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System Design Description Cone Penetrometer System

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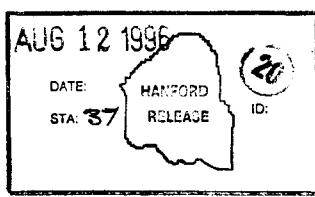
Abstract: The system design description documents in detail the design of the cone penetrometer system. The systems includes the cone penetrometer physical package, raman spectroscopy package and moisture sensor package. Information pertinent to the system design, development, fabrication and testing is provided.

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SYSTEM DESIGN DESCRIPTION
CONE PENETROMETER SYSTEM

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for the
U. S. DEPARTMENT OF ENERGY
RICHLAND OPERATIONS OFFICE
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LIST OF ACRONYM

ARA	Applied Research Associates
ASCII	American Standard Code for Information Interchange
ATP	Acceptance Test Procedure
CCD	Charge Coupled Device
CP	Cone Penetrometer
DOE	Department of Energy
FDC	Functional Design Criteria
GMR	Giant Magnetoresistive Ratio
ICF KH	ICF Kaiser Hanford
ID	Inner Diameter
LLNL	Lawrence Livermore National Laboratory
NA	Numerical Aperture
NFPA	National Fire Protection Association
OD	Outer Diameter
PNNL	Pacific Northwest National Laboratory
SAIC	Science Applications International Corporation
SDD	System Design Description
TOC	Total Organic Carbon
VI	Vendor Information
WHC	Westinghouse Hanford Company

1.0 Introduction

1.1 Background

Currently, Hanford single shell and double shell tank waste is being characterized for a variety of physical and chemical properties. The tank waste exists in liquid, sludge and saltcake form. Several methods exist to sample or otherwise measure the desired properties in situ. However, no single method can obtain all the desired properties.

According to the Hanford Federal Facility Agreement and Consent Order (commonly known as the Tri-Party Agreement), all single shell tanks are to be characterized by 1998 and formally closed by 2018. The method chosen to characterize the tanks is by obtaining solid and liquid waste core samples from the tank and testing these samples in the hot cell. With 149 single shell tanks and 28 double shell tanks at Hanford and a limited capacity to analyze, additional waste characterization methods are needed.

The system design description covers the design of an enhanced cone penetrometer system for in situ characterization. The in situ characterization will be performed on the waste contained in the underground storage tanks. The cone penetrometer will first gather physical and chemical characterization information as it is lowered into the waste, then deploy a moisture probe.

A cone penetrometer system is being designed to temporarily access tank waste through risers and obtain insitu physical, chemical, and moisture data. The cone penetrometer has an instrumented rod described in WHC-S-0241. This sensor package is driven hydraulically through the waste by attaching hollow rods to the sensor package. The cone penetrometer moisture sensor will then be lowered into the cone penetrometer rod, after the cable bundle from the cone penetrometer has been removed. The cone penetrometer is capable of obtaining:

- Waste shear strength and yield strength
- Waste compressive strength
- Tank waste stratigraphy to determine tank waste penetration requirements which will aid core sample truck sample tool selection
- Moisture profile, surface level and temperature profile
- Tank waste chemical species

A team compromised of Westinghouse Hanford Company (WHC), ICF Kaiser Hanford (ICF KH), Pacific Northwest National Laboratories (PNNL), Lawrence Livermore National Laboratory (LLNL), Science Applications International Corporation (SAIC) and Applied Research Associates (ARA) personnel has been formed to develop the necessary measurement system.

WHC was the lead organization for the cone penetrometer system and provided project management and funding support. PNNL developed simulant formulations for hardware capacity testing and for waste classification chart development. SAIC designed, tested and fabricated the moisture sensor system. ICF KH completed seismic and stress analysis. LLNL designed and fabricated the Raman spectroscopy sensor system. ARA tested simulants, designed and fabricated the basic physical properties sensors, the cone penetrometer system platform and integrated the moisture sensor system and Raman spectroscopy sensor system into the cone penetrometer platform.

1.2 Document Overview

The system design description (SDD) documents, in detail, the design of the cone penetrometer system. The overall project was outlined and governed by Engineering Task Plan, WHC-SD-WM-ETP-017. The system is designed and manufactured to achieve the performance objectives dictated in WHC-S-0241 and WHC-SD-WM-FDC-047. WHC-S-0241 is the performance specification for the cone penetrometer platform. WHC-SD-WM-FDC-047 is the functional design criteria for the moisture probe.

This SDD provides information pertinent to the system design, development, fabrication, and testing. A vendor information (VI) file #22700 has been prepared. This VI file contains a collection of vendor drawings, manuals and data sheets and may be retrieved, if more detailed component information is sought. Detailed procedures (installation, operation and removal) will be developed prior to field deployment. All other pertinent documentation is appended to this document or listed as a retrievable reference.

2.0 Functions and Design Requirements

A performance specification for the cone penetrometer system and a functional design criteria (FDC) for the moisture probe were developed for this project. The criteria that guided the system development and project designs is listed below.

2.1 Cone Penetrometer Requirements

- The cone penetrometer is mounted on a skid to allow ease of movement between tanks and hard to reach tank riser locations.
- The cone penetrometer system is compatible with tank riser flanges 4 inch (10.2 cm) to 24 inch (60.9 cm) in diameter.
- The cone penetrometer has the ability to reach close to the bottom of single and double shell tanks (as much as 55 feet (16.8 m) below ground level).
- The cone penetrometer can be safely deployed in the tank environment without penetrating or damaging the bottom of the tank or without system failure such as rod yielding.
- The cone penetrometer is able to penetrate saltcake, sludge and liquid layers. Saltcake penetration limits have been determined through testing.
- The cone penetrometer is compatible with the moisture sensor and the Raman spectroscopy sensor.
- The cone penetrometer system conforms to the requirements set out in performance specification WHC-S-0241 and the functional design criteria WHC-SD-WM-FDC-047.
- The cone penetrometer acquires the data listed in table 1.

Table 1: Data Needs

Data Quality Objective	Current Capability
Safety Screening (WHC-SD-WM-SP-004 Rev 2)	<ul style="list-style-type: none"> Screening for energetics, TOC and cyanide
Organic (WHC-SD-WM-DQO-006 Rev 2)	<ul style="list-style-type: none"> Screening for energetics, TOC, aluminum and iron Water, wt % Temperature
Retrieval (WHC-SD-WM-DQO-008 Rev 0)	<ul style="list-style-type: none"> Temperature Shear Strength Sludge Profile Slurry Profile
Waste Compatibility (WHC-SD-WM-DQO-001 Rev 1)	<ul style="list-style-type: none"> Screening for energetics, TOC, aluminum, carbonate, nitrite, nitrate, phosphate, sulfate and uranium Water, wt %
Historical Data (WHC-SD-WM-DQO-018 Rev 0)	<ul style="list-style-type: none"> Screening for aluminum, iron, chromium, nitrate, carbonate, phosphate, sulfate, uranium and SiO_3 Water, wt %
Flammable Gas (WHC-SD-WM-DQO-004 Rev 2)	<ul style="list-style-type: none"> Screening for energetics, TOC, nitrite, nitrate, phosphate, sulfate, uranium, carbonate, chromium, aluminum, iron, formate and oxalate.
Pretreatment (WHC-SD-WM-DQO-022 Rev 2)	<ul style="list-style-type: none"> Screening for iron, manganese, aluminum and chromium.
Ferrocyanide (WHC-SD-WM-DQO-007 Rev 2)	<ul style="list-style-type: none"> Screening for energetics, TOC and cyanide Water, wt %
Characterization	<ul style="list-style-type: none"> Strata

2.2 Instrument and Control Functional Requirements

- A computer and associated peripherals are used for the operation of the moisture probe.
- Stand-alone computers and associated peripherals are used for the operation of the cone penetrometer.
- Data output is stored in ASCII format to allow downloading to data reduction personnel upon completion of the operation.
- The temperature of the control room is maintained above 40 °F (4 °C) and below 70 °F (21 °C) to allow operation in any period of the year.

2.3 Instrument and Control Performance Requirements

- The system is controlled from the cone penetrometer skid. The CP system is equipped with data storage and retrieval capabilities. The data acquisition system are compatible with the supplied probe and capable of acquiring and logging the tip pressure, sleeve friction, pore pressure, tip temperature, side temperature, depth, downward force, moisture, tank temperature, chemical speciation data, bottom detection, water level, moisture content and surface moisture.
- The computer data acquisition system contains an operator station, I/O channels to accommodate supplier's sensors plus 10 spare I/O channels, a removable cartridge disk drive (90 MB minimum), and a laser printer with graphics package compatible with all input devices.
- The ranges required for the instrumentation are listed in table 2. Tip pressure, sleeve friction, pore pressure, tip temperature, side temperature, depth and downward force are required to measure within 5% accuracy.

Table 2: Instrumentation

Data	Source	Unit of Measure	Range
Tip pressure	Load cell	psi (kPa)	0-15,000 (0 - 103421)
Sleeve friction	Load cell	psi (kPa)	0 - 300 (0 - 2068)
Pore Pressure	Pressure transducer	psi (kPa)	0 - 200 (0 - 1379)
Tip temperature	Thermistor	°F (°C)	60 - 320 (15.6 - 160)
Side temperature	Thermistor	°F (°C)	60 - 320 (15.6 - 160)
Depth	Transducer	feet (m)	0-65 (0-20)
Downward Force	Load cell	tons (kN)	0 - 38 (0- 338)
Moisture Probe			
Neutron counter	B-10 lined counter	counts/sec	0-50,000
Temperature	Thermistor	°F(°C)	60-320 (16-160)
Depth	Cable encoder	feet (m)	0-65 (0-20)
Raman Spectroscopy			
Vibrational Spectra*	Thermal electrically cooled charge coupled device (CCD) detector	N/A	100-3334 cm ⁻¹

*Note: Current chemical species library contains:

sodium chromate	sodium dichromate
butonal	dimethylamine hydrochloride
EDTA	tributylphosphate
acetone	sodium oxalate
dibutylphosphate	ammonium nitrate
formamide	sodium aluminate
sodium cyanate	ketosene (NPH)
sodium nitrate	sodium nitrite
sodium phosphate	sodium carbonate
sodium sulfate	uranyl nitrate
nickel cyanide	sodium ferrocyanide

- Other quantities are derived from measurements taken from these sensors. Derived measurements are listed in table 3. These measurements have been derived from lab data listed in the reference section.

Table 3 : Derived Measurements

Derived measurement	Sensor	Accuracy
Yield strength	Tip pressure, Sleeve friction and Pore Pressure	.02 psi (1500 dyne/cm ³) in sludge
Shear strength	Tip pressure, Sleeve friction and Pore Pressure	.02 psi (1500 dyne/cm ³) in sludge
Compressive strength	Tip pressure, Sleeve friction and Pore Pressure	No requirement
Stratigraphy	Tip pressure, Friction sleeve, Pore pressure	No requirement
Moisture Probe		
Surface moisture	B-10 counter	± 3% water by weight for 0-25% moisture content by weight ± 5% water by weight for 25-50% moisture content by weight
Moisture content	B-10 counter	± 3% water by weight for 0-25% moisture content by weight ± 5% water by weight for 25-50% moisture content by weight
Water Level	B-10 counter	± 1/4 inch (.64 cm)
Raman Spectroscopy		
Relative concentration	CCD	0.1 %

2.4 Safety Requirements

- The system is decontaminated to acceptable levels after use and stored for safekeeping. Decontamination occurs prior to removal of the hardware from the tank, if possible.
- The system will meet all safety, shielding and environmental requirements.
- Radiation dose to workers should be minimized and in compliance with the WHC Radiological Control manual.
- The system will comply with all safety assessment requirements, when completed.
- The system is designed for Class I, Division I, Group B hazardous location as discussed in the National Fire Protection Association (NFPA) requirements.

2.5 Structural Requirements

- Load applied to the tank riser, dome and any ancillary support structure must meet all operating and design specifications for tank farms. Structural analysis of tanks under the loads imposed by the cone penetrometer are discussed in WHC-SD-WM-DA-212.

3.0 Design Description

3.1 Principle of Operation

The cone penetrometer is a hydraulically driven instrumented rod which is pushed into the waste and measures *in situ* the data listed in Tables 2 and 3. The rod is supported by a guide tube which provides structural support to the rod. The rod is assembled by screwing hollowed rod sections into the instrumented tip as the rods push and penetrate the waste. The sensor package, as shown in Figure 1, measures physical properties and chemical species.

