ABSTRACTS

Interagency Workshop on Monitoring for Early Detection of Underground Leaks at Nuclear Facilities

Underground Piping and Tanks Integrity Initiative

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The nuclear power industries Buried Pipe Integrity initiative will be described. The goal of the program is reasonable assurance of structural and leakage integrity of in-scope piping and tanks with special emphasis on components containing licensed material. Information will be presented on the principal buried systems of nuclear power plants and a summary of the leaks that have occurred in different systems. Observations of causes of these leaks, the materials involved, and their recent frequency will be discussed.

Key Concepts for Early Leak Detection and Technical Questions

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Early detection of leaks from nuclear facilities could provide substantial benefits if leaks are detected close to structures, systems and components before fluid reaches the water table. Methods that may be useful for early leak detection have been briefly described and evaluated in a draft NRC white paper entitled: *Monitoring for Subsurface Leaks at Nuclear Power Plants: External to Structures*. We have focused on detection and distribution of moisture and tritium but other parameters such as conductivity and temperature are also important. Some moisture sensors that are commercially available and durable are able to interrogate small soil volumes (about 1 liter) but could be arranged in arrays to attain greater volumes. Others, such as continuous downhole neutron probe moisture measurements interrogate a greater volume (e.g. several cubic meters) but are limited to soil borings. Other methods, primarily geophysical, can assess electrical properties from which moisture distributions, conductivity, and temperatures may be determined. These methods can interrogate large volumes of the subsurface, hundreds to thousands of cubic meters. Real-time downhole beta detection and tritium in soil vapor were also described. The practicality of using these methods in the environment of different nuclear facilities will be the focus of this workshop and will be valuable input to the final white paper and to NRCs Long-Term Research Program.

Soil Physics of Leak Detection using Geoelectrical Methods

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Electrical geophysical methods are sensitive to changes in pore fluid composition and moisture content of porous media. These methods therefore offer opportunities for imaging and monitoring of leaks from storage and containment facilities. The direct detection of an existing leak from a single resistivity survey may be complicated by the fact that electrical resistivity is a property that depends on multiple chemical and physical properties of a soil. However, the monitoring of time-lapse changes in resistivity associated with the transport of leaking fluids is likely to provide more confirmatory evidence of a leak. In theory, it may also be possible to estimate leak volumes or concentrations of a constituent in the leak from petrophysical relations relating resistivity to moisture content and/or chemical composition of the pore fluid. However, such petrophysical relations are inherently uncertain and likely to be spatially variable. Therefore, the transformation of resistivity to quantitative descriptors of the leak composition should be treated with caution. Despite these limitations, numerous successful applications of the detection of leaks from landfills and chemical storage facilities have been documented in the geophysical literature. These examples offer insights into the potential for electrical geophysical methods for monitoring and early detection of underground leaks at nuclear facilities.
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Industrial Applications of Real-Time Electrical Monitoring

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The three main objectives for leak detection and monitoring are to determine onset, rate, and location. The electrical resistivity geophysical method has been shown to be the most promising in meeting these objectives, because resistivity is highly sensitive to changes in saturation and concentration of ionic constituents. Unfortunately, resistivity cannot be directly measured and instead requires it to be indirectly determined by 1) electrical current transmitted into the earth to create an electrical field, 2) voltage measured at multiple locations, and 3) the resulting dataset inverse modeled to create the spatial distribution of resistivity over the domain. In our work, we have shown that all three steps can be used to address the leak detection objectives, provided sufficient temporal detail exist to discern minute changes in any measurement. Additionally, the electrical current and voltage data can be evaluated in real-time to help reduce time in determining the leak parameters. We showcase a couple of leak detection examples from mining and nuclear industries, where infrastructure and sources of noise are prevalent. Lastly, we provide information on the long term leak detection program in place at Hanford to monitor underground waste storage tanks. www.hgiworld.com

3D time-lapse electrical resistivity imaging: Field examples and application potential for leak detection at industrial sites

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Recent developments in autonomous, multi-channel electrical resistivity data collection hardware have enabled monitoring of subsurface processes with high resolution in space and time in terms of the bulk electrical conductivity alterations governed by those processes . We give several examples of how 3D time-lapse electrical resistivity tomography (ERT) has been successfully used to monitor a variety of subsurface processes including surface infiltration, groundwater-river water interaction, subsurface bioremediation, and subsurface desiccation. ERT monitoring also has potential for imaging changes in subsurface conductivity caused by leaking infrastructure within industrial environments. However, this application is problematic due to the deleterious influence infrastructure has on ERT measurements, which is usually referred to as 'noise'. In this talk we investigate the influence electrically conductive buried pipes have on ERT data. We show that in the presence of pipes and under typical conditions, ERT data are likely to be sensitive to leak induced changes in subsurface bulk conductivity, and therefore can be used to image leaks with the appropriate modeling approach. We then show how typical ERT imaging algorithms break down in the presence of infrastructure because they are not designed to accommodate the sharp electrical conductivity contrasts in both space and magnitude arising from electrically conductive infrastructure. We show with a synthetic example how this problem may be rectified by explicitly modeling the infrastructure and allowing for sharp contrasts within the imaging algorithm. Finally I discuss computational requirements of such an approach and the corresponding feasibility in commercial applications.
https://inlportal.inl.gov/portal/server.pt/community/inl_science_focus_area_project/700/sensing

