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2011 FLC Interagency Partnership Award
Section A – Contact Information

NOMINEE #1 INFORMATION

Name: Dr. Sean A. McKenna

Title: Distinguished Member of the Technical Staff

Organization: Sandia National Laboratories, National Security Applications

Address: PO Box 5800 MS-0751

City: Albuquerque **State: New Mexico** **Zip: 87185-0751**

Phone: 505-844-2450 **Fax: 505-844-0735** **E-mail address: samcken@sandia.gov**

NOMINEE #2 INFORMATION

Name: Mr. David Hart

Title: Member of the Technical Staff

Organization: Sandia National Laboratories, National Security Applications

Address: PO Box 5800 MS-0751

City: Albuquerque **State: New Mexico** **Zip: 87185-0751**

Phone:505-844-4674 **Fax: 505-844-7354** **E-mail address: dbhart@sandia.gov**

NOMINATOR INFORMATION

Name: Ms. Jackie Kerby-Moore

Title: Manager, Technology & Economic Development Department

Organization: Sandia National Laboratories

Address: P.O. Box 5800/1515 Eubank Blvd. SE (87123)

City: Albuquerque **State: New Mexico** **Zip: 87185-1495**

Phone: 505-845-8107 **Fax: 505-844-1389** **E-mail address: jskerby@sandia.gov**

NOMINEE #3 INFORMATION

Name: Ms. Katherine Klise

Title: Senior Member of the Technical Staff

Organization: Sandia National Laboratories, national Security Applications

Address: PO Box 5800 MS-0751

City: Albuquerque State: New Mexico Zip: 87185-0751

Phone: 505-284-4456 Fax: 505-844-7354 E-mail address: kaklise@sandia.gov

NOMINEE #4 INFORMATION

Name: Dr. Eric Vugrin

Title: Principal Member of the Technical Staff

Organization: Sandia National Laboratories, Infrastructure and Economic Systems

Address: PO Box 5800 MS-1138

City: Albuquerque State: New Mexico Zip: 87185-1138

Phone: 505-284-8494 Fax: 505-284-3850 E-mail address: edvugri@sandia.gov

NOMINEE #5 INFORMATION

Name: Dr. Mark W. Koch

Title: Principal Member of the Technical Staff

Organization: Sandia National Laboratories, Sensor Exploitation Appliances Dept.

Address: PO Box 5800 MS-1163

City: Albuquerque State: New Mexico Zip: 87185-1163

Phone: 505-844-4731 Fax: 505-844-4157 E-mail address: mwkoch@sandia.gov

NOMINEE #6 INFORMATION

Name: Dr. Shawn Martin

Title: Senior Member Technical Staff

Organization: Sandia National Laboratories, Computer Software Rsrch/Dvlpmnt

Address: PO Box 5800 MS-1318

City: Albuquerque State: New Mexico Zip: 87185-1318

Phone: 505-284-3601 **Fax: 505-845-7442** **E-mail address: smartin@sandia.gov**

NOMINEE #7 INFORMATION

Name: Dr. William E. hart

Title: Distinguished Member of the Technical Staff

Organization: Sandia National Laboratories, Computer Software Rsrch/Dvlpmnt

Address: PO Box 5800 MS-1318

City: Albuquerque **State: New Mexico** **Zip: 87185-1318**

Phone: 505-844-2217 **Fax: 505-845-7742** **E-mail address: wehart@sandia.gov**

NOMINEE #8 INFORMATION

Name: Dr. Regan Murray

Title: Mathematical Statistician Protection Agency

Organization: U.S. Environmental Protection Agency

Address: 26 W. Martin Luther King Dr. (NG 16)

City: Cincinnati **State: Ohio** **Zip: 45268**

Phone: 513-569-7031 **Fax: 513-487-2559** **E-mail address: Murray.Regan@epa.gov**

NOMINEE #9 INFORMATION

Name: Dr. Terranna Haxton

Title: Environmental Engineer

Organization: U.S. Environmental Protection Agency

Address: 26 W. Martin Luther King Dr. (NG 16)

