94-0003530

Department of Energy
Richland Field Office
P.O. Box 550
Richland, Washington 99352

JUN 30 1994

94-OCH-058

The Honorable John T. Conway
Chairman
Defense Nuclear Facilities Safety Board
Suite 700
625 Indiana Avenue, NW
Washington, D.C. 20004

Dear Mr. Conway:

DELIVERABLE OF RECOMMENDATION 93-5 IMPLEMENTATION PLAN, COMMITMENT 3.15

Reference: Letter, C, Defigh-Price, WHC to J. M. Clark, RL "Defense Nuclear Facilities Safety Board 93-5 Implementation Plan Commitment 3.15," dated June 27, 1994.

The enclosed Westinghouse Hanford Company (WHC) letter #9454521, dated June 27, 1994, with enclosure has been reviewed and found to be acceptable to meet the deliverable as agreed to in the commitment. The intent of the commitment was for WHC to evaluate in-situ moisture monitoring alternatives as recommended by the Tank Instrument Advisory Panel.

If you have any questions please contact me or John M. Clark, Acting Manager of the TWRS Office of Characterization, on (509) 376-2246.

Sincerely,

T. R. Sheridan, Acting Program Manager
Office of Tank Waste Remediation System

Enclosure

cc:
K. Lang, EM-36, HQ w/ encl.
C. Defigh-Price, WHC w/o encl.

SEPARATION

PAGE

Westinghouse
Hanford Company

94:3530

P.O. Box 1970 Richland, WA 99352

June 27, 1994

9454521

Mr. J. M. Clark, Acting Manager
Office of Characterization
Office of Tank Waste Remediation System
U.S. Department of Energy
Richland Operations Office
Richland, Washington 99352

Dear Mr. Clark:

MILESTONE DEFENSE NUCLEAR FACILITIES SAFETY BOARD MILESTONE 3.15 COMPLETION

Reference: "Recommendation 93-5 Implementation Plan," U.S. Department of Energy, Richland Operations Office, DOE/RL 94-0001, January 1994.

The Defense Nuclear Facilities Safety Board (DNFSB) Implementation Plan (Reference) Milestone 3.15 states:

> "Commitment 3.15: Engineering Evaluation of Alternatives for In Situ Moisture Monitoring. This document will evaluate all alternatives reviewed or in development to date, including the Tank Instrument Advisory Panel input on alternatives."

The document WHC-SD-WM-ES-306, Rev. 0, "Evaluation of In Situ Moisture Alternatives," was released June 28, 1994. Attached is a copy of the Engineering Evaluation of Alternatives. The report identifies and evaluates all potential moisture sensors applicable for in situ characterization at the Hanford Site. The evaluated moisture sensor included sensors configured for a cone penetrometer. Please note that this document agrees with the Tank Instrument Assistance Panel (TIAP) recommendations dated April 1994. This Engineering Evaluation of Alternatives will be submitted to the TIAP for additional review and recommendations.

RECEIVED
JUN 29 1994
DOE-RL/CCC

I94-CST-117

If you have any questions regarding the study, please contact Ms. R. Y. Seda on 373-0061 or Mr. G. N. Boechler on 373-3041.

Very truly yours,

C. DeFigh-Price

C. DeFigh-Price, Manager
Characterization Program
Tank Waste Remediation System Program Office

klh

Attachment

HQ - K. T. Lang
J. Poppiti

RL - T. Noble
R. O. Puthoff (w/o attachment)

PNL - P. J. Mellinger
P. G. Eller

SAIC - H. Sutter

SEPARATION

PAGE

94:3530

Sta. 4
JUN 28 1994

ENGINEERING DATA TRANSMITTAL

Page 1 of 1
1. EDT 607403

2. To: (Receiving Organization) TWRS Characterization Equipment	3. From: (Originating Organization) Technology Transfer & Infusion	4. Related EDT No.:
5. Proj./Prog./Dept./Div.: Economic Transition	6. Cog. Engr.: John J. Wong	7. Purchase Order No.:
8. Originator Remarks: For Original Release		9. Equip./Component No.:
		10. System/Bldg./Facility:
11. Receiver Remarks:		12. Major Assm. Dwg. No.:
		13. Permit/Permit Application No.:
		14. Required Response Date: 6-28-94

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Impact Level	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	WHC-SD-WM-ES-306		0	Engineering Evaluation of Alternatives - Moisture Sensors	N/A	1	1	

16. KEY

Impact Level (F)	Reason for Transmittal (G)	Disposition (H) & (I)
1, 2, 3, or 4 (see MRP 5.43)	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION
(See Impact Level for required signatures)

(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.
1	1	John J. Wong	JJWong	6/23/94	B2-24						
1	1	Robert R. Silva, Jr.		6/27/94	B2-24						
1	1	G. N. Boechler	R. Seda for G.N. Boechler	6/28/94							
1	1	R. Y. Seda	R.Y. Seda	6/28/94	R1-17						
1	1	R.J. Blanchard	RJBlanchard		R1-17						
~~2~~		~~G. D. Forehand~~									
1											

18. John J Wong 6/23/94 Signature of EDT Originator / Date	19. ~~S. R. Long~~ G. D. Forehand [illegible] 6/28/94 Authorized Representative for Receiving Organization / Date	20. 6/23/94 Cognizant/Project Engineer's Manager / Date	21. DOE APPROVAL (if required) Ltr. No. [] Approved [

Date Received:	INFORMATION RELEASE REQUEST	Reference:
JUN 23 1994		WHC-CM-3-4

INFORMATION RELEASE REQUEST

Complete for all Types of Release

Purpose		ID Number (include revision, volume, etc.)
[] Speech or Presentation [] Full Paper [] Summary [] Abstract [] Visual Aid (Check only one suffix) [] Speakers Bureau [] Poster Session [] Videotape	[] Reference [X] Technical Report [] Thesis or Dissertation [] Manual [] Brochure/Flier [] Software/Database [] Controlled Document [] Other	WHC-SD-WM-ES-306 Rev. 0 List attachments. Date Release Required June 30, 1994

Title	Unclassified Category	Impact Level
Engineering Evaluation of Alternatives -- ~~Sensors~~ MOISTURE SENSORS	UC-	4

New or novel (patentable) subject matter? [X] No [] Yes
If "Yes", has disclosure been submitted by WHC or other company?
[X] No [] Yes Disclosure No(s).

