II. DESIGN AND CONSTRUCTION

ENGINEERING DRAWINGS
A large number of detailed engineering and construction drawings were prepared for this project. Many project details are best seen by reference to selected drawings. Drawings are contained in the Appendix 1.

GENERAL OVERVIEW OF DEMONSTRATION CELL CONSTRUCTION
The bases and drainage structures for the two 10,000 feet square test cells were constructed in 1993 in conjunction with a 22-acre landfill expansion (Module B) at the Yolo County Central Landfill (YCCL) outside Davis, California (see Photo 2, upper). The general location of the test cells within Module B and the larger landfill are shown in Drawing II-1 "SITE PLAN". Configuration of the base is shown in Drawing II-2, CEC CELLS-VIEWING NORTH-WEST (see Photo 2, lower). From April through October 1995 the test cells were filled with municipal solid waste to depths of approximately 50 feet. Waste was placed in each cell in 5 foot lifts, each lift was overlain by about 1 foot of chipped greenwaste to serve as daily cover and surrounded by compacted clay levee side walls. Moisture and temperature sensors were embedded in the waste at various levels during waste placement. The sensor wires run horizontally through the waste and then rise vertically to the surface in flexible vertical risers constructed by filling wire mesh cylinders with gravel, which also serve as gas collection wells. Following waste placement, the cells were covered with a layer of shredded scrap tires (to serve as a horizontal gas collection system), geotextile, cover soil, and then a geosynthetic cover. The sensor wires are connected to a central data logger which is programmed to take periodic readings of the sensors. The collected data is then transmitted off site via radio link. The major elements of the completed test cells are illustrated in Drawing II-3, entitled "METHANE ENHANCEMENT BY ACCELERATED ANAEROBIC COMPOSTING AT THE YOLO COUNTY CENTRAL LANDFILL".

DETAILS OF DEMONSTRATION CELL CONSTRUCTION
The methods of construction of the different system components are described below.

Base layers: Base lining layers for both cells consist of a soil and gravel operations layer over geotextile, drainage net, a 60 mil (0.060 inch thick) high density polyethylene (HDPE) geomembrane, and a 2 foot layer of compacted clay as illustrated in Drawing II-4 MODULE B AND CEC CONTROL CELL COMPOSITE LINER SYSTEM DETAIL (see Photo 3). For the enhanced cell, a secondary containment system was constructed on top of the base lining system as shown in Drawing II-5 CEC ENHANCED CELL COMPOSITE LINER SYSTEM DETAIL (see Photo 3). The double containment was required by the Regional Water Quality Control Board due to the liquid additions that will occur in the enhanced cell. In the enhanced cell, the soil operations layer was compacted, a one-foot thick layer of compacted clay liner was placed, and a 60-mil HDPE liner was installed (see Photo 4). The bottom of both cells slope at 2% in a southerly direction towards a gravel filled trench containing a perforated leachate collection and removal pipe as shown in Drawing II-6 CEC CONTROL AND ENHANCED CELL GRADING PLAN (see Photos 4 - 6).

Leachate Drainage to Manhole: The leachate that is collected in each cell flows through solid pipes in Module B which convey the leachate to separate manholes at the perimeter of Module B (a distance of approximately 650 feet) for measurement, and in the case of the enhanced cell, recirculation. This is illustrated in Drawing II-7 MODULE B PLATE LYSIMETER AND LEACHATE COLLECTION TRENCH CROSS SECTION and Drawing II-8 NORTH AND SOUTH MANHOLES LAYOUT. To prevent the loss of landfill gas through the leachate removal lines, U-traps with 24 inches of liquid head were constructed at the pipe outflows in the manholes (see Photo 7).

Enhanced Cell Secondary Liner: For the enhanced cell, one objective is to demonstrate integrity and leak-free performance of the primary liner system (a regulatory concern). The double containment system incorporated into the enhanced cell will allow for leak detection and leakage volume measurement. Any leakage through the enhanced cell's primary liner system will be captured by the cell's secondary liner system. The secondary liner system drains to its own leachate collection trench, and then through a solid pipe in Module B to a manhole at the edge of Module B. Outflow at this manhole would indicate leaks in the enhanced cell's primary liner system.

