GLOBAL POSITIONING SITE ENVIRONMENT EVALUATOR

Steve Leffler, Ph.D., Harold G. Reeser, and Ed Zaker
Sorrento Electronics
San Diego, California
Wayne Hansen, Ph.D.
Environmental Research Applications
Los Alamos National Laboratory
Los Alamos, New Mexico
Roy W. Sikorski
Motorola Inc.
Government Electronics Group
Scottsdale, Arizona

ABSTRACT

Development of an innovative, integrated, automated system (Global Positioning Site Environment Evaluator - GPSEE^{TM}) for surveying contaminated waste sites is described. This system makes novel use of the Global Positioning System (GPS) satellite constellation for establishing specific locations and current times for surveying radioactive, hazardous, or mixed-waste sites. GPSEE may also be used for waste site contamination surveys after remediation activities to ensure environmental remediation is complete. A base station is established for collecting and recording data and directing field operations for field stations which may be located many miles from the base station. The field operators collect site surveying and contamination data utilizing a variety of chemical and radiological sensors. A major goal for the data collection process is to collect all data utilizing in situ sensors, thereby minimizing the need for collecting soil and water samples. Site contamination data is transmitted electronically to the base station for recording and processing. The GPSEE system is being developed for use at DOE/DOD and a variety of industrial facilities.

INTRODUCTION

Environmental restoration of our contaminated land, lakes, and rivers is both expensive and time consuming. Prior to initiating a restoration project, one must first decide what needs to be done and, second, how the restoration is to be performed. This paper deals with the first part of the remediation process: What needs to be done?

Currently, waste site assessments are performed by collecting multiple surface and subsurface soil and water samples and sending the samples to a laboratory for evaluation. In some cases, the laboratory is moved to the field. This process has proven to be extremely expensive and time consuming. Further, the EPA has documented that an estimated 80% to 90% of the samples that are sent to the laboratory result in a non-detect finding; i.e., no contamination is present above normal background. This places an undue financial burden on the facility owner/operator who must pay for the assessment.

How can this be? How can our current site assessment processes be so obviously inefficient and expensive. We believe the primary reason is that sufficiently accurate sensing systems have not been available to permit on-site screening surveys to be performed.

The DOE, EPA, and other government agencies and private companies have recognized this problem, and more accurate sensing equipment is becoming available for field applications.

The Global Positioning Site Environment Evaluator (GPSEE^{TM}) takes the assessment process one step further. For GPSEE, the specific location and time of site contamination measurements is integrated into the data acquisition system. The specific location in international latitudinal and longitudinal coordinates is provided for each sensor reading. Therefore, the system combines contamination measurements from survey probes with exact topological measurements from global positioning satellite receivers to create a topographical survey of specific waste site contamination. Contamination and topological measurements are processed into a standard data base format for graphic imaging of any portion of the survey site, as well as specific report generation in support of any subsequent remediation investigation or follow-up that may be required. This system is expected to provide the capabilities to detect and locate various forms of contamination in a far more cost-effective and efficient manner than is currently available using existing positioning technology or processes.

SYSTEM DESCRIPTION

Sorrento Electronics (SE) has conceived an integrated, automated system (GPSEE) which may be used for waste site characterization activities. This system uses the Global Positioning System (GPS) satellite constellation for establishing specific locations in real-time for characterization of radioactive, other hazardous, or mixed nuclear-chemical waste sites. The GPSEE system takes advantage of recent improvements in the portability of gas chromatographs, mass spectrometers, and other chemical "sniffing" systems as well as SE's experience with radiation detection technology.

GPSEE consists of both a base station and a field survey station. A base station is established for collecting and recording data and directing field operations for field station(s) which may be located many miles from the base station. The field operator(s) collect site characterization data using a variety of interchangeable or multiple survey probes for radiological, chemical, or atmospheric measurement. A major goal for the data collection process is to collect all data using either in situ or survey type detector probes, thereby minimizing the need for collecting soil and water samples. The site characterization data, including exact position information and time, are transmitted to the base station for recording and processing. Figure 1 provides an illustration of the design concept.

The GPSEE system is being developed for use at DOE/DOD and industrial facilities which may be contaminated with radioactive, other hazardous, or mixed nuclear-chemical wastes. The GPSEE system can be used for waste site characterization surveys both before and after remediation activities. The system can also be used for long-term monitoring to assess contamination migration characteristics.