Information received from others in confidence, such as proprietary data, trade secrets, and/or inventions?
[X] No [] Yes (Identify)

Copyrights? [X] No [] Yes
If "Yes", has written permission been granted?
[X] No [] Yes (Attach Permission)

Trademarks?
[X] No [] Yes (Identify)

Complete for Speech or Presentation

Title of Conference or Meeting

Group or Society Sponsoring

Date(s) of Conference or Meeting

City/State

Will proceedings be published? [] Yes [] No
Will material be handed out? [] Yes [] No

Title of Journal

CHECKLIST FOR SIGNATORIES

Review Required per WHC-CM-3-4	Yes	No	Reviewer - Signature Indicates Approval Name (printed)	Signature	Date
Classification/Unclassified Controlled Nuclear Information	[]	[X]			
Patent - General Counsel	[]	[X]			
Legal - General Counsel	[]	[X]			
Applied Technology/Export Controlled Information or International Program	[]	[X]			
WHC Program/Project	[]	[X]			
Communications	[]	[X]			
RL Program/Project	[]	[X]			
Publication Services	[]	[X]			
Other Program/Project	[]	[X]			

Information conforms to all applicable requirements. The above information is certified to be correct.

	Yes	No
References Available to Intended Audience	[X]	[]
Transmit to DOE-HQ/Office of Scientific and Technical Information	[]	[X]

Author/Requestor (Printed/Signature) Date
John J. Wong June 23, 1994

Intended Audience
[] Internal [X] Sponsor [] External

Responsible Manager (Printed/Signature) Date
Robert R. Silva, Jr. 6/23/94

INFORMATION RELEASE ADMINISTRATION APPROVAL STAMP

Stamp is required before release. Release is contingent upon resolution of mandatory comments.

Date Cancelled	Date Disapproved

SUPPORTING DOCUMENT

1. Total Pages 22

2. Title
Engineering Evaluation of Alternatives - Moisture Sensors

3. Number
WHC-SD-WM-ES-306

4. Rev No.
0

5. Key Words
Moisture Sensors, Engineering Evaluation of Alternatives

6. Author
Name: R.Y. Seda
R.Y. Seda
Signature
Organization/Charge Code N4053

7. Abstract

8. PURPOSE AND USE OF DOCUMENT - This document was prepared for use within the U.S. Department of Energy and its contractors. It is to be used only to perform, direct, or integrate work under U.S. Department of Energy contracts. This document is not approved for public release until reviewed.

PATENT STATUS - This document copy, since it is transmitted in advance of patent clearance, is made available in confidence solely for use in performance of work under contracts with the U.S. Department of Energy. This document is not to be published nor its contents otherwise disseminated or used for purposes other than specified above before patent approval for such release or use has been secured, upon request, from the Patent Counsel, U.S. Department of Energy Field Office, Richland, WA.

9. Impact Level N/A

10. RELEASE STAMP

OFFICIAL RELEASE ⑤
BY WHC
DATE JUN 28 1994
Sta. 4

TABLE OF CONTENTS

1.0 INTRODUCTION 2
2.0 OBJECTIVE AND SCOPE 2
3.0 EVALUATION CRITERIA 2
  3.1 ABSOLUTE CRITERIA 2
  3.2 RANKING CRITERIA 3
4.0 TECHNOLOGIES IDENTIFIED 5
  4.1 TIME-DOMAIN REFLECTROMETRY (TDR) 5
  4.2 RESISTIVITY CONE PENETROMETER (RCPT) 7
  4.3 NEAR-INFRARED REFLECTANCE SPECTROSCOPY (NIRA) 9
  4.4 NEUTRON PROBE (NP) 11
  4.5 FISSION ION CHAMBER DETECTOR (FICD) 14
  4.6 COPPER FOIL THERMALIZED NEUTRON SENSOR (CFTN) 15
  4.7 ELECTRICAL CONDUCTIVITY CELL (ECC) 16
5.0 EVALUATION/RANKING 19
6.0 CONCLUSIONS & RECOMMENDATIONS 19
7.0 REFERENCES 20

ENGINEERING EVALUATION OF ALTERNATIVES

MOISTURE SENSORS FOR IN SITU

TANK WASTE CHARACTERIZATION

1.0 INTRODUCTION

Westinghouse Hanford Company is currently investigating technologies to characterize radioactive tank waste in situ, rather than the conventional sampling and laboratory analysis. Because of safety concerns, there is particular interest in determining the moisture content of tank waste in situ. Sensor technologies that can perform moisture content analysis in situ will be examined and evaluated in this report.

2.0 OBJECTIVE AND SCOPE

This document provides an evaluation of moisture sensor technology that is potentially applicable to in situ tank waste characterization at the Hanford site. The planned sensor delivery platform for in situ tank waste characterization is a cone penetrometer, and this will be factored into this evaluation.

3.0 EVALUATION CRITERIA

There are two types of evaluation criteria that are applied in this evaluation, absolute criteria and ranking criteria. Absolute criteria are pass/fail criteria that are "show stoppers", and will preclude a technology from further consideration. For instance, a technology that created an unsafe condition in the tank (e.g., high temperature) would probably be eliminated from further consideration for this particular evaluation. Ranking criteria are graded assessments of a technology, accounting for the fact that each criteria has a relative "rank of importance" in the evaluation. For instance, relative cost of the technology will be considered in this evaluation, but that criteria is probably not as important as the precision/accuracy of the technology. Consequently, relative cost will be given a lower rank of importance than precision/accuracy, which means relative cost will not weigh as heavily as precision/accuracy in the final evaluation.

3.1 ABSOLUTE CRITERIA

The following absolute criteria will preclude a technology from further consideration. For each of these criteria, a pass/fail (yes/no) grade will be applied to each technology.

