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Revision 0

Engineering Evaluation of Alternatives:

Technologies for Monitoring Interstitial Liquids in Single-Shell Tanks

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Westinghouse
Hanford Company Richland, Washington

Management and Operations Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

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ENGINEERING EVALUATION OF ALTERNATIVES: TECHNOLOGIES FOR MONITORING INTERSTITIAL LIQUIDS IN SINGLE-SHELL TANKS

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ENGINEERING EVALUATION OF ALTERNATIVES: TECHNOLOGIES FOR MONITORING INTERSTITIAL LIQUIDS IN SINGLE-SHELL TANKS

1.0 OBJECTIVE

To identify technologies that can accurately and reliably monitor changes in the quantity of interstitial liquids in single-shell tanks (SST).

1.1 BACKGROUND AND SCOPE

Since 1944, radioactive wastes generated from processing irradiated uranium fuels on the Hanford Site have been stored as alkaline slurries in underground tanks. Between 1943 and 1964, 149 SSTs were built to store radioactive wastes. These SSTs are located in 12 tank farms. Each tank farm contains 4 to 18 tanks and are located in the 200 West and 200 East Areas on the Hanford Site.

The SSTs are carbon-steel lined, domed, cylindrical, reinforced concrete structures. Steel liners cover the sides and bottom, but not the domed top of the tank. The capacity of the SSTs range from 55,000 to 1,000,000 gal, and are 20 or 75 ft in diameter. Tank wall heights vary between 18 to 32 ft. The top of all the tanks are a minimum of 6 ft below the earth surface for shielding purposes.

Inside the tanks is a complicated mixture of discarded hardware, disposed chemicals, radioactive process materials, and decontamination wastes. Numerous vertical pipes (risers) penetrate the dome, and equipment extends into the tank to various depths through these vertical risers. The diameters of risers vary in size, from 4 to 42 in. to permit equipment (e.g., pumps, instruments, air circulators) to be placed inside the tank.

Wastes stored in SSTs consist of various combinations of solids, sludges, slurries, salt cake, and liquids. One-hundred and six SSTs have been interim stabilized (Frater 1993) (i.e., supernate and pumpable liquid have been removed). Forty-three of the SSTs remain to be interim stabilized.

The majority of Hanford SST wastes were generated by three chemical processing operations, the Bismuth Phosphate process, the reduction oxidation (REDOX) process, and the plutonium uranium extraction (PUREX) process. These processes were primarily designed to recover plutonium. The REDOX and PUREX processes also recovered uranium and neptunium. A fourth process, Tributyl Phosphate, was used to recover uranium from the Bismuth Phosphate process wastes. Other wastes generated by ancillary operations include 300 Area Laboratory waste; 100, 200, and 400 Area decontamination wastes; N-Reactor wastes; B-Plant wastes (isotopes separation); evaporator bottom wastes; and Z-Plant wastes.

Liquid waste was accumulated in SSTs until 1980, when double-shell tanks (DST) became available for storing newly generated waste. Currently, there are approximately 37 million gal of waste stored in SSTs (Anderson 1990) on the Hanford Site. Waste volumes in SSTs vary from 5% to 95% of tank capacities. Waste levels in the fullest tanks are 1 to 1-1/2 ft below the top of the shell liner.

Waste in SSTs primarily consist of sodium salts of hydroxide, nitrate, nitrite, carbonate, aluminate, phosphate, and hydrous oxides of iron and manganese (Anderson 1990). The radioactive component mostly consists of fission products (e.g., Strontium-90 and Cesium-137) and actinide metals such as uranium, plutonium, and americium. The wastes have a high pH (~12) to protect the carbon steel liners.

The solids in SST wastes consist of sodium carbonates, iron and manganese precipitates, steel tapes, diatomaceous earth, cement, sand, rocks, failed tank internals, fuel elements, pump heads, tools, railroad ties, and other solid scrap (Krieg 1991). Sludges primarily consist of iron, manganese, and aluminum precipitates. Sludges vary greatly in physical properties and may contain pockets of liquid. Salt cake constitutes the largest part of the waste and consists primarily of sodium nitrate. Damp salt cake appears jelly-like, while dried salt cake is a hard, abrasive, brittle material and can exist in large single crystals. Past cooling of hot tanks has caused preferential encrustation of waste around air circulators and other in-tank equipment to form large "lollipops" that weigh up to 20 tons. Tank walls have also become encrusted. Liquids existing in tanks are mostly sodium hydroxide and nitrate mixtures. Plutonium and other transuranic elements are largely found in the solid/sludge phase, along with Strontium-90. The liquid phase contains high concentrations of Cesium-137.

Liquids have largely been removed from wastes stored in SSTs and pumped to DSTs. The purpose of the liquid reduction program (i.e., interim stabilization) is to prevent or limit potential liquid releases from SSTs while the wastes are being stored preparatory to recovery, processing, and disposal in a manner similar to the DST wastes. Since DST space is limited, it must be carefully conserved to meet current Hanford plant operational and cleanup requirements while continuing to store older wastes. Residual liquids stored in SSTs are pumped to DSTs as space becomes available. In managing SSTs, those determined to be leaking receive priority pumping to prevent or mitigate negative environmental impacts. Early detection of leaking SSTs is of paramount importance if the mitigation process is to be effective. Detection of liquid leaks with current SST instrumentation is difficult, time consuming, and inaccurate. Food Instrument Corporation (FIC) gauges and manual tapes measure the liquid surface level in tanks and are incapable of monitoring interstitial liquids. Studies are underway to replace SST surface level measuring devices.

Salt cake and sludges contain liquids trapped in their void and/or interstitial spaces. Interstitial liquid levels in SSTs are currently detected with the liquid observation well (LOW) system. The LOW system consists of a fiberglass well that is placed deep within the waste through which neutron and/or gamma probes are passed. Data from these instruments together can provide a rough approximation of the liquid level in the waste if interpreted correctly. Attempts to automate the data collection and interpretation have had limited success.

Potential interstitial liquid detection devices are investigated in this report to improve the ability to measure SST interstitial liquids, detect their loss, and improve the ability to interface with modern data acquisition systems. Candidate technologies were identified, screened, and ranked for potential application in SSTs. More in-depth investigation and testing of the best candidate technologies are recommended.

1.2 PURPOSE AND NEED

To improve performance consistent with state regulatory codes (WAC 173-303-640-7-D-ii), supernate and interstitial liquids stored in SSTs require reliable, accurate, and frequent monitoring. Leaks must be detected early enough for mitigative actions to be effective. Measurements have been made difficult by the removal of most of the liquids from SSTs. Various combinations of solids, sludges/slurries, salt cake, and liquids have formed within the SSTs to produce a plethora of physical conditions that are extremely difficult to measure and interpret. Significant quantities of liquid can be released to soils from many SSTs before a leak can be confirmed.

A global search was conducted for this study to identify all monitoring technologies that might be used to detect leakage of interstitial liquids from SSTs. These technologies are evaluated, screened, and ranked for potential use in monitoring SST interstitial liquids. Cost estimates for the two top-ranked technologies, hydrostatic tank gauging (HTG) and thermal differential, and for the currently operating LOW system, are presented in Appendices C, D, and E, respectively. Recommendations are made for testing the technologies that best meet the study selection criteria. Study findings also may be applicable to liquid surface detection, although it is not the primary focus of this report.

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2.0 SUMMARY

A global search of mature, emerging, and conceptual tank liquid monitoring technologies, along with a historical review of Hanford tank farm waste monitoring instrumentation, was conducted to identify methods for gauging the quantity of interstitial waste liquids contained in Hanford SSTs. Upon completion of the search, an initial screening of alternatives was conducted to identify candidates which might be capable of monitoring interstitial tank liquids. The nine candidate technologies that were selected, evaluated, and ranked are summarized in Table 6-1. One additional technology was selected but not ranked (see Section 6.10). Cost estimates for the two highest ranked technologies, HTG and thermal differential, and for the currently operating LOW system, are presented in Appendices C, D, and E, respectively.

There are three principal approaches for gauging the quantity of process materials contained in tanks: level (or volume) measurement, mass measurement, and imaging. Of the three principal approaches, mass measurement is the best technology for quantitative leak monitoring. Examples of mass-based technologies include weighing, hydrostatic techniques, and buoyancy techniques. Level measurement techniques cannot provide quantitative measurements of the SSTs because of the extremely heterogeneous and complex nature of the wastes. That is, during static tank operation, tank leaks do not necessarily result in level changes, nor are level decreases necessarily indicative of tank leaks. Current imaging techniques are also incapable of quantitative tank gauging. Imaging techniques lack the sophistication necessary for quantitative measurements, but may be capable of providing qualitative three-dimensional "maps" or "pictures" of tank wastes.

No single technology can be used to accurately gauge interstitial liquids for all the Hanford SSTs. However, HTG holds the most promise as a generally applicable gauging technology. Hydrostatic tank gauging is a mass-based technique that ranked highest among the tank monitoring technologies evaluated (see Figure 5-5). An HTG system has no moving parts, can be constructed with commercially available parts, is capable of continuous monitoring, is intrinsically safe, and can potentially gauge a one-million gal tank with a relative accuracy of ±500 pounds. HTG is a contacting technique and operational problems could be experienced if severe probe coating occurred. HTG relies on hydrostatic pressure to measure mass and, therefore, could experience difficulties monitoring wastes with very high solids content (or tank wastes with significant nonNewtonian behavior). However, designing, constructing, testing, installing, and operating an HTG device capable of gauging a significant number of Hanford SST wastes with reasonable accuracy and reliability should be straightforward. Definitive HTG instrument design is beyond the scope of this report.

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3.0 CONCLUSIONS AND RECOMMENDATIONS

There are three principal approaches for gauging the quantity of process materials contained in tanks: level (or volume) measurement, mass measurement, and imaging. With the exception of bubblers, mass-based tank gauging technology is not currently employed in the Hanford SSTs. Imaging (i.e., photography and closed-circuit television (CCTV) has been used extensively at Hanford, but not for tank gauging. Unfortunately, because of the extremely heterogeneous and complex nature of Hanford SST wastes, neither level measurement, nor imaging techniques are capable of providing quantitative process material monitoring. Quantitative measurement of the amount or mass of material contained in Hanford SSTs will require the implementation of a mass-based tank gauging system.

Hydrostatic tank gauging is the technology generally recommended for gauging the quantity of process materials contained in Hanford SSTs. HTG is a mass-based technique that has the capability for continuous remote monitoring. HTG has the advantages of no moving parts, intrinsic safety, and potentially gauging a one-million gal tank with a precision of approximately ±500 pounds (i.e., ±62 gal of water or ±0.02 in. of level in a 75 ft diameter tank). HTG is relatively inexpensive and probe design, construction, testing, installation, and operation should be straightforward. HTG should be configured as part of a hybrid tank gauging system (see Section 6.10). A hybrid system employs two or more independent measurement systems which function in concert to provide redundancy, improved accuracy, and maximum information at minimum cost. An excellent hybrid system choice for monitoring interstitial liquids in SSTs might be the combination of HTG with thermal differential technology.

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4.0 UNCERTAINTIES

Assumptions made during the study are described in Section 5.2. If a technology had any potential to gauge interstitial liquids, it was evaluated and ranked. The uncertainty as to whether a candidate technique could be made to work in an SST increased significantly in moving from mature and emerging to conceptual technologies. Cost estimate confidence followed a similar trend. Since the purpose of this study is to identify and rank candidate technologies (not specific instruments) relative to one another, the absolute uncertainty for each candidate technique was not quantified. More definitive engineering studies, involving instrument design and tests, will need to be performed to define the technical specifications and performance characteristics for a candidate interstitial liquid monitoring device.

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5.0 DESCRIPTION OF ALTERNATIVES AND SOLUTIONS

A review of emerging and conceptual technologies for monitoring the quantity of process materials in SSTs was conducted. Technologies were evaluated for having potential to monitor interstitial liquids in SST wastes based on the best available information, and assumptions listed in Section 5.2. Technologies considered and selected as candidates were reviewed according to the criteria in Section 5.1. The selected candidate technologies, and all the other technologies that were reviewed, are presented in Section 5.3.

5.1 CRITERIA

Selection criteria were established to evaluate the potential advantages and disadvantages of selecting a given liquid monitoring technology for the Hanford SSTs. The criteria are listed in this chapter. The criteria are not all inclusive or detailed. They represent a wide range of safety, regulatory, cost, schedule, technical, and operations issues relevant to Hanford tank waste storage. Each criterion was weighted from 1 to 5 in order of importance relative to the other criteria. A weight factor of 5 had the highest importance, and 1 had the lowest.

Table 5-1. Selection Criteria Weight Factor Definitions.

Importance	Weight factor
Low	1
Low/Medium	2
Medium	3
Medium/High	4
High	5

Score factors were given to the selection criteria for each monitoring technology. Score factors reflect the estimated impact on the selection criteria. A score factor of 5 had the highest impact, and a score factor of 0 had the lowest.

Table 5-2. Selection Criteria Score Factor Definitions.

Impact	Score
None	0
Light	1
Light/Moderate	2
Moderate	3
Moderate/Heavy	4
Heavy	5

An interstitial liquid monitoring technology's impact score multiplied by the relative importance weight determines its total weighted score. The higher the total weighted score, the less favorable the monitoring technology.

5.1.1 Safety

Safety concerns include public safety, worker safety, potential environmental impacts associated with instrument installation and operation, waste safety, and tank integrity. Safety concerns were given the highest weight factor (5).

5.1.1.1 Public Safety. Environmental releases to air, soil, and ground water, associated with the installation and operation of interstitial liquid monitoring instrumentation, which could potentially affect the public were considered. Public safety issues associated with instrumentation installation and operation are generally considered negligible for the selected interstitial tank monitoring technologies.

5.1.1.2 Worker Safety. Worker safety involves estimating the potential for industrial accidents, accidental exposure to waste materials, and routine radiation doses associated with a given tank monitoring technology; and gauging the severity of these events with respect to worker health.

5.1.1.3 Environmental Safety. The potential for and magnitude of releases of hazardous and/or radioactive materials to the environment from installation and operation of interstitial liquid monitoring instrumentation were considered. Environmental safety issues are generally considered negligible for the interstitial tank monitoring technologies selected.

5.1.1.4 Waste Safety. Several unresolved safety issues are associated with Hanford SST wastes. Three primary waste safety issues addressed for ranking the interstitial liquid monitoring instrumentation were hydrogen/flammable gas generation, ferrocyanide stability, and criticality.

- Hydrogen/Flammable Gas Generation and Organics

  A number of high-level waste tanks may generate flammable gases (i.e., hydrogen, organics, and/or nitrous oxide) (Crippen et al. 1993). The potential for fire and radioactive/hazardous materials release exists in these tanks. An unfiltered release could also occur in the event of overpressurization of a tank ventilation system during periodic gas venting episodes.

- Ferrocyanide Stability

  Twenty SSTs may contain enough ferrocyanide precipitates to present reactive chemical safety concerns (Simpson et al. 1993). The standard enthalpy change for oxidation of sodium-nickel-iron-ferrocyanide to carbon dioxide paired with the reduction of sodium nitrate to diatomic nitrogen is estimated to be -3050 kJ/gmol, which is a relatively large release of energy. If this reactive potential was released quickly in tanks with significant ferrocyanide concentrations, a serious reactive chemicals incident could result. Examples of serious reactive chemicals incidents include ignition of organic waste components, uncontrolled venting of head space gases, and deflagration or detonation of tank wastes. Elevated temperatures promote the ferrocyanide reaction. The ferrocyanide reaction begins to progress appreciably at temperatures exceeding 220 °C. Exothermic radiolytic phenomena occur in several Hanford SSTs. If SST wastes become dry, the ability for them to dissipate the heat generated by radiolytic phenomena is diminished. Therefore, SST waste drying is a concern in tanks containing significant amounts of ferrocyanide wastes.

- Criticality

  Analytical results from SST core samples consistently show fissile material concentrations that are at least an order of magnitude lower than the 1 g/L allowed by the criticality prevention specification; however, few tanks have been sample-cored. Installation and operation of a liquid monitoring system are not expected to affect criticality.

5.1.1.5 Tank Integrity. Hanford SSTs have exceeded their original design life. Available information on the physical condition of SST structures is limited (Anderson 1990). For the purpose of this study, it was assumed that any internal or external tank wall or tank floor penetration would not be considered. Potential structural integrity concerns associated with installation and operation of liquid monitoring devices involve issues related to riser access and field operations at or around underground storage tanks.

5.1.2 Regulatory Compliance

The ability of selected interstitial liquid monitoring systems to meet Washington Administrative Code (WAC) "Dangerous Waste Regulations" is the principal regulatory concern. WAC 173-303-640-7-D-ii (1991) requires that a release of tank waste in excess of one pound, which is not immediately contained and cleaned up within 24 hours, be reported to the Washington State Department of Ecology. No internal tank monitoring techniques are capable of providing the required degree of accuracy for the Hanford SSTs with complex, inhomogeneous contents. However, in the interest of providing best available technology options, the selected candidates were evaluated for mitigative response capabilities. The selected technologies were judged on response time (real time measurement capabilities), data logging capabilities, system accuracy and precision, automated response capabilities, and ease of data interpretation. Regulatory compliance was estimated to be of slightly less importance than safety, and was given a weight factor of 4.

5.1.3 Cost

Interstitial liquid monitoring technology costs were evaluated in a cursory manner. Cost ratings were based primarily on research, development, and implementation costs. Research and development costs include requirements for developing the principle of operation, the instrument design, and instrument testing. Implementation costs include procurement, installation, operation, and maintenance. Costs were given a weight factor of 2.

5.1.4 Schedule

Interstitial liquid monitoring technology scheduling issues were evaluated. Schedule ratings were based on research and development schedule requirements and implementation schedule requirements. Research and development schedule requirements include time to develop the principles of operation, instrument design, and instrument testing. Implementation schedule requirements include time for procurement, installation, operation, and maintenance. Schedule was given a weight factor of 3.

5.1.5 Technical Feasibility

The technical feasibility of each selected interstitial liquid monitoring technology was evaluated. Technical feasibility ratings were based on issues related to research and development, testing, installation, adaptability, and accuracy. Research and development technical feasibility include the complexity of the principle of operation and instrument design. The technical feasibility of testing considers verification of operating principles, calibration requirements, and computer model development. The technical feasibility of installation considers the number and complexity of required instrument subsystems, tank access requirements, and utility tie-in requirements. Adaptability considers the ability of an instrument to monitor a variety of different waste types, and the flexibility of its data acquisition system. Accuracy considers the ability of a selected instrument to precisely measure changes in SST interstitial liquids. Technical feasibility was given a weight factor of 4.

5.1.6 Maintainability and Operability

The maintainability and operability of each selected interstitial liquid monitoring technology were evaluated. Maintainability and operability ratings were based on instrument accessibility, reliability, and ease of calibration and operation. The maintainability and operability criteria were given a weight factor of 3.

5.1.7 Selection Criteria Weight Factors

Engineering judgement and experience were used to determine the relative importance of each selection criterion. The six-member evaluation team gave safety the highest weight. Regulatory compliance and technical feasibility were also considered extremely important. The selection criteria are not truly independent of one another. Safety can always be increased by adding cost and schedule at an increasingly lower benefit to cost ratio. Similarly, other selection criteria scores may be altered up or down to the detriment or enhancement of other criteria. While performing this preliminary screening, the evaluation team assumed that a balanced approach would be used to trade off potential benefits and costs, and that this evaluation would identify the most promising potential technologies for monitoring SST interstitial liquids.

The impact importance (weight factor) for each of the selection criteria is shown in Table 5-3.

Table 5-3. Selection Criteria Weight Factors.

Criteria	Weight factor
Safety	5
Compliance with Regulations/Laws	4
Cost	2
Schedule	3
Technical Feasibility	4
Maintenance/Operations	3

5.2 ASSUMPTIONS

During the preparation of this study, assumptions were made regarding the intended use of the liquid monitoring devices and data acquisition systems, SST waste storage conditions, and the basis of study evaluations that influence the evaluation and ranking process. Major assumptions include the following:

1. Liquid monitoring devices have potential for measuring changes in the volume or mass of interstitial liquids.
2. Instruments and equipment in direct contact with the waste are not removed from an SST. Small or portable components that can easily be decontaminated in situ are an exception.
3. Monitoring devices do not penetrate the bottom, walls, or dome of a tank. Existing risers in the dome are used or, if required, a new riser is installed in the dome.
4. Conceptual monitoring technologies are assumed to work in principle until testing proves otherwise.
5. Tank farms have electrical and water distribution systems but do not have instrument air.
6. SSTs have restricted access, i.e., radiation zones that impact all instrument calibration, maintenance, and operational activities.
7. A monitoring device should be capable of interfacing with a state-of-the-art remote data acquisition and collection system.
8. SST wastes consist of various mixes of solids, sludges, slurries, salt cake, and high pH liquids with different chemical compositions (e.g., nitrates, nitrites, phosphates, carbonates, hydroxides, silicates, etc.).

5.3 DESCRIPTION OF MASS, VOLUME, AND IMAGE-BASED LIQUID MONITORING TECHNOLOGIES

An exhaustive review of mature, emerging, and conceptual technologies for monitoring the quantity of process materials in tanks was conducted, and a historical summary of Hanford tank farm waste monitoring instrumentation was compiled. The candidate technologies were evaluated for potential to monitor interstitial liquids in Hanford SST wastes based on available information and the assumptions listed in Section 5.2 of this report. Because of the extremely heterogeneous nature of Hanford SST wastes, monitoring technologies based strictly on level and/or volume are not recommended.

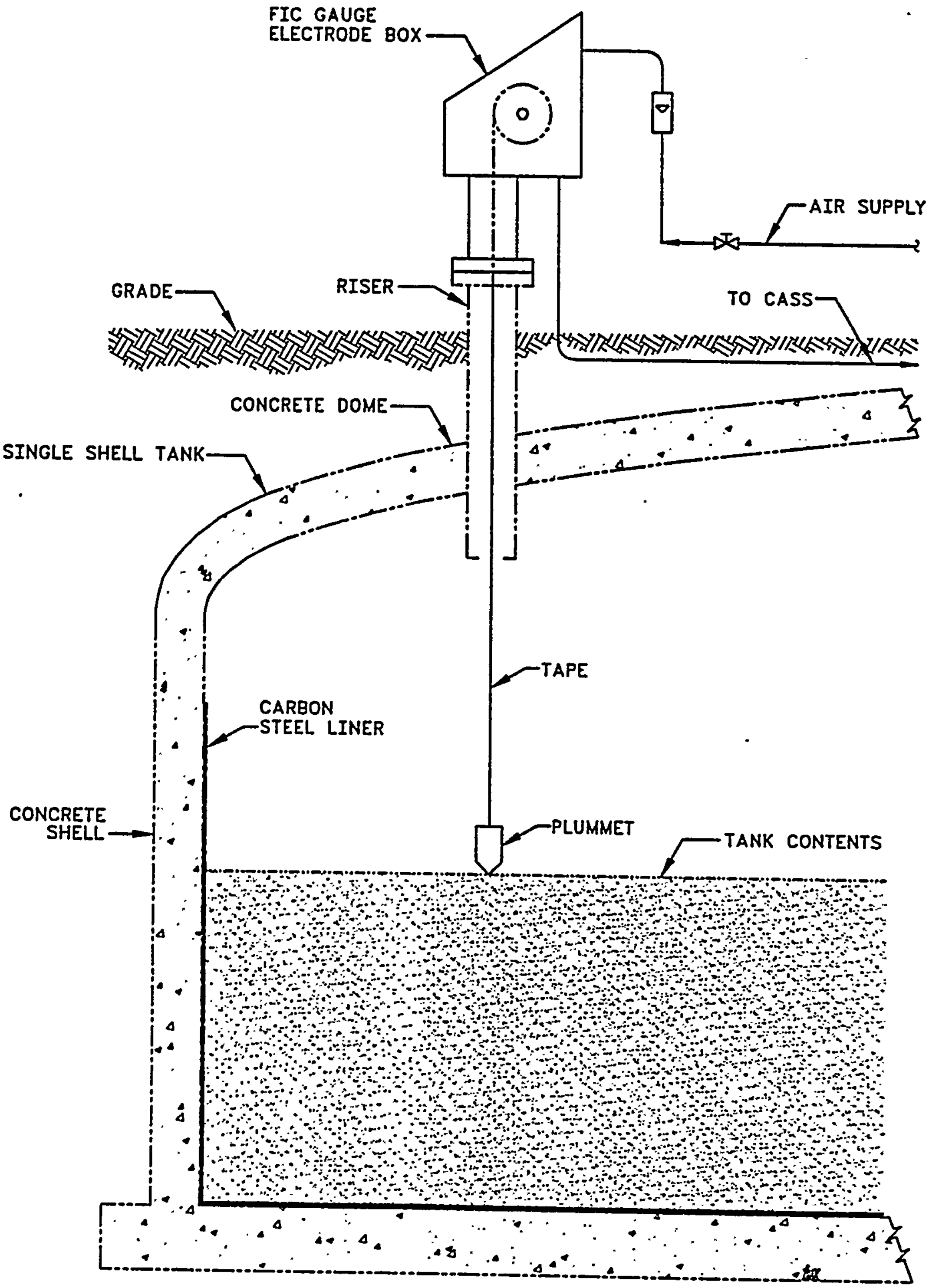
Ten candidate technologies were selected for interstitial liquid monitoring of Hanford SST wastes. The Hanford LOW monitoring system was evaluated because it has capability to monitor interstitial liquids. Since the LOW system is currently operating at the Hanford SST farms, it functions as a baseline for comparison of other selected candidate technologies. Three mature in-tank liquid monitoring technologies were selected as candidates: high-performance bubblers, HTG systems, and fixed radiation level detectors. High-performance bubblers and HTG systems are mass-based monitoring technologies that have the distinction of being the selected candidates with the highest accuracy (precision). Fixed radiation level detectors were selected because they provide interstitial liquid monitoring capabilities similar to the LOW system. Hybrid tank gauging and thermal differential probes were selected as emerging technology candidates. Hybrid tank gauging is a method of coupling independent liquid monitoring systems, preferably with different principles of operation (i.e., mass and volume measurement) in order to minimize measurement error. Thermal differential probes are commercially available devices that measure changes in the thermal conductivity of process media, and may be capable of fairly accurate interstitial liquid gauging. Four conceptual technologies were selected as interstitial liquid monitoring candidates: borehole tomography, dielectric measurement, eddy current measurement, and time domain reflectometry (TDR). Borehole tomography is a technique that may provide two- and/or three-dimensional imagery of tank wastes. Dielectric measurement, eddy current measurement, and TDR may provide interstitial liquid monitoring capabilities similar to those of the LOW system.

5.3.1 Hanford SST Liquid Monitoring Systems

A historical summary of the Hanford tank farm waste monitoring instrumentation was compiled.

5.3.1.1 FIC Gauge. The FIC gauge has been used as a level measuring instrument at the Hanford tank farms for several decades. FIC gauges were originally designed for local operation (H-2-90490), but the system was automated with a centralized computer system (computer automated surveillance system [CASS]) in 1977 to allow remote monitoring (H-2-71778). The FIC gauge is an example of a tape level device with a conductivity surface sensor (see Figure 5-1). The FIC gauge consists of a single wire conductivity measurement powered by a 24-Vac 60-Hz transformer system. Depth is determined by lowering the tape until contact with the level is indicated by current flow through the waste/tank wall. A calibrated measuring wheel determines the amount of unrolled tape. The automated version of the Hanford FIC gauge has an accuracy

Figure 5-1. Hanford Liquid Level Conductivity (FIC) Gauge.



of 0.25 in. of level. The FIC gauge enclosure, located externally to the tank, requires a constant air purge to prevent atmospheric condensation on the device electronics and cabling mechanisms. The FIC gauge is no longer commercially manufactured. Replacements for the FIC gauge are being sought. A potential replacement for the FIC gauge is the RobertShaw 185A Inven-tel Precision Level Gauge (Peters et al. 1993) which is a precision tape level device equipped with a conductivity type sensor. The accuracy of the RobertShaw gauge is ±0.01 in. of level.

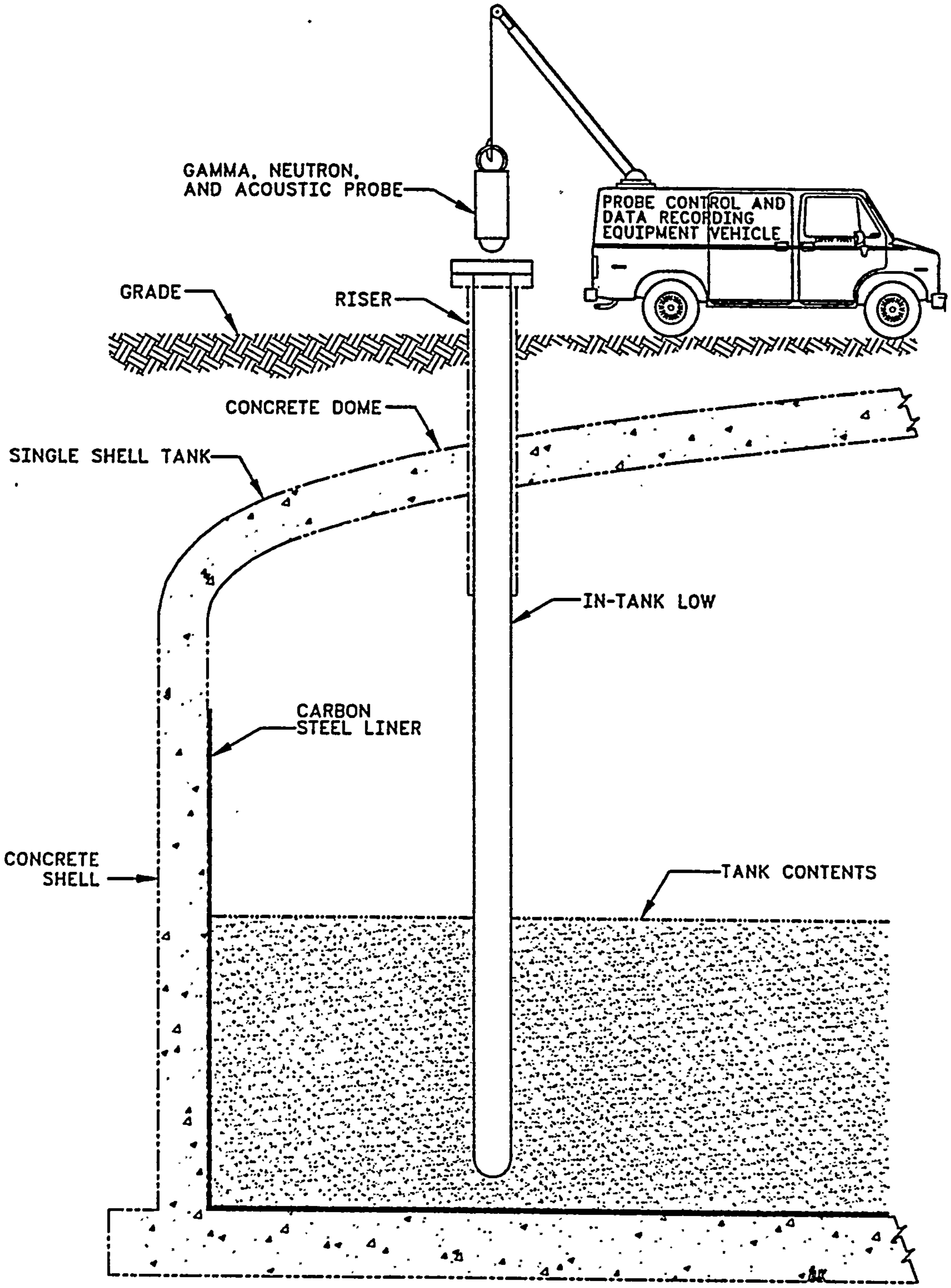
A conductivity probe used in conjunction with a tape level device, similar to the FIC gauge or RobertShaw 185A, will not be damaged by shifting waste tank solids and can be configured for continuous monitoring. However, conductivity probes are potential sparking sources and tank waste solids coating gauge sensors continue to be a problem in many tanks. Because of the heterogeneous nature of the SST waste surface, a surface-sounding tape level device measurement like the FIC gauge or RobertShaw 185A is dependent upon the position at which the surface sensor is lowered into the tank. Neither the FIC gauge nor the RobertShaw 185A is capable of gauging interstitial liquids.

