CHAPTER 8

Performance Monitoring and Operations and Maintenance (O&M)

8.1. Subsurface Monitoring for ISTR Technologies. Subsurface monitoring during ISTR operations is essential for regulation of energy input to the treatment zone, and for measuring success in terms of subsurface heating and removal of contaminants. In general, instrument data are reduced and interpreted daily during active thermal treatment to facilitate timely changes in operational strategy. The frequency for evaluations of other information, such as analytical chemistry data, may be dictated by budgets and laboratory turn-around time. Monitoring costs represent a large portion of the ISTR budget; therefore, it is necessary to develop detailed data quality objectives prior to specifying a monitoring program. Although manually read gauges and meters are commonly used on ISTR projects, consideration should be given to the use of electronic transducers, electrical resistance tomography, and data logging equipment, which may reduce labor costs and provide more efficient data management.

8.1.1. *General.*

8.1.1.1. Monitoring data can be obtained from instruments installed on or in wells, and from instruments that are buried at locations of interest. Wellhead instrumentation can be manual or electronically read devices, while electronic transducers are used for buried instrumentation. Buried instruments generally consist of instrument strings (i.e., assemblies of vertically spaced temperature and pressure transducers) installed in a backfilled or grouted borehole. Instruments that are installed by direct burial should be resistant to both high temperatures and aggressive fluids that will be present in the subsurface.

8.1.1.2. A table of suggested monitoring requirements for ISTR projects is included at the end of this chapter. The table is intended to provide information for planning ISTR projects; actual monitoring will likely vary with site-specific objectives and conditions. In addition, monitoring practices may be varied through different project phases (i.e., startup, initial heating, treatment including pressure cycling, post-treatment extraction and monitoring, etc.), or as the project team gains new insights from the data.

8.1.2. *Fluid Pressure.* Pressure data has several uses for ISTR:

a. Feedback on subsurface pressure conditions may help to prevent blowouts, leakage, or fugitive emissions.

b. Pressure data from a sufficient number of measurement points allows interpretation of subsurface flow patterns.

c. Monitoring of gas pressures may help to evaluate that volatilized contaminants are being captured.

d. Pressure data may help to evaluate the duration and effectiveness of pressure cycles.

8.1.2.1. The gas pressure at each steam injection or groundwater extraction well may be measured by a pressure gauge or transducer on the wellhead or associated piping. If a surface vapor collector layer is used, gauges or transducers may be installed on the collector pipe risers. One or more additional pressure transducers can be installed in the filter pack adjacent to well screens, allowing direct measurement of pressures in the formation without well losses. Gas pressures away from extraction or injection wells can be measured by installing pressure monitoring points (PMP). PMP may be pressure transducers at the bottom of buried temperature instrument strings or they may be small diameter stainless steel wells fitted with either pressure transducers or magnehelic pressure gauges (USACE 2002). PMP are installed at differing depths and intervals of interest. Capture of volatilized contaminants is indicated by negative pressures (vacuum) at PMPs installed at treatment zone boundaries. If steam is not present in the subsurface, hydraulic head can be measured with a water-level probe in an open well, otherwise the hydraulic head or fluid level can be estimated from pressure readings.

8.1.2.2. Gas-flow measurements should be taken at every extraction and injection well. It is also more common to monitor the combined flow rate to track total contaminant removal. Conventional gas-flow measurement, based on the pressure differentials across orifice plates or venturis, can be cost-prohibitive if done at every well. A less expensive alternative is to use a calibrated flow-control valve on each well, with connectors to allow periodic measurements of the pressure differential with a calibrated portable gage. The mass flow rate can then be calculated using an estimated specific gravity for the injected steam, or extracted steam-air mixture.

8.1.3. *Fluid Flow*. Fluid flows are monitored during conductive heating and ERH operations to track removal rates and balance the well field vapor extraction system. During steam injection, measurements of fluid injection and extraction rates are essential for management of energy flow in the treatment area, to estimate contaminant removal rates from each treatment array, and to maintain overall hydraulic control on the project site. Liquid extraction rates are easily measured using conventional flow meters, or by stroke-counters if piston pumps are used. As flow meters do not differentiate between groundwater and NAPL, it may be necessary to estimate the NAPL flow rate at each extraction well as a percentage of the total extraction rate. This may be done by observations in a sight glass, or periodic collection of liquid samples from the wellhead.