1. The instrument/probe/sensor can be fully removed from the tank when the characterization is completed.

2. The technology can fit (or can be adapted to fit) through a 4-inch to 24-inch diameter tank riser.

3. The technology poses no credible potential for damage to a tank.

4. Use of the technology shall not detrimentally alter tank waste properties.

5. Use of the technology shall not cause temperatures in the tank to exceed 180 °C, on both a localized and global tank basis.

6. The technology (instrument/probe/sensor) shall be able to operate in the tank (in situ characterization), surviving the tank environment for the period of time needed to make its measurement.

7. Use of the technology for in situ characterization shall not significantly increase the potential for release of chemical and/or radioactive materials to the environment.

3.2 RANKING CRITERIA

The ranking criteria are assigned a level of importance (scale from 1 to 10, 1 being the least important, and 10 being the most important in this evaluation). Each technology will be graded against the ranking evaluation criteria on a scale of 1 to 10, a value of 1 being the lowest grade, and a 10 being the highest. The grade for each criteria will be multiplied by the rank of importance of that criteria, and these (grade)*(rank of importance) products will be summed to obtain a final evaluation value. The final evaluation values of all the candidate technologies will be compared, and the technologies with the highest final evaluation values will be recommended for further investigation.

Radius of Investigation: For in situ characterization, some technologies will perform "point" measurements while others will perform "field-of-view" measurements. This simply refers to the volume or area of material that the sensor sees for one measurement. The importance of this is that if the measurement is too small, many measurements will need to be obtained to arrive at an accurate average of the sampled area/volume. If the measured area/volume is too large, the sensor may not "see" spots that are very different than the average value. For moisture sensing, defining the sensed volume is important, and hence, is given a relatively high rank of importance.
Rank of importance: 8

Range of Operation: For in situ tank waste characterization, moisture sensor technology should be able to operate over a wide range, along the order of 5 to 60% or more moisture by weight (i.e., per weight of waste material).
Rank of importance: 9

Precision/Accuracy: Measurement precision/accuracy is especially a concern on the low end of the moisture range, and should be +/- 5% in the 5-30 wt% range, and +/- 10% in the 30-60% or higher range.
Rank of importance: 7

Ease of Interpretation of Data: Traditional laboratory moisture analysis is most often accomplished by drying a sample and weight the mass loss. If no volatiles are in the sample, the moisture content can simply be equated to the mass loss. Unfortunately, this simple method cannot be adapted to in situ sensing, and sensor technologies must rely on other properties to arrive at moisture content. This complicates interpretation of data, and a technology must be calibrated or "tuned" for each specific application. For some of these technologies (e.g., spectroscopic methods), computer algorithms and database libraries have been developed solely to transform signals into useable output. The ease or complexity of interpreting data from a moisture sensor must be considered in this evaluation. This criteria is assigned a lesser rank of importance than some of the other items because data interpretation can be simplified by statistical and computer methods.
Rank of importance: 5

Interferences: Tank waste is not expected to be homogenous within the tank or from tank to tank. The sensing technology must be able to operate in a matrix that have unpredictable chemical and physical variations, be relatively insensitive to potential interferences, and be able to function in the environment of the tank. Interferences could include such items as sensitivity to other chemical constituents in the waste (such as organics), radiation, temperature, humidity, and density variations. Specific interferences will be particular to each technology. For instance, spectroscopic data may be difficult to interpret because spectral peaks from chemical constituents may overwhelm the spectra, making it difficult to see the water peak. The ability of a technology to handle interferences is very important because calibration of an instrument in a laboratory environment to pure standards will usually not apply when the instrument is moved to the field. Also, the waste within each tank and from tank to tank vary in composition unpredictably.
Rank of importance: 8

Deployment Requirements: Instrumentation has been lowered into Hanford tanks through liquid observation wells (LOWs) as well as directly into the waste. TWRS is also currently developing a cone penetrometer system for in situ tank waste characterization. Sensors and sensor packages that can fit or can potentially be adapted to fit into a cone penetrometer system is especially of interest, and will be given a higher grade in this category.
Rank of importance: 5

Relative Cost: The total cost of the moisture sensor/sensor system is considered in the evaluation, but is not weighed heavily. This criteria accounts for development costs as well as equipment, installation, operation, and maintenance costs.
Rank of importance: 2

Technology Maturity: The maturity of the sensor technology is considered because developmental needs will affect total cost and schedule to implementation. Validation and verification of an unproven technology will also be a major concern.
Rank of importance: 4

Reliability in Environment: The part of the sensor package that must be near the tank waste must be relatively resistant to radiation, at least to the extent that sensors do not have to be continuously replaced. This criteria also accounts for the harshness of the tank environment (pH, high salt content, temperature).
Rank of importance: 6

4.0 TECHNOLOGIES IDENTIFIED

4.1 TIME-DOMAIN REFLECTROMETRY (TDR)

A waveform travelling down a coax or waveguide is influenced by the type of material surrounding the conductors. If the dielectric constant of the material is high, the signal propagates slower. Because the dielectric constant of water is much higher than most other materials, a signal within a wet or moist medium propagates slower than in the same medium when dry. Ionic conductivity affects the amplitude of the signal but not the propagation time. Thus, moisture content can be determined by measuring the propagation time over a fixed length probe embedded in the medium being measured. This process of sending pulses and observing the reflected waveform is called Time-Domain Reflectrometry (TDR). TDR is also used to determine the location of failures in telecommunication cables, and used on cables grouted in boreholes to monitor rock mass deformation.

The simplest probe, which has been used to determine soil moisture, consists of two parallel rods inserted into the soil. These are attached directly to a twin lead cable. The two-rod probe and the twin lead cable carry a "balanced" signal. Another type of probe that has come into use recently is the unbalanced probe. The probe has three or more rods. A central rod is connected to the signal lead of the coax. The other rods are arranged radially around the center, and are connected to the shield of the coax. The volume of soil sampled with this configuration is smaller than with a balanced design and is concentrated around the center electrode.

The probe systems are calibrated for specific soils, and waveform signals are interpreted by an algorithm to output water content. The electrical properties of the soil, which affect a TDR signal, are also affected by ionic content and density.

Additional literature on TDR systems can be found in:

Baker, J.M., and Allmaras, R.R., "System for Automating and Multiplexing Soil Moisture Measurement by Time-Domain Reflectrometry," *Soil Science Society of America Journal*, Vol. 54: pp. 1-6, 1990.