5.3.1.2 LOW. A sophisticated custom-designed waste monitoring system has been operating with reasonable success in the Hanford tank farms for approximately seven years. The monitoring system at Hanford is called the Drywell Van In-Tank Liquid Observation Well Surveillance System, commonly referred to as the In-Tank LOW or LOW (see Figure 5-2). The LOW system has a 3-in. inside diameter fiberglass drywell, which extends above the tank dome and down in the tank waste to within approximately 1.5 ft of the tank bottom. Three different types of probes are lowered into the drywells on a calibrated cabling system: gamma probes, neutron probes, and acoustic probes. The cabling system and attached electronics are mounted on a mobile vehicle (i.e., a van) that can be driven from drywell to drywell. The LOW system is intrinsically safe, is noncontacting, and operates on a semi-continuous basis (i.e., data is collected only when a probe is lowered into a drywell). The cabling system, specific probe characteristics, and signal processing systems are integrated and complex. A detailed technical reference of the Hanford LOWs and their operational characteristics are available in Stong (1986), Schuster (1993), and H-2-91786.

The Hanford LOW system is not a continuous monitoring system. A drywell van must be driven to each SST LOW and probes lowered into and retracted from the drywell. The LOW system can gauge the interstitial liquid level with an accuracy of approximately 0.1 ft. The LOW system has some capability to directly gauge interstitial liquid in a mixed liquid-solid matrix. Because of the heterogeneous nature of the SST waste surface and the limited sensor penetrations into the tank contents, the level measurement and interstitial liquid measurement are dependent upon the fixed position of the LOW in the tank.

5.3.1.2.1 Acoustic Probe. The acoustic probe has a transducer that is coupled to the LOW column with an acoustical or sound coupling medium. The acoustic pulse is measured by a KB6000 Acoustic Inspection Unit (Stong 1986). The acoustic (high-voltage electric) pulse is sent to the transducer in the probe by the KB6000, where it is converted to an ultrasonic pulse. The interface between the outer LOW wall and the tank contents causes acoustic reflection that is detected by the transducer, and measured by the KB6000. The fiberglass/liquid interface produces almost no reflective pulse amplitude.

Figure 5-2. Van Mounted Liquid Observation Well Surveillance System.



The fiberglass/air interface produces a maximum pulse reflection. The reflected pulse from saturated salt is almost zero. From wet salt it is somewhat higher. However, a large signal is obtained from dry salt. The depth of the field in tank waste is almost zero.

5.3.1.2.2 Gamma Probe. The Hanford LOW gamma probe has a neon-filled, halogen-quenched Geiger-Mueller (G-M) detector and measures gamma radiation at a specified fixed counting efficiency. During LOW development activities, it was empirically determined that the principal gamma emissions originate in the liquid phase of the tank waste. The field of view around the LOW is approximately 1 ft in diameter in liquid and up to 2 ft in diameter in relatively dry saltcake.

5.3.1.2.3 Neutron Probe. The neutron probe has a fast neutron source and a boron triflouride-type tube detector with the gas enriched to 96% Boron10. The detector is at a fill pressure of 25 cm Hg. The tube contains carbon to reduce gamma-induced neutron pulse degradation, and the specific neutron sensitivity is approximately 6 cps in a uniform neutron flux of 1 neutron/cm^2/second. The neutron source is 1.5 Ci 241Am/Be contained in a 2.0 in. by 0.75 in. double-encapsuled U.S. Department of Transportation approved pellet. The neutron detector is sensitive only to fully moderated (i.e., thermal energy equivalent) neutrons. Water contains hydrogen atoms that are efficient in moderating the fast neutrons emitted by the probe source material. Therefore, in the absence of other moderators, the observed count rate from this probe is a direct function of the moisture present in the surrounding media. Within the in-tank environment of the LOW, the moisture content of the dry saltcake and the wet saltcake, the liquid phase is sufficiently different to provide characteristic neutron probe count rate variations. The concentric field of view around the LOW is up to 36 in. in diameter and is centered vertically at the source position at the end of the probe.

5.3.1.2.4 In-Tank Drywells. LOWs installed in Hanford SST 241-SX-104 have been bent and broken by shifting tank waste solids, and subsequently are filled with tank waste. It may be possible to dip gamma and neutron probes into broken LOWs without probe failures; however, this has yet to be determined. The principle of neutron probe operation probably would not be affected by dipping the probe in tank waste. The gamma probe most likely would experience some baseline shift because of sample "pull along" if it was dipped in tank waste. The acoustic probe would not function if it was dipped directly into the tank waste. If neutron and gamma probes were used in broken LOWs; provided they were physically capable of withstanding the tank waste environment, able to pass through any existing pinch points in broken LOWs, and able to penetrate the waste, they almost certainly would have to become tank specific dedicated units. Setting up and maintaining dedicated sampling probes undoubtedly would be expensive and would extremely complicate present monitoring logistics. Furthermore, probes that came into physical contact with tank wastes would become hazardous waste materials, as would cable and objects contacting contaminated cable, causing a litany of additional decontamination and disposal issues.

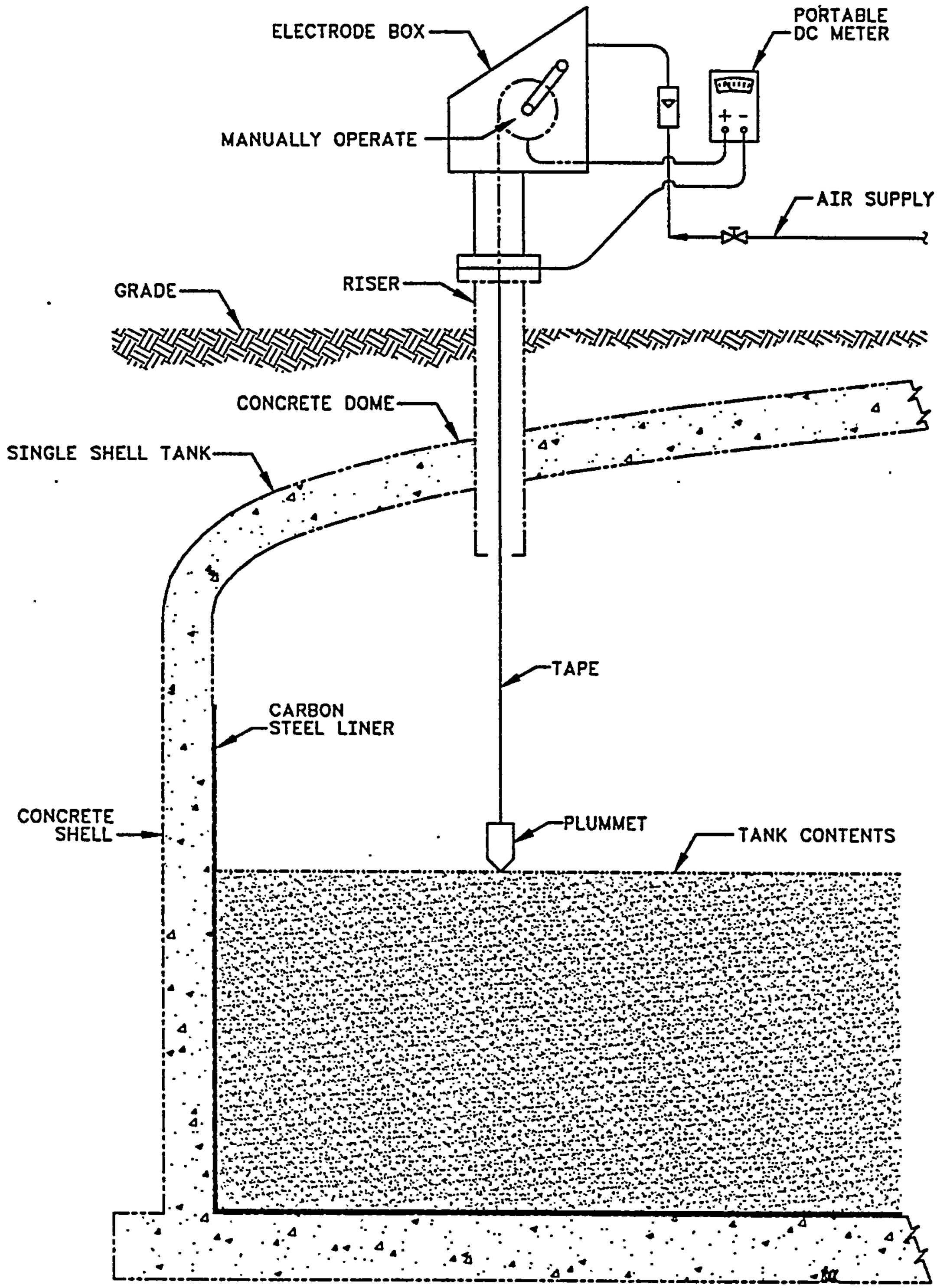
It has been suggested that damaged LOWs might be filled with an inert liquid or gas that would displace tank waste occupying the interior of the LOW. This practice would not be recommended for several reasons. If some type of inert fluid was used to fill a damaged LOW, it would have to be pumped continuously into the drywell and the tank to maintain a positive pressure in the damaged drywell. Increased pumping raises a variety of compatibility and waste volume issues. Furthermore, even if all those issues were addressed, diffusional flow of tank waste from the vessel into the LOW must be considered. Diffusional flow considerations, coupled with residual wastes that may not have been adequately conveyed out of the drywell by the inerting fluid, ultimately may raise the same types of contamination issues associated with dipping probes directly into the tank waste. Similar issues related to contamination and operational problems associated with maintaining a positive pressure in the damaged LOW apply to using an inerting gas.

If the structural problems experienced by the LOWs in Tank 241-SX-104 are due solely to the strength of the construction material, replacing the LOWs with carbon steel or another metal capable of withstanding the waste tank environment may be a consideration. The current acoustic probe would not function in a carbon steel dry-well. The neutron probe would function equally in a steel dry-well or in fiberglass. The gamma probe may experience some radiation shielding, but the curve shapes should be the same. Advanced organic composites (i.e., carbon fiber-reinforced high-strength plastics) may provide the necessary strength for a drywell material of construction. An advanced plastic composite would provide for probe performance characteristics similar to fiberglass. However, the acoustic probe is not being used to gauge Hanford SSTs. If there are no future plans to use the LOW acoustic probes, an appropriate metal would be the preferable material of construction for replacement LOWs. Ordinary steels generally are much stronger composites, have greater toughness, and are less expensive than carbon fiber.

It may be possible to re-sleeve a broken LOW. Re-sleeving could be accomplished by inserting a new dry-well, with an outside diameter less than 3 in. into the broken LOW. A type of steel with a sufficient gauge thickness that could provide adequate mechanical strength might be a good choice. However, the current acoustic probe design will not function in a metallic dry-well. Commercial systems for sleeving wells with a variety of polymeric liners exist (Lowry 1993), but they are not recommended for the broken LOW application, because of engineering limitations related to puncturing, buoyancy, and lack of mechanical support. If a metallic sleeving material were used in a broken LOW, significant installation issues related to fluid displacement, contamination, and calibration would need to be addressed.

5.3.1.3 Manual Tape. Manual tapes have been used to gauge tank waste levels in the Hanford tank farms since operations commenced on the site (H-2-95331). The manual tape gauge is similar to the FIC gauge design, but it is manually reeled out (see Figure 5-3). Length markings are on the side of the tape for readout. A DC source of excitation with a volt meter is used to indicate contact with the waste level. The current path is through the tank contents and tank wall to the ground. Depth must be indexed to some fixed point on the riser. No visual observation of the tank surface can take place when these tapes are lowered to the tank surface level. Because of the heterogeneous nature of the SST waste surface, the manual tape measurement is dependent upon the position where the surface sensor is lowered into the tank. The manual tape is incapable of gauging interstitial liquids.

Figure 5-3. Hanford Manual Liquid Level Conductivity Gauge.



5.3.1.4 Prototype of Hanford's SSTs Liquid Detection Systems (historical account of technologies tested for SST application at Hanford).

5.3.1.4.1 CCTV. CCTV is an optical technique that has been used to monitor the Hanford SSTs (Sumsion 1991, Sontag 1991). CCTV monitors tank interiors and tank waste surfaces. CCTV can be used for level gauging if an appropriate level marker is used. The biggest operational problem with CCTV in Hanford waste tanks is the inability of cameras to last in a radiation environment. Camera operational life may be extended by using robotics to insert and withdraw a camera from service, or by improving radiation shielding in the camera internals. CCTV is a very useful technique for observing the interiors of waste tanks. However, like other optical devices, CCTV is incapable of gauging interstitial liquids.

5.3.1.4.2 Laser. A Stanley Tool Laser Measuring Device was tested on simulated Hanford SST waste by Peters et al. (1993) at Pacific Northwest Laboratory (PNL). The device uses visible red light at 670 nm wavelength and an optical phase technique to determine the distance to target (waste surface). The accuracy of the Stanley Tool Laser Measuring Device was approximately ±0.5 in. level. The Stanley Tool Device is not radiation hardened; therefore, in actual Hanford SST use, a mirror would be placed at the input end of a riser to prevent direct radiation shine from reaching the device. The mirror placement was tested with simulated Hanford SST waste. Because of the low power of the laser and the loss of signal strength as a result of reflection from the first surface aluminized mirror, the Stanley Tool Device could not detect the target at a depth of 43 ft.

Westinghouse Savannah River Site (WSRS) has been testing the Distomat Laser Surveying Instrument as a possible replacement for the zip cord level detector. The WSRS completed preliminary testing of the device on January 28, 1993 (Phillips 1993). By using a water liquid surface and looking through a pipe, tests showed an accuracy of ±0.1 in. of liquid level. Testing has progressed to field trials on actual tanks. As of March 1993, the gauge had been tested on one tank and it worked. The manufacturer's stated accuracy for this gauge is ±0.4 in.

A laser level gauging device could probably be configured to measure the waste levels of the Hanford SSTs. Laser gauges are noncontacting, therefore, they are not subject to problems associated with coating, fouling, and shifting waste. Laser level gauging devices can be configured to be intrinsically safe, and are capable of continuous monitoring. Condensation of tank waste on portals and/or optics could be problematic for laser level gauging devices. Because of the heterogeneous nature of the SST waste surface, a laser level device measurement is dependent upon the positioning of the laser beam in the tank. Furthermore, heterogeneous waste surfaces generally will impact the accuracy of laser level monitoring devices. Laser level measuring devices are incapable of gauging interstitial liquids.

5.3.1.4.3 Photography. Photography is an optical technique used fairly extensively at Hanford for characterizing waste surfaces inside SSTs (Everett et al. 1969). Photography can be used for level gauging if an appropriate level marker is used. However, there are shortcomings in terms of real time capabilities. The biggest operational problem with photography in Hanford waste tanks is the inability of film to last in a radiation environment. Film and camera operational life may be extended by using robotics to insert and withdraw cameras from tanks, or by improving radiation shielding in cameras internals. Photography is a very useful technique for observing the interiors of waste tanks. However, like other optical devices, photography is incapable of gauging interstitial liquids.

5.3.1.4.4 Radar. An Enraf Series 872 Radar Gauge was installed in Tank 241-SY-101 for testing (Peters et al. 1992). The laboratory testing of the radar gauge showed equivalent response to the existing FIC gauge and, as a noncontact gauge, reduced maintenance problems. The gauge had the additional advantage of being qualified as intrinsically safe for hydrogen gas. The field testing in Tank 241-SY-101 showed that the readings are very susceptible to what passes into the field view of the gauge (White 1992).

A Cannon-Bear Model 1420 Radar Liquid Level Gauge was tested on simulated waste by Acree (1992) because the Enraf 872 responded effectively in laboratory tests. The advantages of the Cannon-Bear over the Enraf device are; it can be installed in a 4-in. diameter riser, and is standard equipped with a 4-20 mA output signal. The device was mounted on the end of a 10-ft long, 4-in. schedule 40 iron pipe that simulated a 4-in. SST riser. The published level accuracy of the Cannon-Bear gauge is ±0.5% of maximum range for liquid surfaces. The published maximum range of the device is 50 ft. Testing with a liquid surface over a span of 6 in. has shown that the gauge performs better than the published specifications, although nonlinearities of approximately ±1 in. were observed. Testing with semi-dry Hanford SST waste simulant for a surface level shows that the gauge performs worse than it does with liquid levels. Because the manufacturer, TN Technologies, Inc., has no plans to improve the resolution of the gauge, it was recommended that Westinghouse Hanford Company not use the Cannon-Bear Model 1420 Radar Liquid Level Gauge for level monitoring in waste storage tanks at Hanford. However, the device was shipped to Los Alamos National Laboratory (LANL) for additional testing and evaluation. The LANL will attempt to improve the gauge response through additional testing and communication with the manufacturer.

5.3.1.4.5 Ultrasonic. Ultrasonic level devices can be used for continuous and point-level measurement. The point detectors, for measurement of gas/liquid, liquid/liquid, liquid/foam, or solid/gas interfaces, can be grouped by design into dampened sensor and on/off transmitter categories, and by method of packing as single-element and two-element units. The continuous level detector designs can be categorized as under-liquid sensors and above-liquid sensors. Most designs use a 20 kHz or higher oscillator circuit as the ultrasonic signal generator. Some designs incorporate filters or discriminatory circuitry in electronics to prevent false readings that might be caused by random noise.

Dampened sensor-type level switches are used for point-level detection. As long as the sensor face is in the vapor phase of the tank, it vibrates at its constant resonant frequency, but is dampened out when contacted by the process material. On/off transmitter-type level switches are used for point-level detection and contain transmitter and receiver elements that can be located on the same probe or on opposite sides of the tank. If the elements are located in the same probe, the unit receiver can detect transmitter signals while the probe is submerged. If the elements are located separately, the receiver can detect the transmitter signal only in the gas phase.

The continuous ultrasonic level detector (i.e., SONAR) measures the time required for an ultrasonic pulse to travel to the process surface and back. The source is an oscillator-type ultrasonic speaker; and the receiver, in most designs, is a metal disc that is electrically and mechanically resonant. The transmitter can be mounted under or above the liquid level. The transmitter and receiver may be mounted as one or two units. On liquid level applications, the aiming angle must be within 2 degrees from the vertical. When measuring solids levels, the angle of response should be tested.

Several ultrasonic level detection device configurations are noncontacting, have no moving parts, are intrinsically safe, and are available with sophisticated programmable electronics for continuous monitoring. Noncontacting ultrasonic devices are not subject to the problems associated with shifting tank solids; however, because of the heterogeneous nature of the SST waste surface, the level measurement is dependent upon beam positioning. Nonuniform surface reflectivity and the slurry-like nature of some of the tank waste surfaces will cause difficulty with signal returns. Ultrasonic level detectors are incapable of gauging interstitial liquids.

Two ultrasonic level detection systems have been used at Hanford. One system is the acoustic probe used in conjunction with the previously described in-tank LOW system (see Section 5.3.1.3). The second system is a prototype ultrasonic level switch described by Werry (1991). The prototype system involves a manual probe equipped with an ultrasonic switch and temperature sensing devices (i.e., resistive temperature devices [RTD]) used in conjunction with CCTV. The ultrasonic level switch has monitored the level of the Hanford 241-S Tank Farm 302A Catch Tank. The ultrasonic level switch cannot gauge interstitial liquids. Because of the limited depth of field of the in-tank LOW acoustic probe, interstitial liquid monitoring capabilities are limited.

5.3.1.5 Saltwell Instrumentation System (SST Bubblers). A saltwell instrumentation system has been installed and is operating in the Hanford SST farms. The saltwell system is essentially a modified level control loop, consisting of flow instrumentation, a dip tube system, a weight factor recorder, a diaphragm operated valve control system, switches and valves, a leak detection loop, radiation detection, and heat trace systems (Islam 1991). The saltwell system functions to minimize the quantity of pumpable liquids in the SSTs. The saltwell system dip tubes are essentially bubblers, which measure the pumpable liquid level in the tanks.

The saltwell system dip tubes show the liquid level in the saltwell screen to be calculated and the saltwell system to be placed in automatic mode. The tubes are 1/2-in. carbon steel pipes, through which a constant volume of air is pumped. One tube is located about 1 in. from the bottom of the tank. The second is 10 in. above the first. The third is exposed to the atmosphere. A weight factor transmitter transmits a signal proportional to the pressure difference between the top and bottom dip tubes. A specific gravity transmitter transmits a signal proportional to the pressure difference between the bottom two dip tubes. A three-pen weight factor recorder records the instantaneous weight factor and specific gravity of the pumpable SST liquid. The weight factor transmitter measures liquid level over a range of 0 to 500 inches of water. The specific gravity transmitter has a measurement range of 0 to 2 (0 to 20 inches water). The saltwell instrumentation system has performed reasonably effective.

Saltwell dip tubes were not used as an interstitial liquid gauging system, but might be capable of functioning in that capacity. To configure the saltwell dip tubes as interstitial liquid gauging devices would require upgrading the pressure transmitters (for improved accuracy) and examining issues related to dip tube plugging, instrument air requirements, and SST waste morphology. An advanced SST bubbler design, and a description of its limitations, is discussed in Section 5.3.2.2.

5.3.1.6 Zip Cord. A zip cord method is used to measure SST waste levels in support of the FIC gauge and manual reel tapes (Maupin 1993). The zip cord consists of a measured length of electrical cord connected to a metal plummet, or donut-shaped weight, that is manually lowered through a tank observation port riser. The upper end of the cord is graduated in inches and is referenced to the riser flange. Tank waste level can be sensed by feel, or by the rise of an ohmmeter to indicate a completed electrical circuit between the zip cord and ground. The zip cord level measurement is read visually, and is capable of gauging SST waste levels with an accuracy of approximately 0.5 in. The zip cord is not capable of gauging interstitial liquids.

5.3.2 Mature In-Tank Liquid Monitoring Technologies

An exhaustive review of mature in-tank liquid monitoring technologies was conducted. Reference citations for technologies listed in Section 3.2 include *Fundamentals of Industrial Control* (1992), *Instrument Engineers Handbook* (1982), *Measurement and Control Basics* (1988), and *Process Instruments and Controls Handbook* (1985). The predicted performance characteristics of the mature technologies as applied to Hanford SSTs are based on citations from Anderson (1990), Babad et al. (1993), Camaioni et al. (1993), Crippen et al. (1993), Epstein et al. (1993), Krieg (1991), Krieg et al. (1990), Miller et al. (1993a,b) and Simpson et al. (1993).

5.3.2.1 Antenna Level Sensors. Antenna level sensors can be used for point-level detection or continuous-level detection. Continuous antenna level sensors are suspended from the top of a vessel and hang down into the vessel. Level changes in the vessel result in linear changes in capacitance between the antenna and vessel wall and, in turn, gives linear frequency differentiation between the antenna and reference oscillator. Level changes are registered by proportional changes in the differentiated frequency signal.

Antenna level sensors are subject to certain problems and limitations. The most notable shortcomings of antenna level sensors are poor accuracy of continuous detectors (i.e., ±15%); conducting and nonconducting buildups on the probe that may ruin the accuracy of the measurement; measurements becoming increasingly nonlinear as the level moves away from the calibration point; and changes in the capacitance of the media that ruins instrument calibration.

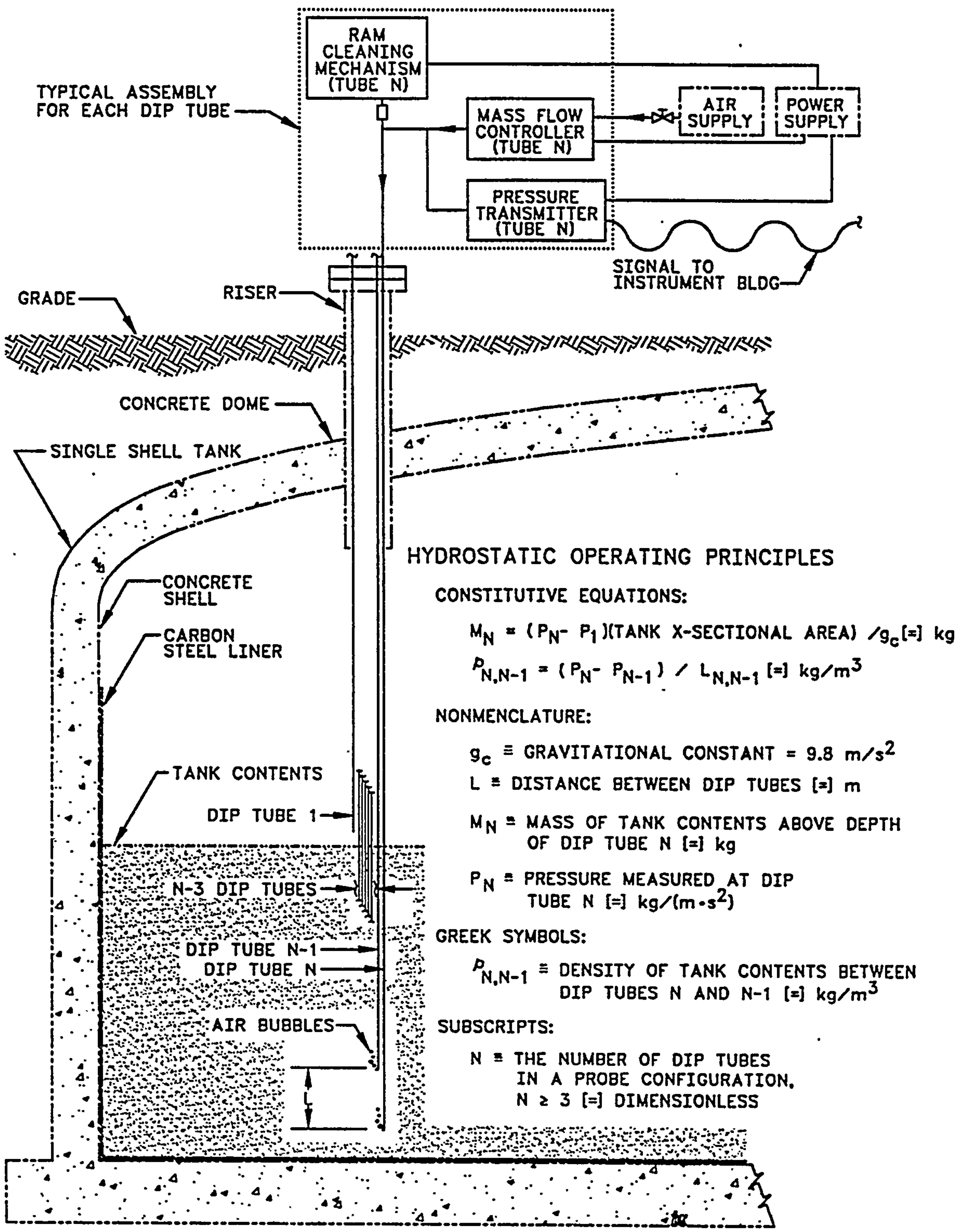
Antenna level sensors have no moving parts, can be configured to be intrinsically safe, and are designed for continuous level monitoring. However, the extremely heterogeneous nature of the SST tank waste would make calibration of an antenna level sensor difficult. Solid tank waste that is coating the antenna level sensor will be a problem. A coated probe probably will not function properly. Because of the heterogeneous nature of the SST waste surface, the antenna sensor level measurement would be dependent upon the position at which the antenna was placed in the tank. Because waste is not being added or removed from most of the Hanford SSTs, instrument nonlinearity because of deviations probably would not be a problem. The quoted accuracy of ±15% is inadequate for the Hanford SSTs, but modern designs may have improved accuracy. Antenna level sensors almost always are installed in a fixed configuration to be in continuous contact with the tank contents. An antenna level sensor with a fixed configuration installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break, and cause instrument malfunction. Antenna level sensors are incapable of gauging interstitial tank liquids.

5.3.2.2 Bubblers. A bubbler consists of a dip tube immersed in a process liquid (or slurry) of interest that is pressurized with a gas until bubbles appear at the bottom of the dip tube (see Figure 5-4). If the specific gravity of the liquid and the vessel pressure are known, the gas pressure in the dip tube can be converted to hydrostatic head. The gas pressure can be measured in different ways for continuous level readout.

