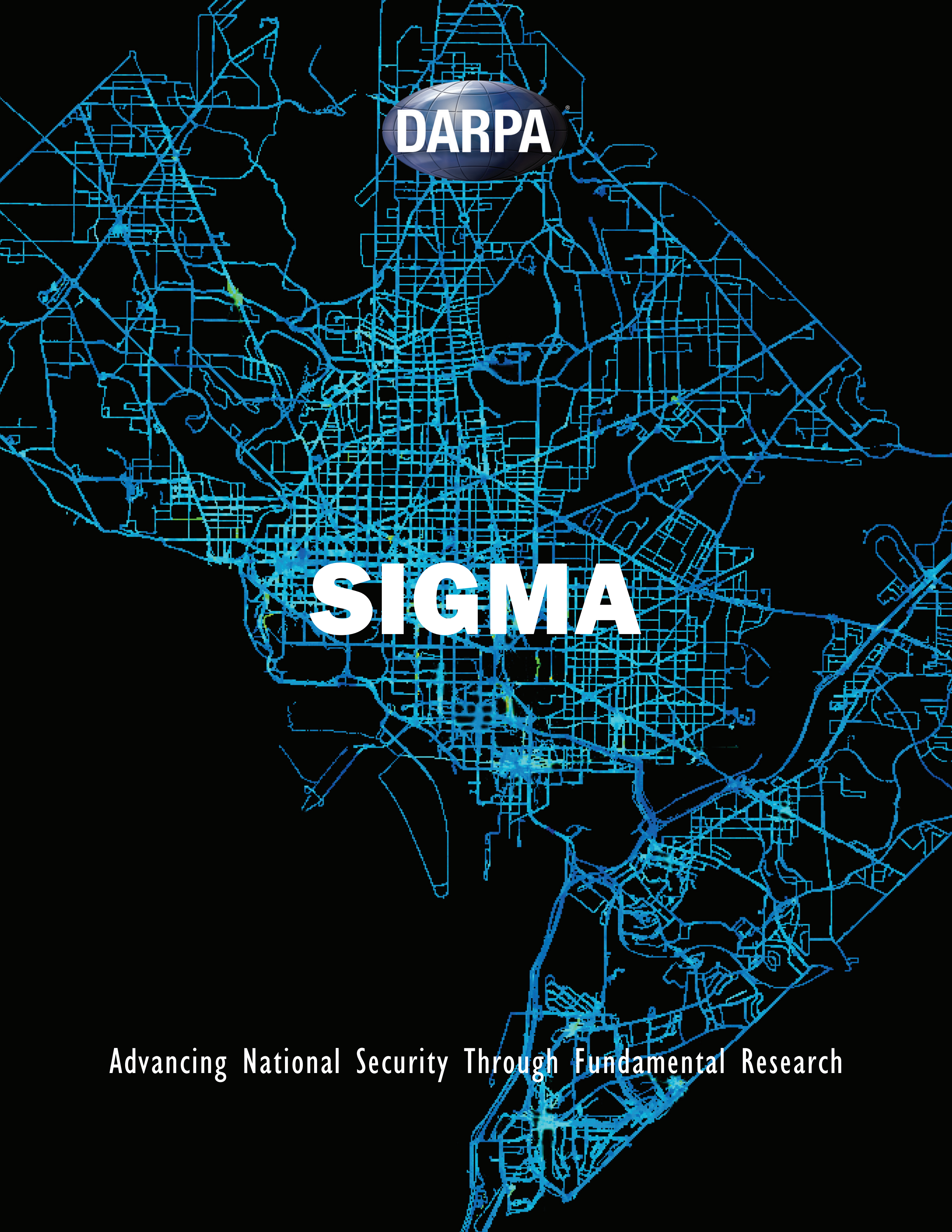

DARPA

SIGMA

Advancing National Security Through Fundamental Research

SIGMA

THE NEED AND OPPORTUNITY

Terrorist attacks involving the use of radiological and nuclear materials pose a potential threat to U.S. citizens and service members. Early detection of these materials and devices made from them is a critical part of the U.S. strategy to prevent attacks. Sensitive, compact, real-time, and low-cost detectors, along with innovative deployment and networking strategies, would significantly enhance detection and deterrence of such an attack. Current handheld radiological detectors are expensive and lack networking capability. In addition, existing neutron detectors used for nuclear materials detection at, for example, ports of entry, are large, expensive, and rely on exotic materials, such as helium-3, a rare isotope of helium that can capture a neutron from radiating nuclear sources. These limitations have prohibited wide-scale and continuous deployment of radiation detection systems. Adding further complexity to the situation, abundant sources of non-threatening radiation in hospitals, on sites, and in industry settings can trick existing detectors, causing false alarms.

THE DARPA SOLUTION

The SIGMA program began in 2014 with the challenge to the technology community of transforming nuclear and radiological threat detection for city-scale monitoring. The task required fundamental advances in a range of fields including sensing, data fusion, analytics, and social and behavioral modeling. Even so, within just a few years, innovative performers contracted to work in the program had developed and demonstrated an automated, low-cost, networked radiation detection capability for counter-terrorism and continuous city-to-region scale radiation monitoring. SIGMA has succeeded in making large-scale radiation sensor networks technically feasible and operationally practical. Realizing this capability required significant advances in:

- low-cost, high-capability detectors that can be networked together;
- scalable network architecture using commercial cellular communications and open-source network infrastructure that can handle tens of thousands of real-time sensor feeds; and
- efficient algorithms that maximize detection and source-tracking capabilities while minimizing false alarms and system latency that can prolong detection times.