Ledieu, J., et al, "A Method of Measuring Soil Moisture by Time-Domain Reflectrometry," *Journal of Hydrology*, Vol. 88: pp. 319-328, 1986.

Topp, G.C., et al, "Electromagnetic Determination of Soil Water Content: Measurements in Coaxial Transmission Lines," *Water Resources Research*, Vol 16.3: pp. 574-582, 1980.

Vendor(s)/Developer(s): Campbell Scientific, Inc. of Logan, Utah (801-753-2342) has developed a TDR system for soil moisture measurements. Sandia National Laboratories of Albuquerque, New Mexico (contact: Dr. Robert Knowlton, 505-848-0425) has developed short parallel wave-guide probes that are inserted in soil cores for instantaneous moisture content determination, and in the subsurface for monitoring moisture changes through time. Sandia is also developing a TDR system for a cone penetrometer configuration. Westinghouse Savannah River Company (Hilton Tilley 803-725-1876) is also investigating this technology as a method for detecting liquid level in underground storage tanks. Mohr and Associates has a TDR system that is being used for detecting the ratio of steam to water in high-pressure boiler systems.

Absolute Criteria

On preliminary evaluation, TDR passes all of the absolute criteria, though sizing and adaptation for in situ tank waste characterization has not been attempted yet.

Ranking Criteria

Radius of Investigation: 5

TDR examines a volumetric field-of-view rather than making a "point" measurement. The design of the TDR probe geometry determines the size of the field-of-view volume, but the minimum volume that can be interrogated is not known. Because of the uncertainty in the precise field-of-view, a 5 (out of 10) is assigned for this criteria. The field of view for TDR is not a constant, but varies according to the attenuation of the materials viewed.

Range of Operation: 8

Based on discussions with Campbell Scientific, the technology can resolve soil moisture over a wide range (from dry to saturated soils). The technology appears to perform over a similar operating range, if applied to tank waste.

Precision/Accuracy: 2

For soil applications, TDR can resolve moisture content with very high precision/accuracy (less than +/- 5%). However, this requires calibration with the target soil. Because of the inhomogeneity and unknown composition of tank waste, precision and accuracy of the sensor for in situ tank waste characterization is not expected to be very good. Significant development will be needed to engineer this technology for this application.

Ease of Interpretation of Data: 1

This is a major area of concern. Waveform data needs to be related to moisture content. Due to the uncertainties in interferences, radius of investigation, waste inhomogeneity, and unknown composition (i.e., uncertainties in ability to perform accurate calibration), interpretation of data will be extremely difficult. In fact, this method may be no more than a qualitative "screening" tool.

Interferences: 2
The inhomogeneity of the waste (liquid, solid, sludge, gas pockets) will complicate interpretation of data. Because the exact composition of the waste is unknown, accurate calibration the TDR system will be difficult.

Deployment Requirements: 8
Sandia National Laboratories has been developing a TDR system configured into a cone penetrometer system for soil applications. Conceivably, this system could be adapted for in situ tank waste application.

Relative Cost: 6
The equipment and other implementation costs appear be high compared to any other technology. However, some equipment development will be needed to adapt the technology to tank waste applications, and a significant amount of development will be needed to develop the tools necessary to interpret and validate the data.

Technology Maturity: 5
TDR systems have been used in soil applications for quite a few years, but tank waste applications have not been investigated. Several developmental needs are expected to be identified once the technology is thoroughly assessed for this application.

Reliability in Environment: 9
The sensor is composed of metal components, and the rest of the sensor package and electronics can probably be isolated outside the tank.

Issues/Concerns: The two primary issues of concern with TDR is whether accurate moisture measurements can be obtained from an inhomogeneous, unknown matrix, and whether the technology can focus on a narrow enough "field-of-view" to distinguish layers within a tank. This technology is not very mature for in situ tank waste application, and extensive development will be required.

4.2 RESISTIVITY CONE PENETROMETER (RCPT)

The resistivity cone penetrometer provides a rapid, reliable, and economic means of determining soil permeability and stratigraphy in addition to providing relative measurements of electrical resistivity. The device has been used to determine groundwater and soil resistivity on a near continuous basis, which allows for accurate profiling of contaminated groundwater plumes. Groundwater problems that can be investigated with this device include corrosive soils, salt water intrusion, and environmental contamination. Any soil contaminate that has a typical electrical conductivity higher than that of water can be detected.

The Hogentogler Electrical Conductivity module utilizes a standard four electrode array required to eliminate errors due to gas generation and plating. The device has a custom electronic servo system and auto-ranging technique to ensure accuracy over the entire 0-10,000 milliSiemens/m groundwater conditions. The module also includes a secondary technique to eliminate the effects of the extraneous electrical path through the steel body of the cone penetrometer device. Hogentogler's module comes complete with software the provides tabular listings and digital plots of conductivity in mS/m (or resistivity in ohm-m). The module also interfaces with the module to auto-range the optimum data accuracy.

Since the device measures electrical resistivity and changes in resistivity, the sensor is probably more useful for determining the presence or absence of liquid in the waste. Ionic strength (i.e., salt content) of the liquid will affect electrical resistivity measurements, and would probably be unreliable for accurate moisture determination (unless that waste was homogeneous and the salt concentrations did not vary in the waste).

Vendor(s)/Developer(s): Hogentogler & Co., Inc. is a manufacturer of geotechnical testing apparatus primarily related to the civil engineering professions. The company is presently the largest manufacturer of cone penetrometer equipment, in situ environmental testing equipment for gas and water sampling, and related support vehicles in the United States.

ARA is another manufacturer of geotechnical testing apparatus.

Absolute Criteria

This technology passes all of the absolute criteria with little uncertainty.

Ranking Criteria

Radius of Investigation: 5

The resistivity cone penetrometer can measure near-continuously as it is driven into the waste. The field-of-view is relatively small because of the placement of the electrodes, and would not extend very far from the penetrometer shaft. The device would only sense differences in the waste matrix very close to the cone penetrometer.