8.1.4. *Temperature*. Temperature is the most critical parameter to be monitored on an ISTR project, requiring the best resolution. Temperature data have the following uses:

a. Evaluation of heat migration and distribution, and effectiveness of energy delivery to the subsurface.

b. Identification of zones where heating has achieved target temperatures, or where thermal destruction is occurring.

c. Determination of the presence of groundwater (groundwater will be present at locations where the temperature is below the boiling point).

d. Estimation of steam pressures and evaluation of steam flow patterns (when the temperature is above the boiling point, saturated-steam pressure can be calculated directly from the temperature).

e. Comparison of observed data with predictions from design calculations or modeling.

8.1.4.1. *Temperature Monitoring.* Monitoring temperature at multiple depths and multiple locations is recommended. Temperature measurements should be recorded at least once daily; the rate of temperature change on ISTR projects is typically appropriate for twice-daily readings. Temperature measuring point (TMP) sensors are typically thermocouples installed in vertical strings set in the filter packs of injection or extraction wells, and at one or more locations in backfilled boreholes between each well. A typical vertical spacing for temperature sensors is 1 to 2 m. In general, there are three types of TMP locations:

a. Thermal sources-TMPs located in or near electrodes, thermal wells, or steam injection wells will show the maximum temperatures being achieved at the site. For conductive heating projects, these temperatures will indicate the level of thermal destruction of contaminants.

b. Between thermal sources-TMPs located between electrodes, thermal wells, or steam injection wells can help determine when target temperatures have been achieved within the treatment zone, and if energy is penetrating adequately to areas away from electrodes and wells. TMPs are generally set at the centroid between electrodes, heater wells, or steam injection wells as this is the location that would be slowest to heat.

c. Margins of treatment zone-TMPs at the edges of the treatment zone indicate achievement of target temperatures to the full extent of the material to be treated, and can provide protection for sensitive areas beyond the treatment zone.

8.1.4.2. *Thermocouples*. Thermocouples are the most common temperature-measuring device. The temperature readings are obtained electronically, and are based on the voltage difference across a bimetallic sensor element. Many different types of thermocouples are available for different uses. Types E and K thermocouples, with stainless steel sheaths and Teflon insulation, are the best suited for high temperatures and potentially corrosive groundwater and NAPL. Consideration must be given to the expected temperatures and the heat tolerance of the cable insulation. Use of some thermocouples at electrodes during ERH or very near heater wells at TCH sites may not be appropriate. Thermocouples can be read by an automatic data logger, or manually by connecting a meter to the thermocouple leads. Where large numbers of thermocouples are installed, TC extension wire is often run to an indicator board located at the edge of the exclusion zone, allowing operational staff to scan through and record the entire set of temperature readings quickly at designated intervals. In ISTD remediation, subsurface temperatures and pressures typically change at a rate that is appropriate for periodic (i.e., twice daily) manual measurement, extension wires are generally run to a single location outside the treatment zone for more efficient data retrieval.

8.1.4.3. *Fiber-Optic Distributed-Temperature Sensors (DTS)*. DTS systems measure temperature by means of laser signals transmitted along an optical fiber. The optical fiber is

created by placing double loops of thin (¼-inch) tubing in wells and backfilled borings, and pumping the tubing full of an optical fluid. A single, continuous fiber can cover a large area with many wells and instrument borings, using vertical loops in each well or instrument string. DTS systems can provide vertically continuous temperature data, but are typically designed to record temperatures at 1-m vertical intervals. Because the electronic controller is the most expensive item in the system, DTS is most economical for larger sites.