Physical properties are measured with the tip pressure, pore pressure and sleeve friction sensors. Load cells at the tip (tip pressure) measure resistance of the materials ahead of the tip while side load cells (friction sleeve) measure the friction as the cone pushes into the material. Filtered hydrostatic pressure (pore pressure)

is obtained using a sensing device also located within the tip. Physical properties and stratigraphy are correlated from these measurements.

Chemical species are identified using the Raman spectroscopy sensor. The Raman spectroscopy sensor is a tool used for characterization of an unknown chemical constituent via their vibrational spectra. A near-infrared, mode stabilized, semiconductor laser shines light into a radiation hardened fiber optic cable. The light shines through the fiber optic cable to a sapphire window, which provides a transparent viewing port to the waste. A silvered hypotenuse right angle prism connects the optical axis of the probe window with the optical axis of the vertical penetrometer. Light is reflected or scattered on the waste. A small shift in frequency occurs when the molecules reflect or scatter the light. The shift occurs when the molecule undergoes a vibrational transition at a characteristic frequency when reflecting or scattering a light wave. The returning Raman signals are collected with seven fiber optic cables and filtered through a long pass filter to remove scattered laser light. A monochromator emits a range of wavelengths to the charge coupled device (CCD), which is employed as a Raman signal detector. A computer is used to analyze the spectra collected from the CCD. Species identification and relative concentrations can be deducted from these measurements.

The moisture probe is used to measure moisture content, surface level and temperature. To measure the amount of moisture in the waste, a technique based upon neutron thermalization is used. This technique has been used for many years in other applications to measure moisture on the surface of the soil and within oil logging holes. In this method, neutrons are emitted by a source (usually from a radioisotopic source) out into the material under inspection. The source neutrons, which initially have an average energy of about 2 MeV, scatter from the nuclei of the waste and lose some energy each time they scatter. Because the neutrons have the same mass, they lose most of their energy and most quickly, when they scatter from hydrogen nuclei (protons). The neutrons scatter several times and eventually slow down to thermal energies (0.025 eV). A thermal neutron sensitive device located near the neutron source detects source neutrons which become thermalized by the hydrogen within the waste and scatter back to the detectors. The more water present, the more hydrogen and the greater the count rate in the thermal neutron detector. Therefore, the detector count rate can be related to the moisture contents of the waste material. Note that since the technique is sensitive to the amount of hydrogen in the waste, it is also sensitive to the amount of organics which contain hydrogen, however, this will have little effect on the moisture measurements taken in the Hanford waste tanks.

3.2 System Overview

The cone penetrometer system is a portable skid mounted instrument designed to penetrate the different layers of liquid, sludge and saltcake by hydraulically pushing a push rod and guide tube into the waste. Figure 2 depicts the overall system. The sensor package resides in the push rod while the guide tube provides structural support to the push rod. Measurements are taken as the rod pushes into the waste. These measurements consist of physical and chemical data. Once the push rod has reached the bottom of the tank, the cable bundle for the chemical/physical sensors is removed. The moisture sensor is lowered into the cavity which the cable bundle once occupied. A profile of the moisture level, water level and temperature is obtained. A winch controls the rate that the moisture sensor is lowered into the tank. Once the profile is obtained, the moisture probe is removed and the push rod and guide tube are removed and decontaminated from the tank.

The top assemblies for the cone penetrometer are ARA H000-1A and SAIC 544001 for the moisture probe and LLNL Engineering Sketch of Raman Probe Optical Elements Layout.

3.3 Sensor Package

The cone penetrometer sensor package contains sensors to measure tip stress, sleeve friction, pore pressure, tip and side temperature, inclination, bottom detection and chemical speciation at the tip of the push rod. The moisture probe is deployed after these measurements are taken.

Both sleeve and tip stress load cells are located near the tip. Micro Measurement foil strain gages were used to provide greater sensitivity over the broad stress ranges. Given the wide temperature range of the load cell and the low signal measurement to be taken, a temperature compensated strain gage was used. The apparent strain functions supplied by the strain gage manufacturer are supplied to the data acquisition system and corrected based on the measured temperature.

The pore pressure transducer measures tank waste pressure. The transducer is isolated from the tank waste with a high viscosity silicone oil and a stainless steel frit filter. The transducer is a Kulite semiconductor Products, Inc. XT-140-200. The filter is made of porous polyethylene material with saturation fluid of a high density silicone oil (Dow Corning 200R fluid, 10,000CS). The pore pressure transducer consists of a 100 ohm strain gage bridge.

Tip and side temperature are measured through two Digi-Key thermistors. The tip sensor is located in the tip of the probe bonded to the tip stress load cell strain gage. The side sensor is bonded to a stainless steel button which is bonded to a Kevlar button, which is screwed into the side of the mandrel. The bonding material is STYCAST 1266. The thermistors have a resistance value of 10,000 ohm at 68°F (20°C).

The probe inclination measurements will be accomplished with a Spectron SP500 electrolytic tilt sensor. The sensor is 0.5 inch (1.3 cm) diameter by 0.625 inch (1.6 cm) tall cylindrical glass envelop filled with a proprietary electrolytic fluid. Four electrodes are located 90° apart around the circumference and one electrode is located in the center of the sensor. The sensing bulb is located in an insert inside the cone cavity. The sensor is excited with a 10 volt peak to peak square wave, applied between electrodes at opposite sides of the sensor.

The bottom detector consists of a coil and two giant magnetoresistive ratio (GMR) sensors which are excited by the application of a 100 Hz 3.25 mA peak-to-peak current. The coil is 0.5 inches (1.3 cm) in diameter, 0.188 inch (0.5 cm) thick, and 1 inch (2.5 cm) tall. The coil has 1600 turns of 34 AWG copper wire around a steel core that contains the two GMR sensors. The air core inductance value of the coil is 7 to 10 millihenries. The GMR sensor is a NVSB series sensor manufactured by Nonvolatile Electronics, Inc. The sensor senses the increase in magnetic flux in the iron core in the center of the coil, as the bottom detector approaches the steel bottom of the tank. Test results and a detailed description are located in VI file 22700.

The Raman spectroscopy probe was developed by Lawrence Livermore National Laboratory. The system consists of the housing, laser, monochromator, charge coupled device and the fiber optics. Figure 3 depicts the Raman spectroscopy system. The housing is 420 stainless steel tube which houses the lenses and window assembly. Laser light is focused and the raman signal collected by means of an f/1.67 lens near the window assembly. The sapphire window, at which the Raman spectroscopy sensor interrogates the material, is brazed directly into the wall of the housing assembly with an indium silver alloy. The near infrared Spectra diode laser (785 nm) has 300 mW Laser Output which shines light into a radiation hardened fiber optic cable. The laser utilizes an external cavity design to provide stable single wavelength output. The sending fiber optic is a 200 μ m optical fiber and the collection fibers are seven 200 μ m optical fibers arranged in a six around one configuration. These are coupled at the housing with a LEMO connector to a 320 μ m sending fiber optic and to a 900 μ m collection fiber. These fibers are PolyMicro Technologies, polyamide coated, low OH content, radiation hardened

fibers. The fiber optic cable has been tested to 532.5KRad of exposure with a resulting 21% maximum signal loss. Laser input to the probe is provided by a single fiber which is independent of the collection fibers. The housing collection fiber is filtered with a long pass filter to remove scattered laser light; the laser excitation fiber is filtered with a laser band pass filter to remove silica Raman generated in the optical fiber. The filters are a CVI 785 nm line filter, 800 nm Chroma Raman dichroic long pass filters and a 800 nm Chroma Raman edge long pass filter. The monochromator is a Kaiser Optical Systems monochromator, which utilizes all transmissive holographic components rather than reflective elements as found in conventional and eschelle grating systems. The Kaiser monochromator has an input numerical aperture (NA) of 0.28 and can be coupled directly to the output from an optical fiber with no magnification nor signal loss due to slit mismatch. A thermal electrically cooled two dimensional CCD array is employed as high sensitivity low background noise Raman signal detector. The CCD camera is supplied by Princeton Instruments, P/N TECCD-1024EM. The detector is a 1024 x256 pixel array with $27 \times 27 \mu\text{m}$ pixels, giving an active signal collection area of 27.65 mm wide (spectral dimension) and 6.9 mm high spatial dimension. The spatial dimension is separated into two fields, one covering 100 to 1800 cm^{-1} and another 1800 to 3334 cm^{-1} .

The cables connecting the data acquisition to the sensor package will be removed prior to performing moisture probe scans. These cables include the fiber optic cables and the electronic cable. The electronics cable, manufactured by Belden, is an insulated cable, rated at 500 VAC between conductors. To disconnect these cables, three LEMO connectors are used. One LEMO connector (P/N FGG-3B-330 and PHG-3B-330 receptacle) is used for the electronic cable and two LEMO connectors (FGG-0B-053CRBE30G and PFG-0B-053CASE30G) are used for the fiber optical fibers. These connections are keyed and has a positive lock to prevent accidental disconnection by tension in the cable. The outer collect will have a small steel wire which can be pulled when the cable is disconnected. The electrical cables will be removed prior to the Raman optical cables.

The neutron probe contains two B-10 lined detectors mounted in a 0.9 inch (2.2 cm) diameter, 24 inch (60.9 cm) long stainless steel housing which is lowered into the penetrometer by a 0.4 inch (1 cm) diameter custom cable. The housing also contains a temperature sensor and a Cf-252 neutron source. The cable is attached to the probe body via a potted connection. The custom multi conductor cable, manufactured by Consolidated Products, has a semi conductive insulator and contains a kevlar strength member, two RG-174 signal cables and two shielded single cables. Details on the moisture probe are described in WHC-SD-WM-SDD-062.

3.4 Data Acquisition

The data acquisition system provides real time data recording, display and control of safety systems from the probe sensors, trailer sensors, rig sensors and the operator. A variety of probe sensor data will be acquired by moisture probe data acquisition system, raman spectroscopy data acquisition system and the cone penetrometer data acquisition system. The data destinations are the CRT screen and the magnetic disk storage. Details on the data acquisition systems are contained in ARA's CPT Data Acquisition Software Design Description, listed in the reference.

All instrumentation, materials and software are industry standard and are capable of modification or replacement with minor maintenance protocol. Documentation is available for all components, and where pertinent, includes the part number, design drawings, service and/or operations manuals.

3.5 Data Acquisition and Control

3.5.1 Overview

The data acquisition and control system consists of three systems. These are the cone penetrometer, moisture probe and Raman spectroscopy data acquisition systems. All systems are composed of a computer display and integral keyboard, associated electronics, and interfaces to the sensor electronics. The consoles are located to maximize access for the operator and service personnel. The system is capable of recording a minimum of 32 DC analog (16 variable gain and 16 fixed gain) and 8 digital inputs at a sample rate of greater than 100 samples per second. The system is capable of storing at least 12,000 data sets. A data set will include all the recorded sensor data at a given time, time of recording and an other associated information.

3.5.2 System Computer

The cone penetrometer is controlled by the cone penetrometer control stand and data acquisition system. The operator interfaces with the system through a point and click on the computer monitor screen using the system mouse and keyboard for alphanumeric input. Using the computer monitor screen, mouse, and keyboard, the operator can select the operating mode and input necessary parameter values. The computer automatically controls

the system, acquires, displays and stores probe and position data. The software is a customized program designed to record and display data from all downhole sensors along with a variety of uphole sensors. The system will monitor a number of these sensors for indication of potentially hazardous situations and either alert the operator or shut down the CPT push system depending on the severity of the situation. The raman spectroscopy computer controls and acquires data from the raman spectroscopy sensor. The moisture probe computer controls and acquires and stores data for the moisture probe. Table 4 features the different computers which will be used for the system.

Table 4: Computer Hardware

Cone Penetrometer	Raman Spectroscopy	Moisture Probe
IBM compatible microcomputer Microsoft Windows 3.1 90 MHz Intel Pentium processor 1.0 Gb IDE hard drive 16 Mb RAM 17 inch(43 cm) and 15 inch (38 cm) color monitors HP 5.0 laser printer Colorado tape backup device 3.5 inch (9 cm) floppy disk drive HP VEE CITT Standard modem	Compac computer 100 MHz Pentium processor hard drive 16 Mbyte Random Access Memory 17 inch (43 cm) monitor 3.5 inch (9 cm) floppy drive Keyboard HoloGrams software	Cone Penetrometer System OR IBM Compatible AST-system Microsoft Windows National Instrument's LabView 75 MHz CPU Clock Speed 8 MBytes Random Access Memory 540 MByte Hard Drive Disk 3.5 inch (9 cm), 14 MByte Floppy Disk Drive One Serial Port and One Parallel Port Logitech 101 Key Keyboard Color flat panel display

3.5.3 Hardware Interfaces

The data acquisition is composed of an IBM compatible microcomputer and an external signal conditioning unit made by Hewlett-Packard. The signal processor features a 1 Mb nonvolatile RAM and front control panel and is designed to accept various input/output and signal conditioning boards. The unit has 32 channel Scanning A/D converter 9E1313A (with 16 bit resolution), a Quad 8-bit Digital input/output board and a 4 channel D/A converter board. These components are connected to each other via a GPIB serial interface. The analog inputs will be sampled at a rate of at least 100 samples/second. Figures 4 and 5 show the interfaces between the control stand and the data acquisition system and the sensors. These inputs are from sensors mounted on the CP probe and the CP skid and support trailer. The data acquisition system has the capability of sending collected data output to another system via a CITT standard or equivalent industry standard modem.

