190
2	Block 1, Test 3	0.464	0.446	0.018
3	Block 1, Test 4	0.182	0.216	-0.034
4	Block 1, Test 5	-0.009	0	-0.009
5	Block 2, Retest 7	0.664	0.628	0.036
6	Block 2, Retest 8	0.291	0.307	-0.016
7	Block 2, Test 9	0.054	0	0.054
8	Block 2, Test 10	1.054	1.017	0.037
9	Block 3 Test12	0.254	0.255	-0.001
10	Block 3 Test 13	0.973	0.994	-0.021
11	Block 3 Test 14	0.501	0.596	-0.095
12	Block 3 Test 15	0.004	0	0.004

There were two evaluation tests that were re-run during Block 2 due to the uncertainty of the tightness of a valve from the transfer pipeline. The new evaluation tests are labeled as Retest 7 and Retest 8.

The results can be used to calculate a threshold value for determining whether a measured leak rate is significantly different from zero, indicating a potential leak, or is only minimally different from zero, indicating only measurement error. A two-sided test analysis approach has been used in this evaluation, meaning that the method would test for liquid incursion into the tank as well as for a leak or loss of product from the tank.

When there is no leak, it is possible that a leak detection system might produce a negative estimate, indicating an inflow into the tank. Such a finding could indicate a leak, if, for example, part of the tank was below the water table, which might produce an inward pressure at some points in the tank. Some leak detection methods may guard against that possibility.

Considering this, a two-sided threshold was used for this evaluation. This is calculated by using a two-sided t-value (with 11 degrees of freedom here) to multiply the standard deviation, with a leak being declared if the estimated leak rate fell outside the resulting interval. In this case, the t-value is 2.201 and the threshold is ±0.147. Then a leak would be declared if the measured leak rate were less than –0.147 or greater than +0.147. This would result in a 5% chance of error when the tank was tight. Note that the standard deviation is used in this calculation (not the standard error of the mean) because the standard deviation is an estimate of the error associated with a single leak rate measurement, whereas the standard error of the mean is the error associated with estimating the mean of several leak measurements (12 in this case). Generally, a tank test only measures a single leak rate.

5.2 Test for the Effect of Product Level

These tests were conducted in three blocks, corresponding to three different levels or depths of product. The data can also be used to test whether the different product levels affected the leak detection method significantly. To do this the induced leak rate was subtracted from the measured leak rate and the differences were analyzed using a one-way or one-factor analysis of variance (ANOVA). Table 2 indicates the blocks or different product levels where the evaluation tests were performed. For MTC LDS, the mean differences were found: Block 1 averaged –0.054, Block 2 averaged 0.028, and Block 3 averaged -0.028. The analysis of variance gave an F-statistic of 1.78 with 2 and 9 degrees of freedom, corresponding to a P-value of 0.223, which was not statistically significant at the 5% level. The critical value for F was 4.256. Thus, it is reasonable to conclude that the different product depths did not affect the MTC LDS method.

Table 3 is a summary of the findings of the data analysis.

Table 3 - Summary of the Test Results for the MTC LDS

Required Test Time	48-hours
Required Product Level in Tank	Between 125-feet and 190-feet
Maximum Size of Tank (evaluation only applicable to Red Hill)	Red Hill Tanks with nominal volume of 12,500,000-gallons
Maximum Temperature Difference (between product delivered and product in the tank)	Not Evaluated
Required Product Settling Time After Delivery or Fueling Operations	Not Evaluated for product delivery, Minimum wait period of 168-hrs, after product level drop
Standard Deviation of the Test Data	0.067-gph
Threshold	0.147-gph
Bias (not statistically significant at 5% level)	-0.018 (not significant)
Minimum Threshold for a 5% P_{FA}	0.147-gph
Minimum Detectable Leak Rate for 95% P_D (when the minimum threshold is used)	0.294-gph

5.3 Test Times

Each of the 12 tests conducted in this evaluation had a duration of exactly 48-hours. This test duration time was established in the evaluation test plan. Alternate test duration times were not evaluated.

5.4 Product Levels

For this evaluation, per the test plan, testing was conducted with tank product levels at 189-feet 10-inch, 159-feet 11-inch and 125-feet 0-inch. The results of this evaluation indicate that tank product levels at Red Hill between 125-feet and 190-feet nominal product level height are acceptable for conducting leak detection tests. Product level heights outside of this range were not evaluated.

5.5 Size of Tank

The volume of Tank 9 at Red Hill is nominally 12,500,000-gallons. For leak detection systems, the performance can be affected by the size and geometry of the tank. For most mass-based technologies, performance is related to the surface area of the fuel in the tank (but not the depth of the tank); for some systems, performance is a function of both volume and surface area. The MTC LDS is a mass-based technology.

The evaluation test plan specifies that the results of this evaluation are applicable to the tanks at Red Hill. This is due to the test plan being developed specifically for this unique installation and the environment where the tanks are installed. The possibility of scaling the Red Hill evaluation test results was not evaluated.

5.6 Temperature Differences and Waiting Time After Product Deliveries and Drops

As part of the evaluation test plan, differences in product temperature were not evaluated. During the evaluation, after a product level drop, there was a minimum 168-hour wait period before the official first test on each block began.

6.0 CONCLUSIONS

The following conclusions and recommendations are based on the results of the testing described in this report.

1. For the MTC LDS, the Probability of Detection (P_D) of a 0.294-gph leak (or water incursion) is 95.0% when the threshold is set at ±0.147-gph. The corresponding Probability of False Alarm (P_{FA}) is 5.0% when the threshold is set at ±0.147-gph.

2. The minimum test duration time evaluated for a leak detection test to be valid, is 48-hours.

3. The Red Hill tank must be between 125-feet and 190-feet nominal product level height before conducting a valid leak detection test.

4. As specified by the evaluation test plan, the results of this evaluation are valid only for the tanks with nominal volume of 12,500,000-gallons at the Red Hill Fuel Storage Complex. The installation and location of the fuel storage tanks at the Red Hill Fuel Storage Complex provide a very stable environment for leak detection that is not typically found at other fuel storage facilities. Therefore the results of this evaluation of the MTC LDS should only be considered applicable to the fuel storage tanks at the Red Hill Fuel Storage Complex.

5. Product delivery was not a part of this evaluation, therefore, product settling time for conducting leak detection testing after product delivery was not determined.

6. Leak detection tests may be initiated 168-hours (minimum) following a product level drop, provided a minimum of 48-hours of quality data are collected and analyzed.

7. Scaling was not included in this evaluation. If scaling is to be considered at a facility other than the Red Hill Fuel Storage Complex, additional evaluation tests should be performed in order to verify the application of scaling the evaluation results. Several other factors may need to be considered including test duration times, tank size, tank installation/location, and product settling time after fuel transfers.

