Low-Cost Instrument for Long-Term Monitoring of Hazardous Contaminants in Drinking Water

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Problem Statement

The Environmental Protection Agency (EPA), along with other agencies throughout the government including the Department of Homeland Security, is undertaking significant efforts to protect United States citizens and the environment against terrorist threats. Following the events of September 11, 2001, improved technologies are needed to detect acts of terrorism and contain and respond to the subsequent public safety hazards. Specifically, the EPA needs technologies and instruments to detect, measure, monitor and warn of the presence of toxic contaminants in drinking water. Chemical contaminants of concern to the EPA include pesticides, toxic industrial chemicals, chemical warfare agents, and persistent bioaccumulative toxins, both metal-based (e.g., mercury) and organic-based (e.g., polychlorinated biphenyls, or PCBs). An innovative technology that could detect, identify, and localize hazardous contaminants in drinking water would be immensely valuable to water utility operators, emergency response personnel, and other decision-making officials charged with protecting the nation's water supply.

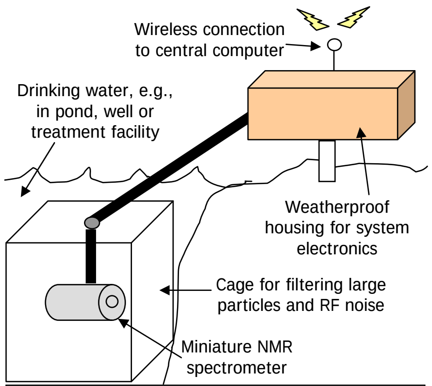

Figure 1. Schematic of prototype NMR-based remote drinking water monitoring instrument.

Technology Description

RMD proposes to design and build a miniature, permanent magnet-based nuclear magnetic resonance (NMR) spectrometer with unprecedented capabilities, which can be lowered into drinking water system components (i.e., water collection, pretreatment, treatment, storage, and distribution systems) (**Figure 1**). NMR utilizes the same technologies as those used to scan the human body in clinical magnetic resonance imaging (MRI) machines, and uses no harmful radiation (**Figure 2**). NMR proton spectra will provide continuous and precise monitoring of the water concentration of hazardous chemical contaminants such as PCBs, as well as toxic industrial byproducts including chlorinated hydrocarbons such as carbon tetrachloride and trichloroethylene, in addition to many other hazardous compounds detectable by NMR. Presence of metal-based toxins in the water can be detected by monitoring the transverse and longitudinal relaxation rates of the water proton signal. A major advantage of this technical approach is that because it is NMR-based, **any number of chemical compounds can be simultaneously monitored without modification to the hardware or software**. The device will continually measure the proton NMR spectrum of the water in which it is immersed. Peaks in the water spectrum will be digitally compared against standard proton NMR spectra, stored in the device's database, of the hazardous compounds of interest and concern to the EPA and local water management authorities. The comparison will be done completely automatically via a computer algorithm, with no user intervention, and will provide the local drinking water concentration of any toxic contaminants detected by the device. Furthermore, changes in water relaxation times can be automatically monitored to detect the presence of metal-based toxins in the water.

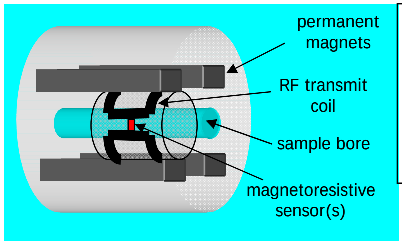

Figure 2. Detailed schematic of NMR spectrometer. Permanent magnets will provide a strong, homogeneous static magnetic field. A central cylindrical bore in the outer housing will fill with water and serve as a sample region. The NMR signal, affording identification of hazardous chemical contaminants in the water, will be detected by very sensitive magnetoresistive devices.

Expected Results

The Phase I research will establish the feasibility of an envisioned NMR-based water monitoring prototype, to be developed in Phase II. We will establish feasibility by building a bench top NMR spectrometer to experimentally determine the system parameters, including optimal magnetic field strength and optimal magnetoresistive sensor design, necessary to detect traces of hazardous chemical compounds in water.

Relevant system parameters to be determined for a Phase II device will include:

- Optimal static magnetic field
- Optimal design for magnetoresistive sensor
- RF power needed
- RF pulse sequence timing and number of echoes
- Optimal water suppression method
- Total acquisition time required for reliable detection of chemical contaminants
- Minimum detectable concentration of various contaminants
- Total power required for Phase II system electronics
- Total projected weight of Phase II instrument
- Projected size of Phase II instrument

Once the parameters are established, we will be able to definitively ascertain, based on Phase I experimental data, the feasibility of designing and building in Phase II a working NMR-based prototype for monitoring drinking water systems and alerting authorities in case of terrorist acts against the water supply. The prototype will be capable of unparalleled capabilities in long-term monitoring of drinking water contaminants at very low cost. The device would directly benefit the ongoing efforts of the federal government to develop and implement systems that support homeland security.

Potential Environmental Benefits

The proposed work is responsive to EPA's stated need for long-term monitoring of drinking water and wastewater to detect hazardous chemical contaminants that result from acts of terrorism. The ability of the device to simultaneously monitor any number of hazardous organic and inorganic compounds, along with its low-cost, portability, and remote and networking capabilities, makes it eminently suitable as a first-line sentry against terrorist attacks on municipal water supplies. A number of these low-cost systems, wirelessly connected to a central computer, can be deployed at various strategic sites within a drinking water system such as a water treatment facility. **Time-sequenced maps of contaminant concentrations, overlaid on a facility map, can serve to pinpoint any source of contaminant release within the facility, affording timely information to alert emergency response personnel.** The networked system can also be used to provide hazardous compound concentration maps that would provide visualization and monitoring of contamination remediation efforts. A networked system is superior to periodic manual sampling at multiple locations in terms of human resources and timeliness of results.

The great versatility of the envisioned Phase II prototype imbues it with enormous potential for applications outside the specific EPA need addressed in this work. The research and development efforts of Phase I and II would benefit the larger context of safe water under non-threat situations. The prototype would find many applications within the commercial sector such as within the petroleum industry as an oil well-logging device to precisely measure relative oil, water, and mineral concentrations in extraction wells. In addition, the device could be used to monitor water or other contaminant infiltration into petroleum storage facilities. It would also find utility in the construction industry as a means of surveying groundwater at prospective sites for toxins that could make the site unsuitable for residential housing or other building construction, and could monitor those construction sites for possible contamination due to building activities. Finally, the instrument would find numerous monitoring applications within the agricultural sector and food industry; for example, the device could be placed in milk pipelines and storage tanks to continuously screen for foreign substances, providing a vital safeguard for the nation's public health.

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