3.5.4 Operator Interfaces

A graphical operator interface is used to simplify the operation of the software. The user inputs through a standard keyboard and/or point device. This interface contains information pertinent to the operation of the system as well as project specific test setup parameters. Output includes numerically and graphically sensor measurements as a function of rod depth. The interfaces minimize operator use of the keyboard by providing easily understandable icons and automatic file naming conventions. Appendix A contains the control logic for the Hanford skid for safety items.

3.5.4.1 Software Architecture

The control software for the cone penetrometer contains several functional blocks: Device Setup, Channel Configuration, Test/Site Parameters, Penetration Acquisition, Monitor System, Instrument Verification, Review Penetration and Exit.

Device Setup:

When this button is depressed, the user can select from a pull down menu of available sensors. Each sensor has its diameter, maximum load rating and total push footage displayed. This screen allows the user to view the operating parameters of all available sensors.

Channel Configuration:

When this button is depressed, the user sets the operating parameters of a specific sensor. The user can change gain and filter settings for an analog sensor, conversion factors for linear sensors, excitation sensor and hardwired voltage, alarm conditions, and action levels.

Test/Site Parameters:

When this button is depressed, the user can activate an input screen of site specific parameters. These parameters include

filename, tank, riser, project, operator, crew, client representative, weather and sample rate.

Penetration Acquisition:

When this button is depressed, the user initiates the data recording process for penetration data. The first part of the process activates the site parameters and test parameters input and allow the operator to modify any default values. In the next screen, the operator is presented is the primary screen which contains graphical displays for 4 sensors. The graphs displays the recorded data versus depth. Above the graphs is an alarm indicator. This indicator is green as long as the alarm is not on. If the alarm condition is turn on, the indicator turns red. The alarm conditions are specified by the operator in the device setup option. There are seven check boxes below the numerical sensor data. These allow the operator to toggle between views of the data being recorded or different modes of recording data.

Monitor System

This module is used to monitor the safety parameters of the system.

Instrument Verification

This module is used to verify sensor operation and sensor calibration validity. Sensors verified include tip and side load cells, tip and side thermistors, pore pressure and inclinometer.

Review Penetration

This module is used to review raw data during a system pause or at the end of a run.

Exit

This module allows the user to exit the program.

3.5.5 Data Analysis

The data analysis of the data from the cone penetrometer is handled off line.

3.5.6 Electronic Enclosure

The electronics are mounted in two full height (6 feet/1.8 m) control room racks and a control stand. This includes the data acquisition system, computers and moisture probe electronics. ARA drawing H138-3A, H062-7A and H056-3A show the layout of the equipment in the Data Acquisition Rack and the control stand. The control room also contains two stainless steel work benches. The wall space near the bench top is equipped with two electrical outlets.

The control station contains control levers and pressure gages for the hydraulic push and clamping cylinders. Decontamination water pressure and temperature, hydraulic fluid temperature and level and engine status are displayed at the console. Figure 7 shows the general layout of the control room.

3.5.7 Calibration

The system has been calibrated by testing the probe in test beds with sludge and saltcake simulants. These test beds, built during earlier development phases of the project, established the calibration factors relating to the shear strength, yield strength and compressive strength. See the reference for more information.

3.6 Push System

The guide tube is lowered into the tank riser by a crane. The push rod and guide tube are secured to the platform through a four clamp system. The system is designed so that both of guide tube and rod will never be dropped inside the tank by always having a hydraulic clamp in the closed position. These have been set up so that both cannot be opened simultaneously in normal operation. A latching relay clamps the primary clamp when the rod clamping safety switch is on. Once the primary clamp is fully clamped, a pressure switch is activated which supplies power to unclamp the secondary clamp. When the secondary clamp is fully open, the latching relay is reset. In addition to the hydraulic clamps, a mechanical "C"

clamp is in place, so that the push rod and guide tube cannot be dropped accidentally in the tank.

The four hydraulic clamps are used to secure the guide tube and push rod. These are clamp A (Rod Push Clamp), clamp B (Rod Safety Clamp), clamp C (Guide Tube Push Clamp) and clamp D (Guide Tube Safety Clamp). The safety clamps are fixed to the skid structure. The push clamps are mounted on the hydraulic cylinders used for lifting and lowering the clamp.

A proportional valve is used to control the push force of the rods. The operator can control the force using a joystick mounted on the control panel. The operator adjust the maximum flow using a potentiometer which is also mounted on the control panel. These signals control the valve. The guide tube operates in a similar manner.

Both the rod and guide tube system include a reducing valve to maintain the safe pressure of the system. Each is controlled by the data acquisition computer and have a potentiometer which allows the operator to manually reduce the maximum allowable pressure.

3.7 Push Rod and Guide Tube

The push rod consists of a 1.75 inch (4.4 cm) OD by 1.00 inch (2.5 cm) ID rod made out of 4130 seamless tubing. The push rod threads into an 2.00 inch (5.2 cm) OD by 1.25 inch (3.2 cm) ID adaptor which connects to the probe body and Raman spectroscopy sensor. The guide tube sizes are 3.5 inch (8.9 cm) OD by 2.25 inch (5.7 cm) ID and 6 inch (15.2 cm) OD x 2.25 inch (5.7 cm) ID. The guide tube is made out of 4130 steel alloy. The cable bundle and push rod is prestrung prior to penetration.

A rod rack, which allows the signal cable to be strung through the rod in place, is located near the CP skid. The tray is capable of holding six CP rods. These racks are stackable and can store a rod string up to 75 feet long. A special rack is provided to allow guide tubes and push rods to be strung sequentially on the same tray.

3.8 Decontamination System

The CP push rod and guide tube are decontaminated during removal from the tank. The decontamination unit interfaces with a riser/decontamination adaptor. The

decontamination unit is located on the support trailer. The decontamination unit is a self contained heating system which heats 120 gallon (454.2L) container of water from 50 °F to 130 °F (10 to 54.4 °C) in 4 hours and maintain it at 130 °F (54.4 °C) in ambient temperatures ranging from 10 °F to 100 °F (-12.2 to 37.8 °C). The unit contains a pumping system that supplies 3.8 gpm (14.4 liters per minute) (minimum) of water at 400 psig (2758 kPa) (minimum). The generator power supply provides power to the decontamination unit. The decontamination fluid is "potable" or "pure" water.

The decontamination water is stored in a 120 gallon (378.5 L) capacity aluminum water tank. The water is heated by a Chromalox 7.5 kW MT-3 immersion heater and a thermistor controlled 4.5 kW MT-3 immersion heater. Water is pumped with a plunger pump hydro model No. 2340B. All necessary gauges and operational controls for the unit are visible and accessible to the operator while the decontamination unit is in operation. These include water temperature and level at the skid control stand. All gauges and operational controls are in close proximity such that the operator can read the gauges and operate the unit simultaneously.

3.9 Ventilation

An electric air conditioner/heater has a minimum capacity to regulate to 75 °F (23.9 °C) with 120 °F (48.9 °C) outside temperature, three people inside the skid enclosure and 70 °F (21.1 °C) with a -30 °F (-34.4 °C) outside temperature, 50 MPH (80.5 km/h) wind with no people in the skid. The volumetric airflow rate provided is twenty five air changes per hour. A 0.1 inch (24.9 kPa) positive pressure exists when the doors are closed. The supply filter is a 80% efficient or greater for particles greater than 5 microns.

Primary heating is provided by two wall mounted force air fan heaters with 13650 BTU/hr (4 kW) capacity. The heaters are located under the interior work bench and are controlled by an individual thermostat located on the control stand side wall. Two air conditioning units are located on the roof of the control room. The AC system has a 26,000 BTU/hr (7.62 kW) capacity. The system is cooled by two Coleman #6798A700 air conditioners. Each unit is independently controlled by a thermostat on the control panel of the AC unit. The roof mounted HVAC provides ventilation to the control room when doors and windows need to be closed.

3.10 Maneuverability

The CP system maneuvers over the riser and locates it within 0.25 inches (0.64 cm) of the riser's dead center. This is accomplished by a x-y positioner which positions the push system over the riser. The positioner has a range of movement of 12 inch (30.5 cm). The x-y positioner clamps mechanically in the x direction and hydraulically in the y-direction.

3.11 Leveling

A four point outrigger leveling system provides a maximum 41 inch (104 cm) of leveling travel. The skid is equipped with four leveling cylinders, one located in each corner. Three hydraulic levers control the leveling of the skid. These are the rear leveling pads, the front left leveling pad and the front right leveling pad. The rear cylinder is hydraulically common to the rear leveling pad. A skid leveling bubble is used as a guide to level the unit.

3.12 Power Distribution and Interconnections

The system uses 110 VAC power which will be supplied from the penetrometer control room power distribution system. The power requirements are estimated to be 225 Amp Max, < 30KVA. The system is connected by cables from the control room to the downhole probe and moisture probe.

3.13 Support Trailer

The support trailer houses the power unit, generator, decontamination unit and hydraulic pump. The trailer used is 7 feet (2.1 m) wide by 12 feet (3.6 m) long 9200 lb (50 kN) GVW trailer. The trailer houses the diesel engine, electrical generator, hydraulic pump and reservoir, decontamination system and cable and hose storage. The engine is a 120 hp (89.5 kW), four cylinder turbo diesel John Deere Power Unit Model 4039 engine with a 56 gallon (212 L) fuel tank (approximately 3 day supply). A low fuel warning light located in the skid, illuminates at an operational reserve of 6 hours. The engine powers a Marathon Electric P4C060A0 1800 RPM, 240 Volt, 60 Hz, 1 phase generator and Oilyear hydraulic pump with a 150 gallon (568 L) hydraulic oil reservoir. The generator can deliver up to 15 kW (60 Hz, 220 v). A Bell Power engine displays RPM, voltage, frequency, oil pressure, water temperature and engine amperage. The 3000 psi (20684 kPa) hydraulic pump can deliver up to 30 gallons per minute (113 L/min). The decontamination water tank, heater and pump are mounted on the support trailer. The heater and pump are powered by the generator. Fifty (50)

feet (15 m) of electrical cables and hoses (hydraulic and decontamination water) are stored on the support trailer. Each has a unique fitting to avoid cross linkage. The hoses include the hydraulic fluid supply line, hydraulic fluid signal line, hydraulic fluid filtered return line, hydraulic unfiltered return line and decontamination water line. Electrical cables include two signal cables and a power cable.

3.14 Ballast

Ballast weights are fully encased lead filled steel boxes. The ballast are set up as 2 front ballast (15,000 lb/66.7 kN each) and four rear ballast (6,000 lb/26.7 kN each). The system can be arranged with no ballast, half ballast (27,000 lbs/120 kN) and full ballast (54,000 lbs/240 kN). The skid weighs approximately 20 tons (178 kN).

4.0 Design Criteria Compliance

4.1 National Electrical Code Compliance

Since the waste tank gas contains flammable constituents, the environment inside the tank, above the convective layers is considered a Class I, Division I hazardous location. Since the flammable gas of concern is primarily hydrogen, this was designated as a Group B location. Consequently electrical equipment and devices used in areas of the instruments which are directly exposed to the tank atmosphere during normal operation as well as any other devices connected or coupled to the same wiring were designed to conform to the National Fire Protection Association (NFPA) requirement for service in Class I, Division 1, Group B hazardous location.

In essence, the cone penetrometer is enclosed in an explosion proof enclosure. Equipment which could not fit in the enclosure was made intrinsically safe by use of barriers and special conduits. Figure 6 shows the general layout of the intrinsically safe equipment and explosion proof enclosure. Electrical equipment 36 inch (91.4 cm) away from the hydraulically driven guide tube were made intrinsically safe per WHC-SD-WM-DGS-005. A detailed discussion of the NFPA classification as related to the cone penetrometer may be found in WHC-SD-WM-DA-201.