ATTACHMENT A

EPA Forms for the MTC LDS

Results of U.S. EPA Standard Evaluation

Volumetric Tank Tightness Testing Method

This form tells whether the tank tightness testing method described below complies with the performance requirements of the federal underground storage tank regulation. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods." The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name	Mass Technology Corporation
Version number	MTC LDS
Vendor	Mass Technology Corporation
(street address)	4302 State Highway 42
	Kilgore, Texas 75663
(phone)	(903) 986-3564

Evaluation Results

This method, which declares a tank to be leaking when the measured leak rate exceeds the threshold of 0.147 gallon per hour, has a probability of false alarms [P(FA)] of 5 %.

The corresponding probability of detection [P(D)] of a 0.500 gallon per hour leak is 99.98 %.

Therefore, this method X does ☐ does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency (0.500 gallon per hour at P(D) of 95% and P(FA) of 5%).

Test Conditions During Evaluation

The evaluation testing was conducted in a 12,500,000 gallon **X** steel ☐ fiberglass tank that was 100 foot in diameter and 250 foot tall.

The tests were conducted with the tank product level between 125 and 190 foot.

The temperature difference between product added to fill the tank and product already in the tank ranged from not evaluated °F to not evaluated °F, with a standard deviation of not evaluated °F.

The product used in the evaluation was JP-5 .

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for using the method are followed.
- The tank is no larger than _not included in this evaluation_ gallons.
- The tank contains a product identified on the method description form.
- The tank product level height is between 125 and 190 foot.
- The waiting time after adding any substantial amount of product to the tank is at least _not included in this evaluation_ hours.
- The temperature of the added product does not differ more than _not included in this evaluation_ degrees Fahrenheit from that already in the tank.
- The waiting time between the end of "topping off," if any, and the start of the test data collection is at least _not included in this evaluation_ hours.
- The total data collection time for the test is at least _48_ hours.
- This method **X** can ☐ cannot be used if the ground-water level is above the bottom of the tank.
- Other limitations specified by the vendor or determined during testing: After a fuel drop, there was a minimum 168-hour product settling time before any test began during the evaluation.

> **Safety disclaimer: This test procedure only addresses the issue of the Leak Detection Method's ability to detect leaks. It does not test the equipment for safety hazards.**

Certification of Results

I certify that the Leak Detection Method was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation.

Craig D. Wilcox President
(printed name)

Ken Wilcox Associates, Inc.
(organization performing evaluation)

[signature]
(signature)

Grain Valley, Missouri 64029
(city, state, zip)

Jairus Flora, Jr., Ph.D.
(printed name)

June 20, 2018
(date)

[signature]
(signature)

(816) 443-2494

Results of the Evaluation of VPSI Leak Detection Method On Red Hill Tank 9 at Joint Base Pearl Harbor-Hickam

Final Report

PREPARED FOR:

Michael Baker International

June 20, 2018

Ken Wilcox Associates, Inc.

1125 Valley Ridge Drive, Grain Valley, MO 64029, USA

Phone (816) 443-2494, Fax (816) 443-2495

E-mail cwilcox@kwaleak.com, Web http://www.kwaleak.com

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PREFACE

This report was prepared by Ken Wilcox Associates, Inc., for Michael Baker International. The purpose of this report is to present the results of the testing of the Vista Precision Solutions, Incorporated (VPSI), Leak Detection System (LDS), identified as the VPSI LDS, on the Bulk Field-Constructed Tank 9 at the Red Hill Bulk Fuel Storage Facility, located at Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The testing was conducted in a tank 250-feet tall with a diameter of 100-feet with a nominal capacity of 12,500,000-gallons. All evaluation testing was conducted at the Red Hill Bulk Fuel Storage Facility at JBPHH. The leak simulations, data collection, data analysis, and reporting were conducted by Ken Wilcox Associates, Inc. This report was prepared by Craig D. Wilcox and Jairus D. Flora, Jr., Ph.D.

This report presents the results of testing of the VPSI Leak Detection System (LDS) evaluated at Red Hill.

KEN WILCOX ASSOCIATES, INC.

Craig Wilcox

Craig D. Wilcox, President

June 20, 2018

Jairus D. Flora, Jr.

Jairus D. Flora, Jr., Ph.D.

June 20, 2018

1.0 INTRODUCTION

Vista Precision Solutions, Incorporated (VPSI) developed the VPSI Leak Detection System (LDS) specifically for this project. Ken Wilcox Associates, Inc. (KWA) conducted an independent third-party evaluation of this leak detection system following a procedure that meets the requirements of the evaluation protocol drafted specifically for this project. Testing was conducted in a nominal 12,500,000-gallon underground bulk, field-constructed tank with a diameter of approximately 100-feet and a height of 250-feet.

The United States Environmental Protection Agency (EPA) requires that all tank testing equipment be tested to define the equipment's performance parameters. The equipment must be capable of detecting leaks at a rate defined by the regulating agencies with a probability of detection of 95% or greater. At the same time, the method must not produce false alarms (declaring a leak when the tank is tight) more than 5% of the time.

The evaluation test plan was developed based on the existing protocol, "Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods", United States EPA, March 1990. The evaluation test plan was developed, reviewed and finalized over communications with the project stakeholders. The EPA protocol specified that a minimum of 12 tests would be conducted for the bulk field-constructed tank leak detection evaluation. The evaluation test plan included testing in three different test blocks, at three different product levels. There were a total of 4 evaluation tests performed for each block, with Block 1 product level at 189-feet 10-inches; Block 2 at 159-feet 11-inches; and Block 3 at 125-feet 0-inches.

The evaluation test plan specified that leak rates should be induced equivalent to multiples of the target threshold: zero, half the target threshold, the target threshold, and two times the target threshold. The target threshold was 0.50 gallons per hour (gph). The 4 nominal induced leak rates that were used during the evaluation were 0.00-gph, 0.25-gph, 0.50-gph and 1.00-gph. The induced leak rates were kept blind to the vendor during the entire evaluation. The VPSI LDS leak rates were reported to Michael Baker International within 24 hours after each test was concluded.

2.0 DESCRIPTION OF TESTING LOCATION

The VPSI LDS was tested at the Red Hill Bulk Fuel Storage Facility, on Tank 9 Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The Red Hill Bulk Fuel Storage Facility includes a number of bulk field-constructed tanks and a bulk pipeline system at JBPHH. The test tank was a field-constructed tank with a nominal capacity of 12,500,000-gallons. The test tank nominal dimensions are 250-feet tall with a diameter of 100-feet. Tank 9 is a field constructed vertical underground storage tank, shaped like a capsule, with domed top and domed bottom, that was constructed inside the mountain at Red Hill.