Range of Operation: 2

The device can measure resistivity over a wide range, but this is of relatively little value if the measurement cannot be related to percent moisture. Salts and other components in the matrix that affect conductivity adversely influence the accuracy of the moisture content measurements in the range of interest.

Precision/Accuracy: 1

The device can measure resistivity accurately, but can probably only be used reliably to detect the presence or absence of liquid. Changes in measured resistivity could be due to differences in moisture content as well as differences in waste matrix composition.

Ease of Interpretation of Data: 1

Once again, the data can probably show the presence or absence of liquid, but not the percent of moisture by weight or volume present. As a screening tool, this sensor may be useful for finding liquid levels, and distinguishing strata/layers in the waste.

Interferences: 5
Chemical constituents in the waste will affect electrical resistivity measurements.

Deployment Requirements: 9
Technology has already been configured for a cone penetrometer.

Relative Cost: 8

Technology Maturity: 8

Reliability in Environment: 9

Issues/Concerns: For moisture, the device can probably only be used to detect the presence or absence of liquid (i.e., liquid level determination). On preliminary evaluation, a method to obtain quantitative information with this technology for tank waste application is not apparent.

4.3 NEAR-INFRARED REFLECTANCE SPECTROSCOPY (NIRA)

Remote optical spectroscopy, combined with chemometric methods for calibration, has been shown to be very useful for monitoring manufacturing processes. Near-infrared reflectance analysis (NIRA) or spectroscopy has been used commercially to obtain moisture content of materials, molecular weight of organic materials, and other quantitative analyses. The typical operating sequence of a routine instrument for NIRA involves measurement of reflected intensity off a sample surface at a number of wavelengths and off a standard reference reflecting surface at those same wavelengths. The reflectance measurement in practice is a relative measurement to a standard reflector. In the near-infrared, what is "seen" is the result of vibrations of light atoms that have strong molecular bonds. For moisture content, NIRA sees O-H bonds; light is absorbed by O-H bonds, and the reflected wavelength is compared to other parts of the spectra that are used as reference bands. The reflected intensity is related to concentration of O-H bonds which is equated to water content. Moisture Systems Corporation focusses on the 1940 nm and 1430 nm lines for moisture content determination. This technology will require development for direct application to in situ tank waste characterization:

- Feasibility must be established showing that optical measurements from tank waste material can be related to changes in the moisture content. Wavelength regions that are sensitive to the water content of the waste must be identified, and quantitative models must be developed to predict the moisture within an acceptable accuracy range.

- Factors that influence the optical measurements must be characterized (e.g., compositional effects, scattering, refractive index, and matrix effects).

- Feasibility must be established proving remote monitoring within the geometry of the waste tanks.

- Engineering is required to implement the remote monitoring optical system in the tank waste. Issues to consider include design of the sensing system, resolution of environmental effects (head space humidity and scatter), and transfer of the moisture calibration methods from the laboratory to field systems. A significant amount of engineering would also be required to integrate the technology into a delivery system such as a cone penetrometer so that the technology could be applied to more than just the tank surface. Fiber optics is a likely delivery/deployment tool for this technology, and is currently being investigated by developers.

Vendor(s)/Developer(s): WHC is working on an NIRA system for tank waste surface moisture measurements. SAIC has proposed an IR spectroscopy system integrated into a cone penetrometer. Moisture Systems Corporation is a commercial developer and supplier of NIRA systems for near-real-time, in-process moisture determination.

Absolute Criteria

This technology passes all of the absolute criteria, though fiber optics survivability in a radiation environment is a concern.

Ranking Criteria

Radius of Investigation: 4

This technology is a surface point measurement (small surface area interrogated per measurement), and the number of readings needed to obtain a high confidence measurement of moisture content is expected to be high. This technology is good for surface measurements, and will not penetrate very far into the waste away from the sensor.

Range of Operation: 8

Spectroscopic methods could be developed to operate over the range of moisture expected in the tank.

Precision/Accuracy: 7

Though laboratory spectroscopic methods are quite accurate, the accuracy of data obtained remotely from inhomogeneous tank waste of unknown composition is uncertain. For instance, intensity of the light scattered back from a NIRA instrument varies with angle from normal, and diminishes at larger angles. A slight vertical difference in positioning of a sample would result in a difference in the angle observed by the fixed optical components, resulting in a signal that would be difficult to interpret. Proper design of the sensor delivery system would probably resolve these concerns.

Ease of Interpretation of Data: 6

Water spectral lines for NIRA are well known. Uncertainty arises in interpreting the intensity of these lines as they relate to concentration (i.e., percent moisture).

Interferences: 6
In general, absorptions in the near-IR are weak since these absorptions consist of overtones or combinations of fundamentals. However, the absorption of water in either liquid or gas form is very strong. In fact, some of the overtones of water are stronger than direct absorptions of other molecules. However, one concern is variance in sample rheology (e.g., particle size) may affect spectroscopic responses. There are also other OH^- absorptions that overlap the edges of the bands where one sees very strong water absorption.

Deployment Requirements: 4
Developers have considered deployment of NIRA for in situ applications, and fiber optics would probably be used in conjunction with a delivery platform. This approach seems feasible in theory, but has not been actualized yet for in situ tank waste characterization. In a cone penetrometer configuration, a "window" would have to be integrated into the penetrometer so that the infrared light can be delivered to the waste and the reflected wavelengths can be detected.

Relative Cost: 5
In addition to equipment development, a great deal of effort will need to be spent to characterize the factors that affect the spectra, as well as develop chemometric methods to interpret the data.

Technology Maturity: 5
Laboratory and in-process equipment is well developed, but development of this technology for a specialized application like Hanford tank waste has not been accomplished.

Reliability in Environment: 5
Fiber optics will probably be the tool of choice for in situ NIRA, and radiation resistance is an issue. Electronics, detectors, and interpretative tools can probably be located outside the tank, so radiation resistance will be not be an issue for most of the hardware. For a cone penetrometer configuration, the fiber optic will probably not actually contact the waste, so high salt/pH attack will not be a problem.

Issues/Concerns: The maturity of this technology for in situ tank waste application is a concern from the perspective that significant development efforts will be required to validate and implement the technology.