The GPSEE system provides the following principal benefits:

1. The need for collecting soil or water samples is minimized and even eliminated for many types of contamination.
2. The GPSEE system complies with EPA's proposed new policy which requires waste site characterization data to be traceable to specific latitude and longitude coordinates and time of data collection.
3. GPSEE will be designed to interface with the Geographic Information System (GIS).
4. The automated electronic system for collecting and recording data and reporting results is very flexible, efficient, and cost-effective.
5. The high efficiency of this system will result in a reduction in the man-hours needed, thereby reducing personnel exposure and costs.
6. Multiple field stations may be supported from a single

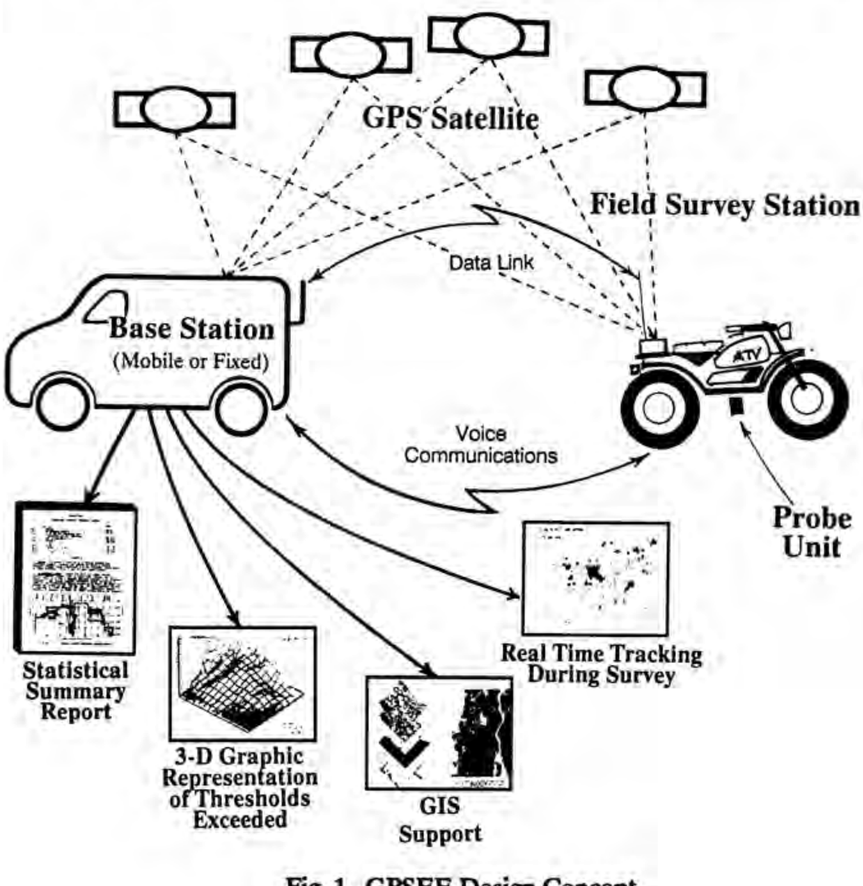

Fig. 1. GPSEE Design Concept.

base station.

7. Waste site characterization reports are automatically prepared, utilizing the expert system report generator, and are available with minimal compilation soon after field operations are complete.
8. Quality assurance and certification that the site has been restored.
9. Fast and self-contained system for quick radiological accident response.

DESIGN DESCRIPTION

The GPSEE system, as shown in Fig. 2, is composed of both a field survey station for the measurement and collection of site parameters and a base station for data management, analysis, and GPS real-time differential (RTD) reference. The field survey station consists of both a field control unit for data logging and detector control and a probe unit, as shown in Fig. 3, for measurement of environmental parameters. Both the field control unit and the base station contain GPS receivers, and the base station PC-386 controller performs the RTD correction.