The accuracy of conventional bubblers is about ±2%. Bubblers typically are not used in industry because of their limited accuracy and because they introduce foreign matter into the process. However, if proper materials of construction are used, bubblers are hearty and easily maintained. Using a two-bubbler configuration allows the density of the process liquid to be directly measured. Bubblers generally are the most inexpensive type of level detection instrumentation. Inert gases, such as nitrogen, may be used as the dip tube gas, and provide operational safety benefits in cases where flammability concerns exist. Situations where solids fouling problems exist, a bubbler can be configured to blow itself out periodically, with a high-pressure burst of purge gas, and/or it may be equipped with a clearing ram.

Bubblers operate under hydrostatic principles and directly measure mass. A hydrostatic mass-based measurement will not vary with changing waste density; with waste inhomogeneity; or with horizontal probe positioning at a given depth; provided the tank contents exhibit Newtonian (or near Newtonian) behavior, and there are no physical barriers that span any internal tank plane that would function to compartmentalize the tank contents. Bubblers have the advantage of no moving parts, and they may be configured for continuous monitoring. Furthermore, a bubbler could be used to introduce a tank head space purge gas. Bubblers are particularly useful in flammable environments because they have no associated electronics in contact with the process. However, the bubbler gas could cause evaporation of tank contents at the gas bubble/tank waste interface. Because many of Hanford tanks wastes are saturated solutions containing solids, this evaporation phenomenon likely would cause local crystallization on the bubbler tube tip, eventually leading to complete bubbler plugging, if some type of tube clearing or purging mechanism was not provided for in the installation. The quoted accuracy of ±2% can be improved significantly with modern designs that incorporate microprocessor controlled gas flows, precision machined bubble tubes, and high accuracy pressure sensors. Bubblers almost always are installed in a fixed configuration to be in continuous contact with tank contents. A bubbler with a fixed configuration, installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break, and cause instrument malfunction. Bubblers can directly measure total process material mass and are capable of gauging interstitial tank liquids.

Figure 5-4. Bubbler Liquid Monitoring System.



5.3.2.3 Capacitance Probes. Capacitance probes use the principle that the capacitance for a given conductor/dielectric/conductor combination is a linear function of conductor/dielectric interfacial area. A conducting or nonconducting probe can be placed in a vessel, and the capacitance between the probe and vessel wall can be measured. As the liquid level in the vessel varies, so will the conductor/dielectric interfacial area, and the measured capacitance between the probe and vessel wall. The changes in capacitance are measured with an instrument calibrated in units of level.

One of the two primary limitations of capacitance probes is the problem of probe coating by process material. This problem is particularly severe for the case of conductive process material. The problem can be overcome with implementation of a proximity capacitance probe. However, proximity capacitance probes are used only in single-point, high-level switch applications. The second primary limitation of capacitance probes is that calibration is lost with changes in the dielectric constant of the liquid being measured. Inhomogeneity of tank liquid can imply inhomogeneity in dielectric constant, making level detection by capacitance probes very difficult.

Capacitance probes have no moving parts, are available in intrinsically safe configurations, and are capable of continuous level gauging. Because waste is not being added or removed from most of the Hanford SSTs, instrument nonlinearity because of deviations in level would be negligible. However, tank waste that coats the probe will be a very big problem. A coated probe will not function properly and, even if probe coating could be avoided, the inhomogeneity of the tank waste most likely would lead to instrument nonlinearity. Because of the heterogeneous nature of the SST waste surface, the capacitance probe level measurement would be dependent upon the position that the probe was placed in the tank. Capacitance probes usually are installed in a fixed configuration to be in continuous contact with the tank contents. A capacitance probe with a fixed configuration, installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break, and cause instrument malfunction. Capacitance probes are incapable of gauging interstitial tank liquids.

5.3.2.4 Conductivity Probes. Conductivity probes consist of two electrodes: one is in contact with the process liquid at all times and the second is suspended to a depth of interest within the vessel. When the process liquid rises to the level of the second probe, the process liquid acts as a switch that completes an electrical circuit. Conductivity probes are primarily used as level switches; however, conductivity probes may be used as sensors on tape level devices.

Conductivity probes may be configured for continuous level monitoring. However, conductivity probes are potential sparking sources in flammable environments. The FIC gauge currently used at Hanford is a conductivity probe attached to a tape measuring device (White 1993, Peters et al. 1993). Solids that coat the FIC gauge are a big problem in many of the tanks. The Hanford tank farms are currently looking for a replacement for the FIC gauge. Because of the heterogeneous nature of the SST waste surface, the conductivity probe level measurement is dependent upon the position at which the probe is placed in the tank. A conductivity probe used in conjunction with a tape level device will not bend or break with shifting tank solids. Conductivity probes are incapable of gauging interstitial tank liquids.

5.3.2.5 Displacer Level Detectors. Operation of displacer level detectors is based on Archimedes' Principle, i.e., a body wholly or partially immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced. Displacer detectors determine level in a vessel by measuring the apparent weight changes of an immersed, or partially immersed, displacer. Differences in the design of displacer level detectors are related primarily to differences in the various types of force detecting mechanisms used (microprocessor based servos for modern gauges), differences in seal configurations used to separate the displacer from the force detecting mechanism, differences in available device inputs and outputs, differences in the precision of machined parts, and differences in (or the existence or absence of) device software. The displacer offers several advantages compared to float detectors: one displacer may be used to detect the level of liquids with a variety of densities, level spans are easily adjusted by moving the displacer to a different level, and moderate surface turbulence is less apt to cause switch chatter because the cable is in tension. However, high degrees of turbulence, displacer coating, high solids contents, and tank inhomogeneity are potential sources of level measurement error for displacer level detectors.

An Enraf Nonius Model 854 Advanced Technology Gauge (ATG) tape level measuring device is being installed in one of the Hanford SSTs for study as a possible replacement for the FIC gauge (White 1993, Peters et al. 1993). The Enraf Nonius displacer uses a high precision servo motor and cabling system. The device can measure liquid level changes to accuracies exceeding $\pm$0.1 in. and can be used to measure density at any depth with an accuracy of $\pm$0.1 g/cc. The Enraf device is an integrated hardware/software system primarily designed for tank farm inventory management. The Enraf Nonius system is intrinsically safe and is capable of recalibrating itself to compensate partially for solids buildup or coating of the displacer element. The primary function of the Enraf Nonius ATG gauge is level measurement. The ATG gauge is capable of accurately detecting gas/fluid interfaces and has some capability (i.e., sensitivity to density changes is $\pm$0.1 g/cc) to detect fluid/fluid and fluid/solid interfaces. Because of the heterogeneous nature of SST waste surfaces, the Enraf ATG gauge level measurement is dependent upon gauge positioning. However, if the Enraf Nonius ATG displacer gauge could penetrate the Hanford SST waste surface, the system could provide limited density as a function of depth data. Density is a mass-based measurement that will not vary with horizontal probe positioning at a given depth, provided the tank contents exhibit Newtonian (or near Newtonian) behavior and no physical barriers that span any internal tank plane would function to compartmentalize the tank contents. The Enraf ATG gauge could be used as a mass-based tank gauging system and, therefore, has the potential to gauge interstitial tank liquids in a limited capacity. Unfortunately, the Enraf Nonius ATG gauge displacer, and similar displacer systems, almost certainly will be unable to penetrate SST waste surfaces to make density measurements. Therefore, the Enraf ATG gauge most likely would be incapable of monitoring interstitial liquids in Hanford SSTs.

5.3.2.6 Float Level Detectors. Float level switches and indicators incorporate in their design a float that follows the liquid level or the interface between liquids of differing specific gravities. An array of float-operated switches and indicators fall into three primary categories: direct connected for atmospheric tanks, sealed units for pressure tanks, and tilt switches for liquids and solids. For continuous readout in sealed tanks, magnetic floats are generally used. The most accurate level measuring devices commercially available are specialized float level devices that use magnetostrictive technology. Magnetostrictive devices can measure level changes of 0.0025 in.

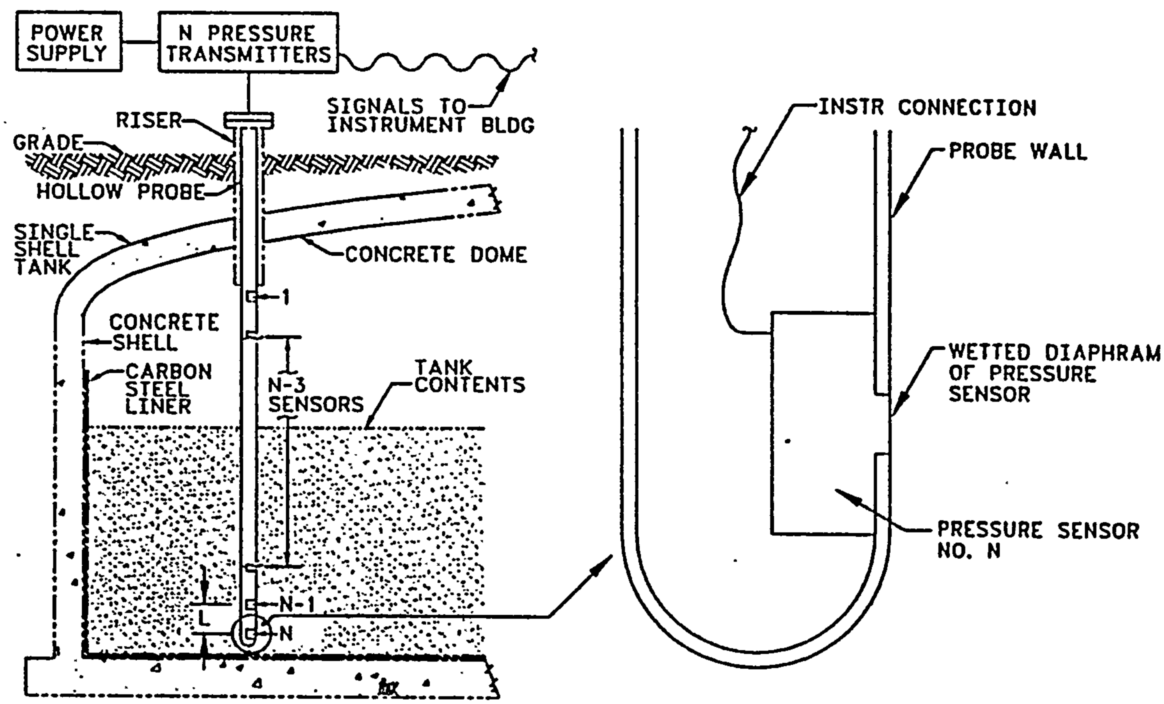
Float detectors are reliable, accurate, and inexpensive. However, fouling of guide tubes and other close-tolerance moving parts in dirty or plugging services is common. The float magnets tend to attract pipe scale and other ferrous metal particles that can interfere with proper switch operation and float movement.

Magnetic disc-type float level detectors are the most accurate float type devices for liquid level measurement, and are intrinsically safe and easily configured for continuous monitoring. Solids coating and plugging problems will be a big operational problem for any type of float level device. Because of the heterogeneous nature of the SST waste surface, float level measurement depends on the position that the probe is placed in the tank. Float level devices usually are installed in a fixed configuration to be in continuous contact with the tank contents. A float level device with a fixed configuration, installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break, and cause instrument malfunction. Float level detectors are incapable of gauging interstitial tank liquids.

5.3.2.7 HTG. The basic components of an HTG system are three high accuracy pressure probes (see Figure 5-5). Typically, a high accuracy pressure probe is placed at or near the tank bottom, a second probe is placed at a shallower depth, and the third probe is placed in the tank head space. Process material mass is calculated by subtracting the head space pressure from the pressure measured by the first probe, multiplying by the cross-sectional area of the tank, dividing by the gravitational constant, and subtracting the mass of liquid below the first pressure probe. The density of the tank process material is calculated by subtracting the pressure of the second probe from the first and dividing by the distance between the two probes. Tank level is calculated by subtracting the head space pressure from the pressure at the first probe, dividing by the density, and adding the distance at which the first probe is mounted above the tank bottom. Volume is calculated by a function that considers product level and tank geometry. HTG systems configured with multiple high accuracy pressure sensors (see Figure 5-5) can measure density stratifications, and can be programmed with logics for self diagnostics and statistical analysis of data.

High accuracy HTG systems must be configured with high accuracy pressure sensors. Therefore, this report will only consider modern, high accuracy pressure sensor designs. Detailed descriptions of old-fashioned HTG systems (e.g., manometers, bellows meters, etc.) can be found in the general references cited in the introduction of this chapter. There are two basic modern pressure sensor configurations: diaphragm pressure sensors and differential pressure (D/P) sensors. Diaphragm pressure sensors measure isolated hydrostatic pressure across a diaphragm. Differential pressure sensors measure the D/P across a diaphragm. Differential pressure sensors can be sealed (under vacuum or any desired pressure) across one side of the D/P cell diaphragm, giving them a configuration similar to that of a diaphragm-type sensor. A variety of sophisticated electronic devices for measuring a mechanical deflection created by pressure are used in diaphragm and D/P type sensors, some that include capacitive transducers, inductive (or variable reluctance) transducers, differential transformer transducers, force balance

Figure 5-5. Hydrostatic Tank Gauging Liquid Monitoring System.



HYDROSTATIC OPERATING PRINCIPLES

CONSTITUTIVE EQUATIONS:

$M_N = (P_N - P_1)$ (TANK CROSS SECTIONAL AREA) / g_c [=] kg

$\rho_{N,N-1} = (P_N - P_{N-1}) / L_{N,N-1}$ [=] kg/m^3

NONMENCLATURE:

g_c ≡ GRAVITATIONAL CONSTANT = 9.8 m/s^2

L ≡ DISTANCE BETWEEN PRESSURE SENSORS [=] m

M_N ≡ MASS OF TANK CONTENTS ABOVE DEPTH OF PRESSURE SENSOR N [=] kg

P_N ≡ PRESSURE MEASURED AT PRESSURE SENSOR N [=] $kg/(m \cdot s^2)$

GREEK SYMBOLS:

$\rho_{N,N-1}$ ≡ DENSITY OF TANK CONTENTS BETWEEN SENSORS N AND N-1 [=] kg/m^3

SUBSCRIPTS:

N ≡ THE NUMBER OF PRESSURE SENSORS IN A PROBE CONFIGURATION, $N \geq 3$ [=] DIMENSIONLESS (servo) transducers, strain gauge transducers, piezoelectric transducers, photoelectric transducers, potentiometric transducers, and vibrating wire transducers (Statham 1991). A typical example of the performance characteristics of a high accuracy pressure sensor might be a transducer with a full span of 400 in. of water, a turndown ratio of 40:1, and an accuracy of ±0.2% span. Such a pressure sensor could be incorporated into an HTG system designed to monitor a 75-ft diameter, 1 Mgal tank full of water and could be capable of measuring mass changes in the tank with an accuracy of approximately ±500 lb (62 gal of water or 0.02 in. of level in a 75 ft diameter tank).

As the name implies, HTG systems operate on hydrodynamic principles like bubblers. Although HTG technology has existed for a very long time, the development of highly accurate pressure probes has produced a new interest in application of this technology (*Advances in Instrumentation and Control* [1990b, 1989d, 1990f]). Mass is the most direct and accurate measurement calculation made by HTG systems. If a tank inventory system is to be based on mass, the HTG system typically will be several times more accurate than systems that determine level and back calculate for mass. A hydrostatic, mass-based measurement will not vary with changing waste density; waste inhomogeneity or probe positioning; provided the tank contents exhibit Newtonian (or near Newtonian) behavior and no physical barriers that span any internal tank plane would function to compartmentalize the tank contents. HTG systems have the advantage of no moving parts, and they may be configured for continuous monitoring. Because the Hanford SSTs are concrete reinforced buried tanks, an HTG system almost certainly would have to be configured as a fixed probe (see Figure 5-5). A fixed probe HTG configuration installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break, and cause instrument malfunction. HTG systems can measure total process material mass and are capable of gauging interstitial tank liquids.

5.3.2.8 Impedance Probes. The impedance probe is a modification of the capacitance probe, designed to overcome problems associated with process buildup. Impedance probes use a secondary probe that is insulated from the ground and primary probe, is driven in phase, and at the same voltage as the primary probe. The secondary probe breaks the resistive path to ground when the probe is coated. The impedance probe is designed to overcome some of the capacitance probe weaknesses. However, accuracy still can be affected by coating thickness and changes in process dielectric or conductivity.

Impedance probes have no moving parts, are available in intrinsically safe configurations, and are capable of continuous level gauging. But, even with the design improvements incorporated into the impedance probe relative to the capacitance probe, tank waste that coats the probe will be a problem. A coated probe probably will not function properly. Even if probe coating could be avoided, the inhomogeneity of the tank waste probably would lead to instrument nonlinearity. Because of the heterogeneous nature of the SST waste surface, the impedance probe level measurement would be dependent upon the position that the probe was placed in the tank. Because waste is not being added or removed from most of the Hanford SSTs, instrument nonlinearity because of deviations in level can be ignored. Impedance probes usually are installed in a fixed configuration to be in continuous contact with the tank contents. An impedance probe with a fixed configuration, installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break and cause instrument malfunction. Impedance probes are incapable of gauging interstitial tank liquids.

5.3.2.9 Level Gauges. Level gauges primarily consist of a metal chamber, gasket, glass, cushion, and cover. The assembly is bolted together and physically plumbed to the structure. The level gauge is read through the sight glass. Level gauges may be used for remote monitoring of hazardous services, and designed for continuous monitoring with digital readout. Examples of more advanced level gauge systems include oscillator detectors and photoelectric cells. Level gauges must be plumbed physically to the process equipment and may be subject to fouling problems.

Level gauges have no moving parts and are capable of continuous monitoring. A standard site-type level gauge is impractical for application to the Hanford SSTs. Designing a more elaborate configuration may be possible; however, coating and fouling issues will present problems for any design. Intrinsically safe designs are possible. Because of the heterogeneous nature of the SST waste surface, the level gauge measurements would be dependent upon the position that the device was placed in the tank. Level probes usually are installed in a fixed configuration to be in continuous contact with the tank contents. A level probe with a fixed configuration, installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break and cause instrument malfunction. Level gauges are incapable of measuring interstitial tank liquids.

5.3.2.10 Magnetic Level Switches. Magnetic level switches have a permanent magnet attached to a switch, along with an attracting sleeve attached to displacers that tilt the switch. If the sleeve drops (because waste levels drop) below the magnetic position, the magnet is pulled away from the sleeve, activating the device contacts. Magnetic level switches are designed primarily for point level measurement.

Magnetic level switches have moving parts and are potential sparking sources in flammable environments. Because of the heterogeneous nature of the SST waste surface, the level measurement depends on the position that the switch is placed in the tank. A magnetic level switch with a fixed configuration, installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break and cause instrument malfunction. Magnetic level switches are incapable of gauging interstitial tank liquids.

5.3.2.11 Optical Level Switches and Monitors. Optical level switches and monitoring devices use a light beam to detect the presence of liquid, and they are available in a variety of configurations. All designs use a light source and a detector. Nonintrusive designs where light beams are reflected off liquid surfaces are subject to problems in processes where slurries, floating solids, or changing surface reflectivity are encountered. Intrusive devices have limited accuracy in processes where coating problems and material inhomogeneity exist.

Several optical level detection device configurations are noncontacting, have no moving parts, are intrinsically safe, and are available with sophisticated programmable electronics for continuous monitoring. Noncontacting optical devices are not subject to the problems associated with shifting tank solids. However, because of the heterogeneous nature of the SST waste surface, the level measurement depends on beam positioning. Nonuniform surface reflectivity will be a major obstacle to overcome for the successful application of optical level detection technology at Hanford SSTs. Optical level measuring devices, namely, laser level detectors, are being studied as potential candidates for Hanford SST liquid level measurement instrumentation (White 1993, Peters et al. 1993, Phillips 1993). Optical level devices are incapable of measuring interstitial tank liquids.

5.3.2.12 Radiation Level Sensors. Radiation level sensors consist of a source and a detector. The source usually emits gamma radiation and is sized carefully to have adequate strength and life with a minimum radioactive nuclide loading. Typical source materials are Cobalt-60 and Cesium-137. Detectors for continuous level monitoring usually are G-M tubes or gas ionization chambers. A gamma radiation incident on a G-M tube causes an electrical breakdown between the tube anode and cathode. The frequency of the breakdown is related to the intensity of the incident gamma radiation. Ionization chamber detectors are supplied with an applied breakdown voltage, usually below 6 volts. Incident gamma radiation ionizes the ionization chamber inert gas, and continuous current in the microampere range cause the current to flow. The amount of current is proportional to incident radiation field intensity.

There are two basic methods for making continuous level measurements using fixed sources and detectors: strip source method with strip detector configuration, and the point source method with strip detector configuration. The strip source method is more expensive, but is preferred because signal response is linear with changing level. The highest accuracy radiation level detectors use a movable point source with a movable point detector. The accuracy of the movable system is directly related to the accuracy of being able to monitor source and detector position. The Hanford in-tank LOW system is an example of a point source/point detector configuration. Radiation level detection can be appealing for hard to handle, toxic, and corrosive processes because vessel wall penetrations are not necessarily required. Radiation level detection systems, like the Hanford in-tank LOW system, do have some capability to gauge interstitial liquid in a mixed liquid-solid matrix. However, unlike other types of tank gauging technologies, special safety, maintenance, and disposal issues are associated with the use radiation level detection instruments.

5.3.2.13 Resistance Tapes. Resistance tape level detectors respond to changes in tank level with change in loop resistance. The basic unit consists of a conductive base strip and a resistive element, both enclosed in a jacket. As the level of liquids or solids rises in the tank, the hydraulic pressure of the material compresses the jacket, causing progressive contact between the resistance element and the conducting strip. The variation in the upper resistive leg of the device is directly proportional to the level of the tank contents.

To maintain accuracy, the pressure inside the tape jacket must equal the pressure in the tank. Care must be taken to keep the inside of the tape jacket dry. Changes in material specific gravity will affect accuracy of the resistance tape. Lateral movement of material contents within a tank can cause measurement inaccuracies or malfunction. The unique construction of the resistance tape allows it to be used to measure the level of solids, slurries, and various liquids that are corrosive to more conventional level detection devices.

Tank waste crystallization may cause resistance tape devices to become "locked" open or closed at some point along the tape, resulting in a false level reading. Intrinsically safe designs that provide for continuous monitoring are possible. Because of the heterogeneous nature of the SST waste surface, resistance tape device measurements would depend on the position the device was placed in the tank. Resistive tape devices usually are installed in a fixed configuration to be in continuous contact with the tank contents. A level probe with a fixed configuration, installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break and cause instrument malfunction. Resistance tape devices are incapable of measuring interstitial tank liquids.

5.3.2.14 Rotating Paddle Switches. The rotating paddle switch level detector detects the presence or absence of solids in a silo. A small, geared, synchronous motor keeps the paddle in motion at very low speed. There is no torque on the paddle drive assembly when solids are absent. When the level rises to the paddle, the paddle is stopped and torque is applied to the drive assembly; detection of the torque is used to actuate a switch.

Rotating paddle switches are used only for point level detection of solids. Rotating paddle switches are contacting devices with moving parts, and they will be subject to coating and fouling problems. Rotating paddle switches usually are installed in a fixed configuration to make contact with the tank contents. A level switch with a fixed configuration, installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend or break and result in instrument malfunction. Rotating paddle switches are incapable of measuring interstitial tank liquids.

5.3.2.15 Slip Tubes. The two basic slip tube designs are rotary and vertical. The rotary unit is operated by opening a head assembly until process vapor discharges through a bleed connection. The handle and slip tube assembly is then rotated to find the liquid/vapor interface. The liquid vapor interface is established when liquid bleeds out. An approximate indication of tank level can be obtained by reading the position of the handle on the scale mounted behind it. The vertical slip tube is operated similarly in pressure vessels. A tube is lowered into a tank until the tip makes contact with the liquid. Liquid, rather than vapor, starts bleeding out the cap assembly. The level scale is marked on the tube.

Slip tubes are inaccurate, and they can be dangerous. The rotary designs can leak at the packing gland. The vertical design requires the operator on top of the tank to tap a pressurized vessel until liquid emerges from the slip tube. Standard slip tube technology is totally inappropriate for application to the Hanford SSTs because of the high potential for operator radiation exposure. Slip tubes are incapable of measuring interstitial tank liquids.

5.3.2.16 Tape Level Devices. There are four primary tape level device designs that can be used for continuous level monitoring. They are: inductively coupled float and probe detector, wire-guided float detector, wire-guided thermal sensor, and the surface sensor device.

The inductively coupled float consists of a probe suspended from the roof of a tank. The probe consists of several insulated conductors encapsulated in a probe jacket that act as a guide to a float containing an inductively coupled transducer. The probe jacket provides mechanical strength to the float guide, and power to the transducer. The receiver mounted to the top of the tank reads which conductors have been inductively coupled and, from this information, can determine where the float is located along the probe and thus measure the liquid level.

The wire-guided float is very similar to an ordinary float level detector, except, wire-guides are ran from the tank dome to the tank bottom where the float is attached. The guides prevent lateral drift of the float because of surface motion.

The wire-guided thermal sensor operates on the principle that liquids are better conductors than gases. A probe with two vertically displaced sensors is lowered or raised by a line attached to a motor until the lower sensor is immersed in the liquid and the upper sensor is in the head space gas. The motor is calibrated and the liquid level is measured by knowing the length of the extended line. Wire-guided thermal sensors also can be used to determine temperature gradients in a tank liquid. A detailed discussion on the principles of operating thermal sensors is provided in the *Instrument Engineers Handbook* (1982).

Surface sensors use a sounder that is lowered on a line by a servo motor. When the sounder makes contact with the tank material surface, the decrease in line tension is detected by the servo motor and the tank level is measured. Capacitance probes and displacers often are substituted for sounders as surface detection devices.

Inductively coupled float devices have no moving parts, are designed for continuous monitoring, and are intrinsically safe. However, solids coating and plugging will present significant operational problems for inductively coupled float level devices and wire-guided floats. Furthermore, because of the heterogeneous nature of the SST waste surface, float level measurement depends on the position the probe is placed in the tank. Float level devices usually are installed in a fixed configuration to be in continuous contact with the tank contents. An inductively coupled float or wire-guided float with a fixed configuration installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break, and cause instrument malfunction. Inductively coupled float devices are incapable of gauging interstitial liquids.

Wire-guided thermal sensors are intrinsically safe, are designed for continuous monitoring, and are not subject to problems associated with shifting tank waste solids. Solids coating of the sensor is likely, causing sluggish sensor performance. As solids buildup on a thermal sensor increases, the sensor performance declines until the solids coating grows large enough to insulate the sensor and render it totally ineffective. Because of the heterogeneous nature of the SST waste surface, wire-guided thermal sensor level measurement depends on the position the device is placed in the tank dome. Wire-guided thermal sensors can be configured to prevent damage by shifting tank waste solids. Wire-guided thermal sensors are incapable of gauging interstitial liquids.

The FIC gauge, the Robert Shaw 185A Inven-tel Precision Level Gauge, and the Enraf Nonius ATG gauge are examples of tape level devices with surface sounders (White 1993, Peters et al. 1993). Tape level devices with surface sounders have moving parts and can be susceptible to coating problems.

However, tape level devices are available with intrinsically safe configurations for continuous level monitoring, and they generally are undamaged by shifting tank contents. Because of the heterogeneous nature of Hanford SST waste surfaces, surface sounding tape level device measurements depend on the position the surface sensor is lowered into the tank. Most surface sounding tape level devices are incapable of gauging interstitial liquids.

5.3.2.17 Tuning Fork Switches. Tuning fork switches are driven by a piezoelectric crystal circuit that oscillates at its natural resonant frequency. When process liquid contacts the oscillating fork, the oscillation frequency of the sensor shifts and a contactless solid-state switch (or relay) is activated. Tuning fork switches are suitable for applications where float switches and ultrasonic gap switches are used, and other applications, where these devices are not applicable because of material buildup, turbulence, agitation, air bubbles, foam, or suspended solids.

Tuning fork switches are point level measuring devices and are particularly well suited for viscous materials. Tuning fork switches are available in intrinsically safe configurations, and have no moving parts. Because of the heterogeneous nature of the SST waste surface, level measurement depends on the position the device is placed in the tank. Tuning fork switches usually are installed in a fixed configuration. A level probe with a fixed configuration installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break, and cause instrument malfunction. Configuring an array of tuning fork switches for continuous level measurement would be difficult. Tuning fork switches are incapable of gauging interstitial liquids.

5.3.2.18 Vibrating Reed Switches. Vibrating reed switches consist of a driver, paddle, and pickup. The driver coil induces a vibration in the paddle. The vibration is damped out when the paddle is covered with process material. The pickup end contains a permanent magnet and a coil that generates a millivolt output signal when the paddle is vibrating. When the paddle is covered, the signal decreases, and a control relay is deenergized. Vibrating reed switches are used only for point level detection.

Vibrating reed switches are antiquated devices, prone to the same fouling and plugging problems of any contacting level device. Vibrating reed switches are not intrinsically safe, and have moving parts. Because of the heterogeneous nature of the SST waste surface, level measurement depends on the position the device is placed in the tank. Vibrating reed switches usually are installed in a fixed configuration. A level probe with a fixed configuration installed in a Hanford SST containing shifting solid waste (i.e., Tank 241-SX-104), could bend and/or break and cause instrument malfunction. Configuring an array of vibrating reed switches for continuous level measurement would be difficult. Vibrating reed switches are incapable of gauging interstitial liquids.

5.3.2.19 Weighing. Knowing the weight of an empty containment system, the weight of the system containing process material, the density of the process material, and the vessel configuration allows the process level to be calculated. Mechanical, pneumatic, hydraulic, and electronic force-sensing (usually load cells) systems indicate vessel gross weight changes.

Trying to install weigh cells in the Hanford tank farms would be virtually impossible. However, bubblers and HTG systems, that are hydrostatic devices, measure pressure to directly calculate mass. It would be possible to design a "mass probe" using these types of carefully spanned, high sensitivity, pressure sensing devices. The devices would be capable of gauging interstitial tank liquids.

5.3.3 Emerging In-Tank Liquid Monitoring Technologies

An exhaustive review of emerging in-tank liquid monitoring technologies was conducted. Emerging technologies include instrumentation and techniques that have become commercially available recently, or that will be commercially available in the near future.