8.1.4.4. *Electrical Resistance Tomography (ERT).* ERT is a geophysical technique whereby electrical energy is passed through the region of interest by multiple paths, allowing creation of a high-resolution 2 or 3 dimensional image of subsurface resistivity. The multiple transmission paths are the result of progressive activation of vertically spaced electrodes, which are installed in boreholes surrounding the region of interest. Surface electrodes may also be used along with the buried electrodes. Relatively few boreholes are required to provide good ERT coverage, and few if any electrodes are required within the treatment area itself. Interpretation of ERT imagery is not straightforward, however, because resistivity is affected by several factors, including soil and fluid temperature, soil mineralogy, fluid saturation and chemistry, salinity, and presence of NAPL or gas. A baseline ERT image must be generated before the start of the thermal treatment, and subsurface fluid and energy flow are evaluated from images of resistivity. Some of the ambiguity of ERT interpretations can be reduced by the concurrent use of directly measured temperature data from thermocouples or DTS.

8.1.5. *Chemistry.* Chemical testing of extracted fluids provides data for estimating mass-removal rates, contaminant destruction rates, and the proportion of contaminants recovered in each operational phase. The analytical data can also be used to evaluate the overall effectiveness and potential duration of the treatment.

8.1.5.1. *Liquid.* Liquids may be sampled directly from monitoring points, or extraction wells, via sampling taps on each wellhead. Many useful parameters, such as pH, conductivity/TDS, dissolved oxygen, carbon dioxide, and turbidity can be measured daily with portable instruments and field kits.

8.1.5.1.1. The frequency of sampling for site COCs, such as PAHs, PCPs, and VOCs, will depend on treatment progress and laboratory turn-around; typical sampling intervals vary from 72 hours to 2 weeks. Sampling should follow standard operating procedures for handling hot liquids, including using proper PPE (full-face shield over safety glasses, chemical-protective and insulating gloves, waterproof suit or rain gear). Ideally, low flow purging and sampling procedures should be followed. Groundwater being pumped from the well should run through a cooling coil in an ice bath before reaching the pump, flow through cell, or sampling point. Immediately capping the jars and immersing them in ice should prevent loss of volatile components.

8.1.5.1.2. A submerged screen monitoring well also poses a significant risk to samplers. If the well is opened while the subsurface is hot, this provides the conditions analogous to a natural geyser and steam may flash and blow hot water out of the well. Submerged screen wells must

not be opened when the subsurface is hot. Figure 8-1 depicts a modified monitoring well that allows safe and accurate sampling of groundwater (provided that the depth to water is less than 25 feet) using a peristaltic pump. The Teflon sample line is connected to a stainless steel cooling coil that is immersed in ice water. The coiling coil is connected to a peristaltic pump for sampling. This cools the groundwater to about 4°C before it reaches the sample container. Such a sample technique protects the worker from hot or pressurized liquids. The cooling technique prevents loss of VOCs and allows accurate measurements.