Global Positioning System

When fully operational, the GPS is planned to include a constellation of 18 transmitting satellites and 3 in-orbit operational spare satellites in 12-hour orbits, which transmit spread spectrum signals that may be used for worldwide, all-weather navigation 24 hours a day. Two-dimensional, worldwide, 24-hour positioning is planned for the first quarter of 1991; and three-dimensional, worldwide, 24-hour positioning is planned for the first quarter of 1993. GPSEE computes position from measurements made by tracking the signals from four satellites and by decoding ephemeris data that is broadcast on the signals. One of the signals broadcast from the GPS satellites is known as C/A code and is intended to be the primary signal for civilian use. Another signal transmitted from GPS is known as P code and is up to ten times more accurate. Although the P code is presently public knowledge and can be used by civilian users, the U.S. Department of Defense intends this signal for primary military users only and has announced plans to change this code when the system becomes operational. At that time, only selected users with access to the new code will be able to use this signal for positioning.

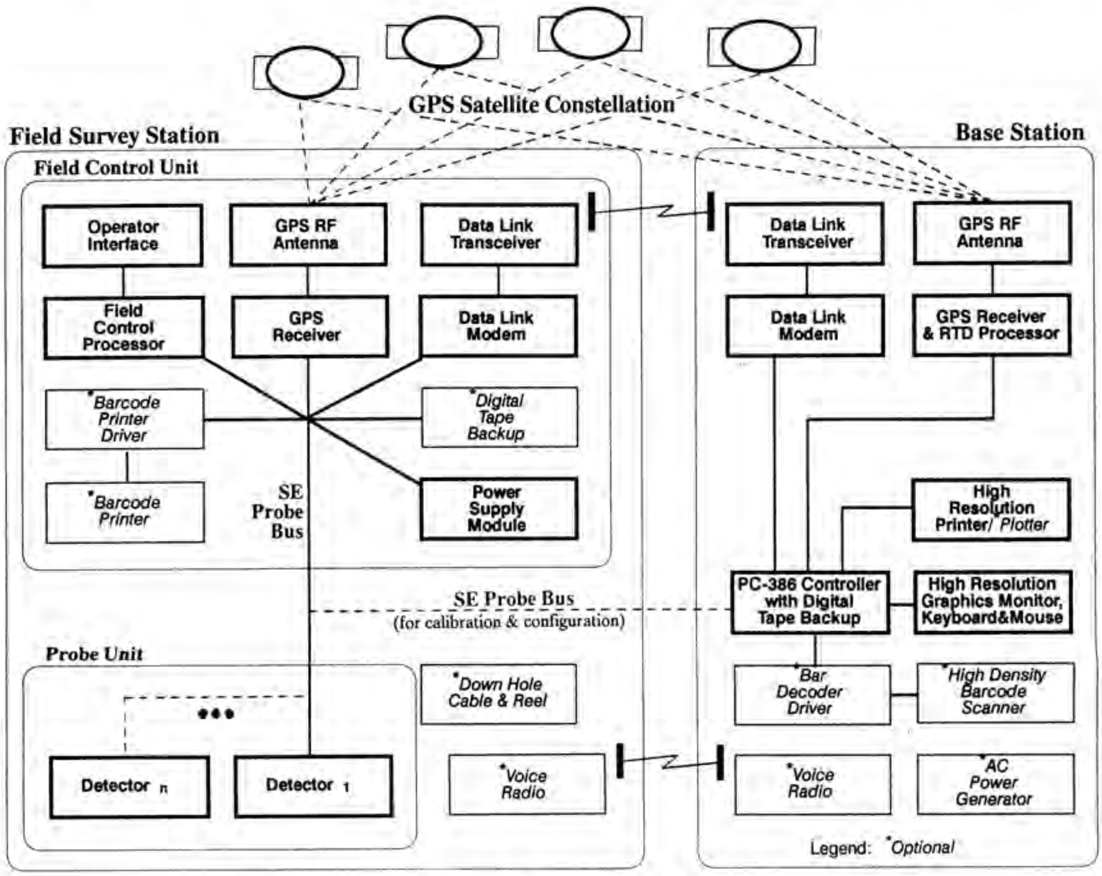

Fig. 2. GPSEE™ System Block Diagram.

