Contract No. and Disclaimer:

Nanofluidics Revolution: Protecting the World One Drop at a Time

Principal Investigators: Adrián Méndez Torres[1], Poh-Sang Lam[1], Michael Bronikowski[1], Jay Gaillard[1], Paul Wach[2], Emily Wade[1], Guiren Wang[2], Stacey L. Lance[3], Olin E. (Gene) Rhodes, Jr.[3], and Jack C. Yu[4]

[1.] *Savannah River National Laboratory, Aiken, South Carolina 29808*

[2.] *Department of Mechanical Engineering, University of South Carolina, Columbia, South Carolina 29208*

[3.] *Savannah River Ecology Laboratory, University of Georgia, Aiken, South Carolina 29808*

[4.] *Department of Surgery, Medical College of Georgia, Georgia Health Sciences University, Augusta, Georgia 30912*

Scientists at the Savannah River National Laboratory (SRNL) in collaboration with the University of South Carolina are investigating a new measurement technique using nanofluidics for fast and easy verification of the presence of special nuclear material (SNM) in aqueous solutions. Research is specifically geared toward developing small-footprint high sensitivity lab-on-a-chip devices for the detection and separation of plutonium. It also laid the groundwork for developing ultra-sensitive sensors used in structural health monitoring system for *in situ*, noninterrupted detection of the leaching and migration of radionuclides outside the cementitious barriers for nuclear waste storage facilities. This innovative method has promise for the nuclear industry's processing technologies, environmental protection, and safeguards.

Nanofluidics is a technology that involves the transport of very small liquid samples, on the order of micro- or pico-liters, confined to nanoscale structures. The lab-on-a-chip device has a small portable footprint, on the order of a few square milli- or centimeters, and is usually made of glass with embedded nano- or micro-channels through which a fluid can flow across the chip. Depending on the size of the nanofluidics channels that are built into the chip, ionic selectivity can be controlled by dominant intermolecular forces that vary with the size of the nanochannel. The lab-on-a-chip technology with integrated spectroscopy, a field known as optofluidics, has a great potential for the future of SNM detection, and its feasibility lies in the systems portability, small sample size, and eliminated needs for optical alignment.

In the nuclear industry, Nanofluidics has the potential for use in plutonium tracking and monitoring in irradiated nuclear fuel (INF) reprocessing and mixed-oxide (MOX) fuel fabrication facilities. MOX fuel is a substitute for conventional low-enriched uranium fuel and is composed of oxides of plutonium and uranium that are natural, reprocessed or depleted. During the MOX fuel fabrication, plutonium is processed into a form that makes it less attractive due to proliferation concerns. This creates a need for a monitoring technique for aqueous polishing. It is also important to measure the plutonium ions during advanced fuel cycle reprocessing including conditioning, recycling, or removal of fissile material from INF. The ability to verify the plutonium content throughout aqueous processes will enhance material production and control technology. These analytical requirements can potentially be supported by the nanofluidics technology being studied at SRNL.

The nanofluidics technology explored at SRNL can be extended to detect a variety of radioactive isotopes. The ability to quickly detect the presence of such material in very small, droplet-sized liquid samples can also be used in environmental sampling. Advanced environmental sampling technology would be extremely useful in areas affected by nuclear incidents, such as the communities impacted by the Fukushima Daiichi nuclear disaster in Japan. Portable detection is important during the aftermath of such events where measurements can be performed *in situ* on groundwater samples and on agricultural products such as tea leaves, a major Japanese commodity. This allows for the detection and mitigation of possible radioactive contamination to protect the public. As part of this effort, SRNL is collaborating with Savannah River Ecological Laboratory (SREL) to develop high fidelity instrumentation based on nanofluidics devices for detection and speciation of metals and radionuclides within an ecosystem. Nanofluidics devices such as lab-on-a-chip can help with the infield verification of contaminants in an ecosystem, which is a key aspect to establish the fundamental connection between the environments and the human health risks.

From an international safeguards perspective, it is vital to protect nuclear facilities worldwide and ensure that certain materials are not being diverted to be used for proliferation activities. Currently, *in situ* measurement of SNM in liquid is challenging. New techniques are in demand to verify the presence or absence of SNM in processing, to rapidly analyze small samples, and to verify possible diversion methods. In response to the discovery of a clandestine nuclear program in Iraq, the International Atomic Energy Agency Board of Governors approved an Information Circular in 1997, creating an Additional Protocol that reinforces safeguards procedures with the goal of nonproliferation. These more stringent guidelines have led to a push for technological improvements in highly sensitive, efficient, and convenient methods for the detection of SNM.

Currently, the most reliable analytical method to aid in SNM control and accountancy is isotope dilution mass spectrometry (IDMS). This technique involves tedious procedures and requires highly skilled operators to separate the analyte from complicated matrices such as INF solutions. The process is also large-scale and costly. Another method to measure SNM is radiation detection, which is limited due to high background noise level in the presence of an amalgam of other radioisotopes, such as actinides and fission products, in the INF solutions. This complication leads to difficulties in lower level detection, noise discrimination, and self-shielding attenuation in the solutions due to process configurations, such as pipe volumes and distances.

Spectroscopic analysis for the detection of analytes within a liquid has been popular for decades and can provide high selectivity (to isolate detection signals of desired analytes) for lab-on-a-chip devices. Typical spectroscopic systems have large footprints which are not readily portable. Implementing a method for portable detection with a very small sample volume would be a significant advantage for nuclear safeguards, where detection procedures must be performed in the field. Furthermore, the spectroscopic system must be aligned to reduce interfering signals – a procedure which requires rigorous discipline and is time consuming.

In order to fabricate a portable optofluidic lab-on-a-chip, optical waveguides must be integrated directly into the chip in-plane with the fluidic channels. The waveguide facilitates delivery of the photon excitation beam to the adjacent liquid sample and the collection of the beam subsequently emitted from the sample. This architecture increases the efficiency of detection and eliminates the need for system alignment. Potentially, these portable optofluidic chips can be deployed easily to nuclear facilities around the world, and the analysis of the samples can be achieved rapidly to meet the safeguards requirements.

The experiments being conducted at SRNL will lead to innovative analytical techniques for rapid and simple confirmation of plutonium and other radioisotopes in aqueous solutions. The project goals are aimed at furthering nanofluidics development to produce portable and sensitive nanofluidic lab-on-a-chip instruments for the detection of nuclear materials in a wide variety of situations. Not only is this technology of paramount interest in the nuclear and anti-proliferation fields, but it also can be applied to many other fields, such as in the medical sciences, where a minute amount of substances in small liquid samples needs to be measured. As a resent discussion with the researchers at the Institute for Regenerative and Reparative Medicine at Georgia Health Sciences University, the fluid-structure interaction may be considered in fluidics to explain the Whole Body Vibration (WBV) test results with the murine samples, in which the serum glucose and inflammatory markers may be reduced. This treatment has a tremendous impact on the war against obesity worldwide. Meanwhile, fluidics technology may be used in soft tissue modification to prevent and cure pressure ulceration, which also has a major economic impact in caring the elderly and paralyzed patients. In deep space exploration, the U.S. National Aeronautics and Space Administration (NASA) has initiated research in electrokinetic pumping in near weightless environments using micro/nano fluidics principles to eliminate the mechanical parts and the fluid transfer momentum. This emerging technology will lead to endless opportunities in Nuclear Energy, Environmental Management, National Security, Nuclear Waste Management, Medical Applications, and Advanced Engineering.