Manholes: Manholes (prefabricated HDPE, of conventional commercial construction) are used to collect and hold leachate draining from cells. The enhanced cell manhole also serves as a reservoir to which water can be initially added, and leachate subsequently recirculated to the enhanced cell as needed. The manholes are designed to allow drainage into the landfill leachate disposal system if required, but are valved so that volumetric measurements can be made prior to draining. The manhole for the enhanced cell is shown in Drawing II-9 MANHOLE 1 PLAN AND SECTION (see Photo 7).

Compacted clay sidewalls: The clay used to construct the cell sidewalls was taken from the on-site borrow source, and was of the same type used to construct the compacted clay liner system for the demonstration cells and module B. The clay was pre-moistened at the borrow site using a water truck and disc, and a minimum of 24 hours was allowed for the water to fully saturate and soften the clods. The moisture content of the soil was adjusted to a value between 0 and 3 percent above optimum.

Scrapers were used to transport the clay for the construction of the levees. The subgrade was scarified and moistened to a depth of 2 to 4 inches before the clay was spread to an even 8-inch loose thickness. Four to six passes of a Tenco 5X 5 sheepsfoot compactor pulled by a Caterpillar D8 were needed to achieve a final compacted lift thickness of 6 inches at 95% relative compaction (see Photo 11). The mating surface of each lift was left rough and kept moist to make sure that a potential flow path for gases or liquids was not created. Each subsequent lift was placed over the prior lift using the above procedure.

Following compaction of each lift, 6 inches of clay was cut away and the previous lift was tested for density according to ASTM D 2922 (nuclear gage) (see Photo 11) and moisture content according to ASTM D 1557 (oven drying). Areas which tested below 95% relative compaction were reworked and tested. If the moisture content of the clay was not acceptable, it was adjusted by wetting or aerating, as required, to within 0 to 3 percent above optimum moisture content.

Although permeability tests were not conducted during the construction of the clay levees, but since the above procedure were strictly followed, it has been shown in previous clay liner construction projects that with the on-site soil permeabilities of 10^{-7} cm/sec or lower can easily be achieved.

It was important to place waste on both sides of the sidewalls, as they were constructed, to shore and maintain their integrity. First, clay was placed in lifts until the sidewalls reached a height of 5 feet. A five foot lift of waste was then placed inside this perimeter, and then a waste lift was placed outside the clay sidewall perimeter. The addition of waste lifts and sidewall construction continued until the desired cell waste and sidewall depth was reached. Drawing II-10 FILL PLAN, Drawing II-11 CROSS SECTIONS LEVEE CONSTRUCTION 5 FOOT LIFTS, AND Drawing II-12 CROSS SECTIONS FILLING SEQUENCE 5 FOOT LIFTS.

<u>Waste Selection for Cells:</u> The waste placed in the cells was deposited by waste trucks (packer trucks) containing residential or commercial solid wastes. This waste is from typical packer truck collection routes serving households or commercial establishments such as small businesses, restaurants, markets, etc. Self-haul vehicles were diverted from the cells since they tend to have loads containing bulkier items than packer trucks. No waste entering the landfill on weekends was placed in the cells since the majority of weekend waste is from self haul vehicles. Other bulky loads or loads that consisted of nearly all of the same material were also diverted from the demonstration cells. All loads entering the landfill are weighed and a log of tonnages placed in the demonstration cells was maintained (see Photos 8 and 9).

<u>Waste Placement</u>: The bottom of the control cell lies about 2.5 feet lower than that of the enhanced cell due to the placement of the secondary liner in the enhanced cell. Therefore, the control cell contains slightly more waste than does the enhanced cell, as they were both filled to the same height. The control cell received 8,737 tons of waste and the enhanced cell received 8,568 tons. Placement of waste was in five-foot deep lifts. A total of nine lifts were required to fill cells to their final configuration. An alternative daily cover of chipped greenwaste about 1 foot thick was used to cover the waste. It is expected that chipped greenwaste as daily cover rather than soil will facilitate necessary liquid permeation. Normal waste compaction procedures were followed; this involved about 5 passes over each lift resulting in an average waste density of 1,027 pounds per cubic yard for the enhanced cell and 1,014 pounds per cubic yard for the control cell (see Photos 8, 9 and 16). These densities include all material placed in the cells; both the solid waste and alternative daily cover.