Fiber-Optic Distributed Temperature Sensing:
Theory and Application to Monitoring Problems

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Fiber-optic distributed temperature sensing (FODTS) is an emerging technology with potential for diverse applications in hydrology, petroleum geoscience, reservoir management, and geotechnical and environmental engineering. Depending on instrument settings, FODTS can measure temperature at high spatial resolution (~1 m), high precision (~0.1 degree Celsius), and high frequency (about every minute) along cables up to several kilometers long. Higher resolution, precision, and frequency are possible using specialized cables and (or) instrumentation or setting tradeoffs between resolution, precision and sampling frequency.

Laser light is transmitted down one or more fiber-optic cables and backscatter is analyzed to estimate temperature all along the cables. Although FODTS technology has been commercially available for over a decade, recent decreases in instrument costs and expansion of capabilities have led to much wider use. Common applications include studies of groundwater/surface-water exchange, snowpack monitoring, dam/levee seepage, and leak detection in pipelines. This presentation reviews FODTS technology, instrument capabilities, case-study applications, and potential for monitoring leaks at nuclear power plants and associated infrastructure.

http://water.usgs.gov/ogw/bgas/fiber-optics/waquoit.html

Finding Leaks Using Hydrogeophysical Data and Numerical Models

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Geophysical methods are capable of providing high-resolution images of a specific geophysical attribute of the subsurface, which may reflect spatially variable, but stagnant geological features, time-dependent changes in fluid content and fluid properties, or a combination thereof. To successfully use such images for leak detection and specifically for predicting the system behavior in support of risk assessment, it is essential (1) to unravel the various factors that contribute to the variations in the geophysical attribute, (2) to relate the geophysical attributes to hydrogeological properties that affect flow and transport, and (3) to reduce ambiguities, non-uniqueness, instabilities, and other inversion artifacts. These issues are typically resolved (in part) by choosing an appropriate geophysical method with optimized measurement configuration, inverting the data using regularization techniques, and eventually transferring the geophysical image to a hydrogeological model using some petrophysical relationship. This approach can be enhanced by performing a joint inversion of geophysical and hydrogeological data using a flow and transport simulator that is coupled to a geophysical forward code within an optimization framework. The main contribution of hydrogeological modeling is that (1) additional data can be included to constrain the inverse problem, (2) regularization is based on physical rather than somewhat arbitrary geometrical criteria, and (3) the parameters determined are more directly related to features and processes that are of interest for leak detection and ultimate contaminant transport prediction. We will discuss the role that flow and transport simulations may play for early detection of underground leaks at nuclear facilities, and the advantages and limitations of a joint hydrological-geophysical approach for characterization of the subsurface and monitoring of contaminant movement.

Assessing the Likely Value of Geophysical Data

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Geophysical methods offer unprecedented opportunities to image subsurface structures and to monitor temporal changes in property distributions. The methods range in their resolution, coverage, and sensitivity. But, all are subject to limitations due to their indirect nature. A previous talk highlighted the importance of understanding and defining petrophysical relationships and properties. Others have shown the importance of selecting a geophysical method that is sensitive to processes of interest and then designing a survey to make the best use of the instrument's spatial sensitivity. Finally, we have heard about the value of combining process- and geophysical instrument-models to perform coupled hydrogeophysical interpretation. In particular, we have seen the value of added context that results from interpreting direct and geophysical data in a common framework. All of these concepts and approaches must be considered when designing monitoring networks for specific applications. I will present an approach that allows for assessment of the likely value of proposed direct and indirect (geophysical) measurements in the context of all known site information and in the context of user-defined cost or risk functions. We refer to the approach as the Discrimination/Inference to Reduced Expected Cost Technique (DIRECT). I will present a simple contaminant treatment example in the talk in the hopes that it will be useful for the general discussion of designing monitoring networks.
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EPRI Project on Advanced Technologies for Groundwater Protection: Automatic Tools and In-Situ Sensors for Groundwater Monitoring

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In 2011 the Electric Power Research Institute investigated technologies for the automatic and in-situ detection of groundwater contamination in monitoring wells. Such an automatic technology would facilitate the early detection of groundwater contamination. EPRI assessed the state of science and technology for detecting radiological and non-radiological (e.g. chemical and physical parameters) signatures in groundwater to identify technologies that would be applicable to nuclear power plant implementation. These technologies were assessed for their maturity, ability to detect tritium at levels typically found in the environment and at nuclear power plants, ability to detect non-radiological signatures that can be correlated to a potential leak or spill, and the functional capabilities of the technology. The results of this study will be documented in an EPRI Technical Report.

Sensors for Tritium Detection

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The presentation covers the state-of-the-art measurement techniques for detecting tritium in underground water at a nuclear power plant. Routinely used sampling techniques and the need of a real-time continuous monitoring system are discussed. Recent developments in sensor and sensing technique for tritium detection are also highlighted and future research needs are suggested.