5.3.3.1 Hybrid Tank Gauging Systems. Hybrid tank gauging systems are typically a combination of level and mass-based (i.e., hydrostatic) systems (*Advances in Instrumentation and Control* [1991c, 1989e]). The hybrid system uses the best qualities of the level and mass systems to provide the most information in one system. The level gauge, whether it is radar, servo, or mechanical, provides the same quality measurement required for volume determinations. The pressure sensor not only provides the direct mass determination; it also provides a means to determine the total average product density of the tank contents. The advantages offered by a combined or hybrid tank gauge system are the best overall when compared to an independent level based or hydrostatic based tank gauging system.

5.3.3.2 Radar Level Gauges. Radar techniques were applied first to land-based storage tanks for level measurement about seven years ago (*Advances in Instrumentation and Control* [1991a, 1991b, 1990c, 1989a]). Advantages of radar level gauges are their noncontact, nonintrusive and environmentally insensitive characteristics. The noncontact attribute of radar gauges makes it an attractive alternative for sticky, viscous, caking, corrosive, high-pressure or otherwise undesirable applications. Because it is nonintrusive, sensor electronics can be separated from the target environment. Microwave energy is unaffected by airborne contamination, such as dust and moisture, and extremes in temperature and noise. Microwaves independently propagate from the transmission medium, allowing them to operate as well in a vacuum as they do in air. Detector ranges of over 500 ft are possible, as are accuracies of better than $\pm 1/16$ in.

Radar gauging is defined typically by most manufacturers as a microwave radar. These devices use the reflection of an electromagnetic wave from the liquid surface in the tank to determine level. This microwave signal is generated by a sensor mounted on top of the tank. A beam transducer emits the signal as a narrow beam that enters the tank through a tank aperture. The reflected signal, or echo, from the liquid surface is received by the same sensor, and distances are derived from the time delay of the reflected signal.

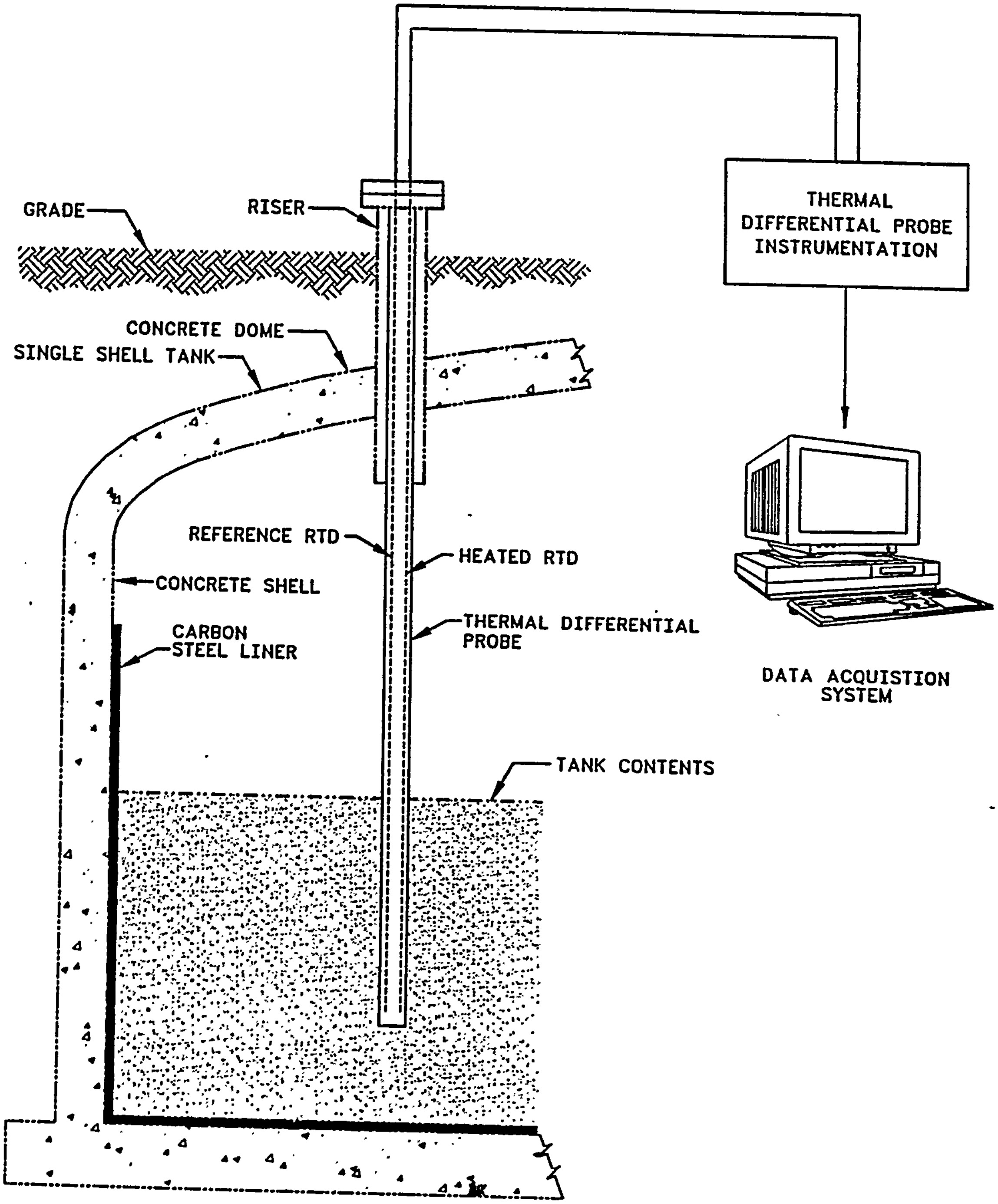
Four different types of radar systems may be used for level gauging. They are; pulse radar, chirp radar, frequency modulation radar, and reflectometer radar (synthesized pulse radar). These systems differ by the use of similar techniques for microwave signal generation, detection, and processing. Common to all four systems is the accuracy of a level measurement is limited by the uncertainty of the electromagnetic conditions. If the tank interior of interest is free from obstructions, radar gauge systems may be configured for free wave propagation. If electromagnetic obstructions are present, wave guides are used. Wave guides, however, are susceptible to problems in situations where the pipe corrodes or can be coated by the process. If a downcomer or stilling well is used as a wave guide, problems can result from rough welds, holes, variable diameter, and the pipe not being perpendicular to the process material. Radar level gauges are incapable of monitoring interstitial liquids.

5.3.3.3 Thermal Differential Monitoring Device. A thermal differential probe is a relatively new technology that measures the level of liquids, foams, and slurries in various industrial process vessels (*Advances in Instrumentation and Control* [1990a]). Both continuous and point level measurements are available. The probe consists of a cylindrical stilling tube containing twin thermally sensitive sensor cables (RTDs) that extend the active length of the instrument in a parallel configuration (see Figure 5-6). When energized, the resistance of the cables is proportional to the average temperature of the liquid and head space gas they are in contact with. Energy is supplied to one RTD cable that self-heats its dry surface to a few degrees above process temperature. A liquid product in a tank generally has a much higher thermal heat transfer coefficient than the head space gas. Thus, when the sensors spanning the tank volume are exposed to both media, a thermal differential is created in the heated sensor because of the quenching effect of the liquid media. The change in resistance of the heated sensor is related linearly to the length quenched by the high heat transfer coefficient media, and, thus, the liquid level can be determined. The parallel unheated sensor experiences the same process conditions as the heated one. Process temperature effects are eliminated by subtracting the two probe outputs, leaving only level related information.

The thermal differential measurement is not affected by changing temperatures, densities, dielectric constants, chemical composition, moisture content, or particle sizes. The device has no moving parts, and simultaneous level and temperature outputs from the same device are possible. The thermal differential probe requires a two-step calibration and provides accuracies from 0.1% to 5% of full scale. The thermal differential probe should not be used in applications where the head space pressure can vary from ambient to 200 psi. Processes with turbulent head space environments also can lead to decreased instrument accuracy. Some instrument lag may occur when waste levels decrease because of the wet "process heel" left on the probe. Thermal differential level measurement technology may have some capability to gauge interstitial liquids.

5.3.3.4 Ultrasonic Level Gauges. Most modern ultrasonic level detection systems are noncontact measurement instruments that are easy to install and maintain. Although ultrasonics for level measurement are not new, the recent incorporation of microprocessors for return signal interpretation has dramatically improved instrument performance (*Advances in Instrumentation and Control* [1989b, 1989c]). Microprocessor-based ultrasonic level meters have enabled signal processing to compensate for sound velocity variations and provide for the ability to reject unwanted signals. However, ultrasonic level gauges are incapable of gauging interstitial liquids.

Figure 5-6. Thermal Differential Liquid Monitoring System.



The principle of operation for ultrasonic level detectors is based on an ultrasonic echo-ranging technique: Elapsed time between transmitted and reflected ultrasonic signals is measured. The elapsed time depends on sound velocity in air, which is a function of temperature. Thus, most ultrasonic level detection instruments use a temperature sensor that measures the temperature of the tank head space. Ultrasonic level measurements can be made independent of medium sound velocity by incorporating a reference reflector and ratio-type computation.

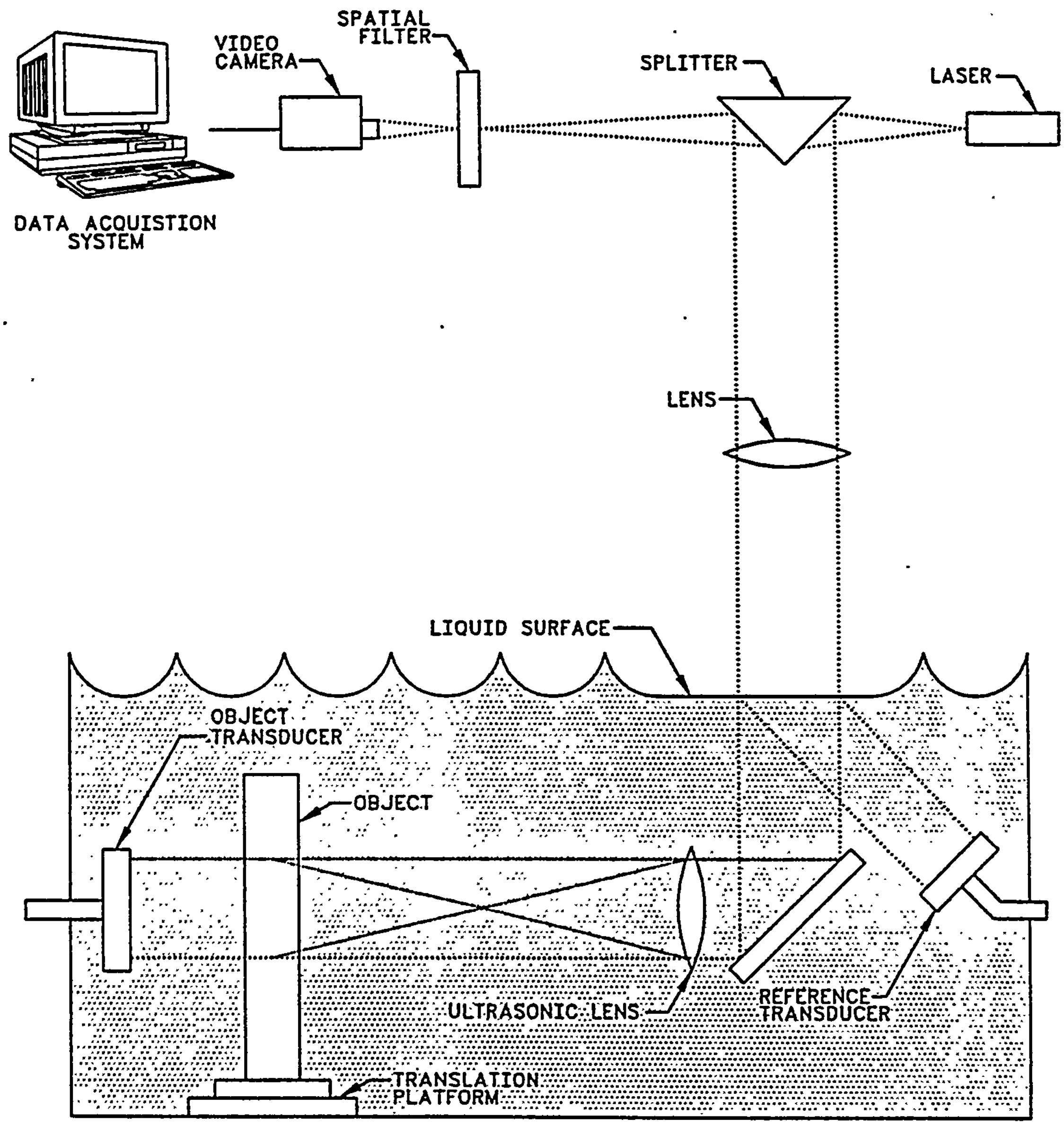
Several types of problems can be encountered using ultrasonics: foaming, liquid turbulence, signal blocking by objects, excessive transducer ringing, and extreme electrical noise. Foaming can have unpredictable effects on the ultrasonic measurement. Depending on the properties of the foam that is occurring, the echo may be; reflected off the top of the foam, reflected from somewhere within the foam, absorbed completely by the foam, or be totally unaffected by the foam. Liquid turbulence will tend to fluctuate readings, weaken echoes, and reduce the useable range. In applications with turbulence, adjustment of the instruments damping and echo loss time constant will help. Signal blocking by objects can result in parasitic echoes. Parasitic echoes can be minimized by; careful placement of the signal generator on the tank, using a stilling well, or using an algorithm implemented with the microprocessor to subtract the echo from the received signal. Ringing, or secondary parasitic echoes, can also be a problem with ultrasonics. Ringing is a result of transmitted signals being refracted and reflected back to the receiver by a surface other than the tank process material. The result of ringing is a false high measurement. Ringing can be controlled by manipulating the threshold decay to target threshold value. Noise can cause false echoes. Noise can be subtracted from the received signal by raising the signal threshold value.

5.3.4 Conceptual In-Tank Liquid Monitoring Technologies

Various conceptual technologies for measuring interstitial fluid content of SST waste were examined. The goal was to identify candidate technology(ies) capable of monitoring interstitial liquids. Unfortunately, techniques as optical imaging and ground penetrating radar do not work effectively because of the lack of signal penetration into the material being evaluated. Technologies that may have the potential for measuring interstitial liquid levels in SSTs are described below. These technologies are being applied to the area of geophysical measurement of moisture in soils.

5.3.4.1 Acoustic Imaging/Holography. Acoustic imaging/holography has been used frequently in nondestructive evaluation (NDE) of materials to determine their internal structure. This technique relies on scanning a source of sound (or the object in front of a fixed source of sound), and looking at the echo return and reference signal to build the image. Figure 5-7 shows a simplified diagram of a typical liquid surface holographic system (Brenden et al. 1974). In the figure, the hologram is formed on the liquid surface and read by the laser. The image is sent to the video camera through a spatial filter. Image processors (hardware and/or software) are used to analyze the three-dimensional image of the object.

Figure 5-7. Acoustic Holography System.



A proposed method of using acoustic holography for remotely measuring tank internal structures (BDM 1993), extends the liquid surface detection to the surface above the waste tank. Discussions with Brenden (1993) indicate that the method would be a very ambitious and difficult to implement the technology.

Acoustic imaging/holography techniques are old, but they have never been applied to a matrix as complex as an SST. A possible approach for applying acoustic holography to the Hanford tanks would be to remove an encapsulated core sample of the waste from the tank and then image it in a liquid surface holographic system outside the tank environment. But, because of the high degree of SST waste inhomogeneity, obtaining a representative core sample would be difficult. Acoustic imaging/holography will not work effectively on moving wastes, and it is generally not suited for Hanford wastes because it relies on low acoustic attenuation of the material under test. The application of acoustic imaging/holography to Hanford SSTs would require the installation of a complex tank internal scanning mechanism. The development of an acoustic imaging/holographic system for monitoring Hanford SST wastes would be expensive. Furthermore, alignment and calibration (general maintainability) of the device would be difficult. An acoustic imaging/holographic system would not be capable of gauging interstitial liquids.

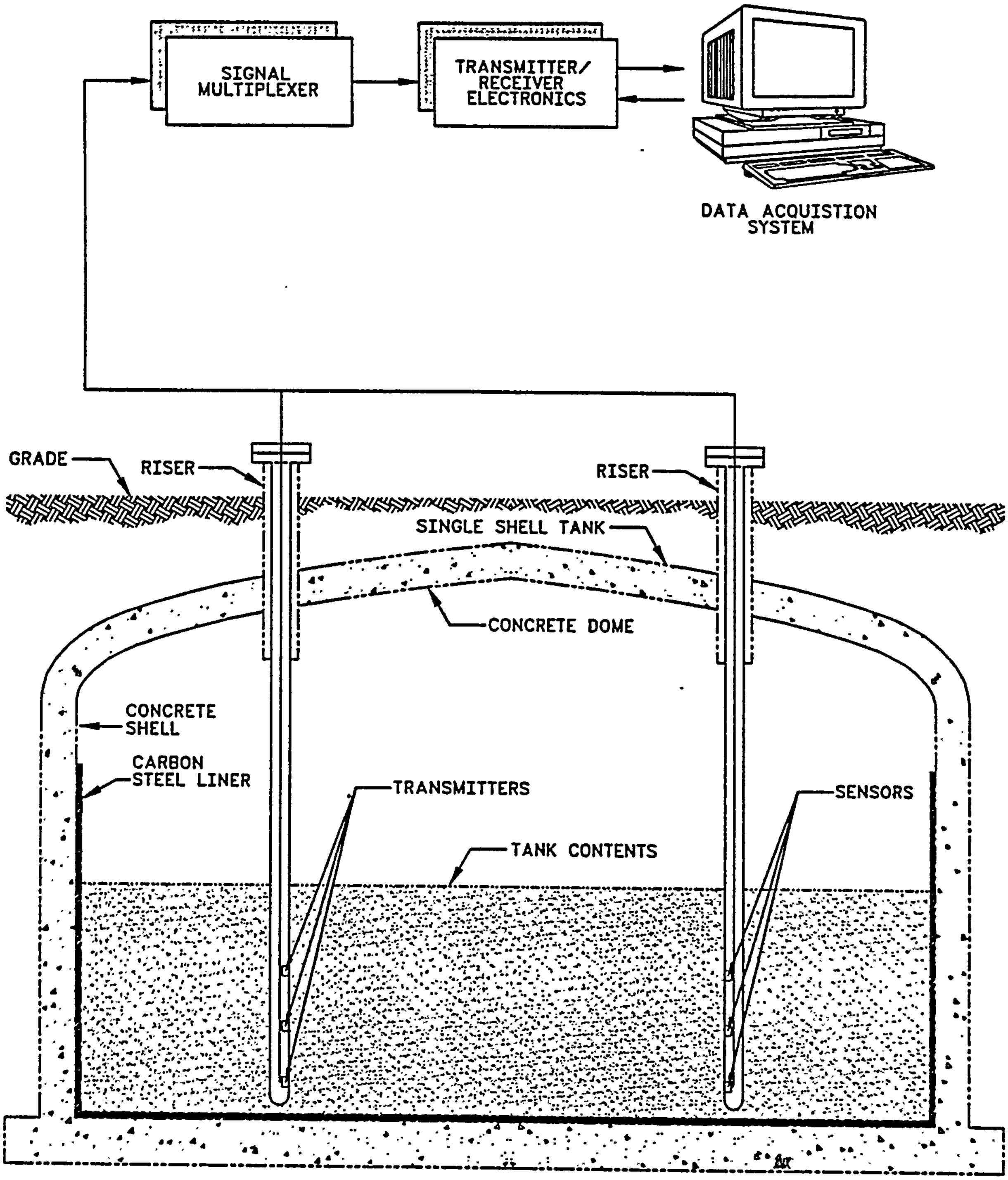
5.3.4.2 Borehole Tomography. Ultrasonic signal attenuation (10-50kHz) in tank waste has been shown to be excessively high (i.e., approximately 1,000 dB/meter). Lower frequencies (i.e., 100-2000 Hz, used typically in geophysical exploration) may be used to penetrate tank waste. Borehole tomography, also referred to as crosshole seismic tomography, measures the velocity of compressional (P) waves and shear (S) waves between two or more boreholes (Telford 1990). By examining the ratio of P and S wave velocities, identification of changes in interstitial liquid levels may be possible according to Rohay (1993) and Elbring (1993). This technology is old and has been used extensively in characterizing geological formations. Figure 5-8 gives a schematic representation of a typical system.

Cross-well imaging is a technique similar to borehole tomography. The configuration for cross-well imaging is similar to that shown in Figure 5-8. The wave forms are collected at the receiver sensors and analyzed to determine the spatial distribution of the physical properties between the receiver and transmitter wells. A thorough explanation of this technology is given by Rohay (1992).

Borehole tomography projects have been proposed by a joint PNL/Lawrence Berkeley Laboratory team (TTP No. RL3-41048), and another was proposed by Sandia National Laboratory to characterize a site in Idaho (TTP No. AL2-41004). A proposal was submitted in 1992 (TTP No. RL3-30079) to try reducing resolution to 1 ft. That project (teamed by PNL, LANL, and the Massachusetts Institute of Technology) was not funded.

Borehole tomography is a proven geophysical technique that could be applied to all Hanford SST wastes. Borehole tomography provides continuous monitoring and two- or three-dimensional imagery of tank wastes. Two-dimensional imaging requires two boreholes and three-dimensional imaging requires at least three boreholes. The application of borehole tomography to Hanford SSTs requires the use of in-tank LOWs. This requires issues related

Figure 5-8. Borehole Tomography Concept.



to shifting waste solids be addressed. Sources and receivers are fairly simple, have no moving parts, and would not be impacted from coating or plugging problems. However, source and receiver robustness may present reliability/ maintainability problems. Borehole tomography is incapable of quantitatively gauging interstitial liquids, but it is capable of measuring qualitative changes.

5.3.4.3 Dielectric Measurement. A capacitance probe has been used in soils to measure moisture content (Dean 1987). The dielectric measurement (capacitance measurement) system relies on the fact that the dielectric constant of soil changes with water content. The capacitance probe uses a minimum of two electrodes separated by the material under measurement. Figure 5-9 shows a simplistic block diagram of how this might be accomplished. A capacitor is formed by the capacitance electrodes (which are part of the probe), and the material under evaluation (which forms the capacitor dielectric). As the moisture content increases, the dielectric constant (ϵ) increases causing the capacitance of the probe to increase. The capacitor is part of the network that determines the output frequency of the oscillator circuit. This frequency is converted to a voltage by the frequency-to-voltage converter that is then read by the data acquisition system.

Capacitance probe arrays could be placed on LOWs, but significant research would be required to calibrate the dielectric constant as a function of interstitial liquid content. In fact, calibration research may be required on a tank-by-tank basis. Capacitance probe arrays have no moving parts, are capable of continuous monitoring, and can be designed with intrinsically safe configurations. However, shifting wastes would seriously disrupt capacitance probe measurements. Shifting waste solids (i.e., Tank 241-SX-104) could cause the probe to bend or break and cause instrument malfunction. Capacitance probes are capable only of localized measurement (at or around the probe), and solids coating will cause decreased probe accuracy. Capacitance probe measurements are incapable of quantitatively gauging interstitial liquids, but they are capable of measuring qualitative changes.

5.3.4.4 Electromagnetic Measurement. Electromagnetic measurement involves measuring electromagnetic parameters from a sending coil to the material under test. Variations in the material (e.g., electric conductivity, electric permitivity, and magnetic permeability) are picked up by the receiving coil.

Electromagnetic induction measurements can be made by using an array of coils to induce electromagnetic fields in a material. The penetration depth of these fields is a function of frequency, conductivity, and permeability. Of these three parameters, only frequency can be adjusted. This technology has been used successfully in geophysical moisture measurement applications. A simplified schematic is shown in Figure 5-10.

Other types of electromagnetic measurements that may be applicable to SST wastes are impedance measurements as described by Ungar (1992). An impedance probe array might be placed in the material to be analyzed, and the combination of the probe and material under evaluation form an impedance (Z) composed of resistance (R, real part) and capacitive reactance (X_c, imaginary part).

$$Z = R + j X_c$$

Figure 5-9. Capacitance Probe Array.

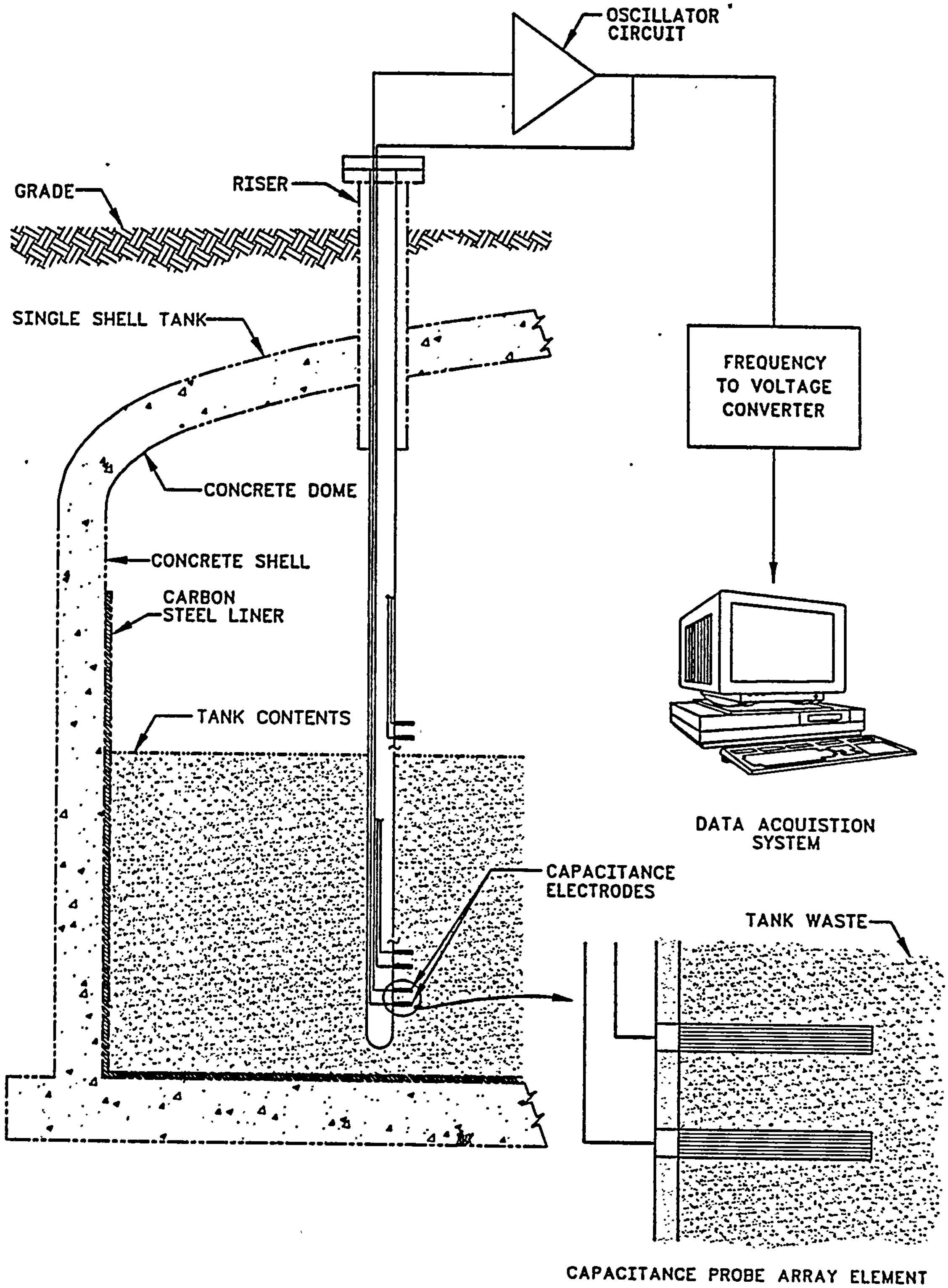
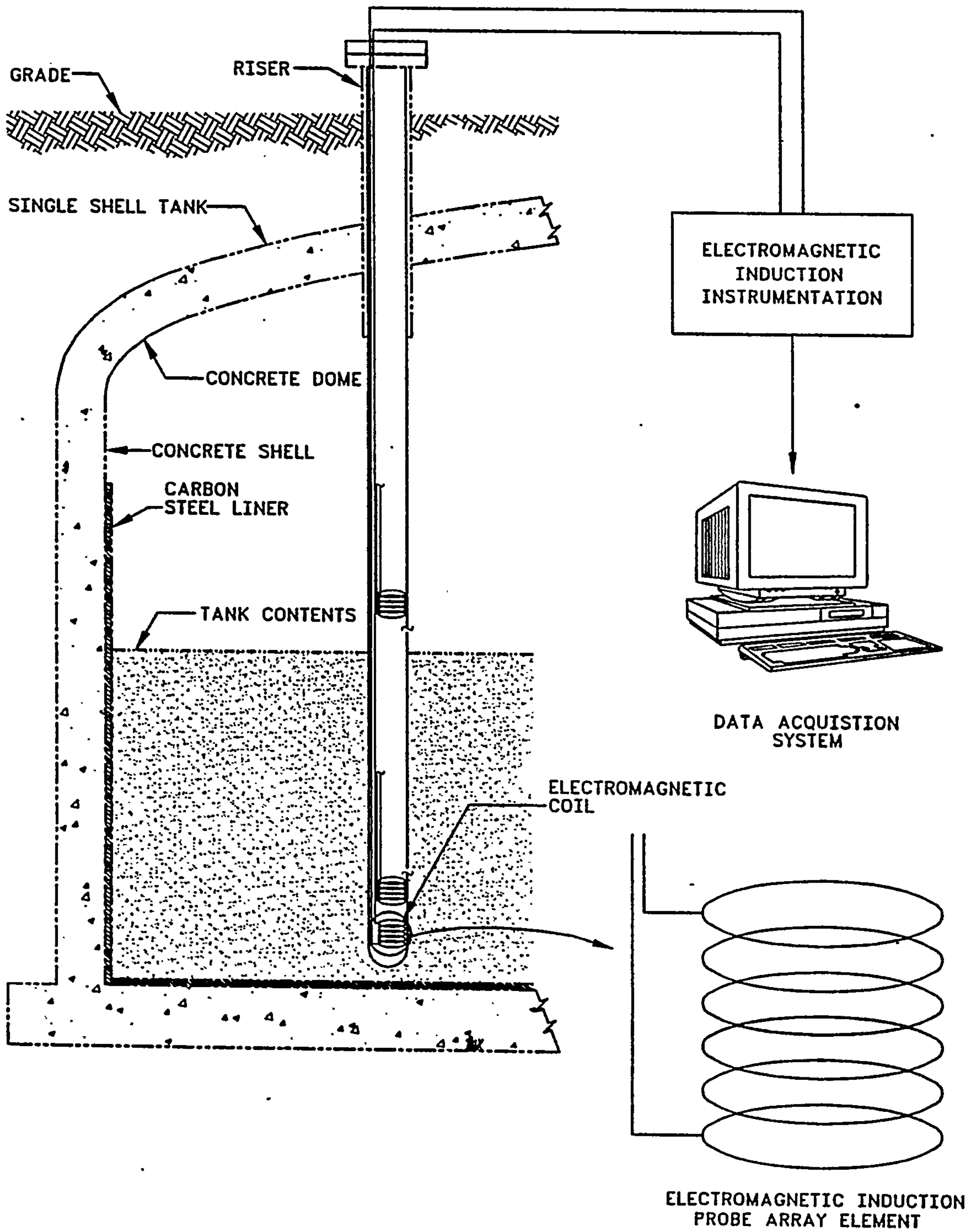


Figure 5-10. Electromagnetic Induction Probe Array.