4.4 NEUTRON PROBE (NP)

Moisture measurement using neutron moderation and diffusion is an established technology that has been used extensively in the well logging industry. The technique uses a neutron source and one or more neutron detectors. Neutrons generated by the source are high-energy neutrons. Scattering interactions with the nuclei in the tank material will degrade the energy of the neutron. Very slow-energy neutrons are known as thermal neutrons, and slightly higher-energy neutrons are known as epithermal neutrons. The low-energy neutrons are counted by detectors. Because hydrogen atoms are the most effective at slowing down neutrons, the neutron scattering is a strong function of the surrounding moisture concentration. Techniques describing the use of neutron diffusion to measure moisture in geological formations are well-documented in the literature. The primary difference between moisture measurement in geological formations and Hanford waste tanks is that an in-tank neutron tool must operate effectively in a high-gamma flux environment and within smaller dimensions. The smaller size and higher dimensional accuracy requirements are issues to consider before applying this technique to tank waste. This technique must also account for material compositions (e.g., neutron emitters, poisons, moderators) and geometries that are unique to the waste tanks.

A neutron probe has been used at the Hanford Site to determine the air/liquid or interstitial liquid interface level in waste tanks equipped with liquid observation wells. WHC is developing a probe for use in liquid observation wells that uses boron trifluoride (BF_3) detectors, the most widely used type of detector. BF_3 detectors are reasonably sensitive to thermal neutrons, and can operate in gamma fluxes up to about 100 Rad/hour. Lead shielding would be used to shield these detectors if the gamma field is higher. The most likely source to be used in this system is californium (^{252}Cf).

Vendor(s)/Developer(s): WHC is being funded to develop a neutron probe for tank waste moisture determination. The device will be lowered into liquid observation wells. WHC has investigated the feasibility of adapting a neutron probe for a cone penetrometer configuration. Proof-of-principle experiments were conducted in 1993 to evaluate in-tank neutron diffusion-based moisture monitoring. An existing probe with minor hardware modifications was tested on tank waste simulants, and computer modelling was performed to estimate the accuracy and account for possible interferences and sources of error.

Absolute Criteria

This technology passes all of the absolute criteria, though there would be some concern with safety if a ^{252}Cf source is needed to accurately determine moisture content. Since neutron and other sources are already used in the tank farms, this is of minimal concern. The neutron source will also affect materials in the tank, but is just an additional source of neutrons (already present in some of the tanks).

Ranking Criteria

Radius of Investigation: 7

The geometry of the detectors and source will determine the radius of investigation. This is more a volumetric field-of-view measurement than a point measurement. The radius of investigation is also a function of the tank material, where moisture levels and other absorbers/scatterers strongly affect this geometry. The field-of-view can be reasonably defined by the geometry of the sensor package. However, geometry will affect signal resolution and accuracy, and optimization will be required.

Range of Operation: 8

This technology could operate between 0 and 80 percent water by weight. At the higher end, the signal becomes saturated, and the resolution will be poor.

Precision/Accuracy: 4
With a calibrated standard, the technology will probably meet accuracy requirements. However, in inhomogeneous waste containing some level of hydrocarbons, the precision and accuracy are uncertain. A reasonable accuracy with this technology is +/-5% (e.g., a result of 25% moisture would suggest the material was between 20% and 30% moisture). One factor that will affect the accuracy is the geometry of the source and the detector(s).

Ease of Interpretation of Data: 3
This technology basically senses hydrogen, and a neutron signal will be affected by hydrocarbons. Differentiating between water and hydrocarbon is not possible, though the amount of hydrogen from organics is expected to be much less than the hydrogen from water (in most cases). Another concern with interpretation of data is that this technology will not see density differences. Hence, calibration will be difficult; moisture per unit volume will be easier to estimate than moisture per unit weight.

Interferences: 3
The presence of organics and other neutron moderators/absorbers (e.g., boron) will affect the neutron flux the detectors see. Ambient neutron fluxes will also increase the uncertainty of the moisture content determination, though background flux should be much less than the flux from the source. However, gamma background is expected to be high, and may interfere with accurate neutron counting.

Deployment Requirements: 4
WHC has evaluated the feasibility of adapting the technology for cone penetrometer applications. Equipment development will be needed, and extensive testing and validation will be required. In high gamma fields, which are characteristic of many of the tanks, lead shield may be required to reduce interferences and false signals. This will be very difficult, if not impossible, to engineer into a cone penetrometer delivery system.

Relative Cost: 7
Similar technology has been used in the tanks (liquid observation wells), but equipment development and validation will be required to integrate the technology into a cone penetrometer configuration. The use of a radioactive source will also complicate equipment design, and would be expected to be more expensive than equipment that does not utilize radioactive sources.

Technology Maturity: 7
Neutron backscatter and detection technologies are relatively well-developed, and WHC is developing a similar system for deployment in liquid observation wells. There are still concerns with data interpretation and validation with this technology.

Reliability in Environment: 9
The sensor is not very susceptible to radiation damage.

Issues/Concerns: None

4.5 FISSION ION CHAMBER DETECTOR (FICD)

SAIC has proposed the development of a fission ion chamber detector for use with a cone penetrometer to determine moisture content of tank waste in situ. Essentially another thermalized neutron counting technology, the fission chamber is an ion chamber detector lined with a thin layer of ^{235}U for the detection of fission products produced by thermal neutrons, or ^{238}U for the detection of neutrons with energies above 1 MeV. Neutrons which interact with the uranium lining produce energetic fission particles which are stopped and detected within the gas medium. The signal produced is extremely large and well separated from those created by Compton scattered electrons, which are produced by interacting gamma-rays. Hence, the fission chamber is very insensitive to gammas. Fission chambers can be made in various lengths and diameters less than 1/2-inch, and require about 500 volts to operate, and can operate in temperatures above 100 C. The sensor (or sensors) would be located in the end of the penetrometer, just above the cone, and a profile of the neutron count rate along the tank height would be collected both as the probe is lowered into the tank and as it is retrieved.

