Deployment Issues for Sensors for Long-Term Monitoring Applications

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Abstract: Low cost, robust sensors are needed for remote, in situ monitoring of contaminants; verification of remedial actions; and monitoring the integrity of landfill covers or other indicators of potential stewardship failures in a variety of media. Subsurface sensing targets include contaminants (organics, metals, radionuclides), diagnostic parameters (dissolved oxygen, etc.), water quality indicators (salinity, pH, Eh, oxidation-reduction potential, etc.), soil characteristics (matric potential, moisture content, etc.), and radiation levels. Some commercially available sensors can meet the general functional requirements for sensing these parameters in soil or groundwater, but are not suited to remote, in situ operation with automated data transmission. Site-specific constraints, such as the size of a borehole or depth to the water table, are the chief obstacles to the deployment of existing sensors. Harsh operating conditions and variable contaminant levels also present challenges for the deployment and operation of sensors for long-term monitoring (LTM) applications. This paper discusses sensor deployment and emplacement issues, sensor requirements and selection criteria, integration of multiple sensors, electronics and communications interfaces, monitoring networks, and transmission of sensor data by telemetry.

The LTM system consists of: 1) a sensor package with one or more microsensors, 2) data acquisition, processing, and data storage components, 3) a power source, and 4) electronic signal processing equipment and telemetry. The miniaturized sensor package is deployed below ground, while the data logger, computer, electronics, and communications interfaces are located above ground in a weatherproof enclosure. When more than one contaminant needs to be measured, the output from a suite of sensors needs to be integrated into a commercially available data storage or logging device and all the data needs to be accessible through a single industry standard data interface program. For instance, monitoring of a RCRA landfill may require many sensors operating in the same well (volatile organic compounds (VOCs), pH, specific conductance, total organic carbon, total organic halogens, etc.).

When selecting sensors for a given application, factors such as measurement frequency, sensitivity, selectivity, depth of deployment, and life cycle cost must be considered. Additionally, real-time, continuous operation or the ability to take periodic measurements may be needed. Customer, regulatory, and stakeholder requirements, from which the critical sub-set of performance, functional, and/or constraining requirements are derived, determine the sensor performance characteristics and impose constraints upon the operation and emplacement of the sensor packages. The sensors must be sensitive enough to meet detection limits required by State and Federal regulators. Instruments designed for other applications (such as, characterization of high-level waste) may not have the required sensitivity to detect contaminants at the ppb or ppt level and usually require a trained operator and frequent calibration. In certain instances, the sensor must have the ability to respond rapidly to changing conditions and distinguish between valence states (i.e., Cr-III vs. Cr-VI), a large dynamic range (up to several orders of magnitude depending upon analyte), few or no chemical interferences, the ability to detect low concentrations of constituents of interest in a difficult or varied solution matrix, non-contact

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detection, etc. The depth of deployment is an issue because the length of coaxial cables or fiber optics required to reach groundwater could cause signal degradation, especially in the western U.S. where the depth to the water table may be more than 500 ft at some sites. In such cases, a signal booster may be necessary. The costs of equipment (sensors, data loggers, telemetry system, etc.), installation, operation and maintenance, data collection, and data transfer for the LTM system must provide a cost savings over traditional monitoring schemes such as periodic manual sampling, laboratory analysis, and disposal of investigation-derived waste. The higher initial start-up cost of installing a sensor system needs to be balanced against the potential long term cost savings based on the life-expectancy of the LTM sensor system. If the site is heavily contaminated, Environmental, Safety and Health issues will impact the installation cost of the sensor system.