City: Cincinnati **State: Ohio** **Zip: 45268**

Phone: 513-569-7810 **Fax: 513-487-2559** **E-mail address: Haxton.Terra@epa.gov**

NOMINEE #10 INFORMATION

Name: Mr. John Hall

Title: Physical Scientist

Organization: U.S. Environmental Protection Agency

Address: 26 W. Martin Luther King Dr. (NG 16)

City: Cincinnati **State: Ohio** **Zip: 45268**

Phone: 513-487-2814 **Fax: 513-487-2559** **E-mail address: Hall.John@epa.gov**

NOMINEE #11 INFORMATION

Name: Ms. Katie Umberg

Title: Physical Scientist

Organization: U.S. Environmental Protection Agency

Address: 26 W. Martin Luther King Dr. (MS 140)

City: Cincinnati **State: Ohio** **Zip: 45268**

Phone: 513-569-7925 **Fax: 513-569-7191** **E-mail address: Umberg.Katie@epa.gov**

2011 FLC Interagency Partnership Award
Section B – Nomination Narrative

CANARY: Event Detection Software

Joint Effort of Sandia National Laboratories & the U.S. Environmental Protection Agency

Product's Primary Function

Rapid and accurate detection of contamination incidents in drinking water is critical for notifying consumers of threats and risks to public health and for making remediation and recovery decisions. Sandia National Laboratories (SNL) and the United States Environmental Protection Agency (EPA) developed the CANARY software to enable online event detection and time-critical decision making in both routine and emergency water quality assessments. CANARY is available under an open-source license to drinking water utilities of all sizes worldwide striving to provide the best quality water to their customers. Earlier this year, R&D Magazine selected CANARY as one of the winners of its prestigious **R&D 100 Award**.

CANARY is a software package that performs on-line, multivariate, event detection from networked sensor data. Employing statistical forecasting and classification algorithms, CANARY continuously analyzes time series signals for anomalous conditions. By combining standard statistical methods in an innovative framework, noisy data are filtered to accurately identify anomalous events while minimizing false positive detections. Through testing on data from partner water utilities and a two-year pilot study, CANARY has been shown to be effective and its performance has been documented. The software is compatible with any sensor technology or information technology platform, and can be easily modified for specific applications. In contrast to proprietary systems, CANARY provides the end-user with transparency in the algorithms and their parameterization, and also facilitates integration of operational information, all of which are important for utility-specific customization. In addition to achieving homeland security goals, CANARY can be used to enhance day-to-day water quality management. Development of CANARY has focused on providing enhanced monitoring of water quality within distribution networks; however, its capabilities are general and applications of CANARY to other online event detection applications are being pursued.

CANARY provides a user-friendly and fully customizable event detection capability that has been developed with extensive feedback from the end-user utility operators. To leverage existing investments in water quality monitoring, CANARY is able to connect with common existing data formats and SCADA databases as well as work with water quality sensors from a wide variety of manufacturers.

The Need for Water Security

Continuous, reliable delivery of safe drinking water to customers is essential to the sustainability of large metropolitan areas, and the distribution networks used to deliver water are a critical component of municipal infrastructure systems. The scale, diversity, and complexity of these networks render them susceptible to accidental and intentional contamination events. The potentially high public health and economic consequences of such events have focused recent research on strategies to make distribution systems robust against contamination. The concept of a contamination warning system (CWS) has been proposed as an integrated tool that employs *in situ* sensors, supervisory control and data acquisition (SCADA) systems, and water quality event detection systems (EDS) to continuously monitor network conditions and warn operations personnel of potential contamination events.

Issued in December, 2003, and January, 2004, Homeland Security Presidential Directives 7 and 9 (HSPD-7, HSPD- 9) establish a national policy for Federal departments and agencies to identify and prioritize critical infrastructure for protection against terrorist attacks, including a mandate to "…develop robust, comprehensive, and fully coordinated surveillance and monitoring systems for…water quality that provides early detection and awareness of disease, pest, or poisonous agents."