4.2 Static Sparking Control

The skid and all auxiliary equipment is bonded (metal to metal connection) to the tank during operation of the cone penetrometer. Grounding is per NFPA 70. WHC-SD-WM-TI-568 Rev 1 outlines grounding and bonding requirements for electrical and non-electrical installation at Hanford tank farms.

4.3 Material Compliance

All material used in the tank or exposed to the tank environment meets the material requirements (see Appendix B).

The components located outside of the tank on the surface level have been designed for ease of maintenance and will not be exposed to the tank corrosive atmosphere or radiation fields and are therefore suitable for use.

4.4 Structural Compliance

The cone penetrometer was analyzed for various design loadings, including riser effects and a design analysis was issued in WHC-SD-WM-DA-212. The analysis conclude that the cone penetrometer posed no structural threat to the tank, other than dropped from an excessive height, which is addressed in the Safety Analysis Document.

A seismic analysis has been completed on the skid (see ETS-W-96-849). The system has been modified to the analysis recommendations. The maximum acceptable length of the hydraulic jack piston rods is 42 inches (1 m).

4.5 Control Requirement Compliance

Successful completion of the software ATP verified the control system meet all the necessary requirements.

5.0 Operation

5.1 Installation

The operation and maintenance manual has been prepared to fully describe the steps required to install the cone penetrometer onto a tank. Appendix C contains an outline of the installation, operation and removal of the skid mounted cone penetrometer.

5.2 Deployment

Figure 2 shows the penetrometer as it samples the tank waste. As the penetrometer penetrates the tank waste, measurements are taken of the physical and chemical properties. The push rod penetrates the waste at 0.8 inch/sec (2 cm/sec) with interruptions to add additional 3 meter length of push rod. The raman spectroscopy sensor takes three 15 second exposures during the 0.8 inch/sec (2 cm/sec) push. During installation of the rods, one 60 second exposures is taken. The rods are 1 meter long. Once the rod is within 1 feet (30.4 cm) of the bottom of the tank, several controls are put into place. The bottom detection system is turned on and the tank bottom push envelope is used to protect the tank bottom. Once the penetration is complete, the cables leading to the sensors are disconnected to allow for a 1.00 inch (2.5 cm) diameter space. The moisture probe is lowered into the rod space. The winch/data acquisition system is programmed to automatically take reading every inch to 10 to 50 seconds through waste thickness. Moisture and temperature data are plotted. A second set of moisture measurements is taken, if data is not satisfactory. The data for is archived for further analysis and historical data.

5.3 Water Addition

The push rod and guide tube are sprayed with water in the riser/decontamination adaptor during push rod and guide tube removal from the tank. Water is supplied to the adaptor by a decontamination unit located on the support trailer. The unit has a capacity of delivering 120 gallons (454.2 L) to the tank.

5.4 Field Operation

Operation of the cone penetrometer system will be in accordance with the O&M manual. ARA will deliver to WHC the O&M manual at a TBD date. The system will not run outside the procedure or envelope outlined in this plan.

5.5 Decontamination and Removal

Decontamination and removal of the system is in accordance with the procedures outline in the O&M manual. Permanent disposal of contaminated rods/guide tubes is not expected to be necessary in the near future and has not been procedurally

addressed. A transport container will be designed for acceptance of the system at the Central Waste Complex in the event of the rods or guide tubes become unusable.

6.0 Maintenance

Troubleshooting and maintenance of the system will be discussed in detail in the O&M manual. ARA will deliver to WHC the O&M manual at a TBD date.

7.0 References

ARA Documents

- ARA/Vertex Drawing H062-7A, "Rack, Data Acquisition ASM"
- ARA/Vertex Drawing H138-3A, "Van Body ASM"
- ARA/Vertex Drawing H000-1A "Platform Top ASM"
- ARA/Vertex Drawing H059-3A, "Schematic, Electrical"
- Design Package #001, "Guide Tube and Push Rod Calculations"
- Design Package #002, "Heating and Cooling Calculations"
- Design Package #003, "Van Body Enclosure Specifications"
- Design Package #004, "Push System Components"
- Design Package #005a, "Hydraulic Schematic and Component List"
- Design Package #005b, "Hydraulic Schematic and Component List"
- Design Package #006, "Subframe"
- Design Package #007, "X-Y System"
- Design Package #008, "Information for Seismic Design"
- Design Package #009, "Support Trailer and Decontamination System Design"
- Design Package #010a, "CPT Probe Package"
- Design Package #010b, "CPT Probe Package - Electrical"
- Design Package #010c, "Side Temperature Button"
- Design Package #011, "CPT Data Acquisition Software Design Document"
- Design Package #012, "Ballast Design"
- Design Package #013, "Depth Transducers and Placement"
- Design Package #014, "Van Body Lighting Design"
- Design Package #015, "Work Bench on DAQ Side and Moisture Probe Storage"
- Design Package #016, "Roof Design"
- Design Package #017, "Pick-up Cradle for Lifting the Skid"
- Design Package #018, "Guide Tube Foot Assembly"
- Design Package #019, "Mechanical Clamps"

- Design Package #020, "Foot Pads"
- Design Package #021, "Software Safety Systems"
- Design Package #022, "Guide Tube Collet, Guide Tube and Rods"
- Design Package #023, "Subframe modifications for Ballast hanging"
- Design Package #024, "Stairs and Railings"
- Development of Correlations between Cone Penetrometer Testing
- W.L. Bratton, M. Gildea, D.E. Chitty and S.P. Farrington, ARA Report No. 5968-1, "Development of Correlations between Cone Penetration Testing Results and Physical Properties for Hanford Sludge Simulant Materials"
- W. Bratton, D.E. Chitty, S.P. Farrington, ARA Report No. 5968-2, "Results and Physical and Mechanical Properties for Hanford Saltcake Simulant Materials"
- W.L. Bratton, D.J. Rooney and R. Hull, ARA Report No. 5968-3, "Development of Bottom Detecting Unit for Hanford Tank Farm CPT Work"

LLNL Document

- Raman Probe Optical Elements Layout

SAIC Document

- SAIC 544001, "Cone Penetrometer Moisture Probe System"

WHC Documents

- WHC-SD-WM-ETP-017, "Engineering Task Plan for Support of the Cone Penetrometer for In Situ Waste Characterization", Rev 1
- WHC-S-0241, Rev 2, "Specification for Enhanced Cone Penetrometer System"
- WHC-SD-WM-FDC-047, Rev 1, "Functional Design Criteria Cone Penetrometer Moisture Sensor"
- WHC-SD-WM-SDD-062, Rev 0, "Cone Penetrometer Moisture Probe System Design Description"
- WHC-SD-WM-ATR-146 Rev 0, "Cone Penetrometer Moisture Probe Acceptance Test Report"
- WHC-SD-WM-DA-201, "National Standards and Code Compliance for Electrical Equipment and Instrument Installed in Hazardous Locations for the Cone Penetrometer"
- ETS-W-96-849, "Cone Penetrometer Skid Seismic Analysis"
- WHC-SD-WM-DA-212, "Structural Analysis of Hanford Waste Storage Tanks Under Loads Imposed by Cone Penetrometer Waste Characterization Device"

- WHC-SD-WM-TI-568 Rev 1, "Grounding and Bonding Requirements for Portable Equipment in the Tank Farms."
- WHC-SD-WM-DQO-001, Rev 1, "Data Quality Objectives for Tank Farms Waste Compatibility Program"
- WHC-SD-WM-DQO-004, Rev2, "Flammable Gas Tank Safety Program: Data Requirements for Core Sample Analysis Developed Through the Data Quality Objectives Process"
- WHC-SD-WM-SP-004, Rev 2, "Tank Safety Screening Data Quality Objective"
- WHC-SD-WM-DQO-006, Rev 0, "Data Quality Objective to Support Resolution of the Organic Fuel Rich Safety Issue"
- WHC-SD-WM-DQO-007, Rev 2, "Data Requirements for the Ferrocyanide Safety Issue Developed through the Data Quality Objectives Process"
- WHC-SD-WM-DQO-008, Rev 0, "Characterization Data Needs for Development, Design, and Operation of Retrieval Equipment Developed through the Data Quality Objective Process"
- WHC-SD-WM-DQO-018, Rev 0, "Historical Model Evaluation Data Requirements"
- WHC-SD-WM-DQO-022, Rev 2, "Data Needs and Attendant Data Quality Objectives for Tank Waste Pretreatment and Disposal"
- WHC-SD-WM-ER-523, Rev 0, "Engineering Report Cone Penetrometer Simulant Test Results and Recommendations"
- WHC-SD-WM-DGS-005 Rev 0, "Equipment Design Guidance Document for Flammable Gas Waste Storage Tank Equipment"
- WHC-SD-WM-ATP-151 Rev. 0, "Cone Penetrometer Acceptance Test Procedure"

Appendix A: Control Logic Table

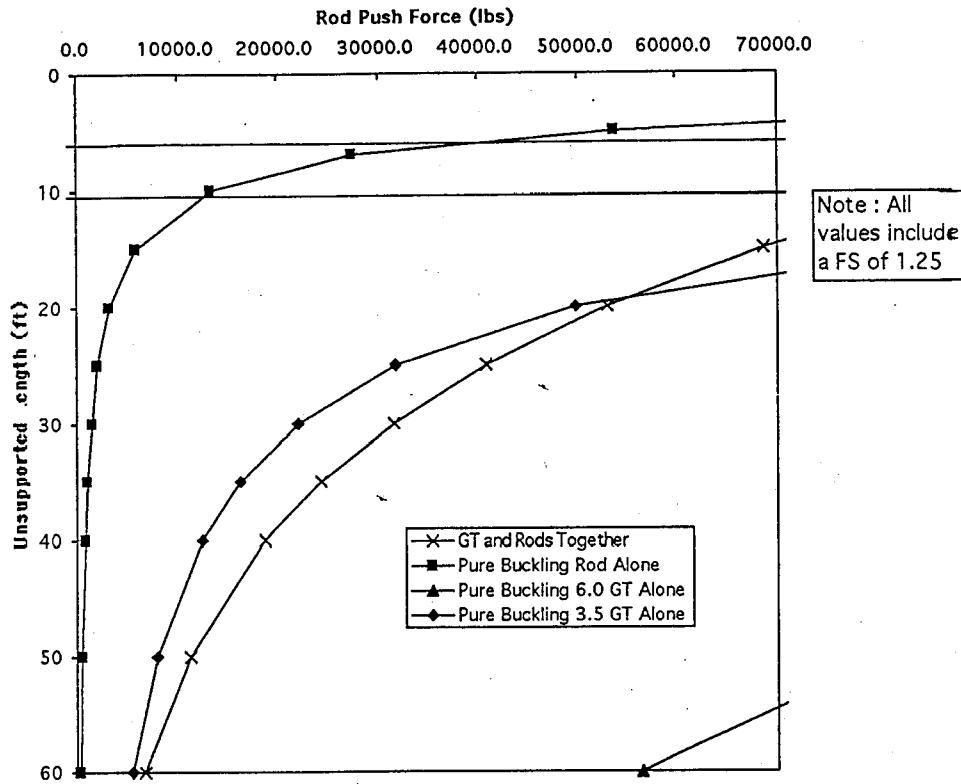
Limit	Action
Tip temperature = 165 °F (74 °C)	<ul style="list-style-type: none"> ● Sound approach alarm ● Data acquisition computer signals to operator
Tip temperature > 180 °F (82 °C)	<ul style="list-style-type: none"> ● Signal to initiate shutdown ● Sound threshold alarm ● Shutdown ● Data acquisition computer signal to operator
Side temperature = 165 °F (74 °C)	<ul style="list-style-type: none"> ● Sound approach alarm ● Data acquisition computer signals to operator
Side temperature > 180 °F (82 °C)	<ul style="list-style-type: none"> ● Signal to initiate shutdown ● Sound threshold alarm ● Shutdown ● Data acquisition computer signal to operator
Cone inclinations = 2°	<ul style="list-style-type: none"> ● Sound approach alarm ● Data acquisition computer signals to operator
Cone inclination > 3°	<ul style="list-style-type: none"> ● Signal to initiate shutdown ● Sound threshold alarm ● Shutdown ● Data acquisition computer signals to operator
Bottom detection system 1 activated (detects ferrous materials approximately 6 inches away)	<ul style="list-style-type: none"> ● Signal to initiate shutdown ● Sound threshold alarm ● Shutdown ● Data acquisition computer signals to operator