In order to lower the product level in the test tank, fuel transfers were conducted through a bulk pipeline that supplies fuel to JBPHH.

The VPSI LDS main console was located in the upper tunnel next to Tank 9. The KWA evaluation equipment was located in the lower tunnel with the leak simulation equipment installed on a small diameter pipeline manifold that was attached to the bottom of the tank. The test tank was nominally made available to KWA staff 24-hours a day for the duration of the evaluation. Leak simulations were induced by KWA staff, Craig Wilcox, who was present for the duration of the evaluation.

3.0 OVERVIEW OF EVALUATION

Table 1 contains the test schedule, test duration, product level and the order the leaks were induced during the evaluation. Table 2 summarizes the VPSI LDS reported leak rate, the induced leak rate and the difference between the reported and induced leak rate that were achieved during the evaluation.

Testing was carried out using the vendor's normal test routine. Leak simulations were induced through a 1-inch diameter pipeline that was connected directly into Tank 9 at approximately 10-feet from the bottom. All leaks induced were kept blind to the vendor for the duration of the evaluation. The leak rate reported by the VPSI LDS was compared to the actual volume of product removed from the tank. A statistical analysis of the data was used to determine the performance characteristics of the test method.

In this report, leak rates are reported as positive numbers—the rate in gallons per hour of product removed from the tank. Any result reported as a negative number is considered as being reported as a liquid inflow into the tank. The leak rates were induced or simulated by removing product from the tank at various constant rates. There were twelve (12) tests conducted. Nine of the tests had leaks simulated and three (3) tests used a zero leak rate, representing a tight or non-leaking tank. Tests were conducted in three blocks with each block, containing 4 official evaluation tests, corresponding to a different level or depth of product in the tank. Block 1 was 189-feet 10-inches; Block 2 was 159-feet 11-inches; and Block 3 was 125-feet 0-inches. There was a product level drop performed before each block of tests began. This was to verify the performance of the leak detection system at different product levels. After a product level drop, there was a minimum 96-hour product settling time to let the product stabilize. After the 96-hour product settling time, the vendor was given a 24-hour setup period to verify that their system was functioning properly. After the 24-hour setup period, the vendor performed a 48-hour preliminary test to ensure the tank was tight before the first official evaluation test began for each block. During this preliminary 48-hour test, the vendor was aware that the tank did not have a leak induced, so these preliminary results are not considered during the statistical analysis of the results. After the preliminary test was completed, the first official tests were performed at approximately 168-hours after the fuel drop was completed.

During the evaluation, the vendor reported the estimated leak rate within 24-hours of the completion of each test. For analysis, the induced leak rate was subtracted from the reported leak rate and these differences were analyzed. The method of analysis used was that found in the quantitative EPA leak detection protocols. The EPA procedure first estimates the probability of false alarm and the probability of detecting a leak rate of the size specified in the EPA regulations for the particular type of leak detection. The requirement for an annual tank tightness test for release detection of field-constructed tanks is 0.5-gph leak rate. The analysis estimates the threshold or criterion for declaring a leak that would give a 5% probability of false alarm (PFA). The analysis also determines the corresponding leak rate that is detectable with a probability of detection (PD) of at least 95%. See specifically Section 7.5.1 of the “Standard Test Procedures for Evaluating Leak Detection Methods – Volumetric Tank Tightness Testing Methods”, United States EPA, March 1990, which gives the procedure for calculating a threshold for determining a significant leak rate with a 5% PFA and Section 7.5.2, which gives the procedure for determining the 95% MDL.

Test times were 48-hours (two days) for each of the 12 tests. Leak simulations were controlled and monitored by KWA throughout the duration of the testing. Product level, volume, temperature and leak rates were recorded by KWA throughout the evaluation.

Leak simulations were conducted by utilizing a variable valve precision flow meter connected to a small diameter pipeline located 10-feet off the bottom of the tank. The head pressure from the fuel allowed for fuel to flow at a constant rate through the flow meter during the duration each test. Nominal leak rates of zero gph, 0.25-gph, 0.50-gph and 1.00-gph were randomly induced during the evaluation. Leak rates were calculated from the total mass of product removed from the tank during the test time and the density of the product. The mass of the product removed was measured by flowing product through the precision flow meter into a 55-gallon barrel that was placed onto a precision scale to measure the mass of the product. Leak rates were also verified by KWA staff periodically during each test by measuring the flow rate with a graduated cylinder and a stop watch. Product level, temperature, and specific gravity readings were recorded throughout the evaluation from the automatic tank gauge (ATG) located at the upper tunnel of Tank 9.

Table 3 - Test Schedule for VPSI LDS Evaluation

Task Name	Scheduled Duration	Nominal Induced Leak Rate
Level Change	level drop down to 189' 10"	
Product Settling Time	96 hours	
Block 1: Test 1 Trial Run Setup		
Block 1: Test 1 Trial Run	48 hours	No Leak
Block 1: Test 2 Setup		
Block 1: Test 2	48 hours	LR4
Block 1: Test 3 Setup		
Block 1: Test 3	48 hours	LR3
Block 1: Test 4 Setup		
Block 1: Test 4	48 hours	LR2
Block 1: Test 5 Setup		
Block 1: Test 5	48 hours	LR1
Level Change	level drop down to 159' 11"	
Product Settling Time	96 hours	
Block 2: Retest 6 Trial Run Setup		
Block 2: Retest 6 Trial Run	48 hours	No Leak
Block 2: Retest 7 Setup		
Block 2: Retest 7	48 hours	LR3
Block 2: Retest 8 Setup		
Block 2: Retest 8	48 hours	LR2
Block 2: Test 9 Setup		
Block 2: Test 9	48 hours	LR1
Block 2: Test 10 Setup		
Block 2: Test 10	48 hours	LR4
Level Change	level drop down to 125' 0"	
Product Settling Time	96 hours	
Block 3: Test 11 Trial Run Setup		
Block 3: Test 11 Trial Run	48 hours	No Leak
Block 3: Test 12 Setup		
Block 3: Test 12	48 hours	LR2
Block 3: Test 13 Setup		
Block 3: Test 13	48 hours	LR4
Block 3: Test 14 Setup		
Block 3: Test 14	48 hours	LR3
Block 3: Test 15 Setup		
Block 3: Test 15	48 hours	LR1

LR1: 0-gph, LR2: 0.25-gph nominal, LR3: 0.5-gph nominal, LR4:1.0-gph nominal

4.0 DESCRIPTION OF THE VPSI LDS

The VPSI LDS is a mass-based system that includes a reference tube in the tank that spans the full vertical height of the tank space. A pressure sensor located inside the reference tube provides data, logged continuously at set intervals, to a local computer for computation of leak rate analyzed using proprietary software.