As part of the overall system, the SIGMA program called for the development of highly sensitive, low-cost neutron detectors using alternative materials to helium-3. Neutron detectors play a critical role in the identification of plutonium-based nuclear threats and are valuable in reducing false alarms by being able to discriminate threatening nuclear sources from common industrial sources of radiation such as density gauges used in civil construction. Helium-3-based radiation detectors have traditionally been the standard, but the global supply of the isotope is diminishing, leading to higher costs. Specifically, SIGMA sought to develop neutron detector technologies with sensitivities twice that of a standard helium-3 portal monitor and with a price point of $5,000 per unit at a quantity of 200 units.

SIGMA made early fundamental research investments in this area with two companies, Arktis Radiation Detectors and Silverside Detectors. Both companies, with additional investments, developed practical technologies and products that are now deployed and providing added security at critical sites around the world.

SIGMA's research funding also enabled development of a low-cost, highly sensitive, pocket-sized detector – wearable by troops and first responders.

The SIGMA program delivered compact, inexpensive, and networked radiation detectors like this one that are now becoming part of the security infrastructure.

Arktis Radiation Detectors deployed operationally at the Port of Antwerp, Belgium

Kromek, one of the contracted performers in the program, shrunk the dimensions and cost of existing portable detectors from a $10,000 shoe-box-sized unit with no networking capability to a lightweight, networked handheld-sized device that costs $400 per unit (at a quantity of 10,000). At the heart of these detectors is a small thallium-activated cesium iodide crystal. When the crystal absorbs the characteristic radiation energies of specific isotopes in its vicinity, it responds by emitting light particles. These, in turn, are converted into electrical signals that serve as signatures the detector system can use to identify the radiating substance and help determine if it poses a threat.

The Kromek detectors, which can attach to a belt or fit in a backpack's outer pocket, are networked with the larger Arktis and Silverside sensors providing city-wide threat awareness via smartphone, tablet, or web-based user interfaces.

Continuous threat monitoring over large areas requires thousands of detector feeds to be collected, aggregated, and processed in real time to provide overall situational awareness to end users. Another performer, Two Six Labs, developed and operationalized a framework that incorporates open source tools to ingest and process the data. Two Six Labs also developed the user interfaces to display results to operators.

The system that has emerged from SIGMA research relies on advanced spectroscopic algorithms developed by Physical Sciences Inc. to process the information provided by the detectors and determine if a potential threat exists. These algorithms run within the Two Six framework and intelligently combine information to reduce false alarms and improve sensitivity.

THE IMPACT

In its five years, the now-completed SIGMA program progressed from a basic and applied research program to a deployed operational system, providing revolutionary radiation-detection capability at multiple locations in the United States and overseas. Arktis, Silverside, Kromek, and Two Six Labs now all offer SIGMA sensors and networking capabilities as commercial products, which will drive down the cost or radiological detection and monitoring for the Department of Defense and other U.S. Government users.

Working through the Joint Program Executive Office for Chemical, Biological, Radiological, and Nuclear Defense (JPEO-CBRND), 1,000 wearable SIGMA radiation detectors are being deployed to U.S. Forces in the Republic of Korea. In 2019, the Department of Homeland Security awarded a commercial contract that specifies Silverside neutron detectors, developed under the SIGMA program, as replacements for current U.S. radiation portal monitors. These monitors provide screening at critical locations, such as border entries and ports.

SIGMA is also operational with the Port Authority of New York and New Jersey, providing advanced radiation threat detection at key locations in the greater New York City area. Overseas, SIGMA technology has transitioned to the United Kingdom's Home Office, and Arktis neutron detectors are deployed and operating at the Port of Antwerp, Belgium, Europe's second-largest port.

LOOKING AHEAD

The success of the SIGMA program has led to a follow-on DARPA effort called SIGMA+. The SIGMA+ program aims to expand SIGMA's advanced capability to detect illicit radioactive and nuclear materials by developing new sensors and networks that would alert authorities to chemical, biological, and explosives threats as well.

In 2018, SIGMA+ devices collected background air-sampling data at the Indianapolis 500 Motor Speedway using new chemical threat sensors. In fall 2018, DARPA conducted additional testing at the speedway to determine the sensors' ability to precisely identify the type and location of a chemical plume's source. The sensors performed extremely well, proving the system's maturity for a full-scale, all-modality deployment at the 2019 Indianapolis 500.

DARPA is currently extending the capabilities for networked chemical detection by investigating additional sensor modalities, including short-range point sensors based on, for example, mass spectrometry, and long-range spectroscopic systems. As these systems are further developed, they will be integrated into the SIGMA+ network architecture to increase the system's capabilities for city-scale monitoring of chemical and explosive threats as well as threat precursors. In 2020, DARPA directed some of the SIGMA effort directly to the challenge of detecting SARS-CoV-2, the virus at the heart of the COVID-19 pandemic, in buildings and other environmental settings.

Depiction of the diversity of threats that the SIGMA+ program's proposed technology is envisioned to detect in real time.

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