Limit	Action
Bottom detection system 2 activated (Bottom tip stress profiles)	<ul style="list-style-type: none"> ● Signal to initiate shutdown ● Sound threshold alarm ● Shutdown ● Data acquisition computer signals to operator
Rod Push force = .80 (Buckling profile)	<ul style="list-style-type: none"> ● Sound approach alarm ● Data acquisition computer signals to operator
Push rod force > .90 (Buckling profile)	<ul style="list-style-type: none"> ● Signal to initiate shutdown ● Sound threshold alarm ● Shutdown ● Data acquisition computer signals to operator
Guide tube push force = .80 (Buckling profile)	<ul style="list-style-type: none"> ● Sound approach alarm ● Data acquisition computer signals to operator
Guide tube push force > .90 (Buckling profile)	<ul style="list-style-type: none"> ● Signal to initiate shutdown ● Sound threshold alarm ● Shutdown ● Data acquisition computer signals to operator
Push rod force > 30 tons (267 kN) (hardwired pressure switch)	<ul style="list-style-type: none"> ● Sound threshold alarm ● Initiate shutdown ● Shutdown
Guide tube force > 20 tons (267 kN) (hardwired pressure switch)	<ul style="list-style-type: none"> ● Sound threshold alarm ● Initiate shutdown ● Shutdown
Decontamination tank temperature < 130 °F(54.4 °C)	<ul style="list-style-type: none"> ● Light indicator lights
Decontamination tank level < 25 gallons (94.6 L)	<ul style="list-style-type: none"> ● Light indicator lights
Hydraulic fluid temperature > 150 °F (65.6 °C)	<ul style="list-style-type: none"> ● Light indicator lights

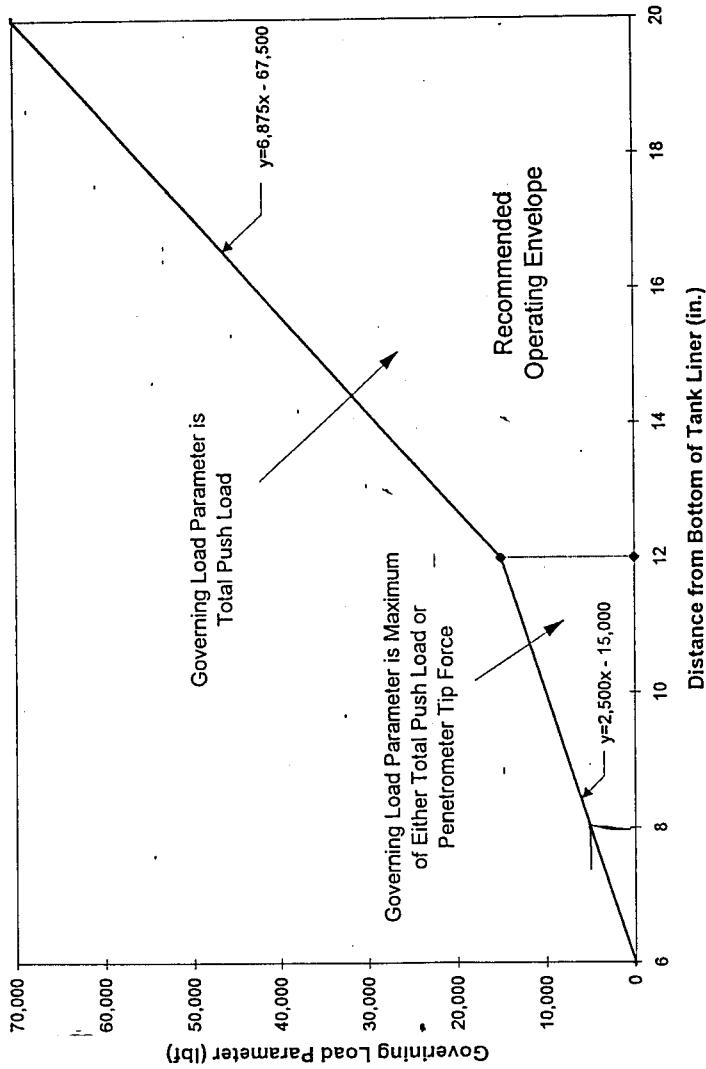
Limit	Action
Hydraulic fluid level < 100 gallons (378.5 L)	<ul style="list-style-type: none"> •Light indicator lights
Skid inclination = 4°	<ul style="list-style-type: none"> •Sound approach alarm •Data acquisition computer signals to operator
Skid inclination > 5°	<ul style="list-style-type: none"> •Sound threshold alarm •Initiate shutdown •Shutdown
Total Pull Force = .80 (Operator Input Dome Load)	<ul style="list-style-type: none"> •Sound approach alarm •Data acquisition computer signals to operator
Total Pull Force > .90 (Operator Input Dome Load)	<ul style="list-style-type: none"> •Signal to initiate shutdown •Sound threshold alarm •Shutdown •Data acquisition computer signals to operator
Loss of power (any loss of 110 VAC)	<ul style="list-style-type: none"> •Emergency lights and alarm •Shutdown
Emergency shutdown palm button activated (Inside/Outside Control Room)	<ul style="list-style-type: none"> •Sound threshold alarm •Initiate shutdown •Shutdown

Shutdown:

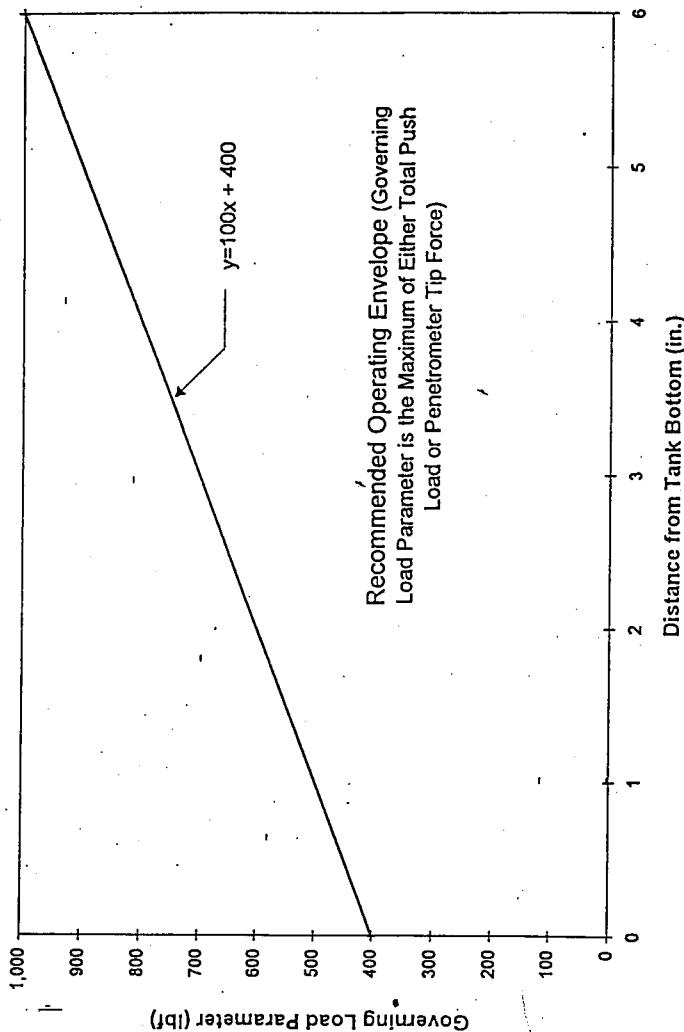
- Close rod safety valve (2)
- Close guide tube safety valve(2)
- Close rod reducing valve (relieve hydraulic pressure to tank)
- Close guide tube reducing valve (relieve hydraulic pressure to tank)
- Close rod proportional valve
- Close guide tube proportional valve
- Lights relay indicator light (system must be reset for operation to continue)



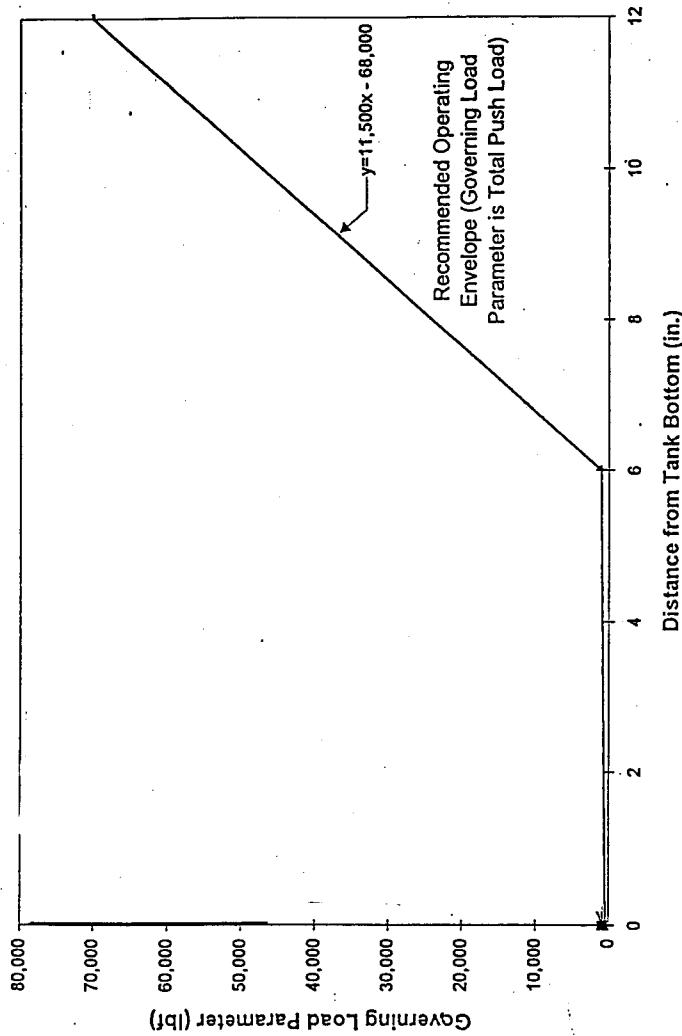
Buckling Profiles

Detail View of Recommended Operating Envelope for Deployment of Cone Penetrometer in
Single-Shell Tanks.

Detail View of Recommended Operating Envelope for Deployment of Cone Penetrometer in Double-Shell Tanks When the Distance from the Primary Tank Bottom is 6 in. or Less.



Recommended Operating Envelope for Deployment of Cone Penetrometer in Double-Shell Tanks.



Appendix B: Waste Compatibility

Introduction:

The purpose of this appendix is to estimate the resistance (compatibility) of the construction materials which are in contact with the tank waste or potentially in contact with the waste. The equipment in contact with the waste must survive the following conditions.

pH: 10-14

Temperature Range: -40 - 212 °F (-40 - 100 °C)

Radiation Levels: 0-900 Rad/hr (Total 3.024×10^5 Rad)

A period of 2 weeks (336 hours) is the total design life of equipment inside the tank environment. Sensor package performance in these conditions covered in the acceptance test (see WHC-SD-WM-ATR-151).

Cone Penetrometer Construction Materials:

The cone penetrometer is a hydraulically driven instrumented rod which is pushed into the waste and measures physical and chemical data. The rod is supported by a guide tube which provides structural support to the rod. The rod is assembled by screwing hollowed rod sections into the instrumented tip as the rod pushes and penetrates the waste. The sensor package, as shown in Figure 1, measures physical properties, chemical species and moisture. Table B1 outlines the components and construction materials in direct contact with the waste or potentially in contact with the waste.

Table B1: Components in Contact with the Waste

Component	Construction Material
Push Rod	4130 Viton Seal
Guide Tube	4130 4340 Viton Seal Neoprene Seal Stainless Steel
2.0 cone/1.75 rod Adaptor	4340

Component	Construction Material
Probe	
Mandrel	4340
Sleeve, Load Cell	4340
Sleeve, Friction	4340
Ring Retainer	4340
Housing Insert, Tip	4340
Filter, piezo	Polyethylene, 250 um
HSG, piezo gage	4340
Mud Block	Viton Seal
Water Seal	Viton Seal
Side thermistor	416 stainless steel
Tip	Hydlar (Kevlar) Titanium (Ti-6A14V) or Ceramic Silicon Nitride ($Si_3 N_4$)
Spray Washer/Riser Adapter	A36 Steel
Raman Spectroscopy	
Body	Stainless steel 420
Window	Sapphire, Silver Indium Solder
Hydraulic Clamps	A36 Steel

Chemical Compatibility:

The primary components of the tanks were assumed to be $NaNO_3$ and $NaNO_2$. Minor components of the waste are 1 M NaOH (approximately 4%). An evaluation on the effects of various chemicals on the construction materials was completed using literature information. The literature search includes information on corrosion rates or resistance of these construction materials in saturated concentration or at the indicated levels of $NaOH$, $NaNO_3$ and $NaNO_2$. Table B2 and B3 shows the different materials properties.