5.0 TEST RESULTS AND DISCUSSION

5.1 VPSI Leak Detection System Results

Using the data in table 2, the mean difference between the VPSI LDS measured leak rates and the induced leak rates -0.028-gph, with the negative sign indicating that on the average, the VPSI LDS measured leak rates were smaller than the induced leak rates. The standard deviation of these differences was 0.076-gph. A t-statistic was calculated to test whether the mean difference was statistically significantly different from zero. A mean difference that was significantly different from zero would represent a bias in estimating the leak rate by that method. The calculated value of the t-statistic was -1.268 (with 11 degrees of freedom). The two-sided significance level (sometimes referred to as the P-value) was 0.231, or 23.1%, showing that the difference was not significantly different from zero at the 5% level. Thus, there was no significant bias in the method.

Table 2 contains the data from the VPSI LDS tests. For each of the 12 tests, the table contains the test number, the block and test name, the vendor's measured leak rate in gallons per hour (gph), the leak rate induced by removing product from the tank, collecting and measuring it in gph, and the difference between the measured and induced leak rates, found by subtracting the induced leak rate from the measured leak rate.

Table 5 - VPSI LDS Results

Test Number	Block and Test Name	VPSI LDS Method Result (gph)	Induced Leak (gph)	Difference (gph)
1	Block 1, Test 2	1.016	1.035	-0.019
2	Block 1, Test 3	0.594	0.446	0.148
3	Block 1, Test 4	0.155	0.216	-0.061
4	Block 1, Test 5	0.003	0	0.003
5	Block 2, Retest 7	0.596	0.628	-0.032
6	Block 2, Retest 8	0.240	0.307	-0.067
7	Block 2, Test 9	-0.082	0	-0.082
8	Block 2, Test 10	1.074	1.017	0.057
9	Block 3 Test12	0.099	0.255	-0.156
10	Block 3 Test 13	0.932	0.994	-0.062
11	Block 3 Test 14	0.585	0.596	-0.011
12	Block 3 Test 15	-0.051	0	-0.051

There were two evaluation tests that were re-run during Block 2 due to the uncertainty of the tightness of a valve from the transfer pipeline. The new evaluation tests are labeled as Retest 7 and Retest 8.

The results can be used to calculate a threshold value for determining whether a measured leak rate is significantly different from zero, indicating a potential leak, or is only minimally different from zero, indicating only measurement error. A two-sided test analysis approach has been used in this evaluation, meaning that the method would test for liquid incursion into the tank as well as for a leak or loss of product from the tank.

When there is no leak, it is possible that a leak detection system might produce a negative estimate, indicating an inflow into the tank. Such a finding could indicate a leak, if, for example, part of the tank was below the water table, which might produce an inward pressure at some points in the tank. Some leak detection methods may guard against that possibility.

Considering this, a two-sided threshold was used for this evaluation. This is calculated by using a two-sided t-value (with 11 degrees of freedom here) to multiply the standard deviation, with a leak being declared if the estimated leak rate fell outside the resulting interval. In this case, the t-value is 2.201 and the threshold is ±0.167. Then a leak would be declared if the measured leak rate were less than –0.167 or greater than +0.167. This would result in a 5% chance of error when the tank was tight. Note that the standard deviation is used in this calculation (not the standard error of the mean) because the standard deviation is an estimate of the error associated with a single leak rate measurement, whereas the standard error of the mean is the error associated with estimating the mean of several leak measurements (12 in this case). Generally, a tank test only measures a single leak rate.

5.2 Test for the Effect of Product Level

These tests were conducted in three blocks, corresponding to three different levels or depths of product. The data can also be used to test whether the different product levels affected the leak detection method significantly. To do this the induced leak rate was subtracted from the measured leak rate and the differences were analyzed using a one-way or one-factor analysis of variance (ANOVA). Table 2 indicates the blocks or different product levels where the evaluation tests were performed. For VPSI LDS, the mean differences were found: Block 1 averaged 0.018, Block 2 averaged -0.031, and Block 3 averaged -0.070. The analysis of variance gave an F-statistic of 1.459 with 2 and 9 degrees of freedom, corresponding to a P-value of 0.283, which was not statistically significant at the 5% level. The critical value for F was 4.256. Thus, it is reasonable to conclude that the different product depths did not affect the VPSI LDS method.

Table 3 is a summary of the findings of the data analysis.

Table 3 - Summary of the Test Results for the VPSI LDS

Required Test Time	48-hours
Required Product Level in Tank	Between 125-feet and 190-feet
Maximum Size of Tank (evaluation only applicable to Red Hill)	Red Hill Tanks with nominal volume of 12,500,000-gallons
Maximum Temperature Difference (between product delivered and product in the tank)	Not Evaluated
Required Product Settling Time After Delivery or Fueling Operations	Not Evaluated for product delivery, Minimum wait period of 168-hrs, after product level drop
Standard Deviation of the Test Data	0.076-gph
Threshold	0.167-gph
Bias (not statistically significant at 5% level)	-0.028 (not significant)
Minimum Threshold for a 5% P_{FA}	0.167-gph
Minimum Detectable Leak Rate for 95% P_D (when the minimum threshold is used)	0.333-gph

5.3 Test Times

Each of the 12 tests conducted in this evaluation had a duration of exactly 48-hours. This test duration time was established in the evaluation test plan. Alternate test duration times were not evaluated.

5.4 Product Levels

For this evaluation, per the test plan, testing was conducted with tank product levels at 189-feet 10-inch, 159-feet 11-inch and 125-feet 0-inch. The results of this evaluation indicate that tank product levels at Red Hill between 125-feet and 190-feet nominal product level height are acceptable for conducting leak detection tests. Product level heights outside of this range were not evaluated.

5.5 Size of Tank

The volume of Tank 9 at Red Hill is nominally 12,500,000-gallons. For leak detection systems, the performance can be affected by the size and geometry of the tank. For most mass-based technologies, performance is related to the surface area of the fuel in the tank (but not the depth of the tank); for some systems, performance is a function of both volume and surface area. The VPSI LDS is a mass-based technology.

The evaluation test plan specifies that the results of this evaluation are applicable to the tanks at Red Hill. This is due to the test plan being developed specifically for this unique installation and the environment where the tanks are installed. The possibility of scaling the Red Hill evaluation test results was not evaluated.

5.6 Temperature Differences and Waiting Time After Product Deliveries and Drops

As part of the evaluation test plan, differences in product temperature were not evaluated. During the evaluation, after a product level drop, there was a minimum 168-hour wait period before the official first test on each block began.

6.0 CONCLUSIONS

The following conclusions and recommendations are based on the results of the testing described in this report.