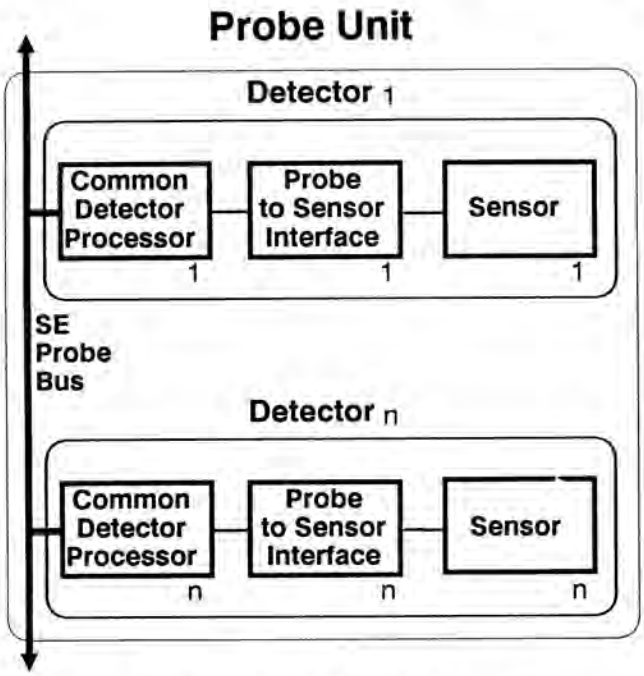

Fig. 3. Probe Unit Block Diagram.

Motorola EAGLE VIII RTD System

For GPS position and time measurements, GPSEE uses Motorola's EAGLE VIII RTD subsystem. The EAGLE VIII is a small, high-performance, eight-parallel channel L1 C/A code digital GPS core receiver. It provides less than 1 meter accurate static and dynamic position, speed and time once per second from the NAVSTAR GPS constellation. Its compact size (7 pounds) and low power consumption (25 W at 12 V) is very well suited to operation in remote areas.

The EAGLE VIII consists of a small antenna-preamp and lightweight receiver-processor. This digital GPS receiver tracks four satellites continuously and simultaneously from the GPS constellation, detecting both the code and carrier phase information from the satellites and deriving position and velocity estimates at a rate of one per second. Integrated tracking of both the carrier and the code is included to permit a very high level of precision to be achieved.

Standard software embedded in the EAGLE VIII provides for differential operation. Enhanced RTD operating mode accuracy is less than 1 meter SEP. Continuous carrier-lock is not required, and operation up to 20 miles from the reference receiver is possible with an appropriate data link transceiver and data link modem.

Differential Operation of GPS

The primary motivation for use of differential GPS is to reduce further the operational errors associated with positioning. By eliminating systematic errors that are common to multiple receivers, the position of one receiver relative to a receiver stationed at a known site can be established with far greater accuracy. Errors that contribute to the position error of one receiver relative to another in this mode of operation are the independent errors such as uncorrelated atmospheric and ionospheric refraction, geometry decorrelation effects, and receiver tracking errors. Satellite ephemeris errors and correlated ionospheric and tropospheric errors are eliminated with differential processing of data from two receivers.

Presently the GPS system will support a level of autonomous accuracy in the range of 10 to 15 meters. However, with denial of accuracy planned by the U.S. Government, this autonomous accuracy will be degraded to 100 meters. However, it is not anticipated that this degradation, which could include some distortion on the C/A code signal as well as the broadcast ephemeris, will significantly influence the accuracy of the Motorola receiver operation in the differential mode. It is clear that when the GPS constellation accuracy is degraded, the differential mode of operation will be imperative for many applications.

Field Control Unit

The field control unit is housed in a highly ruggedized, environmentally sealed box capable of being mounted on an all-terrain vehicle or carried in a backpack, providing mechanical support for the following nine modules: (1) an operator interface module, (2) a field control processor, (3) a GPS radio frequency antenna, (4) a GPS receiver, (5) a data link transceiver, (6) a data link modem, (7) a digital tape backup, (8) a power supply module, and (9) a barcode printer driver.

The operator interface module provides access to the probe unit and field control unit; e.g., alarm warnings, threshold settings, and measurement readings. The operator interface is a single board assembly containing (1) an LCD, (2) display drivers, (3) audio indicator combination alarm buzzer, (4) tone generator, (5) input switches, buttons, or key pad, and (6) debounce circuitry.

The field control processor coordinates the activities of the probe unit, GPS receiver, modem, backup, power supply, and barcode printer with the base station and operator interface. The field control processor is a single discrete PCB assembly containing (1) microcontroller with flash memory and A/D converter, (2) additional nonvolatile memory, and (3) various discrete support components.