Table B2: Metal Material Properties

Material	Sodium Hydroxide	Sodium Nitrate	Sodium Nitrite
Carbon Steel	G < 210 °F (99°C)	G < 150 °F(66°C)	G < 100 °F(38 °C)
Titanium	E < 210 °F(99°C)	E < 90 °F (32 °C)	E < 210 °F(99°C)

Legend: E < 2 mils per year G < 20 mil/yr S < 50 mil/yr U Unsatisfactory

Table B3: Non-Metal Material Properties

Material	Sodium Hydroxide (NaOH)	Sodium Nitrate (NaNO ₃)	Sodium Nitrite (NaNO ₂)	Radiation	Temperature
Neoprene (Chloroprene)	R < 210 °F@10% (R < 71 °C)	R < 190 °F@Sat (R < 88 °C)	R < 150 °F@Sat (R < 66 °C)	10 ⁷	-67 -284 °F (-55 - 140 °C)
	M > 210 °F@10% (M > 71 °C)	M > 190 °F@Sat (M > 88 °C)	M > 150 °F@Sat (M > 66 °C)		
Polyethylene	R < 150 °F@Sat (R < 66 °C)	R < 140 °F@Sat (R < 60 °C)	R < 150 °F@Sat (R < 66 °C)	3.8 x 10 ³	14-230 °F (-10 -110 °C)
	R < 200 °F@10% (R < 93 °C)	R < 90 °F@Sat (R < 32 °C)	--	8.6 x 10 ⁵	Resistant to 340°F (171 °C)
Hydral (Kevlar)	R < 200 °F@Sat (R < 93 °C)	R < 300 °F@Sat (R < 149 °C)	R < 250 °F@Sat (R < 121 °C)	9.5 x 10 ⁸	Resistant to 400°F(204 °C)
	R < 100 °F@15% - 30% (R < 38 °C)	R < 212 °F@Sat (R < 100 °C)	R < 210 °F@Sat (R < 99 °C)	1 x 10 ⁶	Resistant to 437 °F(225°C)
Epoxy	M > 100 °F@15% - 30% (M > 38 °C)	M > 212 °F@Sat (M > 100 °C)	M > 210 °F@Sat (M > 99 °C)		
	R < 3000 °F@Sat (R < 1650 °C)	R < 3000 °F @Sat (R < 1650 °C)	R < 3000 °F @Sat (R < 1650 °C)	--	--

Legend:

R: Resistant

U: Unsatisfactory

M: Moderate Effects

Raman Spectroscopy Testing

The Raman spectroscopy assembly and associated optics were tested for 17 days in a simulant in the PNNL gamma ray pit. The total radiation dose over this period was 350,000 Rad. The key components of the simulant were 4 M NaOH, 2 M NaNO₃, and 4 M NaNO₂, represent the most reactive components of the tank matrix. The effects of radiation on the optics, sapphire window and metal braze material were also investigated.

The quartz optical components exhibited no optical darkening. BK-7 based optics darkened in the visible, but darkening was negligible in the near infrared. The sapphire window was completely untouched by the extended exposure to both radiation and caustic chemicals. The integrity of the indium silver braze had apparently been compromised as evidenced by the presence of a pinhole through the braze which allowed solution to leak within the probe. An investigation to the origin of the pinhole was undertaken at LLNL. ICP/MS and ICP/AES detected 200 nanogram of Indium per gram of solution. This translated to approximately 0.05 mg of dissolved Indium, which represents 0.2% of the total weight of the Indium in the window braze. This amount is less than would be required to form the pinhole through the braze. Assuming uniform dissolution of the surface area of the braze, only 0.25% of the total depth of the braze had been etched away over 17 days. This amount translates to 0.015% per day, or 0.001% per 2 hour penetrometer push event during actual deployment. These calculations, coupled with the fact that the test solution was much more corrosive than the actual tank environment, have lead to the conclusion that the attack on the braze is not an issue of concern.

Previous testing of the fiber optic cable also indicates that radiation exposure is not a concern. The fiber optic were tested to 532.5 KRad of exposure with a resulting 21% maximum signal loss.

Discussion:

The cone penetrometer was evaluated for chemical, temperature and radiation resistance. The assumptions were that the construction materials receive a 3.024×10^5 Rad exposure at temperature ranges between 40 - 212 °F (-40 - 100 °C) and the materials are exposed to primarily NaNO₃ and NaNO₂. NaOH is a minor chemical component of the waste.

In order to evaluate the cone penetrometer, test data, prior tank usage history and literature information was obtained. The Raman spectroscopy sensor passed testing in a simulant composed of NaOH, NaNO₃, and NaNO₂ at a total exposure of 350,000 Rad. Materials such as neoprene and viton have been previously used successfully in other tank systems such as the core sampling system and the cross transfer lines. The effects on steel are also less than the pure solutions of

chemicals chosen to encompass tank waste. Sodium nitrite significantly inhibits the corrosiveness of sodium nitrate on carbon steel.

The cone penetrometer is exposed to tank environment for a short period of time in waste. Carbon steel, titanium (in non-flammable gas tanks) and silicon nitrite ceramic (in flammable gas tanks) is acceptable for tank usage. For non-metal materials, neoprene and viton resist the tank environment. The resistance to tank environment can be drawn from experience from other system currently in the tank, such as the core sample truck and the cross transfer lines. These seals are waste compatible. Other consideration in evaluating materials is the function of part. The polyethylene filter performs well in saturated solutions of NaOH, NaNO₃, and NaNO₂ up to 150 °F (38 °C), but softens after this temperature. The part is used to access the pore pressure (as a filter), so if it softens, the part can still perform its function. The kevlar button used on the cone penetrometer tip was the only part which requires further testing to verify that it is compatible with the waste.

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R.V. Brink, 1993 Handbook of Fluid Sealing, McGraw Hill Inc, New York.

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Appendix C: Cone Penetrometer Installation, Operation and Removal

1. Riser preparation

This is a routine activity performed prior to the installation of the cone penetrometer to verify riser availability and to ensure that there are not obstructions for installation and operation of the cone penetrometer. This inspection will provide the following detailed information:

- * Zip cord measurements to provide distance from top of the riser to waste surface and riser length measurements.
- * Video camera footage to provide a view of the inside of the tank and in particular, the waste surface below the riser.
- * For 4 inch (10.2 cm) risers, the riser will be measured for diameter, ovality and straightness of the riser.

2. Positioning and set-up of skid

- * Install riser adapter and decontamination unit.
- * Unload skid off lowboy transport.
- * Place skid over riser using crane (legs fully extended).
- * Ground all equipment.
- * Position support trailer (off the tank, when possible) and connect to skid. This includes decontamination water, hydraulic lines, electrical power and signal cables.
- * Level skid.
- * Position X-Y to within +0.25 inch (0.6 cm) of riser center.
- * Ballast as required.
- * Re-level skid, if needed.

3. Installation of guide tube and push rod

- * Assemble guide tube to length required to reach top of waste.
- * Lower guide tube in place with crane. Secure guide tube with clamps.
- * Assemble push rod and begin cone penetrometer push (about 4 feet (1.2 m) into the waste).

- * Push guide tube so that it seats into the hard waste (about 2-6 inches into the waste). The guide tube will be assembled only if a hard push is required.
- * Continue cone penetrometer push.

4. Physical properties and Raman spectroscopy test run

- * Push cone penetrometer into waste.
- * Data acquisition system collects data (Raman spectroscopy and physical properties) during push.
- * Data acquisition system monitors all safety conditions.
- * Reach end condition (tank bottom).
- * Disconnect electrical cable and fiber optic cable from probe.

5. Moisture probe test run

- * Load moisture sensor source in probe housing.
- * Calibrate moisture probe in calibration block.
- * Position moisture probe over push rod.
- * Lower moisture sensor in push rod and take moisture/temperature readings.
- * Retract moisture sensor. Remove source and store moisture probe.

6. Equipment removal

- * Start decontamination system.
- * Attach coupler - allow crane to lift both rod and guide tube at the same time. Decontaminate equipment.
- * Cover with plastic containment sleeve and monitor radiation levels using standard tank farm techniques while removing from the riser. Guide tube and push rod will be broken down such that the push rod or guide tube sections in contact with waste are disposed.
- * Seal riser.
- * Remove trailer and skid, in reverse of installation.
- * Remove unit to lowboy for transport.

7. Test Completion

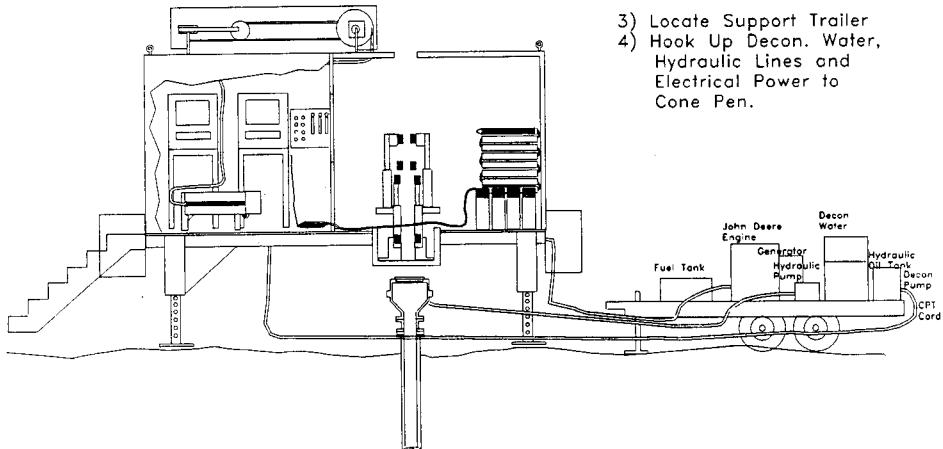
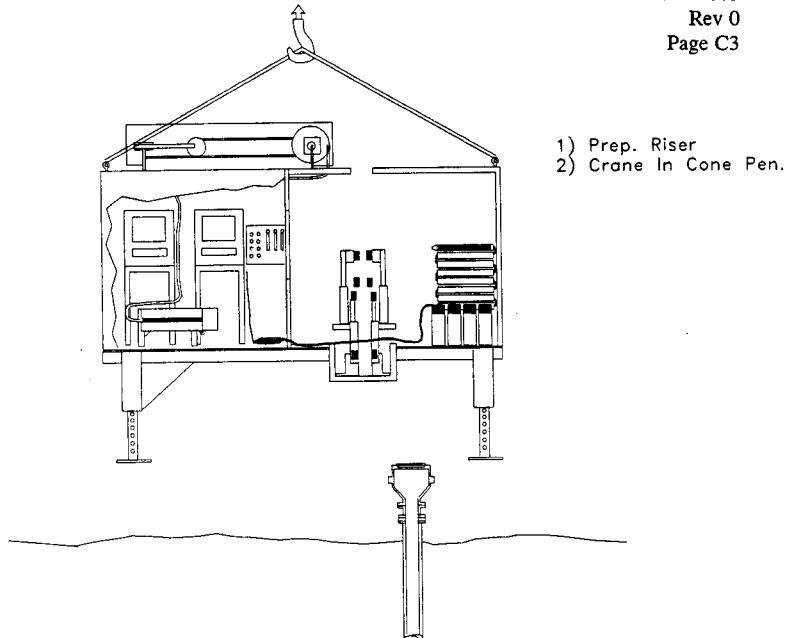
- * Analyze Data.
- * Prepare report.
- * Prepare workplan for next location.