Placement of In-Waste Sensors: As waste was placed in cells, instrumentation was installed at design levels. Drawing II-17 show views of the layout of sensors for moisture and temperature monitoring at three levels within the control cell and four levels within the enhanced cell (see Photo 13). The positions of the instrumentation layers are shown in Drawing II-13 MONITORING SYSTEM FOR WASTE MASS-CROSS SECTION. A Druck PTX 164 pressure transducer was placed in the leachate collection pipe of the enhanced cell to measure the buildup of hydrostatic head in the leachate trench.

Moisture Sensors: In-waste moisture sensors are of two types; gypsum blocks manufactured by Electronics Unlimited, and perforated 1.5-inch diameter PVC pipes filled with pea-gravel with three electrodes spaced 8 inches apart. The gypsum blocks are of the type typically used for soil moisture determinations in agricultural applications. Initial tests prior to actual placement of the gypsum blocks in the cells showed that they deteriorated rapidly in leachate. To increase their life, each gypsum block was embedded in a quart-sized block of plaster of paris. The PVC moisture sensors will send a signal when the surrounding conditions are at or near saturation conditions. The purpose of the PVC moisture sensors is to provide some means of verification of the data provided by the gypsum blocks and for this reason they are placed very near one another. If a PVC moisture sensor is sending a signal the gypsum block would be expected to indicate very high moisture content. The control cell contains 15 gypsum blocks and 4 PVC moisture sensors. The enhanced contains 25 gypsum blocks and 12 PVC moisture sensors. This arrangement is shown in the detail "Gypsum Moisture/PVC Moisture Sensor" of Drawing II-14 MONITORING SYSTEM FOR WASTE MASS-DETAILS.

Temperature Sensors: Temperature sensors are 10 k ohm thermistors encased in 1/4" diameter by 4 inch long stainless steel cylinders manufactured by Thermometrics, Inc. They were also embedded in plaster of paris blocks along with the gypsum blocks. This arrangement allows correlations to be made between temperature and moisture conditions. This arrangement is shown in Drawing II-14 MONITORING SYSTEM FOR WASTE MASS-DETAILS. The control cell contains 11 temperature sensors and the enhanced cell contains 13.

Instrumentation Leads: Forces on wire leads buried within waste can easily break unprotected leads due to waste compaction and subsidence. This problem has been experienced repeatedly in other projects. Thus leads were enclosed in a housing consisting of nylon reinforced PVC flexible tubing. Substantial slack was also left in lead lines as a further measure to limit breakage (see Photos 14 and 15). Leads from sensors run through the waste to a gravel riser which is shown in detail "Settlement Provision Detail" in Drawing II-15 MONITORING SYSTEM FOR WASTE MASS-GRAVEL RISER DETAILS. Within this riser they lead to the surface, and connect to a Micrologger and a remote transmitting unit. This approach to instrumentation lead protection has proven quite successful as all emplaced sensors are providing data. A schematic illustration of the paths of instrumentation leads is shown in Drawing II-17.

Liquid Infiltration System: The basic enhancement strategy is to bring waste up to optimum moisture content for biological reactions by controlled additions of liquid (initially water and later leachate). To facilitate necessary liquid additions, the waste surface was constructed with 14 "trenches" filled with shredded tires as shown in Drawing II-18, CEC ENHANCED CELL LEACHATE INJECTION SYSTEM. The trenches are approximately 3 feet wide, 5 feet deep, and 10 feet long. A 3-inch perforated PVC pipe was placed vertically at the bottom of each trench for leachate injection, and backfilled with shredded tires. Liquid is distributed to each trench by a distribution manifold as shown in Drawing II-18 (see Photos 23 and 24). Liquid levels in these pits are sensed by probes which are constructed of 2-foot sections of 1.5-inch perforated PVC pipe filled with pea gravel, fitted with electrodes spaced 12-inches apart. These electrodes indicate when the depth of liquid in the pits has reached depths of approximately one and two feet. The data logger records the information from the probes and the inflow of liquid to the cell is shut off when the average depth in seven of the pits exceeds one or two feet, depending on the settings in the program. Liquid in the pits then drains into and permeates waste at rates controlled by the waste's permeability. When the average of the probe readings indicates that the average liquid depth is below the 2 feet level, pit filling is resumed. This procedure is repeated until indices, including moisture readings and/or leachate outflow, show that desired moisture levels have been reached.