1. For the VPSI LDS, the Probability of Detection (P_D) of a 0.333-gph leak (or water incursion) is 95.0% when the threshold is set at ±0.167-gph. The corresponding Probability of False Alarm (P_{FA}) is 5.0% when the threshold is set at ±0.167-gph.

2. The minimum test duration time evaluated for a leak detection test to be valid, is 48-hours.

3. The Red Hill tank must be between 125-feet and 190-feet nominal product level height before conducting a valid leak detection test.

4. As specified by the evaluation test plan, the results of this evaluation are valid only for the tanks with nominal volume of 12,500,000-gallons at the Red Hill Fuel Storage Complex. The installation and location of the fuel storage tanks at the Red Hill Fuel Storage Complex provide a very stable environment for leak detection that is not typically found at other fuel storage facilities. Therefore the results of this evaluation of the VPSI LDS should only be considered applicable to the fuel storage tanks at the Red Hill Fuel Storage Complex.

5. Product delivery was not a part of this evaluation, therefore, product settling time for conducting leak detection testing after product delivery was not determined.

6. Leak detection tests may be initiated 168-hours (minimum) following a product level drop, provided a minimum of 48-hours of quality data are collected and analyzed.

7. Scaling was not included in this evaluation. If scaling is to be considered at a facility other than the Red Hill Fuel Storage Complex, additional evaluation tests should be performed in order to verify the application of scaling the evaluation results. Several other factors may need to be considered including test duration times, tank size, tank installation/location, and product settling time after fuel transfers.

ATTACHMENT A

EPA Forms for the VPSI LDS

Results of U.S. EPA Standard Evaluation

Volumetric Tank Tightness Testing Method

This form tells whether the tank tightness testing method described below complies with the performance requirements of the federal underground storage tank regulation. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods." The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name	Vista Precision Solutions, Incorporated
Version number	VPSI LDS
Vendor	Vista Precision Solutions, Incorporated
(street address)	2350 Lindberg Loop
	Richland, Washington 99354
(phone)	(509) 943-2484

Evaluation Results

This method, which declares a tank to be leaking when the measured leak rate exceeds the threshold of 0.167 gallon per hour, has a probability of false alarms [P(FA)] of 5 %.

The corresponding probability of detection [P(D)] of a 0.500 gallon per hour leak is 99.95 %.

Therefore, this method X does ☐ does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency (0.500 gallon per hour at P(D) of 95% and P(FA) of 5%).

Test Conditions During Evaluation

The evaluation testing was conducted in a 12,500,000 gallon **X** steel ☐ fiberglass tank that was 100 foot in diameter and 250 foot tall.

The tests were conducted with the tank product level between 125 and 190 foot.

The temperature difference between product added to fill the tank and product already in the tank ranged from not evaluated °F to not evaluated °F, with a standard deviation of not evaluated °F.

The product used in the evaluation was JP-5 .

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for using the method are followed.
- The tank is no larger than not included in this evaluation gallons.
- The tank contains a product identified on the method description form.
- The tank product level height is between 125 and 190 foot.
- The waiting time after adding any substantial amount of product to the tank is at least not included in this evaluation hours.
- The temperature of the added product does not differ more than not included in this evaluation degrees Fahrenheit from that already in the tank.
- The waiting time between the end of "topping off," if any, and the start of the test data collection is at least not included in this evaluation hours.
- The total data collection time for the test is at least 48 hours.
- This method **X** can ☐ cannot be used if the ground-water level is above the bottom of the tank.
- Other limitations specified by the vendor or determined during testing: After a fuel drop, there was a minimum 168-hour product settling time before any test began during the evaluation.

> **Safety disclaimer: This test procedure only addresses the issue of the Leak Detection Method's ability to detect leaks. It does not test the equipment for safety hazards.**

Certification of Results

I certify that the Leak Detection Method was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation.

Craig D. Wilcox President
(printed name)

Ken Wilcox Associates, Inc.
(organization performing evaluation)

(signature)

Grain Valley, Missouri 64029
(city, state, zip)

Jairus Flora, Jr., Ph.D.
(printed name)

June 20, 2018
(date)

(signature)

(816) 443-2494

APPENDIX B

EXECUTED TEST PLAN

TEST PLAN FOR EVALUATING LEAK DETECTION METHODS AT THE RED HILL FUEL STORAGE COMPLEX

JOINT BASE PEARL HARBOR-HICKAM, HAWAII

Prepared for:

Defense Logistics Agency Energy
Fort Belvoir, Virginia

Prepared under:

Naval Facilities Engineering Command Atlantic
Contract N62470-10-D-3000-0048

Prepared by:

Michael Baker International
Virginia Beach, Virginia

2 November 2017
Executed Test Plan, date of update: 16 May 2018

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1.0 INTRODUCTION

1.1 Purpose of Project

The Defense Logistics Agency (DLA) Energy contracted Michael Baker International (Michael Baker) through Naval Facilities Engineering Command (NAVFAC) Atlantic Contract N62470-10-D-3000-0048 to prepare a test plan to evaluate certain leak detection (LD) test methods that would be applicable for LD testing the eighteen (18) bulk field-constructed underground storage tanks (BFCUSTs) at the Red Hill Fuel Storage Complex, located at Joint Base (JB) Pearl Harbor-Hickam, Hawaii. The test plan to evaluate certain LD test methods is in support of the Administrative Order on Consent (AOC) Attachment A: Statement of Work (SOW) Sections 4.5: New Release Detection Alternatives SOW and 4.6: New Release Detection Alternatives Report. The cited portion of the AOC Attachment A: SOW is in Appendix A.

1.2 Site Background

JB Pearl Harbor-Hickam is located on the island of Oahu, approximately eight miles northwest of Honolulu, Hawaii. The fueling operations at JB Pearl Harbor-Hickam are under the Navy's Fleet Logistics Center (FLC) Pearl Harbor.

The Red Hill Fuel Storage Complex is located approximately three miles north-east of the base and is used as a bulk fuel storage facility. Fuel is issued and received at the Red Hill Fuel Storage Complex from JB Pearl Harbor-Hickam via a transfer pipeline. The Red Hill Fuel Storage Complex consists of 20 BFCUSTs (BFCUSTs 1 through 20) that are constructed of single-walled steel vertical capsules; 100-feet in diameter, with a 50-foot radius hemispherical bottom, a 150-foot barrel, and a 50-foot radius hemispherical top. Two of the 20 tanks (BFCUST 1 and 19) were permanently removed from service prior to 2009. Fuels stored include: commercial aviation jet fuel with military additives (F-24), Jet Propellant 5 (JP-5), and diesel fuel marine (F-76).