For moisture content, the neutron detectors will detect ambient neutrons, or neutrons scattered from a neutron source, located within the penetrometer. The number of thermal neutrons detected will be related directly to the porosity (fraction of empty space within the material) and amount of water (percent by volume) within the waste. The neutron flux at the fission chamber as a function of water content can be estimated from measurements made in the development of compensated neutron porosity sensors for borehole inspections. Typically, these sensors (referred to as sondes) are comprised of a ^{252}Cf source and two ^{3}He proportional counters for detecting the neutrons thermalized within the surrounding material under investigation. A second technique for estimating moisture content would be to detect 2.2 MeV gammas emitted from the absorption of thermal neutrons by protons within the water. Since 2.2 MeV gammas are well separated from the predominant 0.66 MeV ^{137}Cs gamma-rays emitted from the waste, this method appears feasible. If background is too low, a low-level neutron source (^{252}Cf) can be used to enhance the background thermal neutron flux.

Vendor(s)/Developer(s): SAIC has proposed development of an FICD for in situ tank waste characterization applications.

Absolute Criteria

This technology passes all of the absolute criteria, with the caveats noted in the neutron probe section.

Ranking Criteria

Radius of Investigation: 7
Same as neutron probe.

Range of Operation: 8
Same as neutron probe.

Precision/Accuracy: 4
With a calibrated standard, the technology will probably meet accuracy requirements. However, in inhomogeneous waste containing some level of hydrocarbons, the precision and accuracy are uncertain. A reasonable accuracy with this technology is +/-5% (e.g., a result of 25% moisture would suggest the material was between 20% and 30% moisture). One factor that will affect the accuracy is the geometry of the source and the detector(s).

Ease of Interpretation of Data: 3
Same as neutron probe.

Interferences: 4
This technology is not as sensitive to gamma radiation interferences as BF_3 neutron probes.

Deployment Requirements: 6
This proposed SAIC technology will fit into a cone penetrometer configuration, though equipment development will be needed to realize this.

Relative Cost: 6
SAIC's technology is straightforward in theory, but will require equipment development and validation. The use of a radioactive source will also complicate equipment design, and would be expected to be more expensive than equipment that does not utilize radioactive sources.

Technology Maturity: 6
Neutron backscatter and detection technologies are relatively well-developed, but engineering will be required to adapt the technology to a cone penetrometer delivery platform.

Reliability in Environment: 9
Same as neutron probe.

Issues/Concerns: NONE

4.6 COPPER FOIL THERMALIZED NEUTRON SENSOR (CFTN)

A technology similar to the fission ion chamber in the sense that thermalized neutrons are counted and related to moisture content. In this method, ^{63}Cu is converted to ^{64}Cu by neutron irradiation, and the foils are than removed and neutron counts are made in a laboratory. Hence, this is not a real-time method. The main advantage of this method is that the copper foil is now affected by high gamma fields.

Evaluation of the absolute and ranking criteria will be almost the same as the fission ion chamber detector.

Vendor(s)/Developer(s): Battelle Pacific Northwest Laboratory

Absolute Criteria

This technology passes all of the absolute criteria. In fact a neutron probe has been and is currently being used in the Hanford Site tank farms to determine the air/liquid or interstitial liquid interface level in the waste tanks equipped with liquid observation wells.

Ranking Criteria

Radius of Investigation: 7
Same as neutron probe.

Range of Operation: 8
Same as neutron probe.

Precision/Accuracy: 4
Same as neutron probe.

Ease of Interpretation of Data: 3
Same as neutron probe.

Interferences: 4
Copper foil is not affected by high gamma fields like gas-filled boron trifluoride counters.

Deployment Requirements: 2
Though the equipment to deploy the equipment is not expected to be all that complicated, the equipment will need to be deployed multiple times to obtain readings at different layers. This method may be best suited for liquid observation well deployment rather than configured with a cone penetrometer.

Relative Cost: 2
Since the method is not truly in situ, costs are expected to be higher because of radioactive sample handling, laboratory analysis, and multiple equipment deployments for moisture/depth profiles.

Technology Maturity: 4
Technology is mature, but deployment of the technology in the intended configuration and application need to be demonstrated.

Reliability in Environment: 9
Same as neutron probe.

Issues/Concerns: Because the method is not real-time characterization, the logistics of performing multiple penetrations to obtain moisture/depth profiles may be impractical.

4.7 ELECTRICAL CONDUCTIVITY CELL (ECC)

For soil moisture applications, fiberglass or gypsum blocks are placed in the soil. The blocks are specially prepared; for instance, the fiberglass is specially prepared to have micro-cracks that are well characterized and reproducible. Moisture migrates into these cracks. When an equilibrium is established, the moisture in the sensor block is proportional to the moisture in the surrounding soil. The moisture in the sensor block affects the block's (or cell's) electrical conductivity. Hence, the electrical conductivity of the cell is then a function of the moisture content of the soil. This type of sensor is a continuous monitoring probe; for soil moisture applications, electrical conductivity cells can be placed in the soil, and wiring send a signal to data acquisition equipment on the surface.

The applicability of this technology to in situ tank waste moisture determination is unknown, and further investigation is required to fully evaluate this technology. Absolute and ranking criteria evaluation are preliminary only.

Vendor(s)/Developer(s): ELE International/Soiltest Products Division

Absolute Criteria
On initial evaluation, this technology passes all of the absolute criteria. However, since this technology has been used primarily in soils, adaptation to tank waste environment is unknown. The main concern is whether a conductivity cell can survive in the harsh environment (i.e., high pH and high radiation fields) of the Hanford tanks.

Ranking Criteria
Radius of Investigation: 5
A conductivity cell will come into equilibrium with the material surrounding this. The volume of material is uncertain, and the effects of inhomogeneity have not been quantified. The rating of 5 is assigned because ECC performs as well as other sensors that contact the waste directly (e.g., resistivity cone penetrometer).

Range of Operation: 7
Calibrated for soils, the probes can operate in saturated soil; whether this range would apply to tank waste application is uncertain.

Precision/Accuracy: 3
The precision/accuracy will depend on the calibration. If the waste in not homogeneous, then waste with different electrical conductivities will not be discriminated by the probe.