Liquid pumping: Initially, water will be added to the enhanced cell from a groundwater extraction system at the YCCL. Later, leachate generated by the enhanced cell will be recirculated. A Grundfos 10E8 submersible pump capable of pumping 12 gallons per minute to the enhanced cell is permanently installed in the enhanced cell manhole. The pump was sized based on expected liquid needs and permeability of waste which was estimated to be about 10^{-4} cm/sec. Using this permeability rate, it is estimated that the enhanced cell will reach moisture capacity in approximately 5 months without interruptions on delays in pump run times. Groundwater flow into the enhanced cell manhole is monitored with a Signet 2535 low-flow flowmeter. Leachate flow out of the manhole is measured with a Sparling FM625 Tigermag flowmeter. A manually operated pump was installed in the control cell manhole to allow any leachate that accumulates to be pumped into the landfill leachate collection system. Leachate from the control cell manhole is monitored with a Signet 2535 low-flow flowmeter.

Vertical Gas Wells: Gas collection for each cell is by two vertical wells within the waste and through the surface permeable layer of shredded tires. The vertical gas wells in each cell are constructed of a perforated 4-inch diameter PVC pipe with one well surrounded by gravel and the other by shredded tires enclosed in wire mesh (see Photos 12, 13 and 14).[1] The vertical wells were not drilled after filling but were constructed as the waste

1 (One project purpose has been to demonstrate beneficial use of scrap tires in landfill construction and particularly in landfill gas extraction. Scrap tires pose a major disposal problem throughout the U. S.)

was placed, increasing the height of the wells as the waste was placed. Vertical gas well construction is shown in Drawing II-15 MONITORING SYSTEM FOR WASTE MASS-GRAVEL RISER DETAILS and Drawing II-16 MONITORING SYSTEM FOR WASTE MASS-TIRE RISER DETAILS. One key parameter of well performance and a measure of waste permeability is the change in the gas pressure in the waste surrounding the well, induced by extraction of gas at various rates from the well. To assess pressure/flow relations, monitoring lines have been installed for pressure measurements in the waste surrounding the wells (see Photo 24). These consist of 1/4 inch diameter HDPE tubes protected by PVC conduit extended out at various radii from the well. These detect the pressure at their endpoints, thus giving in-waste pressure data as withdrawal proceeds and as the rate of withdrawal is adjusted. The design of the pressure probes is shown in the "Gas Pressure Sensor" detail of Drawing II-14 MONITORING SYSTEM FOR WASTE MASS- DETAILS (see Photo 17). The gas pressure sensor layout is shown in Drawing II-19 CEC HORIZONTAL GAS COLLECTION AND PRESSURE MEASUREMENT LAYOUT and more details are provided in Drawing II-20 GAS SYSTEM DETAILS.

Cell Surface Layers and Membrane Containment: The surface of the waste is completely overlain by a minimum 1-foot compressed layer of shredded tires which are highly permeable to gas flow (see Photo 20). This permeable layer serves to collect and conduct gas to a horizontal, perforated 4 inch diameter PVC pipe placed in the shredded tire layer (see Photo 17). The shredded tire layer is covered by a geotextile and over the geotextile is a layer of soil approximately one foot thick (see Photo 21). The soil layer is capped by a surface membrane for overall gas containment. The surface membrane is anchored and sealed at cell sidewalls as seen in Drawing II-21 COVER DESIGN and Drawing II-22 COVER SYSTEM DESIGN DETAILS. The membrane material is 40 mil linear low-density polyethylene (LLDPE) manufactured by Polyflex, Inc. which was chosen because of its ability to accommodate waste subsidence by stretching without breaking (see Photo 25).

Gas Extraction: Gas can be extracted by either the perforated vertical wells, or through the perforated horizontal pipe in the surface permeable layer of shredded tires, or by combinations of both. The gas flow from the surface permeable layer and vertical gas well extraction can be adjusted in any desired ratio by valve adjustments. This allows well performance tests at all possible flow rates up to the rate of gas generation. A plan view of the gas extraction system is shown in Drawing II-23 GAS EXTRACTION SYSTEM LAYOUT and details are shown in Drawing II-24 GAS SYSTEM DETAILS.