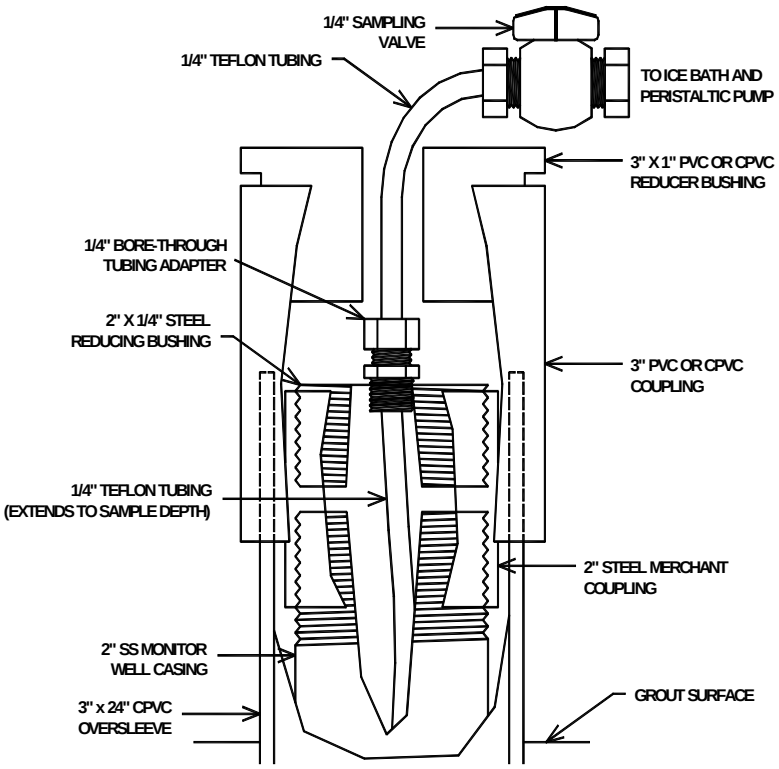

Figure 8-1. Modified Monitoring Well.

8.1.5.2. *Vapor*. Vapor samples are typically obtained from extraction wellheads, with vacuum canisters or Tedlar® bags. Because a portion of the hot vapor sample will condense when it cools, it is necessary to know the contaminant concentrations in both phases of the cooled sample to determine the original concentrations in the hot extracted vapor. As an alternative to vapor sampling, vapor concentrations can be estimated from liquid concentrations by assuming equilibrium partitioning at the original temperature of the extracted fluids. When interpreting vapor concentration data for steam injection and ERH projects, it is important to remember that steam and volatilized contaminants tend to condense in and around unheated extraction wells (see Paragraph 2-1); thus, vapor concentrations derived from vapor or liquid sampling may underestimate the actual mass of contaminants transported to extraction wells in the vapor phase.

8.1.5.3. *Electronic Sensors*. Electronic sensors may be placed in well discharge lines to provide continuous readings of chemical parameters, including TOC, pH, conductivity, and dissolved oxygen. Continuous TOC data are especially useful for tracking contaminant removal trends throughout each operational phase. Electronic instrumentation for chemical parameters may be too expensive to be installed at each extraction well, and may be installed in the main influent lines upstream of the treatment plant. Electronic sensors require periodic calibration and maintenance, and TOC sensors need to be periodically verified with laboratory testing.

8.1.6. *Saturation*. At sites that must undergo dewatering prior to application of conductive heating (e.g., sites where the soil must be superheated to enable treatment of high-boiling SVOCs), monitoring of saturation during dewatering can aid in minimizing the volume of water that must be boiled off during heating. For example, heating may best be initiated when, following drainage, saturation values have diminished and approached asymptotic levels. Saturation levels can be monitored non-destructively by various methods, including use of a neutron moisture meter lowered into an access tube, and time-domain reflectometry (TDR) waveguides pushed into the soil. These methods penetrate deeply into the formation while less costly methods tend to be biased by density or moisture artifacts immediately adjacent to the access tube or probe.

8.2. Operations and Maintenance for ISTR Technologies.

8.2.1. *Thermal Conductive Heating*. Operation and maintenance (O&M) of TCH systems is multifaceted and varies from project to project. Most projects have relatively short operationally periods, with heating ranging from 1 to 3 months. General categories of O&M activities include:

a. Pre-commissioning and start-up.

b. Normal day-to-day operations.

c. Normal maintenance.

d. Data collection and management/record keeping to ensure compliance with health and safety requirements, emission limits and equipment operational ranges.

e. Response to identified problems requiring troubleshooting and contingencies.

f. Emergency or end-of-heating shutdown.

8.2.1.1. O&M of subsurface equipment (e.g., thermal wells) is mostly straightforward, and involves daily monitoring of amperage being delivered to heater circuits, monitoring of subsurface temperatures and pressures (Section 8-1.1), and occasional repair/replacement of faulty components, if necessary. Adjustment and balancing of vacuums and flows among heater-vacuum wells and manifolds is described in the SVE EM (EM 1110-1-4001), except that with thermal conduction systems, only ~50 cm (~20 inches) water vacuum is typically applied at the wellhead, which is usually sufficient to ensure capture of vapors at the treatment boundaries. Toward the end of the heating process, it may be desirable to temporarily convert scattered heater-vacuum wells into passive air injection wells and thereby introduce air into zones that

may otherwise be anoxic. Another optional late-term adjustment is to slightly unbalance the flows at individual wellheads to vary the position of subsurface airflow stagnation zones.