The GPS receiver is Motorola's EAGLE VIII

RTD position processor.

The data link transceiver is a radio on VHF or UHF frequency for sending data and receiving acknowledgements to/from the base station. Every few seconds a burst of data, formatted by the radio frequency modem, is input to the radio for transmission to the base station. The modem handles all buffering and retransmission of data.

The digital tape backup is a streaming tape drive used for development, diagnostics, recording of measurement (as a run-time black box), and recording of field control unit states during the survey for traceability and verification. The digital tape backup has sufficient memory to store 40 megabytes of data (90 hours on four channels).

The power supply module provides power regulation and protects circuitry for both the probe unit and field control unit from battery; i.e., 12 V lead-acid or alkaline batteries. The power supply module is a single board assembly that contains a regulator and voltage and reverse-battery protect circuitry.

The barcode printer driver is an SE probe bus to straight RS-232 converter board, with ultrahigh density barcode generator.

Probe Unit

A GPSEE probe unit contains one or more radiological or hazardous waste sensors and associated electronics within a mechanically rugged package designed to be connected directly to the GPSEE Field Control Unit. Each sensor within a probe is controlled and interrogated by means of a Common Detector Processor (CDP) which is linked to the sensor by means of a Processor to Sensor Interface (PSI) unit. The CDP is a "smart" microcontroller device which is dedicated to the operation and data processing requirements of a specific sensor. It can accept pulse, DC voltage level, and current inputs from the PSI unit which acts as a signal conditioner between the sensor and the CDP and also provides electrical power to the sensor as required.

SE Probe Bus

The SE Probe Bus provides a multidrop hardware interface and digital data protocol for communication between detectors and the field control unit. The bus will accommodate up to 253 detectors which can be individually addressed and controlled. It is designed to transmit and receive digital data packets at transmission rates up to 9.6 kilobaud. Each CDP unit incorporates SE Probe Bus driver electronics so that GPSEE detectors may be connected to the SE Probe Bus without additional engineering or hardware configuration effort.

Common Detector Processor

The Common Detector Processor is a single board assembly consisting of a microcontroller, analog-to-digital converter (ADC) channels, static and variable memory (nonvolatile), logic control lines, and SE Probe Bus driver electronics. A CDP module will respond to commands addressed to it from the Field Control Unit and, in turn, control the operation of a specific sensor through the PSI. The CDP will digitize analog sensor signals and produce digital data packets compatible with the SE Probe Bus data protocol. These data packets will be sent to the Field Control Unit on demand in real-time.

All CDP modules will share a common hardware configuration that will be customizable only in terms of software or calibration data which may be downloaded from the Field Control Unit or other computer systems. This common hardware configuration will reduce the cost of manufacturing, repairing, and calibrating the detectors for the GPSEE system.

Each CDP will be capable of constructing trend or pulse height information within its internal memory and acting on the result under program control. For instance, range control points for a given detector could be downloaded from the Field Control Unit and used to trigger an alarm if they were exceeded. Multichannel analysis could also be performed on gamma detector information to establish the presence or absence of a given isotope.

Processor to Sensor Interface

The Processor to Sensor Interface (PSI) conditions sensor signals to a voltage or current range suitable for input into the CDP and provides control logic and electrical power for a given sensor. The PSI may consist of such things as bias voltage converters, amplifiers, discriminators, electromechanical actuators, or specific controls. Although one-of-a-kind PSI modules may be built, the primary intent is to design PSI units to accommodate a family of sensors such as pH sensors which require and produce a similar range of supply voltages and output signal voltages.

Sensors

A variety of sensors for the GPSEE system will be available for the monitoring of hazardous, radioactive, and mixed waste. The overall design criteria emphasize the development of a modular detector system that reduces time spent on detector calibration, repair, and configuration by means of the microcontroller-based Common Detector Processor modules.

Hazardous Waste Sensors

Two types of hazardous waste sensors are under development for the GPSEE system. The first uses the phenomenon of x ray fluorescence to identify the presence of heavy metals in soil samples, and the second makes use of a field-portable gas chromatograph to measure the concentration of volatile organic compounds.

X Ray Fluorescence Sensor

The x ray fluorescence sensor contains an interlocked radioactive source which is used to stimulate the emission of characteristic x rays from heavy metals within the sample under investigation. A pulse height spectrum is formed within the CDP from the output of a solid state x ray detector. This pulse height spectrum is used to identify the concentration of specific elements within the sample after it is uploaded to the Field Control Unit.