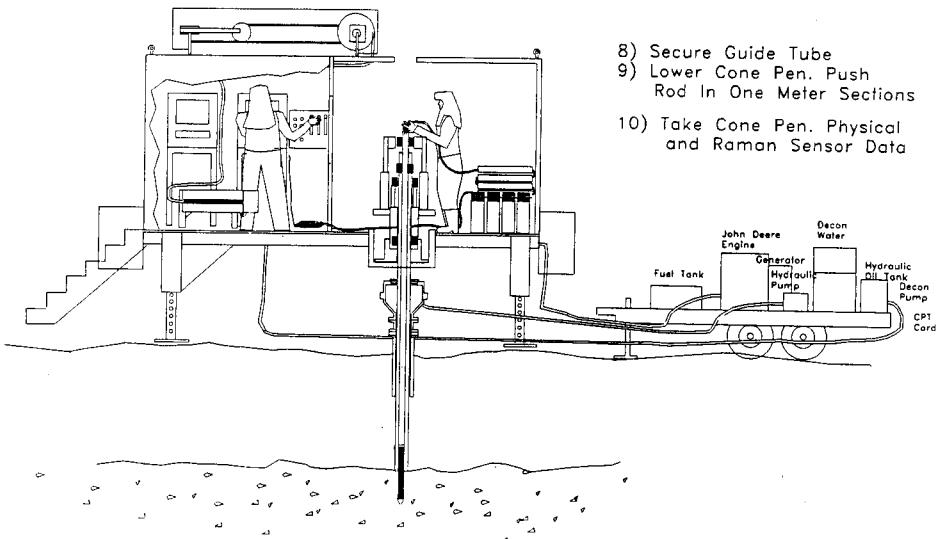
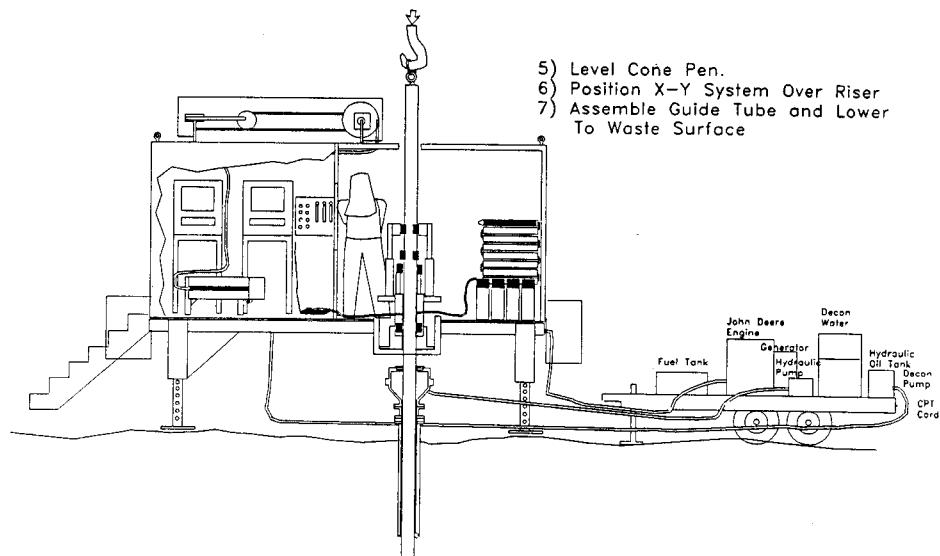
CONE PENETROMETER OPERATIONAL SEQUENCE

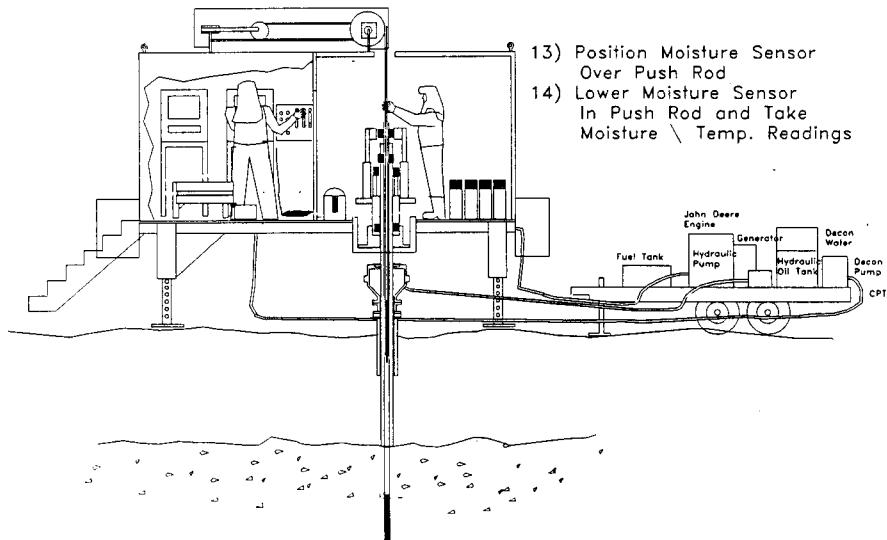
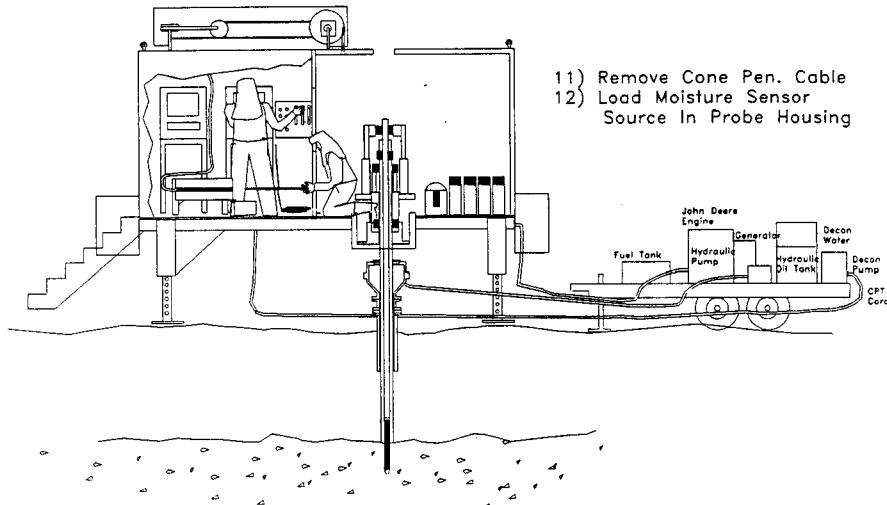
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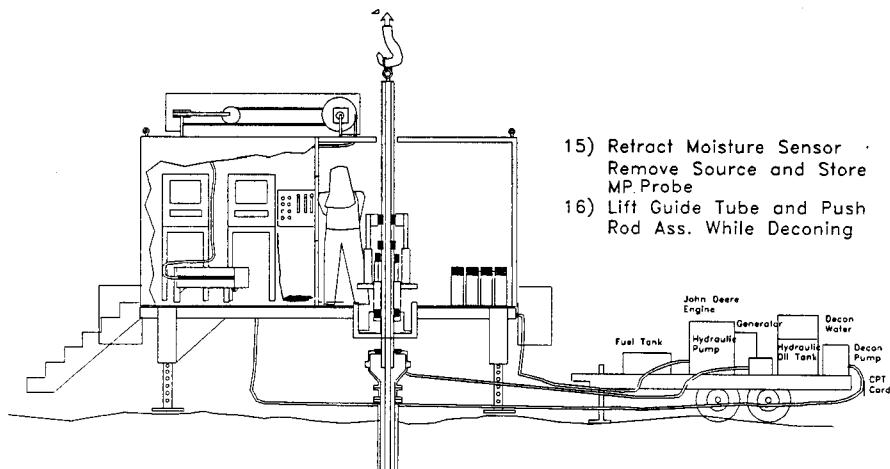
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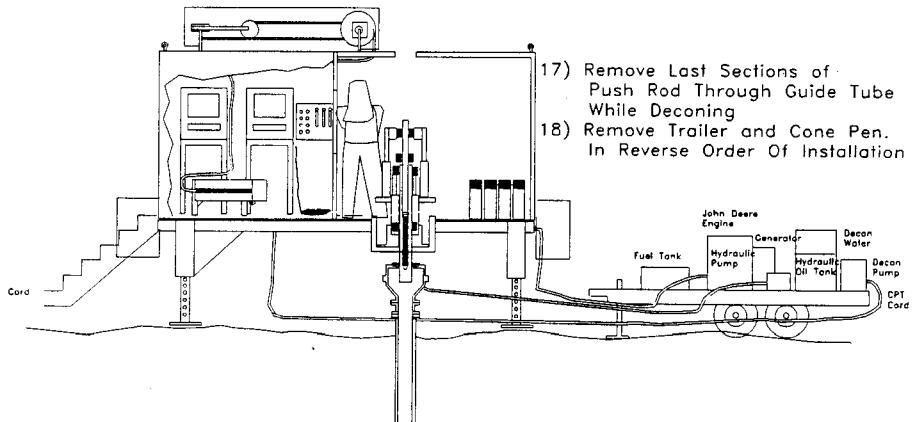








- 15) Retract Moisture Sensor
Remove Source and Store
MP. Probe
- 16) Lift Guide Tube and Push
Rod Ass. While Deconing



- 17) Remove Last Sections of
Push Rod Through Guide Tube
While Deconing
- 18) Remove Trailer and Cone Pen.
In Reverse Order Of Installation

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Appendix D: Figures

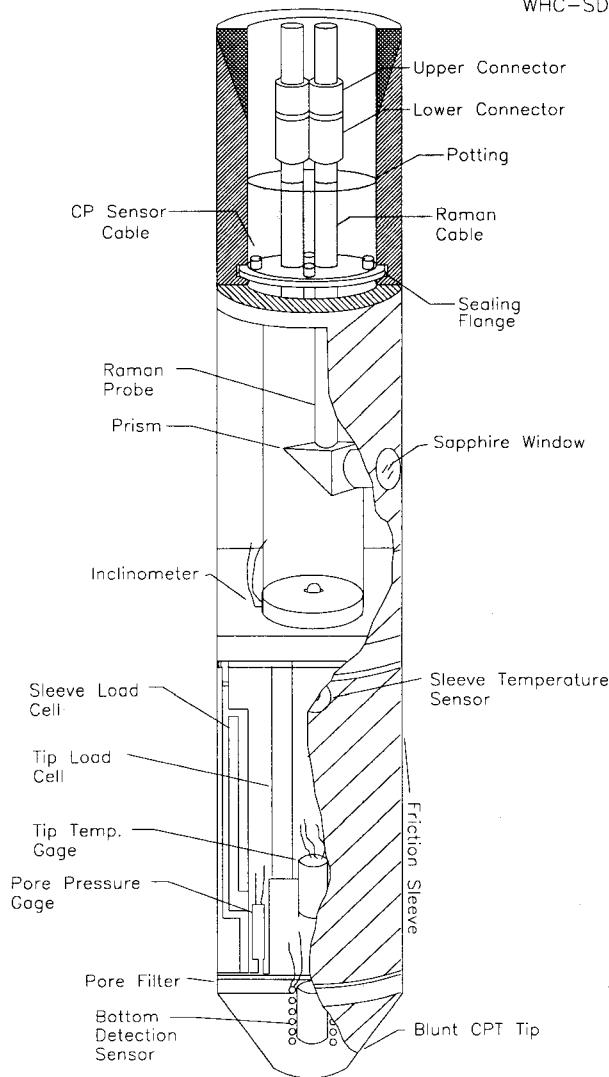


Figure 1: Sensor Package

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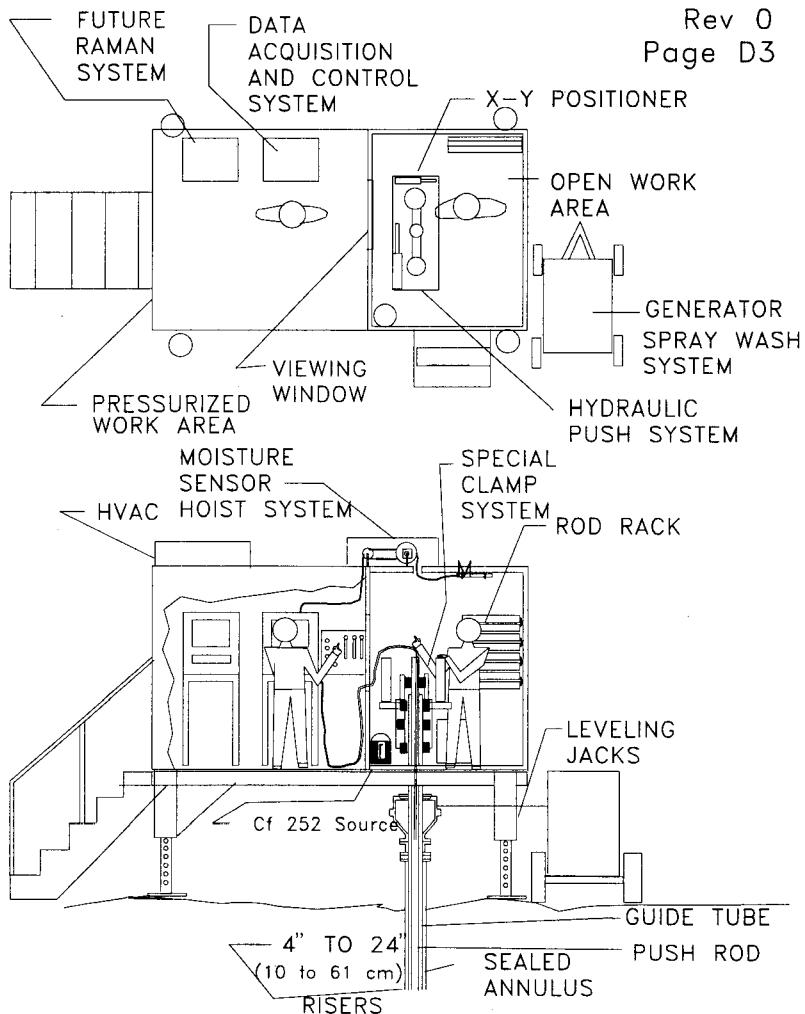