Both R and X_c will vary with moisture content. A schematic view of this type of measurement is shown in Figure 5-11.

Electromagnetic measurements may indicate relative changes in interstitial liquid levels, but calibration for absolute measurements in SSTs may prove to be impossible due to waste material inhomogeneity. Hockey (1993) has researched the use of electromagnetic induction instrumentation to determine the relative level of fluids in waste tank simulants. Although the results are not published yet, initial indications appear promising.

Electromagnetic measurements have no moving parts or active electronic components in the waste tank, are capable of continuous monitoring, and could be made intrinsically safe. However, electromagnetic measurements are a contacting technique; therefore, shifting waste solids could cause the probe to bend or break, and cause instrument malfunction. Furthermore, significant research would be required to determine the electromagnetic properties of Hanford SST wastes as a function of interstitial liquid content, perhaps on a tank-by-tank basis. Electromagnetic measurement techniques are capable only of localized measurement (at or around the probe) and solids coating will cause decreased probe accuracy. Electromagnetic measurements are not capable of quantitatively gauging interstitial liquids, but they are capable of measuring qualitative changes.

5.3.4.5 Fluorescence Measurement. It may be possible to measure interstitial fluids by measuring the amount of fluorescence from a waste sample that is illuminated with a laser source. When a solid is strongly illuminated with monochromatic light of wavelength λ_1, the sample may reradiate energy at a longer wavelength λ_2 (Jenkins 1976). The amplitude of λ_2 may be related partially to the amount of interstitial fluid in the sample volume. Very little has been published on this technology as related to moisture measurement. A graphic representation of this technology is shown in Figure 5-12.

Fluorescence measurement devices may be configured for continuous monitoring with no active components in the SST. All signals could be carried over a radiation-hardened fiber optic cable. However, high power levels of light are suspected to be required for the Hanford application. There has been no direct research to indicate how this technology would work in a Hanford SST. Because of the extreme heterogeneous nature of Hanford SST waste and the infancy of the technique, extensive research would be required to determine whether fluorescence could be used for interstitial liquid monitoring.

5.3.4.6 Nuclear Magnetic Resonance (NMR). Nuclear Magnetic Resonance has been used to measure moisture in soils (Paetzold 1987). When a material is placed in a strong magnetic field, it will absorb radio frequency (rf) energy at specific frequencies. This rf energy will place the nucleus (protons) in a higher energy state so their spin is opposite that of the magnetic field. When the rf energy is turned off, the material radiates rf energy at its characteristic resonant frequencies as the nuclei decay to lower energy states. This information can be used to determine the moisture content in the material under study.

Figure 5-11. Impedance Probe Array.

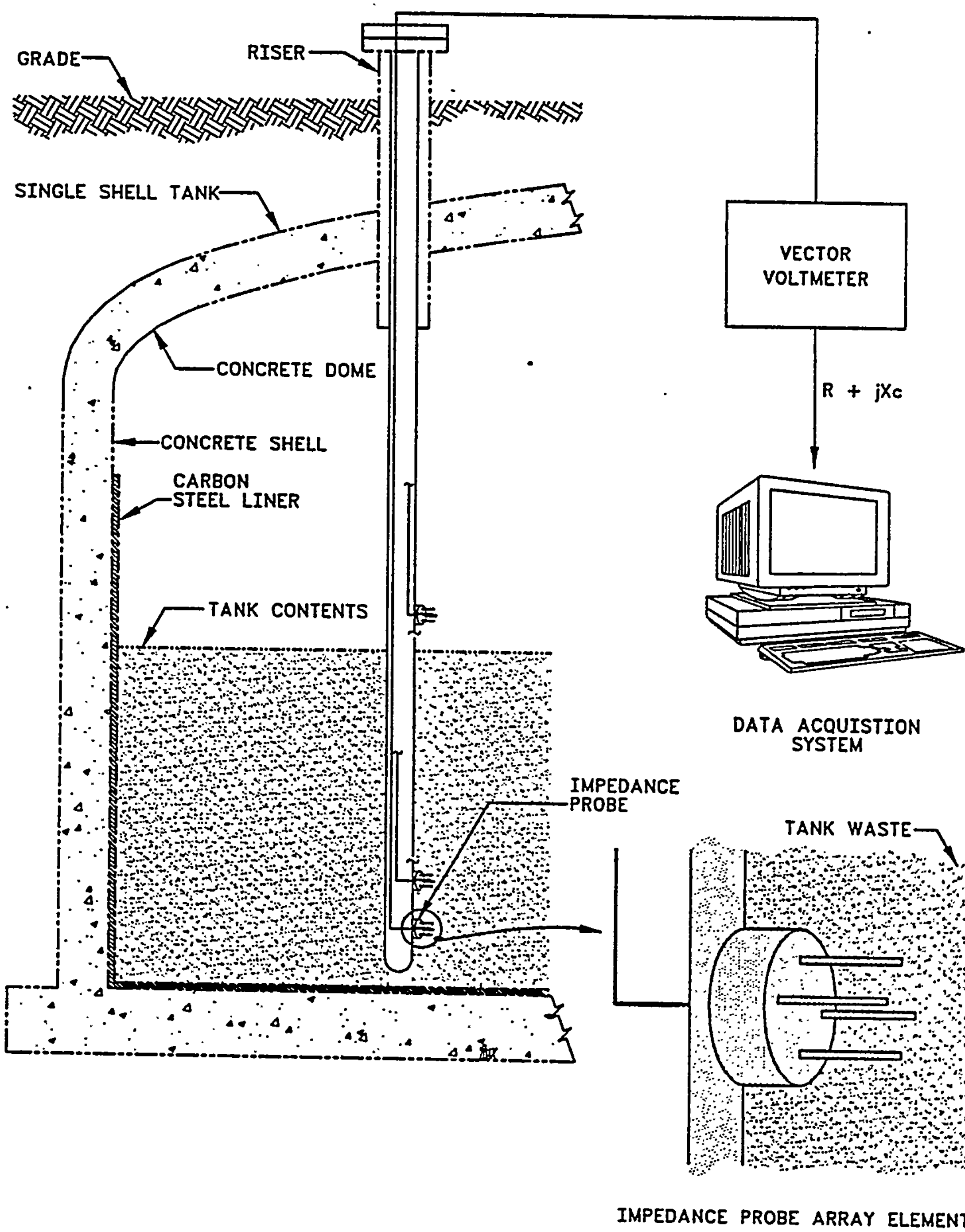
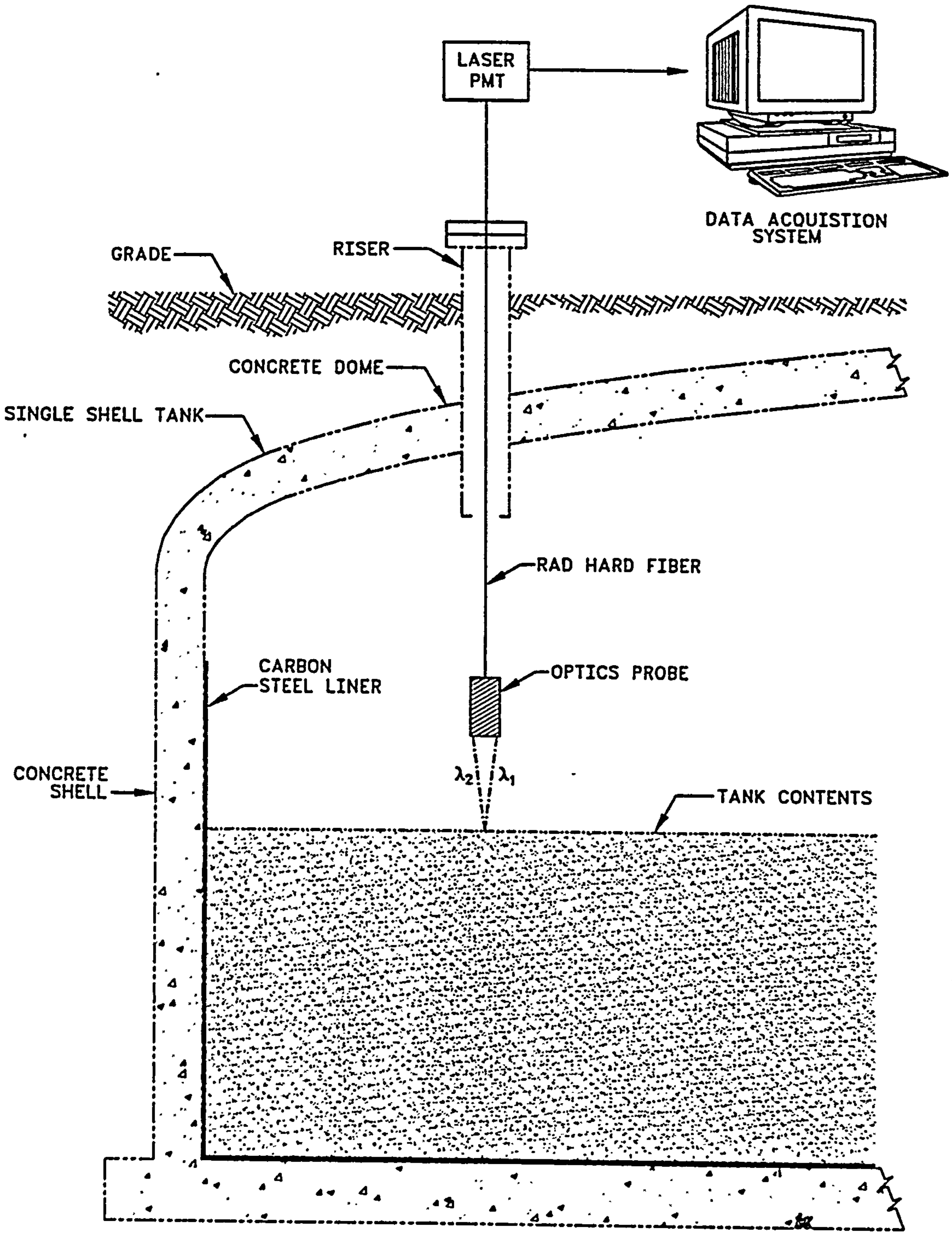


Figure 5-12. Laser Fluorescence Measurement.



An NMR probe used for surface moisture measurement could be placed in a LOW and scanned through the waste for continuous waste monitoring. However, proton NMR has not been tested on Hanford SST wastes and are typically very expensive. Because of the extremely heterogeneous nature of Hanford SST waste and the limited available data on the application of NMR, extensive research would be required to determine whether NMR could be used for interstitial liquid monitoring.

5.3.4.7 Photogrammetry Surface Measurement. Photogrammetry is a method of making dimensional surface measurements by photographs or video images (Deichelbohrer 1993). A minimum of two images are required. Points of interest are read off the image by a computer which calculates the X, Y, and Z coordinates of the points. Photogrammetry is equivalent to stereo viewing. Very high accuracies (level changes of approximately 1/500 in.) could be achieved under optimum conditions.

Photogrammetry is a real-time surface-monitoring technique capable of continuous monitoring and data logging. Photogrammetry probably will be susceptible to operations problems similar to those of CCTV systems, but would be a very useful technique for monitoring the surface of tank wastes. However, like other optical techniques, photogrammetry is incapable of gauging interstitial liquids.

5.3.4.8 TDR. Time domain reflectometry determines the dielectric constant (ϵ) of a material under test. A very short electrical pulse is sent down a cable to the TDR probe. By knowing the length (L) of the probe and the time (t) it takes for the signal to propagate down the probe assembly, the dielectric constant of the material can be determined by the following formula:

$$\epsilon = (ct/L)^2$$

where:

c = speed of light, 3×10^8 m/s.

For more than 20 years, there have been many studies done to characterize the dielectric properties of soils with relation to moisture content. Look (1992) lists the dielectric constants for air (ϵ_{air}), dry soil (ϵ_{soil}), and water (ϵ_{water}) as:

$$\epsilon_{air} = 1$$
$$\epsilon_{soil} = 3 \text{ to } 6$$
$$\epsilon_{water} = 79 \text{ to } 82$$

The substantial difference in ϵ_{soil} and ϵ_{water}, is reason to believe that moisture in soils can be measured. For soils, Topp (1980) established the following empirical relationship to determine the volumetric moisture content (θ_v) that is independent of soil types:

$$\theta_v = -5.3 + 2.92\epsilon - 5.5 \times 10^{-2}\epsilon^2 + 4.3 \times 10^{-4}\epsilon^3$$

Because there have been no known dielectric measurements of SST wastes, studies would be required to determine ϵ_{solid} and ϵ_{liquid} for the different tank components (i.e., sludge, salt cake, aqueous liquor, etc.) before TDR measurements could be attempted. If ϵ_{solid} and ϵ_{liquid} were significantly different, as in soils, empirical relationships could be developed to give qualitative solids content measurements. A conceptual drawing of the use of a TDR interstitial liquid measurement system is shown in Figure 5-13.

TDR techniques have been proposed by Radder (1993) and Tilley (1993) to measure liquid levels from the top to bottom of waste tanks using long probes (see Figure 5-14). Thus, in effect, serially linking the smaller probes discussed in the paragraphs above and using a single pulse source. The received wave form could be analyzed to determine changes in sections of the probe's impedance (or dielectric constant). From these comparisons, relative changes in interstitial liquid level may be obtained.

TDR has no moving parts or active electronic components. It is capable of continuous monitoring and could be made intrinsically safe. However, TDR is a contacting technique. Therefore, shifting waste solids could cause a TDR probe (or LOW) to bend or break and cause instrument malfunction. Even if the probe integrity was not compromised by shifting waste solids, waste movement would seriously disrupt the TDR measurement. Furthermore, electronic measurement techniques are capable only of localized measurement (at or around the probe), and solids coating will cause decreased probe accuracy. Significant research would be required to determine the dielectric properties of Hanford SST wastes as a function of interstitial liquid content, perhaps on a tank-by-tank basis. TDR techniques are incapable of quantitatively gauging interstitial liquids, but they are capable of measuring qualitative changes.

5.3.4.9 Ultrasonic Measurements in LOWs. The amount of ultrasonic energy that can be transferred from the inside wall of a LOW into the material under evaluation is dependent on the quality and quantity of the couplant on the outside wall of the LOW. More acoustic energy will be transferred to the material if more moisture is present. An ultrasonic instrument can be set up to "gate" on the outside wall and record the level of the reflected energy. This type of measurement would measure a relative change in the interstitial liquid level. A graphic representation of an ultrasonic method for measuring relative interstitial liquid levels is shown in Figure 5-15.

Ultrasonic measurements have been made in Hanford SSTs (Schuster 1993). Problems associated with this measurement made the signal appear "noisy." A better method of coupling the acoustic energy into the LOW wall may help reduce the signal noise. Observation is needed to ensure that the coupling between the outer LOW wall and the waste material under it is free of air bubbles. Ultrasonic techniques have no active electronic components in the waste tank and could be made intrinsically safe. However, ultrasonic measurements are a contacting technique; therefore, shifting waste solids could cause an ultrasonic probe (or LOW) to bend or break and cause instrument malfunction. Similar to the current acoustic probe in-tank LOW system, ultrasonic measurements are capable of qualitative interstitial liquid monitoring only in the area immediately surrounding the probe (or LOW). Ultrasonic techniques are incapable of quantitatively gauging interstitial liquids.

Figure 5-13. Time Domain Reflectometry Array.

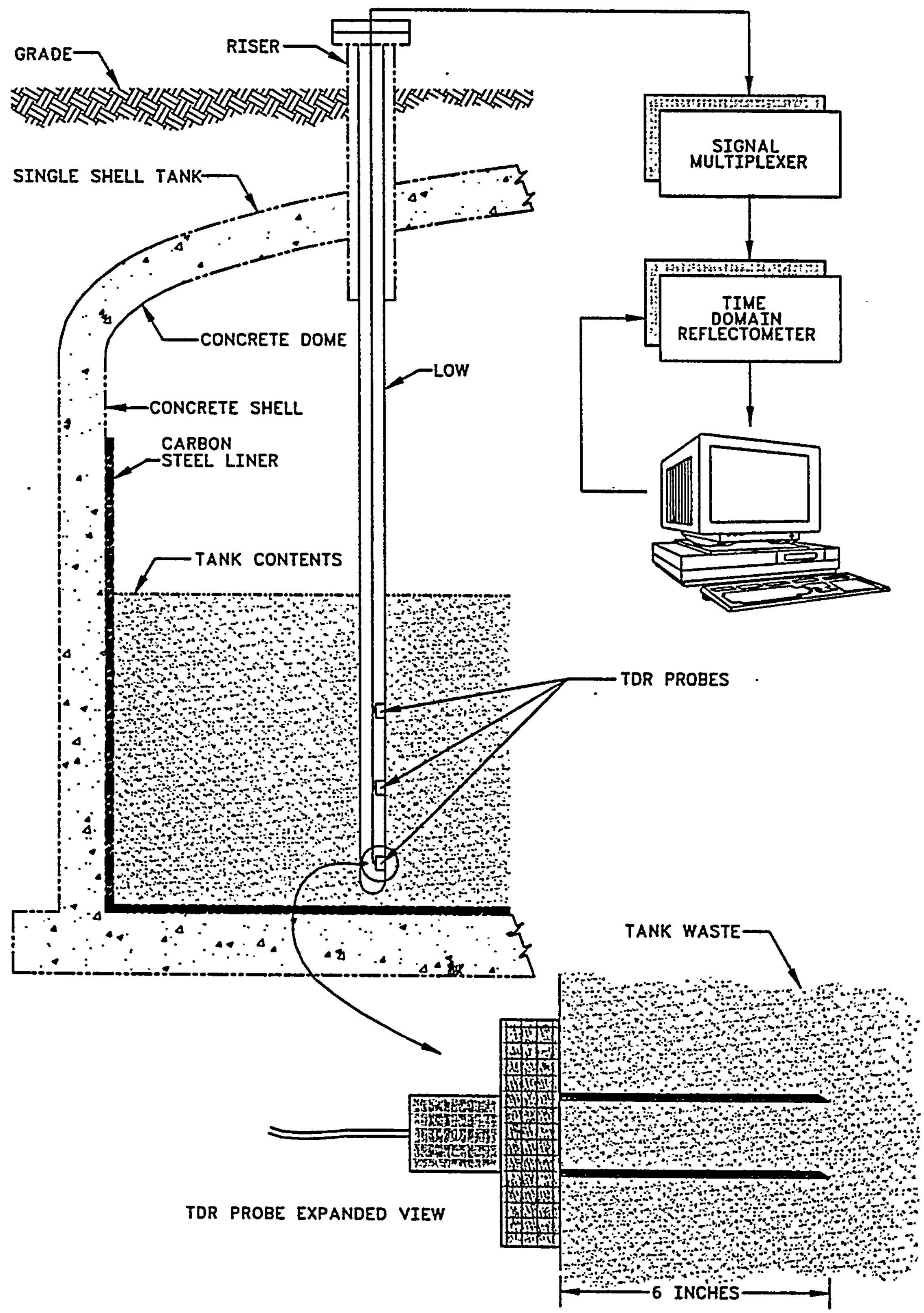


Figure 5-14. Time Domain Reflectometry Element.

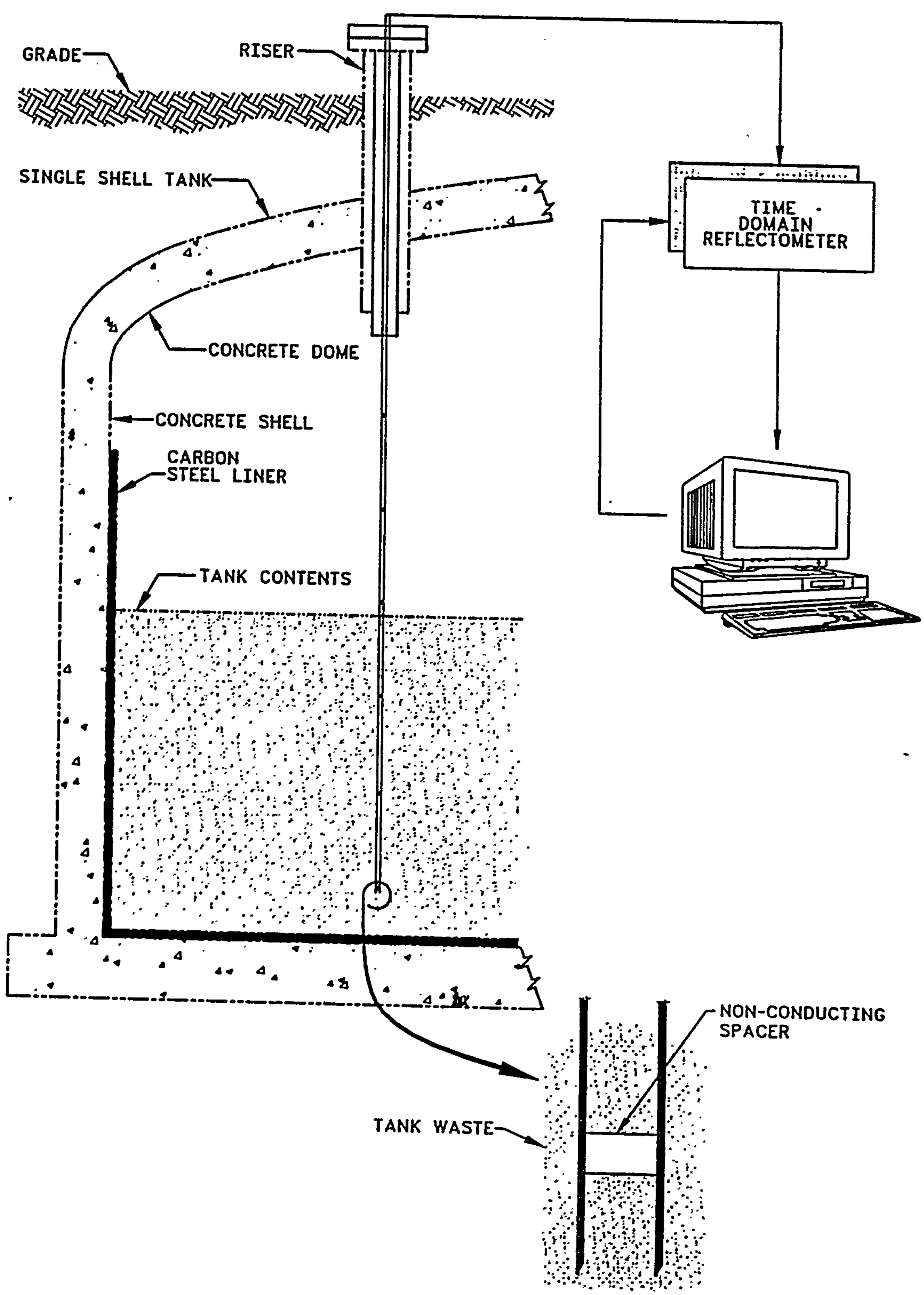
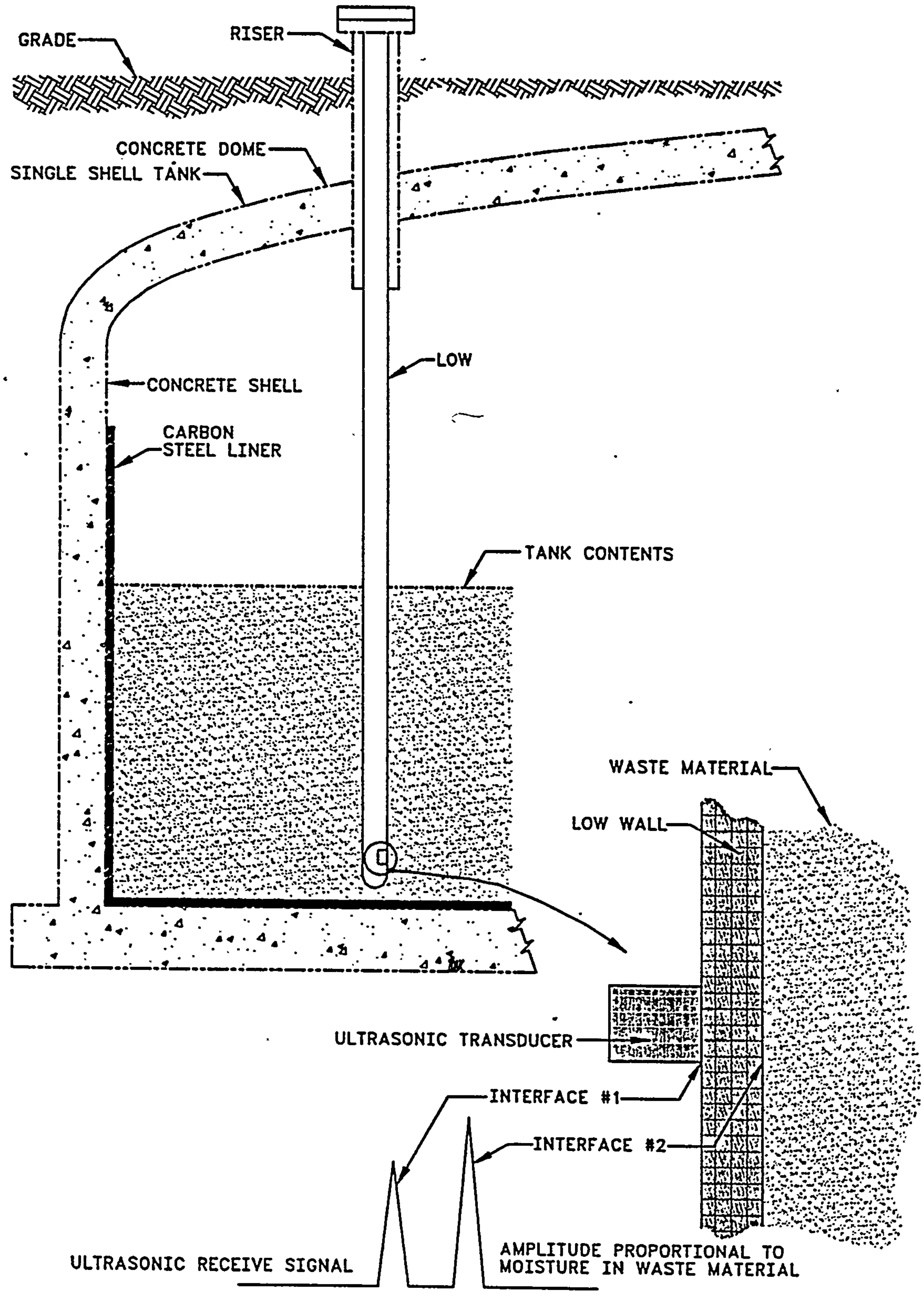


Figure 5-15. Ultrasonic Measurement in Liquid Observation Wells.



6.0 DISCUSSION OF PREFERRED ALTERNATIVE/SOLUTION

An initial screening of all tank monitoring technologies was done to identify candidates for the Hanford SST application. The screening criterion was that a candidate technology must have capability to gauge interstitial liquids. Ten technologies passed the initial screening and were selected as candidates. Nine of the ten candidate technologies were scored and ranked based on the criteria of safety, regulatory compliance, cost, schedule, technical feasibility, and maintenance/operations, as described in Section 5.0. Evaluation results are presented in Table 6-1. A summary of the evaluations is presented in Appendix B. The tenth technology, hybrid tank gauging, was not scored or ranked. Hybrid tank gauging is discussed in Section 6.10.

Important to note, selected candidate technologies were evaluated and ranked relative to one another for the Hanford SST application. No single technology can be used to accurately gauge interstitial liquids for all the Hanford SSTs. It is not recommended that Table 6-1 be used as a springboard for creating a set of absolute technology rankings based upon absolute functional criteria because Hanford SST waste characteristics are too diverse. For example, an SST may contain wastes that consist of a solid, crust-like layer on top, followed next by a dilute sludge, followed by a liquid layer, followed by a concentrated sludge, and finally ending with a crystalline solid at the bottom. Would an HTG system be capable of gauging liquids in such a waste matrix? Probably yes. Does the waste exhibit Newtonian or near-Newtonian behavior, as the HTG system functional criteria require? In general, no. This example serves to illustrate the ambiguous nature of the functional criteria as applied to Hanford SST wastes for the instrument systems evaluated. Waste characteristics, tank gauging needs, and instrument performance must all be carefully considered by cognizant personnel before selecting an SST liquid monitoring system. Table 6-1 is presented as a general guide to aid in that process.