Gas Condensate Removal: As the warm, moisture-saturated gas exits the test cells and cools, liquid condensate forms. This condensate must be drained at low points in the gas system or it may pool and block lines. The landfill gas exits each demonstration cell in a 4 inch diameter pipe and is conveyed to an 8 inch diameter, 10 foot long PVC pipe located just upstream from the gas meters and shown in the detail, "Condensate Knockout and Gas Flowmeter Detail" of Drawing II-24. The purpose of the 8 inch diameter pipe is to provide a larger area for gas flow, thereby reducing the velocity of the flow and facilitating the removal of landfill gas condensate. Condensate that drains from the system is conveyed to a 2,000 gallon HDPE tank. The level of condensate in the tank is measured and the volume calculated prior to draining into the landfill leachate management system. The conveyance of the condensate is entirely by gravity flow. To prevent the entry of air into the system U-traps are installed where a condensate line is open to the atmosphere.

Gas Flow Measurement: Landfill gas flow from each cell is measured separately by corrosion resistant, positive displacement rotary gas meters manufactured by Dresser Industries, Inc. (Model 5M175). The meter is a special service meter, designed for sewage and production gas measurement. These are continuous duty meters which tolerate small quantities of entrained fluids and corrosive gases. Each meter is capable of measuring flows from 42 cubic feet per hour to 5,000 cubic feet per hour with a maximum pressure of 175 pounds per square inch. These meters are temperature compensated and have externally mounted pulsers that send volumetric data to the data logger. The meters are installed after the condensate trap of each cell as shown in "Condensate Knockout and Gas Flowmeter Detail" of Drawing II-24 GAS SYSTEM DETAILS.

Landfill Gas Warming: Most condensate in the gas flowing into the positive displacement meter would be removed by the trap discussed above. However gas exits the trap at 100% relative humidity and more condensation can occur as the gas moves to the meter. To further limit the possibility of any condensate entering the meter, the galvanized steel pipes just prior to the meter are heated by electric heat tapes. A temperature increase of 10 °F between the 8 inch PVC pipe and the meter was deemed sufficient to maintain the remaining moisture in the vapor phase while passing through the meter. The power required to accomplish this at the peak estimated gas flow rate is 500 watts for each cell. To satisfy this requirement each pipe was wrapped with a heat tape 8 feet long and capable of dissipating 72 watts per foot, for a total of 576 watts per pipe. This arrangement is shown in "Condensate Knockout and Gas Flowmeter Detail" of Drawing II-24 GAS SYSTEM DETAILS.

Gas Collection Pipes Connection to Main System: The landfill gas from the demonstration cells will be collected under a vacuum induced by a blower located at the landfill gas-to-electricity facility located at the Yolo County Central Landfill. The blower at this facility applies a vacuum to the gas collection system for the entire landfill, not just the demonstration cells. This includes 83 vertical wells distributed over about 110 acres; the two demonstration cells are tied into this system. The vacuum applied at the blower varies between -10 and -50 inches water depending on the time of year, whether or not electricity is being generated, etc. However, the average applied vacuum at the blower is about -25 inches water, which corresponds to a vacuum at the demonstration cells of about -15 inches water. After passing through the cell, condensate trap, and flowmeter measurement station, the gas enters a 6-inch diameter PVC pipe that conveys the gas to the main gas collection header pipe. This configuration is shown in Drawing II-25 GAS EXTRACTION SYSTEM LAYOUT.

Leak Detection: Leaks through the surface membranes or piping should be shown by the presence of oxygen or nitrogen in the recovered gas. Sources of leaks in pipes can be traced by upstream/downstream measurements in the gas collection pipes.

System Gas Pressure: Gas pressure or pump suction in the methane recovery network can be monitored on-site using a hand-held Pocket Digital Manometer, model PDM205, manufactured by Air-Neotronics Ltd., England.

Gas Quality Analysis: One means of monitoring the processes occurring in the demonstration cells is to analyze the gas they produce. This is accomplished by having a technician sample the gas at the collection wells, and run it through an MTI P200H gas chromatograph. Comparing the landfill gas to a laboratory-prepared reference gas, the chromatograph can provide information about the relative concentrations of carbon dioxide, methane and nitrogen.