8.2.1.2. O&M of aboveground equipment (e.g., of collection piping and process components) may, depending on the nature of the project, range from simple to complex. Relatively simple systems are those involving components typical of SVE off-gas treatment equipment, such as a granular activated carbon (GAC) canister, blower and discharge stack, which often enable passive (i.e., primarily unmanned) O&M.

8.2.1.3. More complex systems would include those addressing harder-to-treat contaminants, such as chlorinated SVOCs (including PCBs), pesticides, and dioxins. Such systems may include the use of insertion heaters within insulated piping manifolds, a cyclone separator, thermal oxidizer, heat exchanger, condensate trap, acid-gas scrubber, GAC vessels, blowers, and discharge stack. Depending on emission limits and other requirements, such systems may include a computer Programmable Logic Controller (PLC); flow, temperature and pressure measuring instrumentation; a continuous emissions monitoring system (CEMS); several rounds of source testing; and may, depending on site requirements, need to be manned around the clock. Typically with complex systems, a minimum of two operators should be available at all times for safety reasons. Occasionally, collection and treatment of liquid condensate at various points within the piping system is also required, and may be integrated into the ISTD off-gas collection and treatment equipment. Ancillary equipment may include fuel (e.g., propane) storage tanks for the oxidizer. It is beyond the scope of this document to discuss all the various O&M and monitoring activities that such systems can entail.

8.2.1.4. Electrical distribution equipment for thermal conductive heating systems typically includes transformers, distribution panels, and circuit breakers. A backup generator and automatic or manual transfer switch is often provided to power the off-gas treatment equipment (although not the thermal wells) in the event of a power outage. Ancillary equipment includes fuel (e.g., diesel) storage tanks for the generator. The O&M requirements of the electrical distribution equipment tend to be minimal.

8.2.2. *Electrical Resistivity Heating*. During a typical VOC remediation, about 20% of the operating time is spent in heating the site to steady temperatures near 100°C - somewhat less than 100°C in the vadose zone where the action of the vapor recovery system pulls air through the site and retards temperatures through evaporative cooling, and somewhat more in the saturated zone where the hydrostatic pressure and boiling point increase with depth. Note that the rate of heating varies by vendor. During heat-up, the ERH energy that exceeds the heat loss rate will result in an increase in subsurface temperatures.

8.2.2.1. When steady-state temperatures have been reached, the ERH power is not reduced. The ERH energy in excess of the heat loss rate will directly result in the evaporation of soil moisture and target contaminants.

8.2.2.2. The most energy and time efficient remediation results from the application of the greatest practical ERH power. The ERH power can be limited by several factors:

a. The ERH electrodes have a practical power limit that usually is in the range of 0.25 to 1 kW per square foot of electrode borehole surface area. Electrode designs with low electrical resistance generally allow higher power application rates. Attempts to exceed the electrode limit will dry (vadose) or steam blanket (saturated zone) the soil adjacent to the electrode and reduce their electrical conductivity, which results in uneven heating.

b. For planning, assume that the PCU will be operated 80% of the time and that the PCU will be operated at about 80% of its capacity during periods of operation. This limits the average ERH power input rate to about 65% of the PCU capacity.

c. The vapor treatment capacity may limit the VOC evaporation rate, especially if an oxidation technology is used. However, varying the ERH power can control the VOC evaporation rate. Within the saturated zone, a reduction of ERH power will be reflected in a reduction of vapor treatment system loading in a few minutes. Within the vadose zone, the coupling is not as strong because the vapor recovery airflow through the soils will cool the soils while maintaining a near-constant evaporation rate. Within the vadose zone, ERH power and vapor recovery flow rates are adjusted to reduce treatment system loading.

8.2.2.3. If the vapor treatment system fails completely, the ERH system is shut down and the subsurface enters a quiescent state. Steam and VOC vapors will begin to diffuse outward from the heated zone, condensing as they encounter the surrounding cooler soils. The rate of outward steam and heat spread is quite slow, usually much less than a foot per day. When vapor recovery is restored, air is pulled through the expanded warm region and, through evaporation, cools the newly warmed soils while returning the moisture and VOCs to the treatment region. If temperature monitoring indicates areas are not reaching the target temperatures, modifications to the power distribution or the installation of additional electrodes in the cooler areas may be necessary and should be undertaken by the operator.