6.1 HTG

Ranking - #1

HTG is a proven, universal mass-based tank gauging technology that was ranked as the best candidate technology for gauging interstitial liquids in Hanford SSTs. An HTG system uses hydrostatics to measure the total mass of the process material contained in a tank. HTG tied for the highest ranking in the category of safety because it has no moving parts, is intrinsically safe, has no in-tank maintenance requirements, and potential for human exposure exists only during probe installation. HTG tied with bubblers for the highest ranking in the category of regulatory compliance because it is the most accurate of the selected candidates, and can provide continuous real-time output for remote monitoring. HTG received the highest ranking in the categories of cost and schedule because all the technology is "off the shelf." HTG requires no additional utilities in the tank farms, requires low maintenance, and research and development associated with designing, building, and testing an HTG probe would be straightforward. HTG is ranked the highest in technical feasibility because of its relatively simple design and because component parts are available, highly accurate, and "off the shelf" (low cost). An HTG system would require periodic calibration in the field, and ranked third in the category of maintenance and operations.

Table 6-1. Selected Candidates for Hanford Single-Shell Tank Interstitial Liquid Monitoring Technology Evaluation.

Ranking	Technology	Safety		Regulatory Compliance		Cost		Schedule		Technical Feasibility		Maintenance and Operations		Total
		Weight factor = 5		Weight factor = 4		Weight factor = 2		Weight factor = 3		Weight factor = 4		Weight factor = 3		
		Score	Weighted score	Score	Weighted score	Score	Weighted score	Score	Weighted score	Score	Weighted score	Score	Weighted score	
1	Hydrostatic Tank Gauging	2	10	1	4	3	6	3	9	7	28	5	15	72
2	Thermal Differential	2	10	2	8	5	10	4	12	9	36	4	12	88
3	Electromagnetic Measurement	2	10	3	12	5	10	4	12	13	52	5	15	111
4	Bubblers	5	25	1	4	6	12	7	21	11	44	7	21	127
5	Liquid Observation Well	8	40	5	20	5	10	4	12	10	40	3	9	131
6	Dielectric Measurement	4	20	4	16	5	10	4	12	14	56	7	21	135
7	Time Domain Reflectometry	2	10	4	16	7	14	6	18	17	68	6	18	144
8	Borehole Tomography	4	20	5	20	8	16	6	18	16	64	7	21	159
9	Radiation Level Sensors	7	35	5	20	5	10	4	12	14	56	11	33	166

6-2

6.2 THERMAL DIFFERENTIAL

Ranking - #2

Thermal differential devices are emerging technologies that recently have become available and were ranked as the second best candidate technology for gauging interstitial liquids in Hanford SSTs. This technology uses RTDs to measure changes in the thermal conductivity of a given process media. These thermal conductivity changes can be correlated to level changes in neat liquids, and might be capable of gauging interstitial liquids in heterogeneous slurries. Thermal differential technology tied for the highest ranking in the category of safety because it has no moving parts, it is intrinsically safe, has no in-tank maintenance requirements, and the potential for human exposure exists only during probe installation. It ranked second in environmental compliance, and is capable of real-time, remote measurement of 0.1 in. level changes in neat liquids, but can only monitor waste at and around a tank probe. If the thermal conductivity of SST waste is a nearly linear function of solids content, and gross horizontal stratifications in waste solids do not exist, a reasonably accurate, neat liquid-equivalent slurry measurement may be possible. If the thermal conductivity of SST waste is a nonlinear function of solids content, more complex signal interpretation software would need to be developed and instrument accuracies would very probably decrease. However, thermal differential probes are capable of measuring qualitative changes around the probe with high sensitivity. Thermal differential measurements scored fair in cost and schedule because they require no additional utilities in the tank farms, little or no maintenance, and the research and development associated with designing, building, and testing would be straightforward. This technology ranked second in technical feasibility because of its relatively simple design, the availability of commercial systems, and the limited testing requirements for implementation. It ranked first in maintenance and operation because, there are no system maintenance or calibration requirements other than installation.

6.3 ELECTROMAGNETIC MEASUREMENT

Ranking - #3

Electromagnetic measurement is a conceptual level-based tank gauging technology and was ranked as the third best candidate technology for gauging interstitial liquids in Hanford SSTs. It uses electromagnetic inductance to measure the percent liquid at a given depth at and around a probe, giving a "picture" of the interstitial characteristics of the process material contained in a tank. Electromagnetic measurement tied for the highest ranking in the category of safety because it has no moving parts, is intrinsically safe, has no in-tank maintenance requirements, and the potential for human exposure exists only during probe installation. The mitigative response capabilities of electromagnetic measurement technology are fair at best. Electromagnetic measurements can only monitor waste at and around a tank probe, and cannot provide quantitative measurements. However, it can provide real-time output for remote monitoring. Electromagnetic measurements scored fair in cost and schedule because it requires no additional utilities in the tank farms, little or no maintenance, and the research and development associated with designing, building, and testing an eddy current probe would be straightforward. The technical feasibility of electromagnetic measurements could be determined quickly. Assuming electromagnetic measurement was a viable technology, it scored poorly on technical feasibility. At best, it could provide data similar to those of the Hanford LOW system, except that electromagnetic measurements would probably be much easier to interpret. Electromagnetic measurement ranked third best in the category of maintenance/

operations because occasional field operations may be required for instrument maintenance and calibration.

6.4 BUBBLERS

Ranking - #4

Bubblers are proven, universal mass-based tank gauging technology that were ranked fourth as a candidate technology for gauging interstitial liquids in Hanford SSTs. Bubblers use hydrostatics to measure the total mass of the process material contained in a tank. Bubblers scored moderately in the category of safety because of the in-field maintenance requirements and because it introduces matter into tanks. Bubblers could serve to dry out localized areas of tank waste, which is a potential (probably insignificant) ferrocyanide stability concern. Bubblers tied with HTG for the highest ranking in the category of regulatory compliance because they are the most accurate of the selected candidates and can provide continuous real-time output for remote monitoring. Bubblers received poor scores in the categories of cost and schedule because of associated utilities requirements, and for political reasons. Bubbler systems require three primary pieces of instrumentation along with a gas source. The gas source utilities requirements would be extremely expensive. The installation of a permanent bubbler gas header would be a large capital item. Using bubbler gas cylinders in the field would require a great deal of field operations. The political issues deal primarily with overcoming prejudices founded on previous experiences with old-fashioned bubbler systems used at Hanford. Trying to sell the idea of using high-performance bubblers at Hanford likely would be an arduous task. Bubblers ranked fair in the category of technical feasibility because of the complexity of a high-performance system. Each bubbler tube would require an automatic mechanical ram (or clearing device), mass flow controller, precision bubbler tube designed for very slow and steady gas flow, and a high precision pressure sensor. The development of a high-performance bubbler system would require a significant effort. Bubblers scored only moderately in maintenance/operations because a bubbler system would require periodic pressure sensor calibration in the field, and if gas cylinders are used, they require changeout in the field.

6.5 IN-TANK LOW

Ranking - #5

The Hanford LOW system is a level-based tank gauging technology currently used in the SSTs. The LOW system was ranked fifth as a candidate technology for gauging interstitial liquids. The LOW system uses neutron, gamma, and acoustic probes on a portable cabling system inside in-tank drywells to measure the percent liquid at a given depth, at and around the drywell, providing a "picture" of the interstitial characteristics of the process material contained in a tank. The LOW system scored poorly in the category of safety because in-field operations are required to obtain data, and broken in-tank drywells present a potential exposure hazard to operators. The LOW system scored poorly in regulatory compliance because it only has capability to monitor tank waste qualitatively at and around a drywell. It cannot provide continuous real-time output or remote monitoring. The LOW system scored fair in cost and schedule because the technology is developed and is currently operating on the Hanford site. The LOW system scored fair on technical feasibility because the system has been proven at Hanford as a qualitative technique. However, the LOW system was ranked the highest in the category of maintenance/operations because all LOW system instrumentation calibration and repair can be done in a maintenance shop.

6.6 DIELECTRIC MEASUREMENT

Ranking - #6

Dielectric measurement is a conceptual level-based tank gauging technology that was ranked sixth as a candidate technology for gauging interstitial liquids in Hanford SSTs. It uses capacitance to measure the percent liquid at a given depth at and around a probe, providing a "picture" of the interstitial characteristics of the process material contained in a tank. Dielectric measurement scored fair in safety because the capacitance sensors must contact the tank waste physically. Therefore, any maintenance or repair would have to be conducted in-tank. The mitigative response capabilities of dielectric measurement are fair at best. Dielectric measurements can only monitor waste at and around a tank probe, and cannot provide quantitative measurements. However, measuring techniques can provide real-time output for remote monitoring. Dielectric measurements scored fair in cost and schedule because capacitance techniques require no additional utilities in the tank farms, and little or no maintenance. The research and development associated with designing, building and testing a dielectric probe would be straightforward. Because dielectric measurement is a conceptual technology, the technical feasibility of dielectric measurements could be determined quickly. Dielectric measurement was assumed to be a viable technology; however, it scored poorly on technical feasibility. At best, dielectric measurements could provide data similar to those of the Hanford LOW system, except that it might be easier to interpret. Dielectric measurement ranked fair to poor in the category of maintenance/operations because the capacitance sensors are required to contact the tank wastes physically.

6.7 TDR

Ranking - #7

Time domain reflectometry is a conceptual level-based tank gauging technology that was ranked seventh as a candidate technology for gauging interstitial liquids in Hanford SSTs. TDR uses electronic pulses to measure the percent liquid at a given depth at and around a probe, and obtains a "picture" of the interstitial characteristics of the process material contained in a tank. TDR tied for the highest ranking in the category of safety because it has no moving parts, is intrinsically safe, has no in-tank maintenance requirements, and the potential for human exposure exists only during probe installation. The mitigative response capabilities of TDR are fair at best. TDR can only monitor waste at and around a tank probe. It cannot provide quantitative measurements. TDR can provide real-time output for remote monitoring. TDR scored poorly in cost and schedule because the technology has never been developed for the purpose of monitoring interstitial liquids in tanks. TDR scored very poorly in technical feasibility. It is not clear whether TDR could ever be used to monitor interstitial liquids in tanks. A great deal of research and development would be required to make that determination. TDR scored poorly in the category of maintenance/operations because even if the technique was possible, data interpretation would be difficult.

6.8 BOREHOLE TOMOGRAPHY — Ranking - #8

Borehole tomography is a conceptual image-based tank gauging technology that was ranked eighth as a candidate technology for gauging interstitial liquids in Hanford SSTs. Borehole tomography uses acoustic energy to generate two- or three-dimensional maps of tank contents. Borehole tomography ranked fair in terms of safety because at least two in-tank drywells would be required to make the system work. The mitigative response capabilities of borehole tomography are poor. The resolution of borehole tomography will be poor, providing only a general picture of the tank contents. However, borehole tomography can provide real-time output for remote monitoring. Borehole tomography scored very poorly in cost and schedule because the technology is so complex, has never been developed for tank gauging, and requires at least two in-tank drywells. Borehole tomography scored very poorly in technical feasibility. It is not clear whether borehole tomography could ever be used to monitor interstitial liquids in tanks. Furthermore, a great deal of research and development would be required to make that determination. Borehole tomography scored poorly in the category of maintenance/operations because even if the technique was possible, data interpretation would be difficult.

6.9 RADIATION SENSORS — Ranking - #9

Radiation-level sensors are proven level-based tank gauging devices that were ranked ninth as a candidate technology for gauging interstitial liquids. Radiation-level sensors ranked very poorly in safety because they require multiple sources per device, multiple devices per tank, more than one in-tank drywell per tank, and a great deal of calibration (requiring field operations). Radiation-level sensors scored poorly in regulatory compliance because they only have the capability to monitor tank waste qualitatively. However, radiation-level sensors can provide continuous real-time output for remote monitoring. Radiation-level sensors scored fairly high in cost and schedule because the technology is proven and is similar to the LOW system currently operating at the Hanford Site. Radiation-level sensors scored poorly on technical feasibility because of the large number of probes, sources, and drywells the system would require. Radiation sensors scored very poorly on maintenance/operations because of the in-field maintenance and calibration that would be required, and the difficulty of data interpretation.

6.10 HYBRID TANK GAUGING SYSTEMS — Not Ranked

Hybrid tank gauging was selected as a candidate technology, but it was not ranked. Hybrid tank gauging systems use multiple independent tank gauging systems, each preferably based on a different principle of operation and designed to complement one another, and provide maximum accuracy. Hybrid systems obviously provide better data than any individual technique, but they have higher associated costs. The ability to design a good hybrid system lies in careful selection of the technologies used to exploit the good attributes of the constituent technologies, while minimizing their associated costs.

An interesting idea proposed by one of the contributors to this report, is an excellent example of a hybrid tank gauging system for the Hanford SSTs. It has been suggested that a circular weigh scale be attached to an SST riser. An in-tank drywell could then be attached to the weigh scale. The in-tank drywell would function as a displacer with the weigh cell providing hydrostatic data that could be used to calculate the mass of the tank waste. The in-tank drywell also could be used for the Hanford LOW system, or another level based monitoring system requiring a drywell. The mass and volume based data generated by the in-tank drywell displacer and LOW system could be obtained with the associated hybrid system cost being little greater than that of a solitary LOW system.

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7.0 NO-ACTION ALTERNATIVE

All Hanford Site SSTs are equipped with a manual tape or a FIC gauge to measure surface levels. All SSTs, except 106-BX, are connected to the CASS. The connection for many tanks is broken and manual readings must be taken. Manual and automatic FIC devices are no longer commercially available. Salt cake bergs floating in liquid or salt encrustations may produce false surface readings with existing SST level monitoring instrumentation. In SSTs where there is no liquid surface, waste surfaces often are broken and uneven, and may shift in response to heat and gas generation. When this happens, surface-level measurement is inadequate for quantitative tank material monitoring or leak detection. Measurement of liquids below solid wastes surfaces in SSTs (i.e., interstitial liquids) is accomplished with in-tank LOWs. Neutron, gamma, and acoustic probes are lowered into the fiberglass drywells to detect moisture as a function of depth. With proper data interpretation, these probes can measure the approximate interstitial liquid waste level near the LOW. Liquid observation well measurements require extensive manual operations, do not provide for continuous monitoring, and are difficult to interpret. Efforts are underway to automate LOW data collection and interpretation; however, the complex nature of LOW data makes the use of automated computer systems difficult. Currently, there are 54 LOWs in operation in 54 SSTs. Liquid observation wells in three tanks have failed because of waste movement. The fiberglass tubes have been bent and/or cracked, permitting in-leakage of hazardous tank wastes. None of the current SST liquid monitoring devices meet the WAC regulatory compliance requirements for detection of one-pound liquid waste releases (WAC 173-303-646-7-D[ii]).

The no-action alternative is to continue the present course of action. Surface levels would continue to be measured using zip cords, manual tapes, FIC gauges, or upgraded devices operating on similar principles. Interstitial liquids and leaks would continue to be monitored in those SSTs where LOWs now exist (57 SSTs). Liquid observation wells would be maintained or replaced as needed.

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9.0 GLOSSARY

ABBREVIATIONS AND ACRONYMS

ATG	Advanced Technology Gauge
CASS	computer automated surveillance system
CCTV	closed-circuit television
cps	counts per second
D/P	differential pressure
DST	double-shell tank
FIC	Food Instrument Corporation
G-M	Geiger-Mueller
HTG	hydrostatic tank gauging
LANL	Los Alamos National Laboratory
LOW	liquid observation well
NMR	Nuclear Magnetic Resonance
PNL	Pacific Northwest Laboratory
PUREX	plutonium uranium extraction process
REDOX	reduction oxidation process
rf	radio frequency
RTD	resistance temperature device
SST	single-shell tank
TDR	time domain reflectometry
WAC	Washington Administrative Code
WSRS	Westinghouse Savannah River Site

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APPENDIX A

ADDITIONAL REFERENCES

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APPENDIX A

ADDITIONAL REFERENCES

INITIAL BRAINSTORMING SESSION

An informal brainstorming session, chaired by Kevin Widener (PNL), was held with several senior staff members of PNL's Applied Physics Center to determine keywords to use in a literature search. The staff involved have experience in soil moisture measurements for the In-situ Vitrification project, laboratory-directed research and development projects for waste tank liquid level measurements, and acoustic holography. The potential technologies identified as applicable to interstitial liquid level measurement were time domain reflectometry (TDR), dielectric measurement, electromagnetic measurements, acoustic measurements, fluorescence measurement, optical transmittance measurement, and nuclear magnetic resonance.

It was determined that the most likely science/engineering field to be interested (and therefore doing research) in this technology is geophysics, especially as related to the petroleum industry.

LITERATURE SURVEY

In addition to using the above technologies as literature search keywords, the following keywords were used: soil moisture, interstitial level or depth, fiber optic level or depth, conductivity, and resistivity.

The initial survey identified 201 items on these keywords. A review of the abstracts was negative. Core sampling is used almost exclusively in these references. There were no citations of instrumentation research and development for measuring interstitial fluids.

A new search was conducted in July 1993 that revealed approximately 500 references. Abstracts for approximately 150 of these references were obtained.

UNIVERSITY INQUIRIES

At the suggestion of a PNL staff member with work experience in the petroleum industry, several universities in Texas were contacted.

- Texas A&M University

  Dr. Spenser from the Geophysics Department was contacted on June 17, 1993. He believed that cross-hole seismic tomography could apply to measuring interstitial fluids. He supplied several references on this technique. Dr. Spenser recommended professors at Stanford University and MIT who were doing related work.

- Texas Tech University

  Dr. Barrick of the Geosciences Department was telephoned on June 17, 1993. He was not aware of any research in this area at Texas Tech. He suggested that we call the University of Texas Austin.

- University of Texas Austin

  An individual in the Geoscience Department suggested that we talk to either Dr. Jack Sharp or Dr. Phil Bennett. We have been unsuccessful in making contact. Bruce Darling, a hydrologist affiliated with UT, thinks that using pressure gauges to determine the hydraulic head and tank mass, or mass loss, might work. However, he has no current research underway in this area.

APPENDIX B

SELECTED INTERSTITIAL LIQUID MONITORING CANDIDATE TECHNOLOGY EVALUATION CRITERIA SCORE SHEETS

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SELECTED CANDIDATE EVALUATION

TECHNOLOGY TITLE: HYDROSTATIC GAUGING	WEIGHT (1-5)	SCORE (0-5)	WEIGHTED SCORE
5.1.1 SAFETY	5		
5.1.1.1 Public Safety		0	
5.1.1.2 Worker Safety		1	5
5.1.1.3 Environmental Safety		0	
5.1.1.4 Waste			
• Hydrogen/Flammable Gas-Organics		0	
• Ferrocyanide Stability		0	
• Criticality		0	
5.1.1.5 Tank Integrity		1	5
5.1.2 Regulatory Compliance	4		
5.1.2.1 Mitigative Response		1	4
5.1.3 Cost	2		
5.1.3.1 Research & Development		1	2
5.1.3.2 Implementation		2	4
5.1.4 Schedule	3		
5.1.4.1 Research & Development		1	3
5.1.4.2 Implementation		2	6
5.1.5 Technical Feasibility	4		
5.1.5.1 Research & Development		1	4
5.1.5.2 Testing		1	4
5.1.5.3 Installation		1	4
5.1.5.4 Adaptability		3	12
5.1.5.5 Accuracy		1	4
5.1.6 Maintainability & Operability	3		
5.1.6.1 Accessibility		1	3
5.1.6.2 Reliability		2	6
5.1.6.3 Calibration		2	6
TOTAL WEIGHTED SCORE			72

SELECTED CANDIDATE EVALUATION

TECHNOLOGY TITLE: THERMAL DIFFERENTIAL

		WEIGHT (1-5)	SCORE (0-5)	WEIGHTED SCORE
5.1.1	SAFETY	5		
	5.1.1.1 Public Safety		0	
	5.1.1.2 Worker Safety		1	5
	5.1.1.3 Environmental Safety		0	
	5.1.1.4 Waste		0	
	• Hydrogen/Flammable Gas-Organics		0	
	• Ferrocyanide Stability		0	
	• Criticality		0	
	5.1.1.5 Tank Integrity		1	5
5.1.2	Regulatory Compliance	4		
	5.1.2.1 Mitigative Response		2	8
5.1.3	Cost	2		
	5.1.3.1 Research & Development		2	4
	5.1.3.2 Implementation		3	6
5.1.4	Schedule	3		
	5.1.4.1 Research & Development		2	6
	5.1.4.2 Implementation		2	6
5.1.5	Technical Feasibility	4		
	5.1.5.1 Research & Development		2	8
	5.1.5.2 Testing		2	8
	5.1.5.3 Installation		2	8
	5.1.5.4 Adaptability		1	4
	5.1.5.5 Accuracy		2	8
5.1.6	Maintainability & Operability	3		
	5.1.6.1 Accessibility		2	6
	5.1.6.2 Reliability		2	6
	5.1.6.3 Calibration			
	TOTAL WEIGHTED SCORE			88

SELECTED CANDIDATE EVALUATION

TECHNOLOGY TITLE: ELECTROMAGNETIC MEASUREMENT

	WEIGHT (1-5)	SCORE (0-5)	WEIGHTED SCORE
5.1.1 SAFETY	5		
5.1.1.1 Public Safety		0	
5.1.1.2 Worker Safety		1	5
5.1.1.3 Environmental Safety		0	
5.1.1.4 Waste		0	
• Hydrogen/Flammable Gas-Organics		0	
• Ferrocyanide Stability		0	
• Criticality		0	
5.1.1.5 Tank Integrity		1	5
5.1.2 Regulatory Compliance	4		
5.1.2.1 Mitigative Response		3	12
5.1.3 Cost	2		
5.1.3.1 Research & Development		2	4
5.1.3.2 Implementation		3	6
5.1.4 Schedule	3		
5.1.4.1 Research & Development		2	6
5.1.4.2 Implementation		2	6
5.1.5 Technical Feasibility	4		
5.1.5.1 Research & Development		2	8
5.1.5.2 Testing		2	8
5.1.5.3 Installation		2	8
5.1.5.4 Adaptability		3	12
5.1.5.5 Accuracy		4	16
5.1.6 Maintainability & Operability	3		
5.1.6.1 Accessibility		2	6
5.1.6.2 Reliability		3	9
5.1.6.3 Calibration		0	
TOTAL WEIGHTED SCORE			111

SELECTED CANDIDATE EVALUATION

TECHNOLOGY TITLE: BUBBLERS

	WEIGHT (1-5)	SCORE (0-5)	WEIGHTED SCORE
5.1.1 SAFETY	5		
5.1.1.1 Public Safety		0	
5.1.1.2 Worker Safety		1	5
5.1.1.3 Environmental Safety		1	5
5.1.1.4 Waste			
• Hydrogen/Flammable Gas-Organics		0	
• Ferrocyanide Stability		2	10
• Criticality		0	
5.1.1.5 Tank Integrity		1	5
5.1.2 Regulatory Compliance	4		
5.1.2.1 Mitigative Response		1	4
5.1.3 Cost	2		
5.1.3.1 Research & Development		2	4
5.1.3.2 Implementation		4	8
5.1.4 Schedule	3		
5.1.4.1 Research & Development		4	12
5.1.4.2 Implementation		3	9
5.1.5 Technical Feasibility	4		
5.1.5.1 Research & Development		3	12
5.1.5.2 Testing		2	8
5.1.5.3 Installation		2	8
5.1.5.4 Adaptability		3	12
5.1.5.5 Accuracy		1	4
5.1.6 Maintainability & Operability	3		
5.1.6.1 Accessibility		2	6
5.1.6.2 Reliability		3	9
5.1.6.3 Calibration		2	6
TOTAL WEIGHTED SCORE			127

SELECTED CANDIDATE EVALUATION

TECHNOLOGY TITLE: LOW	WEIGHT (1-5)	SCORE (0-5)	WEIGHTED SCORE
5.1.1 SAFETY	5		
5.1.1.1 Public Safety		0	
5.1.1.2 Worker Safety		3	15
5.1.1.3 Environmental Safety		1	5
5.1.1.4 Waste			
• Hydrogen/Flammable Gas-Organics		2	10
• Ferrocyanide Stability		0	
• Criticality		0	
5.1.1.5 Tank Integrity		2	10
5.1.2 Regulatory Compliance	4		
5.1.2.1 Mitigative Response		5	20
5.1.3 Cost	2		
5.1.3.1 Research & Development		1	2
5.1.3.2 Implementation		4	8
5.1.4 Schedule	3		
5.1.4.1 Research & Development		1	3
5.1.4.2 Implementation		3	9
5.1.5 Technical Feasibility	4		
5.1.5.1 Research & Development		1	4
5.1.5.2 Testing		1	4
5.1.5.3 Installation		0	
5.1.5.4 Adaptability		4	16
5.1.5.5 Accuracy		4	16
5.1.6 Maintainability & Operability	3		
5.1.6.1 Accessibility		0	
5.1.6.2 Reliability		2	6
5.1.6.3 Calibration		1	3
TOTAL WEIGHTED SCORE			131

SELECTED CANDIDATE EVALUATION

TECHNOLOGY TITLE: DIELECTRIC MEASUREMENT	WEIGHT (1-5)	SCORE (0-5)	WEIGHTED SCORE
5.1.1 SAFETY	5		
5.1.1.1 Public Safety		0	
5.1.1.2 Worker Safety		3	15
5.1.1.3 Environmental Safety		0	
5.1.1.4 Waste		0	
• Hydrogen/Flammable Gas-Organics		0	
• Ferrocyanide Stability		0	
• Criticality		0	
5.1.1.5 Tank Integrity		1	5
5.1.2 Regulatory Compliance	4		
5.1.2.1 Mitigative Response		4	16
5.1.3 Cost	2		
5.1.3.1 Research & Development		2	4
5.1.3.2 Implementation		3	6
5.1.4 Schedule	3		
5.1.4.1 Research & Development		2	6
5.1.4.2 Implementation		2	6
5.1.5 Technical Feasibility	4		
5.1.5.1 Research & Development		3	12
5.1.5.2 Testing		2	8
5.1.5.3 Installation		2	8
5.1.5.4 Adaptability		3	12
5.1.5.5 Accuracy		4	16
5.1.6 Maintainability & Operability	3		
5.1.6.1 Accessibility		3	9
5.1.6.2 Reliability		4	12
5.1.6.3 Calibration		0	
TOTAL WEIGHTED SCORE			135

SELECTED CANDIDATE EVALUATION

TECHNOLOGY TITLE: TIME DOMAIN REFLECTOMETRY

	WEIGHT (1-5)	SCORE (0-5)	WEIGHTED SCORE
5.1.1 SAFETY	5		
5.1.1.1 Public Safety		0	
5.1.1.2 Worker Safety		1	5
5.1.1.3 Environmental Safety		0	
5.1.1.4 Waste		0	
• Hydrogen/Flammable Gas - Organics		0	
• Ferrocyanide Stability		0	
• Criticality		0	
5.1.1.5 Tank Integrity		1	5
5.1.2 Regulatory Compliance	4		
5.1.2.1 Mitigative Response		4	16
5.1.3 Cost	2		
5.1.3.1 Research & Development		3	6
5.1.3.2 Implementation		4	8
5.1.4 Schedule	3		
5.1.4.1 Research & Development		3	9
5.1.4.2 Implementation		3	9
5.1.5 Technical Feasibility	4		
5.1.5.1 Research & Development		3	12
5.1.5.2 Testing		3	12
5.1.5.3 Installation		3	12
5.1.5.4 Adaptability		4	16
5.1.5.5 Accuracy		4	16
5.1.6 Maintainability & Operability	3		
5.1.6.1 Accessibility		3	9
5.1.6.2 Reliability		2	6
5.1.6.3 Calibration		1	3
TOTAL WEIGHTED SCORE			144

SELECTED CANDIDATE EVALUATION

TECHNOLOGY TITLE: BOREHOLE TOMOGRAPHY	WEIGHT (1-5)	SCORE (0-5)	WEIGHTED SCORE
5.1.1 SAFETY	5		
5.1.1.1 Public Safety		0	
5.1.1.2 Worker Safety		3	15
5.1.1.3 Environmental Safety		0	
5.1.1.4 Waste		0	
• Hydrogen/Flammable Gas - Organics		0	
• Ferrocyanide Stability		0	
• Criticality		0	
5.1.1.5 Tank Integrity		1	5
5.1.2 Regulatory Compliance	4		
5.1.2.1 Mitigative Response		5	20
5.1.3 Cost	2		
5.1.3.1 Research & Development		4	8
5.1.3.2 Implementation		4	8
5.1.4 Schedule	3		
5.1.4.1 Research & Development		3	9
5.1.4.2 Implementation		3	9
5.1.5 Technical Feasibility	4		
5.1.5.1 Research & Development		3	12
5.1.5.2 Testing		3	12
5.1.5.3 Installation		2	8
5.1.5.4 Adaptability		4	16
5.1.5.5 Accuracy		4	16
5.1.6 Maintainability & Operability	3		
5.1.6.1 Accessibility		4	12
5.1.6.2 Reliability		3	9
5.1.6.3 Calibration		0	
TOTAL WEIGHTED SCORE			159

SELECTED CANDIDATE EVALUATION

TECHNOLOGY TITLE: RADIATION LEVEL SENSORS

	WEIGHT (1-5)	SCORE (0-5)	WEIGHTED SCORE
5.1.1 SAFETY	5		
5.1.1.1 Public Safety		0	
5.1.1.2 Worker Safety		3	15
5.1.1.3 Environmental Safety		1	5
5.1.1.4 Waste			
• Hydrogen/Flammable Gas - Organics		2	10
• Ferrocyanide Stability		0	
• Criticality		0	
5.1.1.5 Tank Integrity		1	5
5.1.2 Regulatory Compliance	4		
5.1.2.1 Mitigative Response		5	20
5.1.3 Cost	2		
5.1.3.1 Research & Development		1	2
5.1.3.2 Implementation		4	8
5.1.4 Schedule	3		
5.1.4.1 Research & Development		1	3
5.1.4.2 Implementation		3	9
5.1.5 Technical Feasibility	4		
5.1.5.1 Research & Development		1	4
5.1.5.2 Testing		3	12
5.1.5.3 Installation		2	8
5.1.5.4 Adaptability		3	12
5.1.5.5 Accuracy		5	20
5.1.6 Maintainability & Operability	3		
5.1.6.1 Accessibility		3	9
5.1.6.2 Reliability		3	9
5.1.6.3 Calibration		5	15
TOTAL WEIGHTED SCORE			166

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APPENDIX C

HYDROSTATIC TANK GAUGING SYSTEM COST ESTIMATE

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KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAC1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
HTG SYSTEM OPTION STUDY ESTIMATE
DOE_R01 - PROJECT COST SUMMARY

PAGE 1 OF 7
DATE 09/16/93 11:30:01
BY KDE

COST CODE	DESCRIPTION	ESCALATED TOTAL COST	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
000	ENGINEERING	52,000	50	26,000	78,000
700	SPECIAL EQUIP/PROCESS SYSTEMS	197,000	50	98,000	295,000
	(ADJUSTED TO MEET DOE 5100.4)	1,000		-4,000	-3,000
	PROJECT TOTAL	250,000	50	120,000	370,000

INFORMATION ONLY

TYPE OF ESTIMATE	STUDY ESTIMATE	SEPTEMBER 16, 1993
ARCHITECT ENGINEER		
OPERATING CONTRACTOR		

REMARKS: THIS ESTIMATE DOES NOT CONTAIN ESCALATION DOLLARS. COSTS ARE IN 1993 DOLLARS.