The sensor package must have the ability to withstand harsh environments and provide reliable data over the expected range of environmental conditions and events, including temperature, radiation, pH, humidity, lightning strikes, etc. For example, the operating temperature range in the vadose zone is -20°C to 45°C, for groundwater it is -2°C to 30°C, and for instrumentation above ground it is -45°C to 150°C. How long the sensor will last in corrosive media or in harsh chemical or high radiation environments is a key concern. In such instances, the sensor(s) may need to be sealed within an inert package and should be capable of maintaining functionality, calibration, and accuracy for years without replacement or repair, since the sensors are intended to be left in place for extended periods with little or no maintenance. Smart sensors can serve as sentinels to trigger an alarm if a threshold value is exceeded or a sensor malfunction is detected. In the event of a sensor malfunction, the sensor should be retractable for servicing or replacement.

The sensor package must operate remotely with data stored and downloaded by telemetry to a centrally located processing station. The remoteness and topology of the waste sites can cause power supply and communication problems; inasmuch, radio frequency communications interference issues are site-specific. The sensor package should have low power requirements, with power provided by batteries or a renewable energy source, such as solar power, for remote site monitoring. A stable and reliable power source must be available for the telemetry system to ensure the transmission covers the expected distances for deployment.

The physical size requirements for sensors are determined by the available methods of sensor emplacement. For subsurface monitoring using existing boreholes or monitoring wells, the sensor package should typically have a diameter of less than 4 inches, and in some cases, less than 2 inches. Length should be less than 4 feet to allow for discreet interval monitoring in wells. For vadose zone monitoring, sensor configurations need to be shorter than a foot. For new boreholes, the diameter of the sensor package is limited to inside diameter of emplacement technique (e.g., direct push). It must be ensured that the sensor package is protected from mechanical damage or vibration during insertion and positioned at the correct depth.

Regulatory acceptance of the data generated by LTM sensors is critical to their utilization. If the sensors deployed are new and comparative data is lacking, field testing is essential prior to full-scale deployment for all interested parties to evaluate the acceptability of the data. Data obtained from sensors deployed for LTM of VOCs, metals, or radionuclides must be compared to data derived using currently accepted methodologies. During the sensor verification period, the sensor package may be placed in a well in addition to a pump for manual sampling with subsequent laboratory analysis. In addition to providing data to comply with regulatory requirements, in situ sensors would provide timely information to support decision-making for fate and transport modeling, risk assessment, and to aid in evaluation of the monitoring strategy.

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General References:

1. From Cleanup to Stewardship, DOE/EM-0466, U.S. Department of Energy, Office of Environmental Management, October 1999.
2. Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites, National Research Council, National Academy Press, Washington, DC, 2000.
3. A Report to Congress on Long-Term Stewardship, U.S. Department of Energy, Office of Environmental Management, Office of Long Term Stewardship, DOE/EM-0563, Washington, DC, January 2001.
4. Characterization, Monitoring, and Sensor Technology Crosscutting Program, Technology Summary, Fiscal Year 2000, Office of Science and Technology, Office of Environmental Management, U.S. Department of Energy.
5. Research Needs in Subsurface Science, National Research Council, National Academy Press, Washington, DC, 2000.
6. U.S. EPA, Subsurface Remediation: Improving Long-Term Monitoring and Remedial Systems Performance, Conference Proceedings, EPA/542/B-00/002, St. Louis, Missouri, June 8-11, 1999.
7. U.S. EPA, Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, Office of Solid Waste and Emergency Response, OSWER Directive 9200.4-17P, April 21, 1999.
8. Blanchard, B.S., System Engineering Management, John Wiley & Sons, New York, 1998.
9. Fayer, M.J., and Gee, G.W., "Hydrologic Model Tests for Landfill Covers using Field Data," in Landfill Capping in the Semi-Arid West: Problems, Perspectives, and Solutions, eds. T.D. Reynolds and R. C. Morris, ESRF-019, Env. Sci. Res. Foundation, Idaho Falls, Idaho, 1997.
10. The DOE Complex-Wide Vadose Zone Science & Technology Roadmap, U.S. Department of Energy, Preliminary Draft for External Review, September 25, 2000.
11. Looney, B.B., and Falta, R.W., Vadose Zone Science and Technology Solutions, Battelle Press, 2000.