8.2.2.3.1. Various maintenance activities for ERH include those routine activities required for the power control unit, blowers, and treatment system. Also, there will be maintenance of the moisture addition system at the electrodes, and regular inspection of the electrical connections for corrosion and of the piping systems for potential piping failure. The consistent production of fine materials from the vapor extraction system may be a sign that in-situ moisture content is low and that significant mobilization and removal of fine materials from the vadose zone may be occurring. This has happened at least one ERH site.

8.2.3. *Steam Enhanced Extraction*. This section presents an overview of a general O&M strategy for steam injection, including operational guidelines, monitoring parameters, and system modification considerations. The typical field work and O&M procedures will include the following:

a. Collection of background data (water levels, contaminant concentrations, temperature, and other parameters expected to be affected).

b. Maintenance and analysis of water softening and steam generation system (including monitoring of incoming water quality, water softening efficiency, steam production rate, pressure and temperature).

c. Maintenance of the vacuum extraction system.

d. Maintenance of the vapor treatment system (including condenser).

e. Liquid treatment system (cooling, gravity separation, water treatment efficacy, discharge concentrations).

f. Subsurface monitoring and wellhead measurements as described above.

g. Maintenance of the hydraulic control system (including verification of capture or containment).

h. Computation of mass balance (injected steam, water, and air, extracted water and vapor).

i. Computation of energy balance (injected as steam, extracted as steam and heated fluids, heat losses, and calculated average temperatures of treatment zone).

8.2.3.1. Information on subsurface conditions should be updated just prior to the implementation of steam injection to provide a baseline against which the impact of steam injection can be compared and evaluated. An efficient way to ensure that the necessary baseline data are collected is to produce a checklist of parameters to be measured, including measurement locations and methodology. A good estimate of total mass of contaminants and distribution among all phases and subsurface treatment zones is critical for measuring the effectiveness of the steam injection project.

8.2.3.2. The major components of a steam injection system consist of a steam generation and distribution unit, injection/extraction wells, process controls, and an effluent treatment unit. Thermal modeling is usually used to determine steam injection parameters. The goal is to optimize the injection rate and pressure so that maximum heating efficiency, maximum volume of heated area, and optimized steam front shape can be achieved. The variables that can be modified to optimize the remediation system include steam pressure, steam flow rate, and locations of injection and extraction wells. As physical parameters of the steam are interdependent, setting injection rate, pressure, and steam quality should be enough for the system operation.

8.2.3.3. Prior to the start-up of the entire ISTR system, equipment and piping should be inspected and tested. A pre-commissioning/shakedown checklist should be developed and followed. The site Health and Safety officer should also ensure all safety devices are operable and that site personnel have all the necessary training and the appropriate personal protective equipment are available.

8.2.3.5. During operation, particular attention should be paid to the vapor and liquid recovery systems owing to unanticipated consequences of contaminant removal, including unwanted condensation or crystallization of contaminants or inorganic materials. Such

occurrences have caused problems at SEE sites. Piping should be regularly inspected for potential failures or clogging.

Table 8-1. ISTR Monitoring Summary.