A major challenge for water security is the ability to rapidly and reliably detect the presence of contaminants in drinking water distribution systems. To date, large investments in contaminant-specific sensors utilizing micro and nano technologies have not yet demonstrated the engineering reliability necessary for continuous 24/7 monitoring of water in the ambient conditions of municipal distribution systems. In contrast, the installation of commercial, off-the-shelf water quality sensors (e.g., pH, residual chlorine, specific conductivity, etc.) within distribution networks has expanded. Controlled testing of chemical and biological contaminants injected into pipe

loops at EPA's Test and Evaluation Facility demonstrated that for all contaminants tested, at least one water quality sensor responded to the introduction of the contaminant. These results demonstrated that a suite of commercially available off-the-shelf water quality sensors could provide broad-based indication of contamination events in a water distribution system. Injection of less than 1.0 parts per million of a chemical contaminant into a pipe were identified by CANARY in conjunction with these sensors. Event detection in real-world situations presents challenges including reliable recognition of signals above noisy backgrounds, effective integration of changes in the hydraulic operations that impact water quality, and flexibility in connecting to existing SCADA systems with a wide variety of sensor hardware and database software. CANARY has been developed to meet these challenges.

Key Innovations: Limiting False Alarms

Event detection for drinking water, as well as in other security-focused monitoring applications, is a prototypical case of searching for high-consequence events that have a low probability of occurrence. A perfect EDS would have the sensitivity to detect all events (no false negatives) as well as the specificity to alarm only on water quality changes that are due to true events (no false positives). A challenge to achieving this goal of a perfect EDS in water distribution systems are the noisy data associated with in-situ monitoring of complex infrastructure and significant water quality changes caused by hydraulic operations of the network (e.g., valves opening and closing, pumps starting and stopping, changes in flows).

Customized algorithms have been developed for filtering noisy data including a binomial event discriminator (BED) algorithm that applies statistical reliability concepts to the chances of any measurement not being representative of background conditions. Extensive interaction with utilities has led the CANARY team to a deeper understanding of how operational changes can impact water quality and the importance of integrating operational signals into event detection. In addition to a binomial event discriminator (BED) algorithm that integrates results over multiple time steps, two innovative approaches to reducing false positives associated with hydraulic operational changes are available within CANARY. These approaches – composite signals and trajectory clustering - can integrate operational data directly into the water quality event detection process. Competing technologies are focused solely on water quality signals and do not access additional data from the SCADA systems and therefore cannot capitalize on the additional information contained in operational data.

A series of embedded graphical editors facilitate user-based selection and parameterization of the algorithms, as well as the creation and editing of pattern libraries and the generation of graphics illustrating event detection results. CANARY leverages existing investments by connecting to a utility's SCADA database either directly or through third-party software, providing alerts to the system operator when significant water quality changes are detected.

CANARY Impact and Dual-Use Benefits

CANARY is being used today in a number of large utilities around the US including Cincinnati, Philadelphia and the Metropolitan Water District of Southern California, the world's largest water utility. Additionally, CANARY is running on the Singapore national water distribution system. Additionally, other metropolitan water utilities in the US are evaluating CANARY as part of EPA's Water Security Initiative, which is being rolled out to utilities nationwide. There are more than 50,000 community water systems in the U. S., all potential users of CANARY. Additionally, multiple software vendors, both US and foreign, are interested in extending their existing products to integrate CANARY capability.

The public health and economic impacts of a water contamination event are significant and real. As an example, the 1993 *Cryptosporidium* incident in Milwaukee, Wisconsin was the largest known outbreak of waterborne disease in US history. More than 400,000 people were infected, which resulted in over 4,400 hospitalizations and at least 69 deaths. The total cost of this outbreak-associated illness was $96.2 million. With CANARY in place, such an event would be detected earlier, resulting in fewer illnesses and deaths. U.S. EPA analyses estimate that CWS's developed for water utilities participating in the EPA's Threat Ensemble Vulnerability Assessment (TEVA) Research Program could reduce expected fatalities by 48% and associated economic consequences by over $19 billion. This analysis assumes that water quality sensor data can be analyzed with CANARY to reliably detect contaminants.