Gas Chromatograph Sensor

The gas chromatograph (GC) sensor unit will incorporate recent work in the development of micro-GC technology to measure the concentrations of volatile organic compounds within a field-portable, rugged enclosure. Detection limits of 1 to 50 ppb should be obtainable for selected compounds depending on the choice of capillary columns, detector, and injection method.

Beta-Photon Radiation Sensor

For the general surveying of beta and/or photon radiation, a single Geiger-Mueller (G-M) counter under digital time-to-first-count control circuitry may be used to achieve an extended range from 10^{-6} Gy/h to 10 Gy/h (0.1 mrad/h to 1000 rad/h) and 10^{-6} Sv/h to 10 Sv/h (0.1 mrem/h to 1000 rem/h), or as a surface contamination monitor in the range of 0.83 Bq/cm^2 to 167 Bq/cm^2 (50 dpm/cm^2 to 10^4 dpm/cm^2).

The time-to-first-count technique uses a single G-M tube to sample the radiation field by measuring the time interval from an enable signal to the arrival of a radiation event. Since the detector is allowed to fully recover between each sample, the normal count rate limitation imposed by the intrinsic dead time of the detector is overcome. This also leads to a system which cannot be paralyzed by high radiation fields.

A common failure mode for G-M tubes occurs when the quenching gas is depleted and self-quenching no longer occurs. This leads to a condition where the detector goes into continuous discharge mode after responding to a radiation event. Since the time-to-first-count technique involves electronically quenching the detector after each radiation event, the detector will not fail even if it has lost its ability to self-quench.

The use of the time-to-first-count circuit technique produces a wide dynamic range and a fast responding and easily calibrated probe. It is immune to paralysis due to high field strengths, is highly stable, and affords greatly increased detector life.

Low Energy Photon Radiation Sensor

For detection of radionuclides, LANL's Violinist/FIDLER instrument set is incorporated into the GPSEE detector architecture. The Field Instrument Detecting Low Energy Radiation (FIDLER) sensor is a thin, large surface area NaI(Tl) crystal coupled to a photomultiplier tube, capable of detecting photons in the 11 to 100 keV range. The electrical pulse output of the FIDLER sensor is proportional to the energy of the photon (x ray or gamma ray) detected. When a FIDLER sensor is coupled to the multichannel analyzer of the common detector processor, spectral peaks of transuranic elements may be filtered out and measured.

The FIDLER then becomes a versatile and highly sensitive sensor for alpha-emitting transuranics, where alpha activity cannot be directly monitored, because of the distance between sensor and source (i.e., most alpha burn out within a couple centimeters) or because the source may be covered by wind sweep dust or debris. For example, each alpha particle emitted by ^{239}Pu and ^{240}Pu has associated low energy photon (x ray) emission in the energy range of 11 to 21 keV, and the short half-life, beta-emitting isotope, ^{241}Pu, decays to ^{241}Am with associated low energy x rays in the energy range of 11 to 21 keV and low energy gamma rays of 26 and 60 keV energy. Thus, in monitoring for dispersed weapons grade plutonium, GPSEE is capable of filtering associated photon activity with the 1024 channel analyzer of the common detector processor to directly measure the high energy, 60 keV gamma peak, and a lower energy composite peak resulting from the 11 to 21 keV x rays. In this scenario, the probe unit with two detectors (i.e., one high and one low range detector) could be used to simultaneously measure both plutonium and americium surface concentrations in μCi/m^2.

Base Station

The GPSEE base station is a real-time, multiple sensor monitoring, data acquisition, processing, display, and reporting system. It consists of an Intel 80386 based computer, telemetry systems for communication with Field Control Units, a GPS antenna and receiver, high resolution monitor and plotter, barcode scanner and printer, and software for data interpretation and analysis. The base station is capable of maintaining communications with several Field Control Units at the same time.

The heart of the GPSEE base station is the advanced software architecture which provides for sensor monitoring, data processing, real-time data mapping, trend analysis, and sensor control. The control application is based on a commercial off-the-shelf package with the inherent flexibility of a process data base designed to be tailored for a variety of applications. This system can be easily updated to include new sensors as they are developed. This is accomplished by tailoring the software process data base to include specific chemical or radiological sensor data details.