(ROUNDED/ADJUSTED TO THE NEAREST " 1,000 / 10,000 " - PERCENTAGES NOT RECALCULATED TO REFLECT ROUNDING)

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAC1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
HTG SYSTEM OPTION STUDY ESTIMATE
DOE_R02 - WORK BREAKDOWN STRUCTURE SUMMARY

PAGE 2 OF 7
DATE 09/16/93 11:29:48
BY KDE

WBS	DESCRIPTION	ESTIMATE SUBTOTAL	ONSITE INDIRECTS	SUB TOTAL	ESCALATION %	ESCALATION TOTAL	SUB TOTAL	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
112000	DEFINITIVE DESIGN-HTG	36600	0	36600	0.00	0	36600	50	18300	54900
122000	E/I - HTG	15700	0	15700	0.00	0	15700	50	7850	23550
SUBTOTAL 1	ENGINEERING	52300	0	52300	0.00	0	52300	50	26150	78450
212000	PROCUREMENT-(HTG)	73080	0	73080	0.00	0	73080	50	36540	109620
SUBTOTAL 2	PROCUREMENT	73080	0	73080	0.00	0	73080	50	36540	109620
312000	HYDROSTATIC TANK GAUGING	101258	0	101258	0.00	0	101258	50	50630	151888
SUBTOTAL 3	CONSTRUCTION	101258	0	101258	0.00	0	101258	50	50630	151888
420000	PROJECT INTEGRATION-HTG	22600	0	22600	0.00	0	22600	50	11300	33900
SUBTOTAL 4	PROJECT INTEGRATION	22600	0	22600	0.00	0	22600	50	11300	33900
PROJECT TOTAL		249,238	0	249,238	0.00	0	249,238	50	124,620	373,858

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAC1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
STUDY ESTIMATE
DOE_R03 - ESTIMATE BASIS SHEET

DATE 09/16/93 14:28:07
BY KDE

1. DOCUMENTS AND DRAWINGS

DOCUMENTS: KEH PLE'S NOTES FROM VE STUDY ON SST INTERSTITIAL LIQUID LEVEL MEASUREMENT

DRAWINGS: SKETCHES

2. MATERIAL PRICES

UNIT COSTS REPRESENT CURRENT PRICES FOR SPECIFIED MATERIAL.

3. LABOR RATES

CURRENT KEH BASE CRAFT RATES, AS ISSUED BY KEH FINANCE (EFFECTIVE 10-01-92), INCLUDE FRINGE BENEFITS, LABOR INSURANCE, TAXES AND TRAVEL WHERE APPLICABLE, PER HANFORD SITE STABILIZATION AGREEMENT, APPENDIX A (EFFECTIVE 9-2-91). NON CRAFT HOURLY RATES ARE BASED ON THE 1993 FISCAL YEAR BUDGET LIQUIDATION RATES AS ISSUED BY KEH FINANCE (EFFECTIVE 10-01-92).

4. GENERAL REQUIREMENTS/TECHNICAL SERVICES/OVERHEADS

A.) ONSITE CONSTRUCTION FORCES GENERAL REQUIREMENTS, TECHNICAL SERVICES AND CRAFT OVERHEAD COSTS ARE INCLUDED AS A COMPOSITE PERCENTAGE BASED ON THE KEH ESTIMATING FACTOR/BILLING SCHEDULE, REVISION 14, DATED OCTOBER 01, 1992. THE TOTAL COMPOSITE PERCENTAGE APPLIED TO ONSITE CONSTRUCTION FORCES LABOR, FOR THIS PROJECT, IS 93% FOR SHOP WORK AND 134% FOR FIELD WORK, WHICH IS REFLECTED IN THE "OH&P/B&I" COLUMN OF THE ESTIMATE DETAIL.

5. ESCALATION

NO ESCALATION IS CONTAINED IN THIS ESTIMATE AS AN ESCALATION SCHEDULE WAS NOT PROVIDED.

6. ROUNDING

U.S. DEPARTMENT OF ENERGY - DOE ORDER 5100.4 PAGE J-2 SUBPARAGRAPH (M), REQUIRES ROUNDING OF ALL GENERAL PLANT PROJECTS (GPP'S) AND LINE ITEM (LI) COST ESTIMATES. REFERENCE: DOE 5100.4, FIGURE I-11, DATED 10-31-84.

7. REMARKS

A.) ESTIMATE ASSUMES THERE WILL BE NO BURNOUT WHEN PLACING THE PROBES AND DRY WELL IN THE TANK. WORK IS ASSUMED TO BE ON 15% SWP.
B.) ESTIMATE ASSUMES COST ALLOWANCE FOR STEPOFF PAD.
C.) ESTIMATE CONTAINS AN ALLOWANCE FOR ELECTRICAL TIE-IN TO THE INSTRUMENT BUILDING FOR THE HYDROSTATIC TANK GAUGING SYSTEMS.
D.) ESTIMATE ASSUMES AN EXISTING 12" RISER FOR PLACEMENT OF THE PROBE.
E.) ESTIMATE CONTAINS NO ESCALATION. ALL COSTS ARE IN 1993 DOLLARS, PER KEH PLE.
F.) COSTS IN THIS ESTIMATE ARE ALLOWANCES AS DETAIL WAS MINIMAL AND INFORMATION WAS LIMITED.
G.) ESTIMATE DOES NOT CONTAIN COST FOR INITIAL DEFINITIVE DESIGN. DEFINITIVE DESIGN COSTS ARE FOR APPLICATIONS TO SPECIFIC TANKS OR TANK FARMS. INITIAL DEFINITIVE DESIGN OF THESE SYSTEMS WILL BE PERFORMED PRIOR TO THE EFFORTS DEFINED IN THIS ESTIMATE, PER KEH PLE.
H.) DEFINITIVE DESIGN COSTS AND ENGINEERING INSPECTION COSTS WERE BASED ON BENCH MARK PERCENTAGES OF DIRECT CONSTRUCTION, PER KEH PLE.
I.) PROJECT INTEGRATION WAS BASED ON 10% OF DIRECT COSTS, PER KEH PLE.

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAC1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
HTG SYSTEM OPTION STUDY ESTIMATE
DOE_R04 - COST CODE ACCOUNT SUMMARY

DATE 09/16/93 11:29:50
BY KDE

COST CODE/WBS	DESCRIPTION	ESTIMATE SUBTOTAL	ONSITE INDIRECTS	SUB TOTAL	ESCALATION %	ESCALATION TOTAL	SUB TOTAL	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
000	ENGINEERING									
112000	DEFINITIVE DESIGN-HTG	36600	0	36600	0.00	0	36600	50	18300	54900
122000	E/I - HTG	15700	0	15700	0.00	0	15700	50	7850	23550
TOTAL 000	ENGINEERING	52300	0	52300	0.00	0	52300	50	26150	78450
700	SPECIAL EQUIP/PROCESS SYSTEMS									
212000	PROCUREMENT-(HTG)	73080	0	73080	0.00	0	73080	50	36540	109620
312000	HYDROSTATIC TANK GAUGING	101258	0	101258	0.00	0	101258	50	50630	151888
420000	PROJECT INTEGRATION-HTG	22600	0	22600	0.00	0	22600	50	11300	33900
TOTAL 700	SPECIAL EQUIP/PROCESS SYSTEM	196938	0	196938	0.00	0	196938	50	98470	295408
PROJECT TOTAL		249,238	0	249,238	0.00	0	249,238	50	124,620	373,858

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAC1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
HTG SYSTEM OPTION STUDY ESTIMATE
DOE_R05 - ESTIMATE SUMMARY BY CSI DIVISION

DATE 09/16/93 11:29:51
BY KDE

CSI	DESCRIPTION	ESTIMATE SUBTOTAL	ONSITE INDIRECTS	SUB TOTAL	ESCALATION %	ESCALATION TOTAL	SUB TOTAL	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
	ENGINEERING									
00	TECHNICAL SERVICES	52300	0	52300	0.00	0	52300	50	26150	78450
	TOTAL ENGINEERING	52,300	0	52,300	0.00	0	52,300	50	26,150	78,450
	CONSTRUCTION									
15	MECHANICAL	104338	0	104338	0.00	0	104338	50	52170	156508
16	ELECTRICAL	70000	0	70000	0.00	0	70000	50	35000	105000
19	PROJECT MANAGEMENT	22600	0	22600	0.00	0	22600	50	11300	33900
	TOTAL CONSTRUCTION	196,938	0	196,938	0.00	0	196,938	50	98,470	295,408
	PROJECT TOTAL	249,238	0	249,238	0.00	0	249,238	50	124,620	373,858

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAC1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
STUDY ESTIMATE
DOE_R06 - CONTINGENCY ANALYSIS BASIS SHEET

PAGE 6 OF 7
DATE 09/16/93 14:28:09
BY KDE

REFERENCE: ESTIMATE BASIS SHEET — PAGE 3 OF 7
COST CODE ACCOUNT SUMMARY — PAGE 3 OF 7

THE U.S. DEPARTMENT OF ENERGY - RICHLAND ORDER 5700.3 "COST ESTIMATING, ANALYSIS AND STANDARDIZATION" DATED 3-27-85, PROVIDES GUIDELINES FOR ESTIMATE CONTINGENCIES. THE GUIDELINE FOR A STUDY ESTIMATE SHOULD HAVE AN OVERALL RANGE OF UP TO 50% .

CONTINGENCY IS EVALUATED AT THE THIRD COST CODE LEVEL AND SUMMARIZED AT THE PRIMARY AND SECONDARY COST CODE LEVEL OF THE DETAILED COST ESTIMATE.

ENGINEERING

COST CODE 000
WBS 112000,
122000

A CONTINGENCY OF 50% WAS APPLIED TO ENGINEERING BECAUSE THESE COST ARE PERCENTAGES OF CONSTRUCTION AND THERE IS A HIGH CONTINGENCY ON CONSTRUCTION.

AVERAGE ENGINEERING CONTINGENCY 50%

CONSTRUCTION

COST CODE 700
WBS 312000,
420000,
212000

A 50% CONTINGENCY WAS APPLIED TO CONSTRUCTION, PROJECT INTEGRATION AND PROCUREMENT DUE TO A LACK OF DETAIL AND INFORMATION NEEDED FOR THIS PROJECT.

AVERAGE CONSTRUCTION CONTINGENCY 50%

AVERAGE PROJECT CONTINGENCY 50%

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAC1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
STUDY ESTIMATE
DOE_R06 - CONTINGENCY ANALYSIS BASIS SHEET

DATE 09/16/93 14:28:09
BY KDE

REFERENCE: ESTIMATE BASIS SHEET PAGE 3 OF 7
COST CODE ACCOUNT SUMMARY PAGE 3 OF 7

THE U.S. DEPARTMENT OF ENERGY - RICHLAND ORDER 5700.3 "COST ESTIMATING, ANALYSIS AND STANDARDIZATION" DATED 3-27-85, PROVIDES GUIDELINES FOR ESTIMATE CONTINGENCIES. THE GUIDELINE FOR A STUDY ESTIMATE SHOULD HAVE AN OVERALL RANGE OF UP TO 50% .

CONTINGENCY IS EVALUATED AT THE THIRD COST CODE LEVEL AND SUMMARIZED AT THE PRIMARY AND SECONDARY COST CODE LEVEL OF THE DETAILED COST ESTIMATE.

ENGINEERING

COST CODE 000
WBS 112000, 122000

A CONTINGENCY OF 50% WAS APPLIED TO ENGINEERING BECAUSE THESE COST ARE PERCENTAGES OF CONSTRUCTION AND THERE IS A HIGH CONTINGENCY ON CONSTRUCTION.

AVERAGE ENGINEERING CONTINGENCY 50%

CONSTRUCTION

COST CODE 700
WBS 312000, 420000, 212000

A 50% CONTINGENCY WAS APPLIED TO CONSTRUCTION, PROJECT INTEGRATION AND PROCUREMENT DUE TO A LACK OF DETAIL AND INFORMATION NEEDED FOR THIS PROJECT.

AVERAGE CONSTRUCTION CONTINGENCY 50%

AVERAGE PROJECT CONTINGENCY 50%

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
HTG SYSTEM OPTION STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

PAGE 1
DATE 09/16/93 11:29:54
BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE.	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
112000	DEFINITIVE DESIGN-HTG										
112000.00	TECHNICAL SERVICES										
112000.0000000	DEF DES-HTG	000	1 LS	0	0	0	0	36600	0	0	36600
SUBTOTAL	TECHNICAL SERVICES			0	0	0	0	36,600	0	0	36,600
TOTAL	COST CODE 00000 WBS 112000 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			0	0	0	0	36,600	0	0	36,600
TOTAL WBS 112000 DEFINITIVE DESIGN-HTG				0	0	0	0	36,600	0	0	36,600

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
HTG SYSTEM OPTION STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

PAGE 2
DATE 09/16/93 11:29:54
BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
122000	E/I - HTG										
122000.00	TECHNICAL SERVICES										
122000.0000000	E/I-HTG	000	1 LS	0	0	0	0	15700	0	0	15700
SUBTOTAL	TECHNICAL SERVICES			0	0	0	0	15,700	0	0	15,700
TOTAL	COST CODE 00000 WBS 122000 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			0	0	0	0	15,700	0	0	15,700
TOTAL WBS 122000 E/I - HTG				0	0	0	0	15,700	0	0	15,700

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
HTG SYSTEM OPTION STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

PAGE 3
DATE 09/16/93 11:29:54
BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
212000	PROCUREMENT-(HTG)										
212000.15	MECHANICAL										
212000.1500002	CAPILLARY/TRANSMITTER	700	10 EA	0	0	0	60000	0	0	0	60000
SUBTOTAL	MECHANICAL			0	0	0	60,000	0	0	0	60,000
	SALES TAX 7.80 %						4680		0		4680
	WAREHOUSING 14.00 %						8400				8400
TOTAL	COST CODE 70015 WBS 212000 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			0	0	0	73,080	0	0	0	73,080
TOTAL WBS 212000 PROCUREMENT-(HTG)				0	0	0	73,080	0	0	0	73,080

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
312000	HYDROSTATIC TANK GAUGING										
312000.15	MECHANICAL										
312000.1500014	SHOP FAB PROBE	700	1 LS	200	6534	0	2500	0	0	8756	17790
SUBTOTAL	MECHANICAL			200		0		0		8,756	
	CONSUMABLES 6.00 %				6,534		2,500		0		17,790
	SALES TAX 7.80 %						150				150
	WAREHOUSING 20.00 %						206		0		206
							530				530
TOTAL	COST CODE 70015			200		0		0		8,756	
	WBS 312000				6,534		3,386		0		18,676
	(ESCALATION 0.00% - CONTINGENCY 50.00 %)										
312000.15	MECHANICAL										
312000.1500002	GREENHOUSE EXST RISER	700 W	1 LS	24	640	0	200	0	0	858	1698
312000.1500004	REMOVE EXISTING FLANGE	700 W	1 LS	8	261	0	0	0	0	350	61[illegible]
312000.1500006	PREP RISER FOR PROBE	700 W	1 LS	8	261	0	0	0	0	350	61[illegible]
312000.1500008	INSTALL PROBE	700 W	1 LS	48	1568	600	1000	0	0	2101	526[illegible]
312000.1500010	STEP OFF PAD SUPPORT	700 W	3 DAY	48	1118	0	0	0	0	1498	261[illegible]
SUBTOTAL	MECHANICAL		(SWP)	136		600		0		5,157	
	SWP 15.00%				3,848		1,200		0		10,80[illegible]
	CONSUMABLES 6.00 %			20	577						57[illegible]
	SALES TAX 7.80 %						72				72
	WAREHOUSING 20.00 %						99		0		99
	OH&P (ON MARKUPS ONLY)						254				254
										773	77[illegible]
TOTAL	COST CODE 70015			156		600		0		5,930	
	WBS 312000				4,425		1,625		0		12,581
	(ESCALATION 0.00% - CONTINGENCY 50.00 %)										
312000.16	ELECTRICAL										
312000.1600012	ALLOWANCE FOR TIE-IN TO INSTRUMENT BUILDING	700 W	1 LS	0	0	0	0	70000	0	0	70000
SUBTOTAL	ELECTRICAL		(SWP)	0		0		70,000		0	
					0		0		0		70,000
TOTAL	COST CODE 70016			0		0		70,000		0	
	WBS 312000				0		0		0		70,000

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
HTG SYSTEM OPTION STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

PAGE 5
DATE 09/16/93 11:29:54
BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
	(ESCALATION 0.00% - CONTINGENCY 50.00 %)										
TOTAL WBS 312000 HYDROSTATIC TANK GAUGING				356	10,959	600	5,012	70,000	0	14,686	101,257

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
HTG SYSTEM OPTION STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

PAGE 6
DATE 09/16/93 11:29:55
BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
420000	PROJECT INTEGRATION-HTG										
420000.19	PROJECT MANAGEMENT										
420000.1900000	WHC PROJECT MANAGEMENT HTG SYSTEM	700	1 LS	0	0	0	0	22600	0	0	22600
SUBTOTAL	PROJECT MANAGEMENT			0	0	0	0	22,600	0	0	22,600
TOTAL	COST CODE 70019			0	0	0	0	22,600	0	0	22,600
	WBS 420000										
	(ESCALATION 0.00% - CONTINGENCY 50.00 %)										
TOTAL WBS 420000 PROJECT INTEGRATION-HTG				0	0	0	0	22,600	0	0	22,600

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
HTG SYSTEM OPTION STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

PAGE 7
DATE 09/16/93 11:29:55
BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
REPORT TOTAL				356	10,959	600	78,092	144,900	0	14,686	249,237

APPENDIX D

THERMAL DIFFERENTIAL SYSTEM COST ESTIMATE

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KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAD1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
THERMAL DIFFERENTIAL GAUGE OPTION   STUDY ESTIMATE
DOE_R01 - PROJECT COST SUMMARY

PAGE 1 OF 7
DATE 09/16/93 11:33:38
BY KDE

COST CODE	DESCRIPTION	ESCALATED TOTAL COST	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
000	ENGINEERING	34,000	50	17,000	51,000
700	SPECIAL EQUIP/PROCESS SYSTEMS	129,000	50	65,000	194,000
	(ADJUSTED TO MEET DOE 5100.4)	-3,000		-2,000	-5,000
	PROJECT TOTAL	160,000	50	80,000	240,000

INFORMATION ONLY

TYPE OF ESTIMATE	STUDY ESTIMATE	SEPTEMBER 16, 1993	REMARKS: THIS ESTIMATE DOES NOT CONTAIN ESCALATION DOLLARS. COSTS ARE IN 1993 DOLLARS.
ARCHITECT ENGINEER			
OPERATING CONTRACTOR			

(ROUNDED/ADJUSTED TO THE NEAREST " 1,000 / 10,000 " - PERCENTAGES NOT RECALCULATED TO REFLECT ROUNDING)

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAD1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
THERMAL DIFFERENTIAL GAUGE OPTION STUDY ESTIMATE
DOE_R02 - WORK BREAKDOWN STRUCTURE SUMMARY

PAGE 2 OF 7
DATE 09/16/93 11:33:39
BY KDE

WBS	DESCRIPTION	ESTIMATE SUBTOTAL	ONSITE INDIRECTS	SUB TOTAL	ESCALATION %	ESCALATION TOTAL	SUB TOTAL	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
113000	DEF DES - THERM. DIFF. LEVEL GAUGES	24000	0	24000	0.00	0	24000	50	12000	36000
123000	E/I - THERMAL DIFFERENTIAL GAUGES	10300	0	10300	0.00	0	10300	50	5150	15450
SUBTOTAL 1	ENGINEERING	34300	0	34300	0.00	0	34300	50	17150	51450
213000	PROCUREMENT-THERMAL DIFF. GAUGE	19170	0	19170	0.00	0	19170	50	9585	28755
SUBTOTAL 2	PROCUREMENT	19170	0	19170	0.00	0	19170	50	9585	28755
313000	THERMAL DIFFERENTIAL LEVEL GAUGE	95141	0	95141	0.00	0	95141	50	47571	142712
SUBTOTAL 3	CONSTRUCTION	95141	0	95141	0.00	0	95141	50	47571	142712
430000	PROJECT INTEGRATION-THERM. DIFF.	14900	0	14900	0.00	0	14900	50	7450	22350
SUBTOTAL 4	PROJECT INTEGRATION	14900	0	14900	0.00	0	14900	50	7450	22350
PROJECT TOTAL		163,511	0	163,511	0.00	0	163,511	50	81,756	245,267

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAD1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
STUDY ESTIMATE
DOE_R03 - ESTIMATE BASIS SHEET

PAGE 3 OF 7
DATE 09/16/93 14:28:07
BY KDE

1. DOCUMENTS AND DRAWINGS

DOCUMENTS: KEH PLE'S NOTES FROM VE STUDY ON SST INTERSTITIAL LIQUID LEVEL MEASUREMENT.

DRAWINGS: SKETCHES

2. MATERIAL PRICES

UNIT COSTS REPRESENT CURRENT PRICES FOR SPECIFIED MATERIAL.

3. LABOR RATES

CURRENT KEH BASE CRAFT RATES, AS ISSUED BY KEH FINANCE (EFFECTIVE 10-01-92), INCLUDE FRINGE BENEFITS, LABOR INSURANCE, TAXES AND TRAVEL WHERE APPLICABLE, PER HANFORD SITE STABILIZATION AGREEMENT, APPENDIX A (EFFECTIVE 9-2-91). NON CRAFT HOURLY RATES ARE BASED ON THE 1993 FISCAL YEAR BUDGET LIQUIDATION RATES AS ISSUED BY KEH FINANCE (EFFECTIVE 10-01-92).

4. GENERAL REQUIREMENTS/TECHNICAL SERVICES/OVERHEADS

A.) ONSITE CONSTRUCTION FORCES GENERAL REQUIREMENTS, TECHNICAL SERVICES AND CRAFT OVERHEAD COSTS ARE INCLUDED AS A COMPOSITE PERCENTAGE BASED ON THE KEH ESTIMATING FACTOR/BILLING SCHEDULE, REVISION 14, DATED OCTOBER 01, 1992. THE TOTAL COMPOSITE PERCENTAGE APPLIED TO ONSITE CONSTRUCTION FORCES LABOR, FOR THIS PROJECT, IS 93% FOR SHOP WORK AND 134% FOR FIELD WORK, WHICH IS REFLECTED IN THE "OH&P/B&I" COLUMN OF THE ESTIMATE DETAIL.

5. ESCALATION

NO ESCALATION IS CONTAINED IN THIS ESTIMATE AS AN ESCALATION SCHEDULE WAS NOT PROVIDED.

6. ROUNDING

U.S. DEPARTMENT OF ENERGY - DOE ORDER 5100.4 PAGE J-2 SUBPARAGRAPH (M), REQUIRES ROUNDING OF ALL GENERAL PLANT PROJECTS (GPP'S) AND LINE ITEM (LI) COST ESTIMATES. REFERENCE: DOE 5100.4, FIGURE I-11, DATED 10-31-84.

7. REMARKS

A.) ESTIMATE ASSUMES THERE WILL BE NO BURNOUT WHEN PLACING THE PROBES AND DRY WELL IN THE TANK. WORK IS ASSUMED TO BE ON 15% SWP.
B.) ESTIMATE ASSUMES COST ALLOWANCE FOR STEPOFF PAD.
C.) ESTIMATE CONTAINS AN ALLOWANCE FOR ELECTRICAL TIE-IN TO THE INSTRUMENT BUILDING FOR THE THERMAL DIFFERENTIAL LEVEL GAUGE.
D.) ESTIMATE ASSUMES AN EXISTING 12" RISER FOR PLACEMENT OF THE PROBE.
E.) ESTIMATE CONTAINS NO ESCALATION. ALL COSTS ARE IN 1993 DOLLARS, PER KEH PLE.
F.) COSTS IN THIS ESTIMATE ARE ALLOWANCES AS DETAIL WAS MINIMAL AND INFORMATION WAS LIMITED.
G.) ESTIMATE DOES NOT CONTAIN COST FOR INITIAL DEFINITIVE DESIGN. DEFINITIVE DESIGN COSTS ARE FOR APPLICATIONS TO SPECIFIC TANKS OR TANK FARMS. INITIAL DEFINITIVE DESIGN OF THESE SYSTEMS WILL BE PERFORMED PRIOR TO THE EFFORTS DEFINED IN THIS ESTIMATE, PER KEH PLE.
H.) DEFINITIVE DESIGN COSTS AND ENGINEERING INSPECTION COSTS WERE BASED ON BENCH MARK PERCENTAGES OF DIRECT CONSTRUCTION, PER KEH PLE.
I.) PROJECT INTEGRATION WAS BASED ON 10% OF DIRECT COSTS, PER KEH PLE.

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAD1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
THERMAL DIFFERENTIAL GAUGE OPTION STUDY ESTIMATE
DOE_R04 - COST CODE ACCOUNT SUMMARY

DATE 09/16/93 11:33:40
BY KDE

COST CODE/WBS	DESCRIPTION	ESTIMATE SUBTOTAL	ONSITE INDIRECTS	SUB TOTAL	ESCALATION %	ESCALATION TOTAL	SUB TOTAL	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
000	ENGINEERING									
113000	DEF DES - THERM. DIFF. LEVEL GAUGES	24000	0	24000	0.00	0	24000	50	12000	36000
123000	E/I - THERMAL DIFFERENTIAL GAUGES	10300	0	10300	0.00	0	10300	50	5150	15450
TOTAL 000	ENGINEERING	34300	0	34300	0.00	0	34300	50	17150	51450
700	SPECIAL EQUIP/PROCESS SYSTEMS									
213000	PROCUREMENT-THERMAL DIFF. GAUGE	19170	0	19170	0.00	0	19170	50	9585	28755
313000	THERMAL DIFFERENTIAL LEVEL GAUGE	95141	0	95141	0.00	0	95141	50	47571	142712
430000	PROJECT INTEGRATION-THERM. DIFF.	14900	0	14900	0.00	0	14900	50	7450	22350
TOTAL 700	SPECIAL EQUIP/PROCESS SYSTEM	129211	0	129211	0.00	0	129211	50	64606	193817
PROJECT TOTAL		163,511	0	163,511	0.00	0	163,511	50	81,756	245,267

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAD1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
THERMAL DIFFERENTIAL GAUGE OPTION   STUDY ESTIMATE
DOE_R05 - ESTIMATE SUMMARY BY CSI DIVISION

DATE 09/16/93 11:33:41
BY KDE

CSI	DESCRIPTION	ESTIMATE SUBTOTAL	ONSITE INDIRECTS	SUB TOTAL	ESCALATION %	ESCALATION TOTAL	SUB TOTAL	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
	ENGINEERING									
00	TECHNICAL SERVICES	34300	0	34300	0.00	0	34300	50	17150	51450
	TOTAL ENGINEERING	34,300	0	34,300	0.00	0	34,300	50	17,150	51,450
	CONSTRUCTION									
15	MECHANICAL	44311	0	44311	0.00	0	44311	50	22156	66467
16	ELECTRICAL	70000	0	70000	0.00	0	70000	50	35000	105000
19	PROJECT MANAGEMENT	14900	0	14900	0.00	0	14900	50	7450	22350
	TOTAL CONSTRUCTION	129,211	0	129,211	0.00	0	129,211	50	64,606	193,817
	PROJECT TOTAL	163,511	0	163,511	0.00	0	163,511	50	81,756	245,267

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAD1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
STUDY ESTIMATE
DOE_R06 - CONTINGENCY ANALYSIS BASIS SHEET

REFERENCE: ESTIMATE BASIS SHEET PAGE 3 OF 7
COST CODE ACCOUNT SUMMARY PAGE 3 OF 7

THE U.S. DEPARTMENT OF ENERGY - RICHLAND ORDER 5700.3 "COST ESTIMATING, ANALYSIS AND STANDARDIZATION" DATED 3-27-85, PROVIDES GUIDELINES FOR ESTIMATE CONTINGENCIES. THE GUIDELINE FOR A STUDY ESTIMATE SHOULD HAVE AN OVERALL RANGE OF UP TO 50% .

CONTINGENCY IS EVALUATED AT THE THIRD COST CODE LEVEL AND SUMMARIZED AT THE PRIMARY AND SECONDARY COST CODE LEVEL OF THE DETAILED COST ESTIMATE.

ENGINEERING

COST CODE 000 WBS 113000, 123000	A CONTINGENCY OF 50% WAS APPLIED TO ENGINEERING BECAUSE THESE COST ARE PERCENTAGES OF CONSTRUCTION AND THERE IS A HIGH CONTINGENCY ON CONSTRUCTION.

AVERAGE ENGINEERING CONTINGENCY 50%

CONSTRUCTION

COST CODE 700 WBS 313000, 430000, 213000	A 50% CONTINGENCY WAS APPLIED TO CONSTRUCTION, PROJECT INTEGRATION AND PROCUREMENT DUE TO A LACK OF DETAIL AND INFORMATION NEEDED FOR THIS PROJECT.