Media	Technology	Monitoring Objective	Monitoring Activity / Characteristic	Data Use	Monitoring Location	Analyte / Parameter	Monitoring Type / Method	Measurement Equipment, Sensitivity	Typical Monitoring Frequency
Vapor Air	All	Performance	Contaminant Mass Removal	Determine Points of Diminishing Returns for System Shutdown, Treatment Operations Decisions	Vapor Treatment Influent Header	Contaminant VOCs (possibly SVOCs)	Grab Sample, Laboratory or Field Gas Analyser	Varies, Depending on Site Conditions and Contaminants	Varies, Can be Hourly with Automated Field Gas Analyzer, Daily or Longer if Sampled Manually
		Performance	Vacuum Extraction Monitoring	Verify Vapor Control	Vapor Monitoring Points	Vacuum	Gauge or Transducer Reading	Varies, +/-5%, Reading Should be >20% and <80% Full Scale	Daily
		Performance, Compliance	Treatment System Air Emission	Verify Compliance with Permit(s), Make Operational Decisions	Discharge Stack	Contaminant VOCs and any byproducts of treatment as required by permit	Grab Sample	Laboratory Analysis or Field Gas Analyzer, Site Specific Requirements	As Required by Permit, More Frequent at Startup, Daily to Weekly During Operations
		Compliance	Surface Emissions	Regulatory Compliance	Perimeter Monitoring	Contaminant VOCs	Grab Sample, Time Averaged Sample	Laboratory Analysis or Field Gas Analyzer, Site Specific Requirements	Varies
Vapor Steam	SEE	Performance	Boiler Steam Production	Document Quantity of Steam Injected	Steam Injection Header Pipe	Flow Rate Temperature Pressure	Gauge/Meter	Resolution 0.05 kg/sec, Range varies	Near-Continuous
			Steam Pressure and Flow Rates	Evaluate Injection Well Performance	Injection Well Heads	Flow Rate Temperature Pressure	Gauge/Meter Gauge or Thermocouple Gauge	Resolution 0.05 kg/sec, Range varies +/-2 deg C 0-150 deg C, Type K Thermocouples varies	Weekly
Water Conden-sate	All	Performance	Contaminant Mass Removal	Determine Points of Diminishing Returns for System Shutdown, Treatment Operations Decisions	Condenser Liquid Effluent Piping	Contaminant Concentrations Flow Rate Temperature	Grab Samples Meter with Totalizer Gauge	Laboratory Analysis or Field Auto Sampler and Analyzer, Site Specific Requirements +/- 2%, Range Varies +/-2 deg C 0-150 deg C	Weekly to Monthly
Water Ground Water	All	Performance	Ground Water Extraction or Migration Monitoring	Verify Ground Water Contaminant Migration Control	Monitoring Wells and Points	Piezometric Levels	Water Level Indicator Transducers	+/-0.3 cm Stainless Steel or Titanium Construction, Range Varies	Weekly to Monthly

Media	Technology	Monitoring Objective	Monitoring Activity / Characteristic	Data Use	Monitoring Location	Analyte / Parameter	Monitoring Type / Method	Measurement Equipment, Sensitivity	Typical Monitoring Frequency
Water Ground Water	All (if goal is groundwater remediation)	Performance	Natural Attenuation Parameters	Evaluate Degree of Natural Attenuation	Monitoring Wells	Dissolved O, ORP Nitrate Ferrous Iron Sulfate and Chlorides (for Sites with Chlorinated Organics) Alkalinity	Direct Reading Field Instrument EPA 353.2 Field Kit (Hach) EPA 300 EPA 310.1	+/-0.5 ppm, 10% variability Report Limit: 0.1 ppm 0.1 ppm 1 ppm (sulfate) 0.05 ppm (chloride) 1 ppm	Monthly
Water Ground Water	SEE; ERH and TCH if ground water extraction included	Performance	Ground Water Chemistry	Operational Decisions for Water Treatment Plant	Liquid Influent Header, Extraction Wells if Necessary	Total Organic Carbon Cations (Ca, Mg, K, Na, Mn)	Field Analyzer or EPA 415.1 EPA 6010B	1 ppm Mn: 0.1 ppm, Ca: 0.25 ppm Mg: 0.15 ppm Na: 2.5 ppm K: 10 ppm	Monthly
Water Extracted Ground Water	SEE; ERH and TCH if ground water extraction included	Performance	Contaminant Mass Removal	Determine Points of Diminishing Returns for Shutdown, Treatment Operations Decisions	Liquid Influent Header, Extraction Wells	Contaminant Concentrations Flow Rate Temperature	Grab Sample Meter Gauge or Thermocouple	Laboratory Analysis or Field Auto Sampler and Analyzer, Site Specific Requirements +/- 2%, Range Varies +/-2 deg C 0-150 deg C	Site Specific, May be Hourly with Field Analyzer or Auto Sampler, Daily or Longer if Sampled Manually
Water System Effluent	All	Performance, Compliance	Contaminant Concentrations	Verify Compliance with Discharge Permit(s), Make Operational Decisions	Discharge Point or Injection Header	Contaminant Concentrations, other parameters as required by permit (BOD, COD, pH, Temperature, Total Dissolved Solids)	Grab Sample or Time-Averaged Composite	Contaminant and Parameter Dependent	As Required by Permit, Daily to Weekly
NAPL	SEE; ERH and TCH if liquid NAPL is extracted or if vapor-phase NAPL is condensed	Performance	Contaminant Mass Removal	Determine Points of Diminishing Returns for Shutdown, Treatment Operations Decisions	NAPL Storage Tank Monitoring Wells	Flow Rate Tank Levels NAPL Thickness	Meter Sensor or Sight Glass Field Interface Probe	Construction Varied Depending on Flow and Contaminant	Daily
	SEE; ERH and TCH if liquid NAPL is extracted or if vapor-phase NAPL is condensed	Compliance	Waste Disposal Characterization	Determine Proper Disposal of NAPL	NAPL Storage Tank	NAPL Storage Tank	Grab Sample	Requirements Vary	Varies
Soil	All	Performance	Treatment Area Status	Verify Adequate Heating to Achieve Remedial Goals	In-Situ Temperature Monitoring Points	Temperature	Thermocouples, Fiber Optic DTS	Type K Thermocouples +/-2 deg C Range 0-150 deg C (higher for TCH 0-400 deg C)	Daily During Heat Up, Longer Intervals Once Target Tempera-tures Reached