1.3 Project Scope

The scope of this project is to prepare a test plan to evaluate certain LD test methods that would be applicable for the 18 BFCUSTs at the Red Hill Fuel Storage Complex. The evaluation test plan includes three LD testing methods, applied by three equipment vendors: 1) the Gauging System Inc. (GSI), Multifunction Tank Gauge (MTG) system 2) the Mass Technology Corporation (MTC), Precision Mass Measurement System, and 3) the Vista Precision Solutions Inc. (VPSI), Low-Range Differential-Pressure (LRDP) System.

Note: Six (6) LD testing methods, applied by three equipment vendors. The LD testing methods are identified as: GSI 1, GSI 2, GSI 3, GSI 4, MTC, VPSI.

The evaluation of the LD methods is to be based on the United States Environmental Protection Agency's (US EPA's) Standard Test Procedures (Reference 3.1). An independent third-party evaluator (Evaluator) will induce a set of controlled leaks during the evaluation testing, collect the evaluation testing data from the three vendors, and apply computational statistics in accordance with project guidelines on the evaluation testing results provided by the three vendors.

Note: The statistical evaluation of data will be based on the US EPA method, detailed in the Standard Test Procedure found in Reference 3.1.

1.4 Evaluation Testing Protocol

The testing protocol for the LD testing evaluation at Red Hill shall be based on Standard Test Procedures (Reference 3.1), industry standard practices, and points agreed upon by the stakeholders of the AOC. The following points include certain agreed-upon departures to Sections 2, 5, 6 and 7, of the Standard Test Procedures document. NOTE: Section 2.0 provides further details that applies to the testing protocol:

1.4.1 Section 2 – Scope and Applications

a) The LD method's ability to detect a target leak rate (TLR) in gallons per hour (gph), shall have a probability of 95-percent or higher, while operating at a false alarm rate of 5-percent or less.

1.4.2 Section 5 – Apparatus and Materials

a) Section 5.1 – Tanks
   i) Testing will be conducted on a single tank;

ii) An initial test, or trial run, under stable, no-leak conditions will be conducted immediately following each of the changes in tank product level, to confirm tank and equipment functionality.

b) Section 5.2 – Test Equipment

i) In general, the test equipment will consist of a method for monitoring product volume or level; compensation for temperature may also be included. The method will also include instrumentation for collecting and recording the data and procedures for using the data to calculate a leak rate and interpret the results as a pass or fail for the tank;

ii) Test equipment shall be operated by trained personnel who regularly use the equipment in commercial tests, per the LD system manufacturer.

c) Section 5.3 – Leak Simulation Equipment

i) Leaks will be induced in the tank by removing product at a constant rate, measuring the amount of product removed and the time of collection, and calculating the resulting induced leak rate;

Note: Leaks were induced at a constant rate, and held continuously for the full length of each test.

ii) Leak simulation equipment, shall be capable of simulating leaks within +/- 30-percent of the nominal leak rates.

d) Section 5.4 – Product

i) Testing will be conducted without the addition of product at different temperatures than that of the fuel already in the tank. Methods of heating and cooling the fuel shall not be applied during testing.

e) Section 5.5 – Miscellaneous

i) Testing will be conducted at three (3) tank product levels. The procedures established for each tank product level are as follows:

(1) The transfer of product will be initiated, until the target product level height is achieved;

(2) Time is allotted for product settling;

(3) One (1) trial run test, under no-leak conditions, will be run to verify tank and equipment tightness;

(4) Four (4) evaluation tests will be run;

(5) The cycle restarts with the transfer of product to achieve the second (and third) product level height(s);

(6) During evaluation testing, controlled leaks will be induced by the Evaluator; induced leak rates will be kept blind to the vendors.

1.4.3 Section 6 – Testing Procedure

The test procedure utilizes two (2) factors: the size of the leak and tank deformation due to pressure changes associated with product level changes. The empty-fill cycles produced prior to each test will not be incorporated.

a) Section 6.1 – Environmental Data Records, applicable test conditions (i.e. weather and tank data) will be recorded.

b) Section 6.2 – Induced Leak Rates and Temperature Differentials

   i) Fifteen (15) tests will be conducted in total, which includes one (1) trial run test and four (4) evaluation tests, at each of the three (3) tank product levels;

   Note: The three (3) trial run tests were known to the LD Vendors; the twelve (12) evaluation tests were blind to the LD Vendors.

   ii) Four (4) nominal leak rates will be induced by the Evaluator during evaluation testing, as multiples of the target leak rate (TLR): 0-percent TLR, 50-percent TLR, 100-percent TLR, and 200-percent TLR;

   iii) Temperature differential conditions will not be applied during testing;

   iv) The order of induced leak rates applied during evaluation testing will be randomized. One trial run test will be conducted after each of three product transfers. The trial run tests will be conducted under no-leak conditions to verify tank and equipment tightness after each product transfer;

   Note: The order of the induced leak rates applied during evaluation testing was randomized by the Evaluator.

   v) Notational conventions shall be applied;

   vi) Optional Experimental Design shall not be applied to testing;

c) Section 6.3 – Testing Schedule (See Table 1-1)

d) Section 6.4 – Testing Problems and Solutions;

Note: Test 6 (trial run) and Tests 7 and 8 (evaluation tests) were repeated and replaced with Retest 6 (trial run), and Retest 7 and Retest 8 (evaluation tests) respectively, due to unconfirmed tightness of the tank isolation valve.

   i) If a vendor reports an inconclusive or invalid single test, the result will be recorded in the evaluation report, and the test may be conducted again;

   ii) If a vendor reports more than one test as inconclusive or invalid, the Navy will provide final direction on how to proceed on whether testing will be conducted again.

1.4.4 Section 7 – Calculations

The calculations called for in the EPA Tank Tightness Testing Protocol will be performed (calculations are incorporated by reference and not reproduced here). The estimation of the standard deviation of the predicted leak rates shall be included. In addition to these cited calculations, the Evaluator anticipates adding the regression (or general linear model) approach. In this approach, the Evaluator will treat the induced leak rates as independent (X) variables, and the leak rates reported by each vendor as dependent (Y) variables. The Evaluator will thus estimate a regression equation, of the form:

$$Y = a + bX + L_i + \varepsilon,$$

Where Y is the vendor-reported leak rate, a is the intercept, b is the slope, X is the induced leak rate, L_i is a potential effect of the product level (high-level, mid-level, and low-level) and ε is the error. This applied equation will enable the Evaluator to separately estimate bias (represented by a non-zero intercept), a slope significantly different from one, and a possible effect of different product levels L_i on the performance of the leak detection method.

Note: The calculations referred to in the EPA Tank Tightness Testing Protocol, dated March 1990 (Reference 3.1) are the only statistical method applied to this Evaluation.