Figure 2: Conceptual Layout

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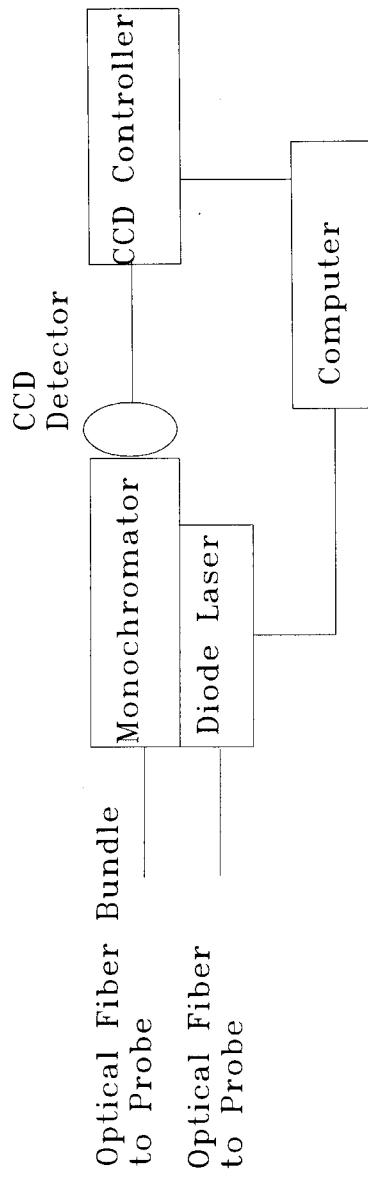


Figure 3: Raman Spectroscopy System

Data Acquisition System

Sensors

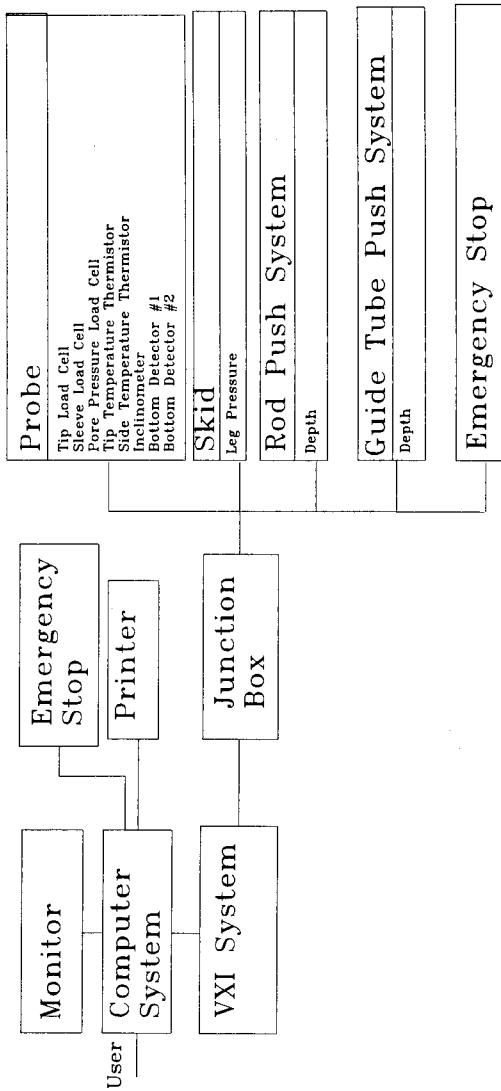


Figure 4: Data Acquisition System

Control Stand

Operation Status Panel

Generator Status Panel

Joystick

Sensors

Decontamination Water System

Water Temperature
Water Level

Hydraulic System

Hydraulic Oil Temperature
Hydraulic Oil Level
RFM

Generator/Engine

Low Fuel

Skid

Tilt Meter
Emergency Stop

Rod Push System

Clamp A Open/Closed
Clamp B Open/Closed
Clamp A Pressure
Push Pressure

Guide Tube Push System

Clamp C Open/Closed
Clamp D Open/Closed
Clamp C Pressure
Push Pressure

Generator/Engine

Voltage
Amperage
Frequency
Oil Pressure
Water Temperature
Engine Amperage

Push Rod System

Valve Control

Guide Tube Push System

Valve Control

Emergency Stop

Figure 5: Control Stand

CONE PENETROMETER ASSEMBLY

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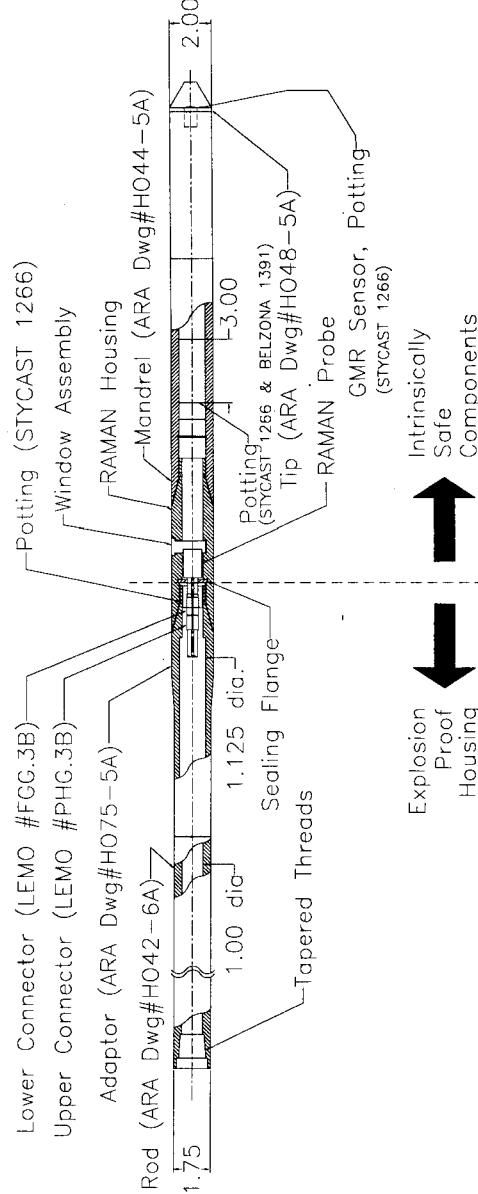


Figure 6: Sensor Package Layout

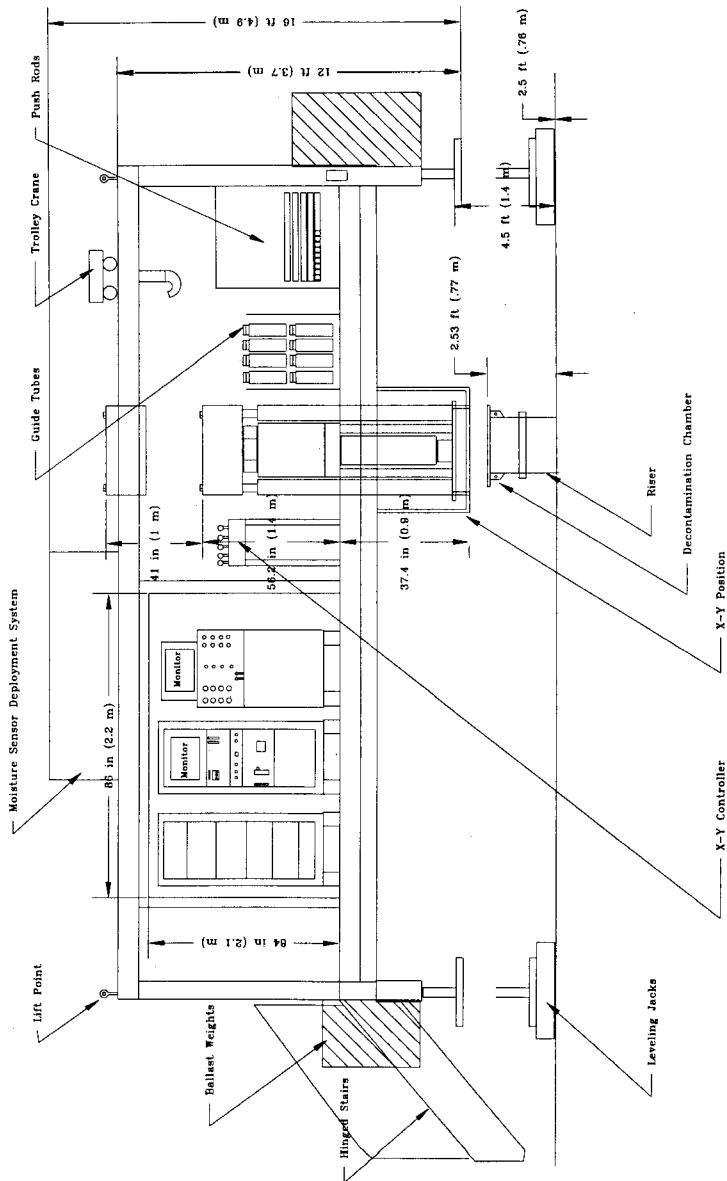


Figure 7: General Layout of Cone Penetrometer Platform (View 1)

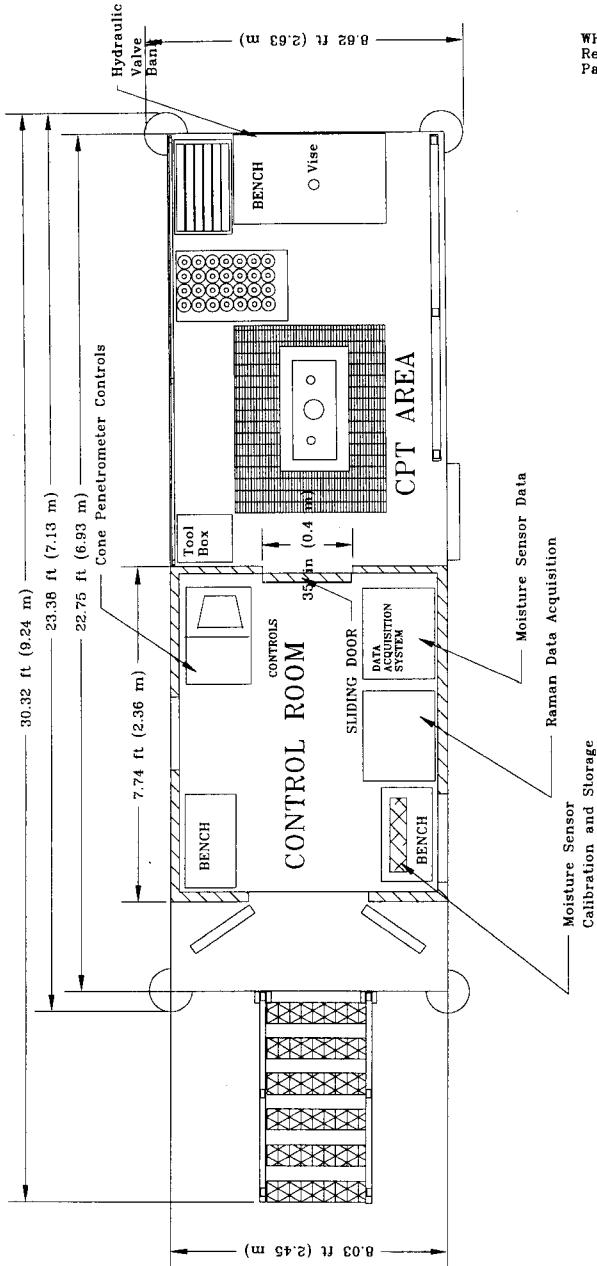


Figure 7: General Layout of Cone Penetrometer Platform (View 2)