In addition to water security concerns, water utilities are interested in the dual-use benefits of online event detection to improve management of their distribution networks. The growing number of installed online water quality sensors and their connection to SCADA systems has significantly expanded the amount of water quality data to the point where system operators and network analysts are "drowning in data." Online tools, such as CANARY, that can be customized to the specific water quality and operational data characteristics at a utility are needed to aid

operators in better managing their systems. Experience shows that as the online analysis capabilities of CANARY are explored, utility operators are able to improvements to system management.

Product Applications

The principal application for CANARY is real-time, online detection of anomalous water quality events, ranging from accidental introduction of poor quality water to intentional injection of chemical, biological, or radiological agents within municipal water distribution systems. This water security application is closely tied to improved management of the distribution network. The dual-use benefits of CANARY to assist operators in making sense of increasing amounts of online data and to provide better understanding of operational factors that alter water quality have made significant impacts within utilities using CANARY. These impacts include improved efficiency of utility operations as well as increased appreciation for the knowledge that can be extracted from data being collected within these networks. CANARY is written to be generally applicable to online event detection from multivariate time series data collected in noisy environments. Other applications being investigated include: Identification of anomalous periods in computer network traffic logs, geophysical logs in measurement while drilling systems and satellite telemetry.

Technology Transfer

The technology transfer model for CANARY is centered on accessibility to state-of-the-art event detection capabilities for any utility. The fundamental basis of this model is a public domain license allowing for free acquisition of the software. CANARY was licensed in the public domain in May of 2009. Furthermore CANARY is designed to leverage existing utility investments in SCADA systems and sensor hardware through centralized processing that only requires a single, standard desktop computer. Ease of access through the LGPL public domain license also benefits software development companies in two ways: 1) elements of CANARY can be integrated directly into commercial, proprietary systems; and 2) proprietary software designed to extend CANARY capabilities can be linked to CANARY as an add-on or a library as and remain proprietary as long as any associated changes to the core CANARY software remain in the public domain.

Support for utilities, contractors and software development companies are provided through a bi-monthly webinar series. Additionally, a web site containing software to download, extensive documentation, test problems and frequently asked questions now has more than 800 downloads from around the world). Under EPA sponsorship, the CANARY team also offers multi-day, hands-on workshops.

Interagency Partnership

Protection of the nation's drinking water systems from terrorist attacks is one of the primary responsibilities of the EPA. In 2002, EPA formed the National Homeland Security Research Center (NHSRC) to address the critical knowledge gaps in EPA's homeland security responsibilities. EPA developed a *Water Security Research and Technical Action Plan* outlining the research efforts needed to develop the tools and technology for preventing and mitigating the impacts of terrorist attacks on drinking water systems.

Sandia National Laboratories has long been focused on national security objectives and since the introduction of the Risk Assessment Methodology for Water in 1999 has been leading the Department of Energy's research efforts in water security. EPA and SNL began working together in 2003 through an Interagency Agreement to focus the combined skill sets and experiences of both organizations on addressing critical water security knowledge gaps. This interagency agreement provided the framework for a close working relationship and leveraged expertise at both Sandia and EPA. Sandia developed software with experimental data developed at the EPA test and evaluation facility. EPA managed the interface with pilot utilities and user groups (e.g., American Water Works Association) and distilled those interactions into direct feedback to Sandia to drive capability development and further improvements in the software. This partnership has been truly collaborative involving expertise and resources from both Agencies. In addition, the project has relied upon outside stakeholders to ensure that the CANARY software satisfied the needs of the users and the water community as a whole. CANARY has filled a critical capability gap in the water sector, enabling water utilities to more rapidly and accurately detect contamination of drinking water.