Note: The regression equation provided in Section 1.4.4 will not be used for this Evaluation.

Table 1-1: Three Block Evaluation Testing Protocol

Test No.	Block No.	Randomization	Nominal Induced Leak Rate	Tank Product Level Factor
1	1	Trial Run Test	No-leak condition	Level 1
2		2	50%TLR	
3		1	0%TLR	
4		3	100%TLR	
5		4	200%TLR	
6	2	Trial Run Test	No-leak condition	Level 2
7		1	0%TLR	
8		4	200%TLR	
9		2	50%TLR	
10		3	100%TLR	
11	3	Trial Run Test	No-leak condition	Level 3
12		2	50%TLR	
13		4	200%TLR	
14		1	0%TLR	
15		3	100%TLR	

Note: The order of the block product levels was determined by operational requirements at the facility.
Note: The order of the induced leaks was randomized by the Evaluator.

2.0 APPLIED TESTING PROTOCOL AND EVALUATION TEST PLAN

2.1.1 Applied Testing Protocol

The following provides details to the evaluation testing protocol discussed in Section 1.4:

a) Testing will be conducted on a single tank, identified as BFCUST 9, currently storing JP-5;

b) Three LD system equipment vendors will conduct testing simultaneously;

c) Testing duration will be set to 48-hours length, per test;

d) The target leak rate (TLR) established for evaluation testing will be 0.5 gallons per hour (gph);

e) A total of fifteen (15) tests will be conducted: three (3) trial run tests and twelve (12) evaluation tests;

f) Three (3) trial run tests will be conducted after each of three product transfers. The trial run tests will be conducted under no-leak conditions to verify tank and equipment tightness after each product transfer;

g) Twelve (12) evaluation tests will be conducted using a two-factor format: 1.) multiple induced leak rates, and 2.) multiple tank product levels:

   i) Four (4) nominal leak rates will be induced during evaluation testing, as multiples of the TLR: 0-percent TLR, 50-percent TLR, 100-percent TLR, and 200-percent TLR. The order of induced leak rates applied during evaluation testing will be randomized and kept blind to the vendors;

   ii) Three (3) tank product levels will be used for evaluation testing:

      (1) Level 1, at 190-feet elevation – located 10-feet below the upper spring line;

      (2) Level 2, at 125-feet elevation – located at the tank midpoint height;

      (3) Level 3, at 60-feet elevation – located 10-feet above the lower spring line;

      Note: The three (3) tank product levels were determined by operational requirements at the facility, and were as follows:

      1. **Level 1, 190-feet elevation**
      2. **Level 2, 160-feet elevation**
      3. **Level 3, 125-feet elevation**

h) After each transfer of product, a four-day (96-hour) product settling time is allotted;

i) Leak measurement equipment, shall be capable of measuring leaks set to multiples of the TLR: 0-percent TLR, 50-percent TLR, 100-percent TLR, and 200-percent TLR, with a minimum of three significant figures of accuracy;

j) Computational statistics will be used to analyze the slope regression, which is defined as the relationship between the induced leak rate and the measured leak rate;

k) Three-block evaluation testing protocol: See Table 1-1.

2.1.2 Evaluation Testing Plan

The following evaluation test plan has been developed to conduct evaluation testing efficiently and includes working on weekends and holidays. Prior to testing, each LD system vendor and the Evaluator will have installed/setup equipment on the subject tank to be tested (BFCUST 9). See the Evaluation Test Plan in Table 2-1.

Table 2-1: Evaluation Test Plan

Task	Task Owner	Description	Duration
1	Navy	Secure BFCUST 9 level @ 190-feet	2-days
2	Navy	Product Settling Time	4-days
3-14	Vendors, Evaluator	Block 1 – Evaluation Testing	16-days
15	Navy	Secure BFCUST 9 level @ 125-feet	2-days
16	Navy	Product Settling Time	4-days
17-27	Vendors, Evaluator	Block 2 – Evaluation Testing	16-days
28	Navy	Secure BFCUST 9 level @ 60-feet	2-days
29	Navy	Product Settling Time	4-days
30-40	Vendors, Evaluator	Block 3 – Evaluation Testing	16-days

3.0 REFERENCES

3.1 *“Standard Test Procedures For Evaluating Leak Detection Methods, Volumetric Tank Tightness Testing Methods”;* United States Environmental Protection Agency. Date: March 1990.

APPENDIX C

PHOTOGRAPHIC RECORD

Photographic Record
Red Hill Bulk Fuel Storage Facility

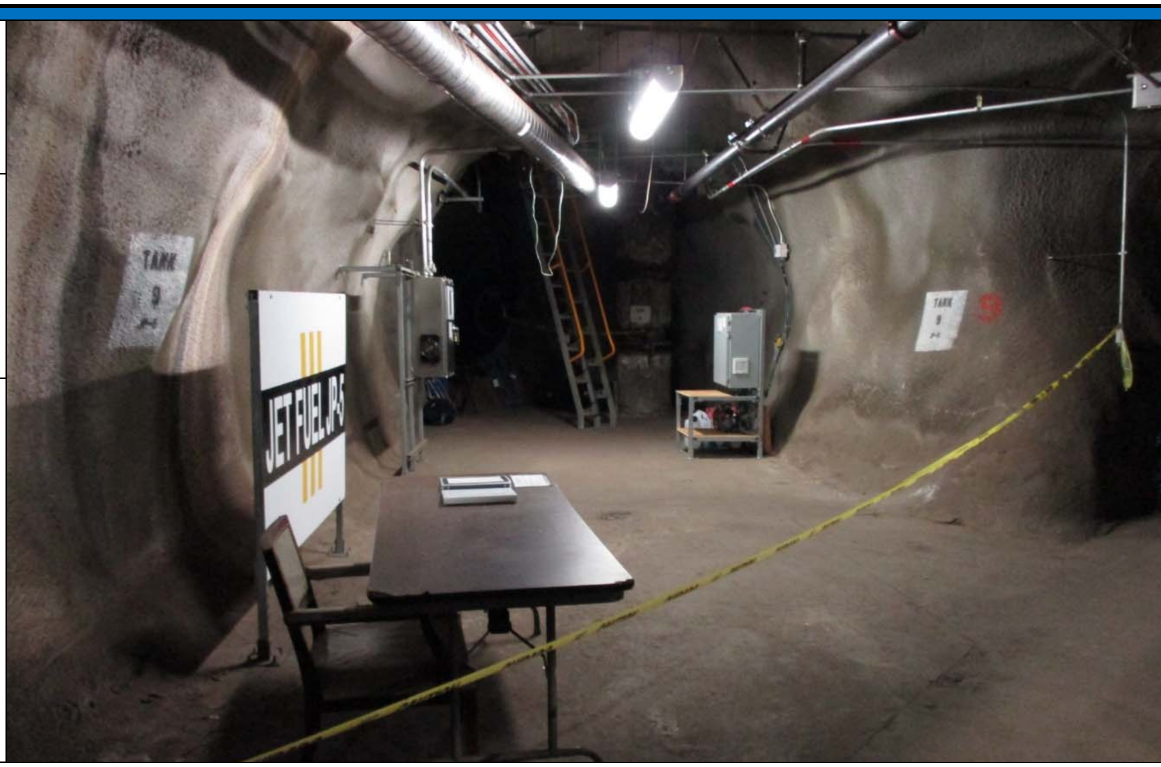
Photo 1

View

Upper Tunnel
Tank 9

Photo by

Michael Baker
Jan 2018



Comment: Evaluation Testing in-progress; LDS vendor equipment in background.