AVERAGE CONSTRUCTION CONTINGENCY 50%

AVERAGE PROJECT CONTINGENCY 50%

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
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** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
THERMAL DIFFERENTIAL GAUGE OPTION   STUDY ESTIMATE
DOE_R07 - ONSITE INDIRECT COSTS BY WBS

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BY KDE

WBS	DESCRIPTION	ESTIMATE SUBTOTAL	CONTRACT %	ADMINISTRATION TOTAL	BID PACK PREP.	OTHER INDIRECTS	TOTAL INDIRECTS
113000	DEF DES - THERM. DIFF. LEVEL GAUGES	24000	0.00	0	0	0	0
123000	E/I - THERMAL DIFFERENTIAL GAUGES	10300	0.00	0	0	0	0
213000	PROCUREMENT-THERMAL DIFF. GAUGE	19170	0.00	0	0	0	0
313000	THERMAL DIFFERENTIAL LEVEL GAUGE	95141	0.00	0	0	0	0
430000	PROJECT INTEGRATION-THERM. DIFF.	14900	0.00	0	0	0	0
PROJECT TOTAL		163,511		0	0	0	0

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
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** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
THERMAL DIFFERENTIAL GAUGE OPTION STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

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DATE 09/16/93 11:33:46
BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
113000	DEF DES - THERM. DIFF. LEVEL GAUGES										
113000.00	TECHNICAL SERVICES										
113000.0000000	DEF DES-THERMAL DIFF. GAUGE	000	1 LS	0	0	0	0	24000	0	0	24000
SUBTOTAL	TECHNICAL SERVICES			0	0	0	0	24,000	0	0	24,000
TOTAL	COST CODE 00000 WBS 113000 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			0	0	0	0	24,000	0	0	24,000
TOTAL WBS 113000 DEF DES - THERM. DIFF. LEVEL GAUGES				0	0	0	0	24,000	0	0	24,000

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
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** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
THERMAL DIFFERENTIAL GAUGE OPTION   STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

PAGE 2
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BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
123000	E/I - THERMAL DIFFERENTIAL GAUGES										
123000.00	TECHNICAL SERVICES										
123000.0000000	E/I-THERMAL DIFF. GAUGE	000	1 LS	0	0	0	0	10300	0	0	10300
SUBTOTAL	TECHNICAL SERVICES			0	0	0	0	10,300	0	0	10,300
TOTAL	COST CODE 00000 WBS 123000 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			0	0	0	0	10,300	0	0	10,300
TOTAL WBS 123000 E/I - THERMAL DIFFERENTIAL GAUGES				0	0	0	0	10,300	0	0	10,300

KAISER ENGINEERS HANFORD
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THERMAL DIFFERENTIAL GAUGE OPTION   STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

PAGE 3
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ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
213000	PROCUREMENT-THERMAL DIFF. GAUGE										
213000.15	MECHANICAL										
213000.1500002	THERMAL DIFFERENTIAL PRESSURE GAUGE	700	1 LS	0	0	0	15000	0	0	0	15000
SUBTOTAL	MECHANICAL			0	0	0	15,000	0	0	0	15,000
	SALES TAX 7.80 %						1170		0		1170
	WAREHOUSING 20.00 %						3000				3000
TOTAL	COST CODE 70015 WBS 213000 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			0	0	0	19,170	0	0	0	19,170
TOTAL WBS 213000 PROCUREMENT-THERMAL DIFF. GAUGE				0	0	0	19,170	0	0	0	19,170

KAISER ENGINEERS HANFORD
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** IEST - INTERACTIVE ESTIMATING **
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THERMAL DIFFERENTIAL GAUGE OPTION   STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

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ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
313000	THERMAL DIFFERENTIAL LEVEL GAUGE										
313000.15	MECHANICAL										
313000.1500014	ALLOWANCE TO CONSTRUCT FLANGE ATTACHMENT TO RISER	700	1 LS	120	3920	0	2500	0	0	5253	11673
SUBTOTAL	MECHANICAL			120	3,920	0	2,500	0	0	5,253	11,673
	CONSUMABLES 6.00 %						150				150
	SALES TAX 7.80 %						206				206
	WAREHOUSING 20.00 %						530		0		530
TOTAL	COST CODE 70015 WBS 313000 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			120	3,920	0	3,386	0	0	5,253	12,559
313000.15	MECHANICAL										
313000.1500002	GREENHOUSE EXST RISER	700 W	1 LS	24	640	0	200	0	0	858	1698
313000.1500004	REMOVE EXISTING FLANGE	700 W	1 LS	8	261	0	0	0	0	350	611
313000.1500006	PREP RISER FOR PROBE	700 W	1 LS	8	261	0	0	0	0	350	611
313000.1500008	INSTALL PROBE	700 W	1 LS	48	1568	600	1000	0	0	2101	5269
313000.1500010	STEP OFF PAD SUPPORT	700 W	3 DAY	48	1118	0	0	0	0	1498	2616
SUBTOTAL	MECHANICAL	(SWP)		136	3,848	600	1,200	0	0	5,157	10,805
	SWP 15.00%			20	577						577
	CONSUMABLES 6.00 %						72				72
	SALES TAX 7.80 %						99				99
	WAREHOUSING 20.00 %						254		0		254
	OH&P (ON MARKUPS ONLY)									773	773
TOTAL	COST CODE 70015 WBS 313000 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			156	4,425	600	1,625	0	0	5,930	12,581
313000.16	ELECTRICAL										
313000.1600012	ALLOWANCE FOR TIE-IN TO INSTRUMENT BUILDING	700 W	1 LS	0	0	0	0	70000	0	0	70000
SUBTOTAL	ELECTRICAL	(SWP)		0	0	0	0	70,000	0	0	70,000
TOTAL	COST CODE 70016 WBS 313000			0	0	0	0	70,000	0	0	70,000

KAISER ENGINEERS HANFORD
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** IEST - INTERACTIVE ESTIMATING **
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THERMAL DIFFERENTIAL GAUGE OPTION STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

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BY - KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
	(ESCALATION 0.00% - CONTINGENCY 50.00 %)										
TOTAL WBS 313000	THERMAL DIFFERENTIAL LEVEL GAUGE			276	8,345	600	5,012	70,000	0	11,183	95,140

KAISER ENGINEERS HANFORD
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** IEST - INTERACTIVE ESTIMATING **
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THERMAL DIFFERENTIAL GAUGE OPTION   STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

PAGE 6
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BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
430000	PROJECT INTEGRATION-THERM. DIFF.										
430000.19	PROJECT MANAGEMENT										
430000.1900000	WHC PROJECT MANAGEMENT THERM. DIFF. GAUGE	700	1 LS	0	0	0	0	14900	0	0	14900
SUBTOTAL	PROJECT MANAGEMENT			0	0	0	0	14,900	0	0	14,900
TOTAL	COST CODE 70019 WBS 430000 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			0	0	0	0	14,900	0	0	14,900
TOTAL WBS 430000 PROJECT INTEGRATION-THERM. DIFF.				0	0	0	0	14,900	0	0	14,900

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** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
THERMAL DIFFERENTIAL GAUGE OPTION   STUDY ESTIMATE
DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

PAGE 7
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BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
REPORT TOTAL				276	8,345	600	24,182	119,200	0	11,183	163,510

APPENDIX E

IN-TANK LIQUID OBSERVATION WELL SYSTEM COST ESTIMATE

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KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAB1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
LOW SYSTEM OPTION STUDY ESTIMATE
DOE_R01 - PROJECT COST SUMMARY

PAGE 1 OF 8
DATE 09/16/93 11:35:09
BY KDE

COST CODE	DESCRIPTION	ESCALATED TOTAL COST	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
000	ENGINEERING	362,000	30	110,000	472,000
700	SPECIAL EQUIP/PROCESS SYSTEMS	761,000	33	251,000	1,012,000
	(ADJUSTED TO MEET DOE 5100.4)	-3,000		-1,000	-4,000
	PROJECT TOTAL	1,120,000	32	360,000	1,480,000

INFORMATION ONLY

TYPE OF ESTIMATE	STUDY ESTIMATE	SEPTEMBER 16, 1993	REMARKS: THIS ESTIMATE DOES NOT CONTAIN ESCALATION DOLLARS. COSTS ARE IN 1993 DOLLARS.
ARCHITECT ENGINEER			
OPERATING CONTRACTOR			

(ROUNDED/ADJUSTED TO THE NEAREST " 1,000 / 10,000 " - PERCENTAGES NOT RECALCULATED TO REFLECT ROUNDING)

KAISER ENGINEERS HANFORD
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** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
LOW SYSTEM OPTION STUDY ESTIMATE
DOE_R02 - WORK BREAKDOWN.STRUCTURE SUMMARY

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BY KDE

WBS	DESCRIPTION	ESTIMATE SUBTOTAL	ONSITE INDIRECTS	SUB TOTAL	ESCALATION %	ESCALATION TOTAL	SUB TOTAL	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
111000	DEFINITIVE DESIGN-MOBILE SURV. SYS.	296000	0	296000	0.00	0	296000	30	88800	384800
111001	DEFINITIVE DESIGN-OBSERVATION WELL	4000	0	4000	0.00	0	4000	50	2000	6000
SUBTOTAL 111	DEFINITIVE DESIGN-LOW SYS	300000	0	300000	0.00	0	300000	30	90800	390800
121000	E/I - MOBILE SURVEILLANCE SYSTEM	60000	0	60000	0.00	0	60000	30	18000	78000
121001	E/I - OBSERVATION WELL	1715	0	1715	0.00	0	1715	50	858	2573
SUBTOTAL 121	E/I - LOW SYSTEM	61715	0	61715	0.00	0	61715	31	18858	80573
SUBTOTAL 1	ENGINEERING	361715	0	361715	0.00	0	361715	30	109658	471373
211000	PROCUREMENT-MOBILE SURVEILLANCE SYS	281690	0	281690	0.00	0	281690	30	84507	366197
SUBTOTAL 2	PROCUREMENT	281690	0	281690	0.00	0	281690	30	84507	366197
311001	CONSTRUCT DRYWELL FOR MOBILE UNITS	19019	0	19019	0.00	0	19019	50	9510	28529
321000	MOBILE SURVEILLANCE SYSTEM	293000	71960	364960	0.00	0	364960	30	109488	474448
SUBTOTAL 3	CONSTRUCTION	312019	71960	383979	0.00	0	383979	31	118998	502977
410000	PROJECT INTEGRATION-LOW	95500	0	95500	0.00	0	95500	50	47750	143250
SUBTOTAL 4	PROJECT INTEGRATION	95500	0	95500	0.00	0	95500	50	47750	143250
PROJECT TOTAL		1,050,924	71,960	1,122,884	0.00	0	1,122,884	32	360,913	1,483,797

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAB1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
STUDY ESTIMATE
DOE_R03 - ESTIMATE BASIS SHEET

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BY KDE

1. DOCUMENTS AND DRAWINGS

DOCUMENTS: ENGINEERING WORK PLAN DRYWELL VAN PROCUREMENT REPORT WHC-SD-WM-WP-197

DRAWINGS: SKETCHES

2. MATERIAL PRICES

UNIT COSTS REPRESENT CURRENT PRICES FOR SPECIFIED MATERIAL.

3. LABOR RATES

CURRENT KEH BASE CRAFT RATES, AS ISSUED BY KEH FINANCE (EFFECTIVE 10-01-92), INCLUDE FRINGE BENEFITS, LABOR INSURANCE, TAXES AND TRAVEL WHERE APPLICABLE, PER HANFORD SITE STABILIZATION AGREEMENT, APPENDIX A (EFFECTIVE 9-2-91). NON CRAFT HOURLY RATES ARE BASED ON THE 1993 FISCAL YEAR BUDGET LIQUIDATION RATES AS ISSUED BY KEH FINANCE (EFFECTIVE 10-01-92).

4. GENERAL REQUIREMENTS/TECHNICAL SERVICES/OVERHEADS

A.) ONSITE CONSTRUCTION FORCES GENERAL REQUIREMENTS, TECHNICAL SERVICES AND CRAFT OVERHEAD COSTS ARE INCLUDED AS A COMPOSITE PERCENTAGE BASED ON THE KEH ESTIMATING FACTOR/BILLING SCHEDULE, REVISION 14, DATED OCTOBER 01, 1992. THE TOTAL COMPOSITE PERCENTAGE APPLIED TO ONSITE CONSTRUCTION FORCES LABOR, FOR THIS PROJECT, IS 93% FOR SHOP WORK AND 134% FOR FIELD WORK, WHICH IS REFLECTED IN THE "OH&P/B&I" COLUMN OF THE ESTIMATE DETAIL.

B.) ONSITE CONTRACT ADMINISTRATION AND CONSTRUCTION MANAGEMENT COSTS, ASSOCIATED WITH THE OVERALL MANAGEMENT OF THE FIXED PRICE CONTRACTS, ARE INCLUDED AS A COMPOSITE PERCENTAGE AND LUMP SUM ALLOWANCE (FOR BID PACKAGE PREP) BASED ON THE ESTIMATING FACTOR/BILLING SCHEDULE. THE TOTAL COMPOSITE PERCENTAGE AND LUMP SUM ALLOWANCE ARE APPLIED AGAINST THE TOTAL FIXED PRICE CONTRACT AMOUNT WHICH IS REFLECTED ON THE KEH SUMMARY REPORT DOER07, INCLUDED WITH THIS ESTIMATE. (FINAL ESTIMATES MAY BE PARTIALLY MANLOADED AND INCLUDED WITHIN THE ESTIMATE DETAIL)

5. ESCALATION

NO ESCALATION IS CONTAINED IN THIS ESTIMATE AS AN ESCALATION SCHEDULE WAS NOT PROVIDED.

6. ROUNDING

U.S. DEPARTMENT OF ENERGY - DOE ORDER 5100.4 PAGE J-2 SUBPARAGRAPH (M), REQUIRES ROUNDING OF ALL GENERAL PLANT PROJECTS (GPP'S) AND LINE ITEM (LI) COST ESTIMATES. REFERENCE: DOE 5100.4, FIGURE I-11, DATED 10-31-84.

7. REMARKS

A.) ESTIMATE ASSUMES THERE WILL BE NO BURNOUT WHEN PLACING THE DRY WELL IN THE TANK, WORK IS ASSUMED TO BE ON 15% SWP.

B.) ESTIMATE ASSUMES COST ALLOWANCE FOR STEPOFF PAD.

C.) THE COSTS FOR THE MOBILE SURVEILLANCE UNITS (VANS) WERE DERIVED FROM DOCUMENT WHC-SD-WM-WP-197, ENGINEERING WORK PLAN DRYWELL PROCUREMENT. THE COSTS TAKEN FROM THIS DOCUMENT INCLUDE ENGINEERING, CONSTRUCTION AND PROCUREMENT COSTS, PER KEH PLE.

D.) ESTIMATE CONTAINS AN ALLOWANCE FOR A DRY OBSERVATION WELL TO BE PLACED IN A TANK WITH AN EXISTING RISER OF 10" TO 12".

E.) ESTIMATE CONTAINS NO ESCALATION. ALL COSTS ARE IN 1993 DOLLARS, PER KEH PLE.
F.) COSTS IN THIS ESTIMATE ARE ALLOWANCES AS DETAIL WAS MINIMAL AND INFORMATION WAS LIMITED.
G.) ESTIMATE DOES NOT CONTAIN COST FOR INITIAL DEFINITIVE DESIGN. DEFINITIVE DESIGN COSTS ARE FOR APPLICATIONS TO SPECIFIC TANKS OR TANK FARMS. INITIAL DEFINITIVE DESIGN OF THESE SYSTEMS WILL BE PERFORMED PRIOR TO THE EFFORTS DEFINED IN THIS ESTIMATE, PER KEH PLE.
H.) DEFINITIVE DESIGN COSTS AND ENGINEERING INSPECTION COSTS FOR THE DRYWELL CONSTRUCTION WERE BASED ON BENCH MARK PERCENTAGES OF DIRECT CONSTRUCTION, PER KEH PLE.
I.) PROJECT INTEGRATION WAS BASED ON 10% OF DIRECT COSTS, PER KEH PLE.

KAISER ENGINEERS HANFORD
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** IEST - INTERACTIVE ESTIMATING **
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LOW SYSTEM OPTION STUDY ESTIMATE
DOE_R04 - COST CODE ACCOUNT SUMMARY

DATE 09/16/93 11:35:13
BY KDE

COST CODE/WBS	DESCRIPTION	ESTIMATE SUBTOTAL	ONSITE INDIRECTS	SUB TOTAL	ESCALATION %	ESCALATION TOTAL	SUB TOTAL	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
000	ENGINEERING									
111000	DEFINITIVE DESIGN-MOBILE SURV. SYS.	296000	0	296000	0.00	0	296000	30	88800	384800
111001	DEFINITIVE DESIGN-OBSERVATION WELL	4000	0	4000	0.00	0	4000	50	2000	6000
121000	E/I - MOBILE SURVEILLANCE SYSTEM	60000	0	60000	0.00	0	60000	30	18000	78000
121001	E/I - OBSERVATION WELL	1715	0	1715	0.00	0	1715	50	858	2573
TOTAL 000	ENGINEERING	361715	0	361715	0.00	0	361715	30	109658	471373
700	SPECIAL EQUIP/PROCESS SYSTEMS									
211000	PROCUREMENT-MOBILE SURVEILLANCE SYS	281690	0	281690	0.00	0	281690	30	84507	366197
311001	CONSTRUCT DRYWELL FOR MOBILE UNITS	19019	0	19019	0.00	0	19019	50	9510	28529
321000	MOBILE SURVEILLANCE SYSTEM	293000	71960	364960	0.00	0	364960	30	109488	474448
410000	PROJECT INTEGRATION-LOW	95500	0	95500	0.00	0	95500	50	47750	143250
TOTAL 700	SPECIAL EQUIP/PROCESS SYSTEM	689209	71960	761169	0.00	0	761169	33	251255	1012424
PROJECT TOTAL		1,050,924	71,960	1,122,884	0.00	0	1,122,884	32	360,913	1,483,797

KAISER ENGINEERS HANFORD
WESTINGHOUSE HANFORD COMPANY
JOB NO. ER 3869
FILE NO. Z075SAB1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
LOW SYSTEM OPTION STUDY ESTIMATE
DOE_R05 - ESTIMATE SUMMARY BY CSI DIVISION

DATE 09/16/93 11:35:15
BY KDE

CSI	DESCRIPTION	ESTIMATE SUBTOTAL	ONSITE INDIRECTS	SUB TOTAL	ESCALATION %	ESCALATION TOTAL	SUB TOTAL	CONTINGENCY %	CONTINGENCY TOTAL	TOTAL DOLLARS
	ENGINEERING									
00	TECHNICAL SERVICES	361715	0	361715	0.00	0	361715	30	109658	471373
	TOTAL ENGINEERING	361,715	0	361,715	0.00	0	361,715	30	109,658	471,373
	CONSTRUCTION									
15	MECHANICAL	593709	71960	665669	0.00	0	665669	31	203505	869174
19	PROJECT MANAGEMENT	95500	0	95500	0.00	0	95500	50	47750	143250
	TOTAL CONSTRUCTION	689,209	71,960	761,169	0.00	0	761,169	33	251,255	1,012,424
	PROJECT TOTAL	1,050,924	71,960	1,122,884	0.00	0	1,122,884	32	360,913	1,483,797

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** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
STUDY ESTIMATE
DOE_R06 - CONTINGENCY ANALYSIS BASIS SHEET

DATE 09/16/93 14:28:09
BY KDE

REFERENCE: ESTIMATE BASIS SHEET — PAGE 2,3 OF 8
COST CODE ACCOUNT SUMMARY — PAGE 5 OF 8

THE U.S. DEPARTMENT OF ENERGY - RICHLAND ORDER 5700.3 "COST ESTIMATING, ANALYSIS AND STANDARDIZATION" DATED 3-27-85, PROVIDES GUIDELINES FOR ESTIMATE CONTINGENCIES. THE GUIDELINE FOR A STUDY ESTIMATE SHOULD HAVE AN OVERALL RANGE OF UP TO 50% .

CONTINGENCY IS EVALUATED AT THE THIRD COST CODE LEVEL AND SUMMARIZED AT THE PRIMARY AND SECONDARY COST CODE LEVEL OF THE DETAILED COST ESTIMATE.

ENGINEERING

COST CODE 000 WBS 111000, 121001	A CONTINGENCY OF 30% WAS APPLIED TO ENGINEERING FOR THE MOBILE SURVEILLANCE UNITS PER WHC REPORT.
WBS 111001, 121001	A CONTINGENCY OF 50% WAS APPLIED TO ENGINEERING BECAUSE THESE COST ARE PERCENTAGES OF CONSTRUCTION AND THERE IS A HIGH CONTINGENCY ON CONSTRUCTION.

AVERAGE ENGINEERING CONTINGENCY 30%

CONSTRUCTION

COST CODE 700 WBS 321000, 211000	A CONTINGENCY OF 30% WAS APPLIED TO FP CONSTRUCTION PER WHC REPORT.
WBS 311001, 410000	A 50% CONTINGENCY WAS APPLIED TO CONSTRUCTION AND PROJECT INTEGRATION DUE TO A LACK OF DETAIL AND INFORMATION NEEDED FOR THIS PROJECT.

AVERAGE CONSTRUCTION CONTINGENCY 31%

AVERAGE PROJECT CONTINGENCY 32%

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FILE NO. Z075SAB1

** IEST - INTERACTIVE ESTIMATING **
SST INTERSTITIAL LIQUID LEVEL MEASUREMENT
LOW SYSTEM OPTION STUDY ESTIMATE
DOE_R07 - ONSITE INDIRECT COSTS BY WBS

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BY KDE

WBS	DESCRIPTION	ESTIMATE SUBTOTAL	CONTRACT %	ADMINISTRATION TOTAL	BID PACK PREP.	OTHER INDIRECTS	TOTAL INDIRECTS
111000	DEFINITIVE DESIGN-MOBILE SURV. SYS.	296000	0.00	0	0	0	0
111001	DEFINITIVE DESIGN-OBSERVATION WELL	4000	0.00	0	0	0	0
121000	E/I - MOBILE SURVEILLANCE SYSTEM	60000	0.00	0	0	0	0
121001	E/I - OBSERVATION WELL	1715	0.00	0	0	0	0
211000	PROCUREMENT-MOBILE SURVEILLANCE SYS	281690	0.00	0	0	0	0
311001	CONSTRUCT DRYWELL FOR MOBILE UNITS	19019	0.00	0	0	0	0
321000	MOBILE SURVEILLANCE SYSTEM	293000	22.00	64460	7500	0	71960
410000	PROJECT INTEGRATION-LOW	95500	0.00	0	0	0	0
PROJECT TOTAL		1,050,924		64,460	7,500	0	71,960

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DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

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BY KDE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
111000	DEFINITIVE DESIGN-MOBILE SURV. SYS.										
111000.00	TECHNICAL SERVICES										
111000.0000002	INSTRMTS., RACK & COMPUTERS DESIGN	000	1 LS	0	0	0	0	35000	0	0	35000
111000.0000004	BOOMS (4) DESIGN	000	1 LS	0	0	0	0	5000	0	0	5000
111000.0000006	PROBES, CONNECTORS & CONTROL DESIGN	000	1 LS	0	0	0	0	26000	0	0	26000
111000.0000008	(4) VANS & UPGRADES DESIGN	000	1 LS	0	0	0	0	30000	0	0	30000
111000.0000010	VENDOR DESIGN	000	1 LS	0	0	0	0	200000	0	0	200000
SUBTOTAL	TECHNICAL SERVICES			0	0	0	0	296,000	0	0	296,000
TOTAL	COST CODE 00000 WBS 111000 (ESCALATION 0.00% - CONTINGENCY 30.00 %)			0	0	0	0	296,000	0	0	296,000
TOTAL WBS 111000 DEFINITIVE DESIGN-MOBILE SURV. SYS.				0	0	0	0	296,000	0	0	296,000

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ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
111001	DEFINITIVE DESIGN-OBSERVATION WELL										
111001.00	TECHNICAL SERVICES										
111001.0000000	DEF DES - ALLOWANCE FOR OBSERVATION WELL	000	1 LS	0	0	0	0	4000	0	0	4000
SUBTOTAL	TECHNICAL SERVICES			0	0	0	0	4,000	0	0	4,000
TOTAL	COST CODE 00000 WBS 111001 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			0	0	0	0	4,000	0	0	4,000
TOTAL WBS 111001 DEFINITIVE DESIGN-OBSERVATION WELL				0	0	0	0	4,000	0	0	4,000

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ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
121000	E/I - MOBILE SURVEILLANCE SYSTEM										
121000.00	TECHNICAL SERVICES										
121000.0000002	E/I MOBILE UNITS	000	1 LS	0	0	0	0	60000	0	0	60000
SUBTOTAL	TECHNICAL SERVICES			0	0	0	0	60,000	0	0	60,000
TOTAL	COST CODE 00000 WBS 121000 (ESCALATION 0.00% - CONTINGENCY 30.00 %)			0	0	0	0	60,000	0	0	60,000
TOTAL WBS 121000	E/I - MOBILE SURVEILLANCE SYSTEM			0	0	0	0	60,000	0	0	60,000

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ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
121001	E/I - OBSERVATION WELL										
121001.00	TECHNICAL SERVICES										
121001.0000002	E/I OBSERVATION WELL	000	1 LS	0	0	0	0	1715	0	0	1715
SUBTOTAL	TECHNICAL SERVICES			0	0	0	0	1,715	0	0	1,715
TOTAL	COST CODE 00000 WBS 121001 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			0	0	0	0	1,715	0	0	1,715
TOTAL WBS 121001	E/I - OBSERVATION WELL			0	0	0	0	1,715	0	0	1,715

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ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
211000	PROCUREMENT-MOBILE SURVEILLANCE SYS										
211000.15	MECHANICAL										
211000.1500002	INSTRMTS., RACK & COMPUTERS	700	1 LS	0	0	0	71000	0	0	0	71000
211000.1500004	BOOMS (4)	700	1 LS	0	0	0	10000	0	0	0	10000
211000.1500006	PROBES, CONNECTORS & CONTROL	700	1 LS	0	0	0	47000	0	0	0	47000
211000.1500008	(4) VANS & UPGRADES	700	1 LS	0	0	0	108000	0	0	0	108000
SUBTOTAL	MECHANICAL			0	0	0	236,000	0	0	0	236,000
	SALES TAX 7.80 %						18408				18408
	WAREHOUSING 11.56 %						27281				27281
TOTAL	COST CODE 70015 WBS 211000 (ESCALATION 0.00% - CONTINGENCY 30.00 %)			0	0	0	281,689	0	0	0	281,689
TOTAL WBS 211000 PROCUREMENT-MOBILE SURVEILLANCE SYS				0	0	0	281,689	0	0	0	281,689

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ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
311001	CONSTRUCT DRYWELL FOR MOBILE UNITS										
311001.15	MECHANICAL										
311001.1500012	SHOP FAB OBSERVATION WELL	700	1 LS	40	1304	0	2500	0	0	1747	5551
SUBTOTAL	MECHANICAL			40		0		0		1,747	
					1,304		2,500		0		5,551
	CONSUMABLES 6.00 %						150				150
	SALES TAX 7.80 %						206		0		206
	WAREHOUSING 20.00 %						530				530
TOTAL	COST CODE 70015			40		0		0		1,747	
	WBS 311001				1,304		3,386		0		6,437
	(ESCALATION 0.00% - CONTINGENCY 50.00 %)										
311001.15	MECHANICAL										
311001.1500002	GREENHOUSE EXST RISER	700 W	1 LS	24	640	0	200	0	0	858	1698
311001.1500004	REMOVE EXISTING FLANGE	700 W	1 LS	8	261	0	0	0	0	350	611
311001.1500006	PREP RISER FOR OBSERV. WELL	700 W	1 LS	8	261	0	0	0	0	350	611
311001.1500008	INSTALL OBSERVATION WELL	700 W	1 LS	48	1568	600	1000	0	0	2101	5269
311001.1500010	STEP OFF PAD SUPPORT	700 W	3 DAY	48	1118	0	0	0	0	1498	2616
SUBTOTAL	MECHANICAL		(SWP)	136		600		0		5,157	
					3,848		1,200		0		10,805
	SWP 15.00%			20	577						577
	CONSUMABLES 6.00 %						72				72
	SALES TAX 7.80 %						99		0		99
	WAREHOUSING 20.00 %						254				254
	OH&P (ON MARKUPS ONLY)									773	773
TOTAL	COST CODE 70015			156		600		0		5,930	
	WBS 311001				4,425		1,625		0		12,581
	(ESCALATION 0.00% - CONTINGENCY 50.00 %)										
TOTAL WBS 311001	CONSTRUCT DRYWELL FOR MOBILE UNITS			196		600		0		7,677	
					5,729		5,012		0		19,018

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ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
321000	MOBILE SURVEILLANCE SYSTEM										
321000.15	MECHANICAL										
321000.1500002	INSTRMTS., RACK & COMPUTERS FAB & INSTALL	700	1 LS	0	0	0	0	80000	0	0	80000
321000.1500004	BOOMS (4) FAB & INSTALL	700	1 LS	0	0	0	0	55000	0	0	55000
321000.1500006	PROBES, CONNECTORS & CONTROL FAB & INSTALL	700	1 LS	0	0	0	0	101000	0	0	101000
321000.1500008	(4) VANS & UPGRADES FAB & INSTALL	700	1 LS	0	0	0	0	57000	0	0	57000
SUBTOTAL	MECHANICAL			0	0	0	0	293,000	0	0	293,000
TOTAL	COST CODE 70015 WBS 321000 (ESCALATION 0.00% - CONTINGENCY 30.00 %)			0	0	0	0	293,000	0	0	293,000
TOTAL WBS 321000 MOBILE SURVEILLANCE SYSTEM				0	0	0	0	293,000	0	0	293,000

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ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
410000	PROJECT INTEGRATION-LOW										
410000.19	PROJECT MANAGEMENT										
410000.1900000	WHC PROJECT MANAGEMENT LOW SYSTEM	700	1 LS	0	0	0	0	95500	0	0	95500
SUBTOTAL	PROJECT MANAGEMENT			0	0	0	0	95,500	0	0	95,500
TOTAL	COST CODE 70019 WBS 410000 (ESCALATION 0.00% - CONTINGENCY 50.00 %)			0	0	0	0	95,500	0	0	95,500
TOTAL WBS 410000 PROJECT INTEGRATION-LOW				0	0	0	0	95,500	0	0	95,500

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ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
REPORT TOTAL				196	5,729	600	286,701	750,215	0	7,677	1,050,923

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