Media	Technology	Monitoring Objective	Monitoring Activity / Characteristic	Data Use	Monitoring Location	Analyte / Parameter	Monitoring Type / Method	Measurement Equipment, Sensitivity	Typical Monitoring Frequency
	All	Performance	Contaminant Removal	Determine Progress toward Soil Remediation Goals	Treatment Area, Locations Determined as Representa-tive	Contaminants of Concern	Grab Soil Samples, Laser-Induced Fluorescence Sensor, Others	Varies	Site Specific, Based on Required Heating Time and Observed Mass Recovery Rates
Utilities	All	Performance	Total Electrical Use	Verify Energy Use for Payment, System Operational Decisions	Main Electrical Drop	Kilowatts	Meter	Varies	Daily
	ERH, TCH	Performance	Electrical Input	Operational Decisions	Electrodes	Current Draw Voltage	Meter	Varies	Daily
	SEE	Performance	Water Consumption	Operational Decisions	Make-Up Water Supply Header	Total Quantity Provided	Meter	+/-5%	Daily
	SEE	Performance	Fuel Consumption	Operational Decisions	Fuel Supply to Boiler	Total Quantity Fuel Flow Rate	Meter with Totalizer	Varies	Daily
Other	All	Compliance	Noise Monitoring	Verify that Noise Levels are not Objectionable	Site Perimeter, Adjacent Community	Noise (db)	Type 1 Sound Level Meter	+/-1 dBA 30-100 dBA	As Needed at Start of Operations
Spent Carbon	All (if carbon is used in vapor or liquid treatment)	Compliance	Waste Disposal Characterization	Determine Proper Disposal of NAPL	Carbon Vessels	Contaminant Concentrations, Other Parameters as Required by Disposal Facility	Grab Sample	Varies	As Needed for Disposal
Spent Filters	All (if carbon is used in vapor or liquid treatment)	Compliance	Waste Disposal Characterization	Determine Proper Disposal of NAPL	Storage Drums	Contaminant Concentrations, Other Parameters as Required by Disposal Facility	Extraction from Filter	Varies	As Needed for Disposal
Other	ERH	Compliance	Surface Voltage	Safety, Verify No Stray Voltages	Various Locations in and near Treatment Area, Especially Exposed Metal Surfaces	Voltage	Meter	Various Ranges from 0-20 to 0-200V	At Start-up and After Changes in the Active Electrode Array