Weather Conditions: Wind speed and direction, rainfall, temperature and barometric pressure are monitored by a Davis Instruments Weather Monitor II weather station. Data is transmitted to the Davis office of the DIWM via modem, and logged to pre-configured IBM clone.

Demonstration Cell Data Acquisition: The enhanced and control cells are monitored for moisture, temperature, and pressure by 112 sensors (see plans, Section II) which are wired to three AM416 Multiplexers connected to a 21X "Micrologger" (Campbell Scientific, Inc) (see Photo 24). The Micrologger polls the sensors for information at preset intervals, and stores the values until they are downloaded. Data is downloaded to the office of the Division of Integrated Waste Management in Davis, CA, at programmable intervals via a dedicated radio link to the Micrologger. A computer at the Davis office runs a program which initiates contact with the Micrologger, downloads the information and stores it in a file. The file may then be processed using a proprietary application called Split, which sorts and prepares the raw data. Once the data has been processed it can be imported to a database or spreadsheet program for graphing or trend analysis.

Data Analysis: Data received from the landfill is analyzed by selective sorting and plotting using the spreadsheet program Excel. Staff at the Davis office of the DIWM are currently exploring the option of writing a specialized application for the database program Access, which will take raw data as transmitted from the landfill, format it and apply analysis profiles automatically.

PLANNED MONITORING PROGRAM

Much of the data acquired from the test cells will be collected and transmitted by the Micrologger using the following regimen: Data will be collected from the sensors at 15 minute intervals, and averaged hourly (four readings). The hourly averages will be stored for later transmission, generally at 2-hour intervals. The following parameters shall be monitored:

1. Temperature. Thermistors in the waste mass will yield temperature data which will be stored in a Micrologger until downloaded to a computer at the office of the Division of Integrated Waste Management. Sampling frequency as stated above.
2. Moisture content. Moisture data will be collected using agricultural moisture sensors. The data will be stored and transmitted to the office computer as with the temperature data. Sampling frequency as stated above.
3. Leachate depth on the base liner. Leachate depth on the base liner of the enhanced cell will be monitored with a pressure transducer that has been placed in the leachate collection trench of the enhanced cell. The purpose of the transducer is to demonstrate that liquid additions can be controlled to prevent the buildup of excessive hydrostatic head on the liner. Sampling frequency as stated above.
4. Liquid volumes. All liquid additions will be metered and recorded. Liquid will be added to the cell continuously at a very slow rate to bring the waste to field capacity. This rate should be approximately 12 gpm for all 14 injection wells. All liquid leaving the cells through the leachate collection and removal system flows to one of two manholes, one for each cell. The volume of liquid in these manholes will be measured prior to recirculation or removal, as needed. The secondary containment liner of the enhanced cell drains to a third manhole to monitor leakage through the primary liner, should any occur. Sampling frequency as stated above.
5. Landfill gas volumes. Landfill gas volumes will be metered and reported automatically to the Micrologger by an appropriate in-line device. Sampling frequency as stated above, except that the data collected at 15 minute intervals will represent integrated volume flow rates during the interval.
6. Landfill gas composition. Gas composition is determined using an MTI gas chromatograph model P200H. Gases of interest are methane, carbon dioxide, and nitrogen. Measurements are planned once weekly for the first 8 months and monthly thereafter. Measured directly by DIWM personnel.
7. Landfill settlement. Surveys will be performed every six months to track the change in elevation of surface monuments placed on the demonstration cells. Measured directly by DIWM personnel.
8. Leachate composition. Leachate characteristics will be analyzed, providing information concerning bacterial activity and strength of leachate. Leachate from the enhanced cell is expected to have a reduced pollution strength with respect to the control cell. Measured directly by DIWM personnel (see Table 1., below).

Table 1
Planned Leachate Testing Program.

PARAMETER	FREQUENCY
Field Testing: pH, Alkalinity, Acidity.	Average of thirteen times per month.
Chemical oxygen demand, ammonia, nitrate, total Kjeldahl nitrogen, total phosphorous, total dissolved solids, sulfide, sulfate, total organic carbon.	- First two months: Each cell once per week - Remainder of first year: Each cell once every two weeks - After first year: Quarterly
Volatile organic compounds	Quarterly
Metals	Quarterly