Photo 2

View

Gauging Gallery
Tank 9

Photo by

Michael Baker
Jan 2018

Comment: Evaluation Testing in-progress; LDS vendor equipment installed through the tank gauging port.

Photographic Record
Red Hill Bulk Fuel Storage Facility

Photo 3	
View Lower Tunnel Tank 9	
Photo by Michael Baker Jan 2018	

Comment: Evaluation Testing in-progress; valve manifold utilized for inducing leaks.

Photo 4	
View Lower Tunnel Tank 9	
Photo by Michael Baker Jan 2018	

Comment: Evaluation Testing in-progress; KWA equipment installed for inducing and measuring leaks.

Red Hill Hypothetical Release Rates

Assumptions for both scenarios:
- Leak rate of .499 gallons per hours being the maximum theoretically possible based on current Tank Tightness Testing certifications (worst case scenario)
- The leaking tank is at the high operating limit of 212' and is holding 269,000 BBLS of fuel (worst case scenario)
- The leaking tank is a JP-5 tank (most likely scenario)
- Tank is idle (no fuel in or out) (most likely scenario)
- Leak is at dead bottom center of tank bottom of tank (worst case scenario)
- As tank empties, the release rate remains constant at .499 gallons regardless of decreased head pressure
- Flow rate of fuel to Tank 55 will average 5,000 BBLS per hour*
- Flow rate from Tank 55 to Red Hill tank will be 5,000 BBLS per hour*

UFM alarm parameter:
~ 306 gallons per 1/16" which is the maximum amount per 1/16" and it will actually be less given the reduction in volume in the upper and lower domes and also this doesn't take into account anything which reduces volume within the tank to include the center tower.
- UFM "Warning" alarm will sound at 1/2" = 2,448 gallons
- UFM "Critical" alarm will sound at 3/4" = 3,672 gallons

Detection:

- At a leak rate of .499 gph the UFM "Warning" alarm will require 4,896 hours or 204 days to alert (2,443.104 gallons), and the UFM "Critical" alarm will require an additional 2,448 hours or 102 days to alert (an additional 1,221.52 gallons).

When certified tight the tanks could leak at a rate of no greater than .499 gph, 11.976 gallons per day, and 4,371.24 gallons per year. (worst case scenario)

Drain Down

SCENARIO I: (Near empty Upper Tank Farm available)

Time +0.0 hours:	Operator will align fuel from the affected tank to Tank 55 which has 7' of fuel in the tank
Time +22.4 hours:	Operator will finish filling Tank 55 which will remove 112,000 bbls from affected Red Hill tank (157,000 BBLS remain in affected tank)
Time +44.8 hours:	Operator will pump up 112,000 BBLS of fuel from Tank 55 to near empty Red Hill tank
Time +45.05 hours:	Operator will align fuel from the affected tank to Tank 55 which has 7' of fuel in the tank
Time +67.45 hours:	Operator will finish filling Tank 55 which will remove 112,000 bbls from affected Red Hill tank (45,000 BBLS remain in affected tank)
Time +77.45 hours:	Operator will pump up 50,000 BBLS of fuel from Tank 55 to near empty Red Hill tank

Time +77.7 hours:	Operator will align fuel from the affected tank to Tank 55 which has sufficient ullage to take the affected tank to low suction
Time +86.3 hours:	Operator will finish filling Tank 55 which will remove 43,000 bbls from affected Red Hill tank (1,500 BBLS remain in affected tank)
Time +86.3 hours:	Fuel workers will remove the remaining fuel (1,500 BBLS) from the tank bottom drain valve to the main pipeline via temporary hose
Time +96.3 hours:	Remaining 1,500 BBLS will finished being removed from tank
Time +96.3 hours:	COMPLETE: Tank is empty (will show near zero on AFHE) with only residuals and sludge remaining

Fuel released during drain down: 48.0537 (~48) gallons lost from determination to empty.

SCENARIO II: (No Upper Tank Farm available)

Time +0.0 hours:	Pump up Tank 55 to tanks with available ullage until 112,000 BBLS ullage is available in Tank 55
Time +22.3 hours:	Operator will align fuel from the affected tank to Tank 55 which has 7' of fuel in the tank
Time +44.7 hours:	Operator will finish filling Tank 55 which will remove 112,000 bbls from affected Red Hill tank (157,000 BBLS remain in affected tank)
Time +66.9 hours:	Operator will pump up 112,000 BBLS of fuel from Tank 55 to near empty Red Hill tank
Time +67.1 hours:	Operator will align fuel from the affected tank to Tank 55 which has 7' of fuel in the tank
Time +67.45 hours:	Operator will finish filling Tank 55 which will remove 112,000 bbls from affected Red Hill tank (45,000 BBLS remain in affected tank)
Time +77.45 hours:	Operator will pump up 50,000 BBLS of fuel from Tank 55 to near empty Red Hill tank
Time + hours:	Operator will align fuel from the affected tank to Tank 55 which has has sufficient ullage to take the affected tank to low suction
Time +108.6 hours:	Operator will finish filling Tank 55 which will remove 43,000 bbls from affected Red Hill tank (1,500 BBLS remain in affected tank)
Time +108.9 hours:	Fuel workers will remove the remaining fuel (1,500 BBLS) from the tank bottom drain valve to the main pipeline via temporary hose
Time +118.6 hours:	Remaining 1,500 BBLS will be finished being removed from tank
Time +118.6 hours:	COMPLETE: Tank is empty (will show near zero on AFHE) with only residuals and sludge remaining

Fuel released during drain down: 59.1814 (~59) gallons lost from determination to empty

*Conservative flow rates used for these calculations

****For this scenario, it could be a little longer than 118.6 hours if we have to switch between multiple tanks, however this would only add a 2-4 hours so total fuel lost is not likely to exceed ~61 gallons