Ease of Interpretation of Data: 2
The ECC data can be directly related to moisture only if the cell is well calibrated to the matrix which the sensor is located (i.e., calibrated to the tank waste in which it will be deployed). Since this is unlikely for in situ tank waste characterization, relating electrical conductivity measurements directly to moisture content of the waste is difficult.

Interferences: 1
In addition to accounting for inhomogeneity of the waste, another concern is the variation in ionic strength of liquid in the tanks. Moisture in the waste will contain dissolved salts which will affect the electrical conductivity of the interstitial liquid that would migrate to the ECC.

Deployment Requirements: 8
ECC does not appear to be difficult to integrate into a cone penetrometer delivery system. The size of soil moisture cells are very small, and can probably be reduced to an appropriate size.

Relative Cost: 8
This technology is well developed, and currently deployed extensively for soil monitoring. Price per unit is very low, but the cost to adapt the technology for in situ tank waste characterization will increase the overall costs.

Technology Maturity: 7
The technology is well developed since it is already being applied to soil monitoring. However, adapting and demonstrating the technology for in situ tank waste characterization will be required.

Reliability in Environment: 5
ECC survivability in a radiation field or high pH environment is uncertain.

Issues/Concerns: Not enough is known about this technology to be able to properly evaluate is at this time.

NOTE: There are some other concepts that are in too early of a stage of development to evaluate, including two Battelle concepts: eddy current measurement (specialized impedance sensing) and a freezing concept (thermal diffusion measurement).

5.0 EVALUATION/RANKING

The summary evaluation follows. Numbers in parentheses are the individual technology scores for each criteria based on the rank of importance (RI). The criteria score is obtained by multiplying the RI number for each criteria by its ranked value (scale 1 to 10). Total scores are the sum of all of these criteria scores.

TECHNOLOGY=======>	TDR	RCPT	NIRA	NP	FICD	CFTN	ECC
CRITERIA							
Radius of Investigation (RI=8)	5 (40)	5 (40)	4 (32)	7 (56)	7 (56)	7 (56)	5 (40)
Range of Operation (RI=9)	8 (72)	2 (18)	8 (72)	8 (72)	8 (72)	8 (72)	7 (63)
Precision/ Accuracy (RI=10)	2 (20)	1 (10)	7 (70)	4 (40)	4 (40)	4 (40)	3 (21)
Ease of Interpretation of Data (RI=5)	1 (5)	1 (5)	6 (30)	3 (15)	3 (15)	3 (15)	2 (10)
Interferences (RI=8)	2 (16)	5 (40)	6 (48)	3 (24)	4 (32)	4 (32)	1 (8)
Deployment Requirements (RI=5)	8 (40)	9 (45)	4 (20)	4 (20)	6 (30)	2 (10)	8 (40)
Relative Cost (RI=2)	6 (12)	8 (16)	5 (10)	7 (14)	6 (12)	2 (4)	8 (16)
Technology Maturity (RI=4)	5 (20)	8 (32)	5 (20)	7 (28)	6 (24)	5 (20)	7 (28)
Reliability in Environment (RI=6)	9 (54)	9 (54)	5 (30)	9 (54)	9 (54)	9 (54)	5 (30)
Total Score=========>	279	260	332	323	335	303	256

TDR = Time Domain Reflectrometry
RCPT = Resistivity Cone Penetrometer
NIRA = Near Infrared Reflectance Analysis/Spectroscopy
NP = Neutron Probe (BF_3 detectors with ^{252}Cf source)
FICD = Fission Ion Chamber Detector
CFTN = Copper Foil Thermalized Neutron Sensor
ECC = Electrical Conductivity Cell

6.0 CONCLUSIONS & RECOMMENDATIONS

Based on the ranking criteria, the fission ion chamber detector and the near-infrared reflectance spectroscopy technologies appear to be the best-suited for in situ tank waste moisture characterization. The neutron probe (utilizing BF_3 detectors) also rated high. The configuration of the probe to fit into a cone penetrometer is uncertain due to shielding requirements to reduce gamma interferences. The resistivity cone penetrometer and the electrical conductivity cell do not appear to be suited for this application, mainly because the dependence on accurate calibration is too great.

Laboratory analysis (by either drying/weighing or spectroscopic analysis are the best methods for determining moisture content of Hanford wastes. The primary concerns with all of the identified potential technologies for in situ tank waste applications is the uncertainty in interpreting data. Resolving errors and uncertainties due to the effects of interferences, geometry, etc. present significant challenges. Validation and verification of the performance of any of these technologies for tank waste application will be rigorous.

7.0 REFERENCES

Advances in Environmental Sensors and Monitoring: Technologies and opportunities to meet changing government regulations, Technical Insights, Inc., 1991.

Borman, Stuart A., editor, *Instrumentation in Analytical Chemistry 1982-86*, American Chemical Society, 1986.

Brodzinski, Dr. Ron L., *Copper Activation Method for Moisture Measurement*, presentation material presented to TIAP, dated July 13, 1993.

Campbell Scientific, Inc. Technical Literature Package, dated 1994.

ELE International, Technical Literature Package, dated 1994.

Hogentogler & Co., Inc., Technical Literature Package, dated 1994.

Ritter, Glenn A., *Feasibility Study for Penetrometer-Based Static-Source Neutron Probe*, Internal Memo (not numbered), Westinghouse Hanford Company, dated November 15, 1993.

Sandia National Laboratories, draft Technical Literature, dated March 1994.

SAIC, Technical Literature Package, dated 1994.

Toffer, Hans, *Potential of Estimating Moisture Content in Waste Tanks Using the Existing Neutron Probe*, Supporting Document #WHC-SD-WM-RPT-037 Rev. 0, dated July 29, 1992.

Veltkamp, Dr. David (University of Washington), *CPAC Moisture Study: Phase 1 Report on the Study of Optical Spectra Calibration for Moisture*, Supporting Document #WHC-SD-WM-ER-288 Rev. 0, Westinghouse Hanford Company, no date available.

Watson, W. Todd, et al, *Using an Active Neutron Probe for Moisture Concentration Monitoring of Hanford Site Waste Tanks*, Supporting Document #WHC-EP-0695, Westinghouse Hanford Company, no date available.