The system operator interface consists of the computer monitor display which provides menu-driven graphics for system control and a mouse or keyboard for operator input. In most cases, the display presents an overview of the data acquisition system with symbology responding to real-time sensor data. This real-time data can be displayed in a variety of ways, including single and multiple variable trends.

All sensor data blocks are tagged with their corresponding GPS position information in a format suitable for use with Graphical Information System (GIS) software for further analysis. This data may be downloaded to other computer systems for additional processing if desired.

Options

Barcoding of field samples with site name, latitude, longitude, elevation, data/time, and measurement at the time the sample was taken may be desirable for clean and easy handling of samples and to ensure traceability or verification of site characterization/remediation activities. Laminated barcode labels may be generated as needed in the field, using the field survey station with the addition of a barcode printer driver board and a thermal high density barcode printer. The format of the sample label is easily customized by SE barcode software handlers to include any number of measurements, where each measurement is a barcode with 12-character alphanumeric representation below the barcode. Barcodes can then be read in the laboratory using the base station PC-386 controller or any other compatible PC with a high density barcode scanner and bar decoder driver board.

In addition to barcoding, other GPSEE options include (1) voice communications between the base station and the field survey station; (2) down hole cable and reel for the probe units down a borehole; (3) an all-terrain vehicle for hosting the field survey station--remotely or manually operated; (4) a motor home or van to host the base station; (5) a van trailer for all-terrain vehicle, maintenance equipment, spares, and miscellaneous support equipment; (6) an AC power generator for a remote base station; and (7) C-size pen plotter for detailed graphic site representations.

FIELD EVALUATION

Calibration and Configuration

The field control unit and all the detectors are provided with a standard SE probe bus interface that provides the base station PC-386 controller (or any other compatible PC) with the capability of performing all configuration control, calibration, and diagnostic testing of the field survey station equipment.

Configuration control software is used to download configuration items (e.g., display modes, tone generator constants, measurement units, and format) to the field control processor and to download field control and detector software to all processor flash memories. All field processors use flash memory, which is downloadable from the base station, rather than the more manually intensive removable PROM.

Calibration software is used to make all detector calibration adjustments via automatic measurements and downloadable constants.

Diagnostic test software is used to fault isolate trouble to the printed circuit board and sensor level via automatic field checking. The design goal of all field equipment is to produce modular hardware of sufficiently low cost to be considered "throw-away" should failure occur.

Field Testing

System acceptance testing will be completed at Sorrento Electronics prior to delivery of the equipment for field testing. The system testing will include verification of GPS position accuracy, contamination detection sensitivity, and the integrated automated features of the system. The capability to transfer sensor and position data via the radio frequency link from a field station to the base station will be demonstrated. Field acceptance testing of the complete system is planned to be performed at Los Alamos National Laboratory in September 1990.

SITE Demonstration

Discussions with the EPA are continuing during the evolution of the system. Suggested features to enhance the acceptance of the system have been added to the system. To ensure broad acceptance on the technical merits of the system, a comprehensive Superfund Innovative Technology Evaluation (SITE) Measurement and Monitoring Technologies demonstration program is being planned for early 1991.

SUMMARY

The hardware that makes up the GPSEE system is, for the most part, considered to be off-the-shelf type equipment. Requirements for hardware development are focused mainly on the probe unit (see Figure 3). The probe unit permits the system to be used with a wide variety of commercially available sensors for low level waste (LLW), hazardous, and mixed-waste detection. Extensive software development is needed for the system to operate as intended. Commercially available software is used where practical and is adapted to meet the specific needs of the system.

This system will permit contractors to perform comprehensive surveys of surface and subsurface contamination at LLW sites at a far lower cost and in less time than current methods permit. The system also provides a practical method for screening hazardous waste sites for absence/presence of contamination with a very high cost-benefit ratio relative to current methods. Contractors have compared the potential value of GPSEE with prior completed projects, and each of these comparisons have indicated GPSEE will provide significant cost and schedule benefits. For certain screening applications, cost benefit ratios in the 10 to 12 range have been projected.

Field demonstration of this system is scheduled for September 1990 and an EPA-SITE demonstration is being planned for early 1991 when the Global Positioning Satellite system is fully operational.