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Title: The Los Alamos Science Pillars The Science of Signatures

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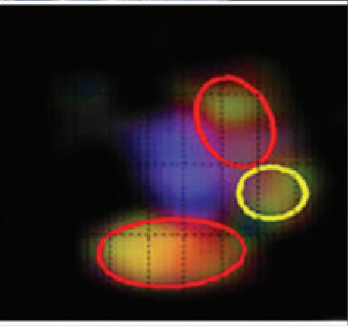
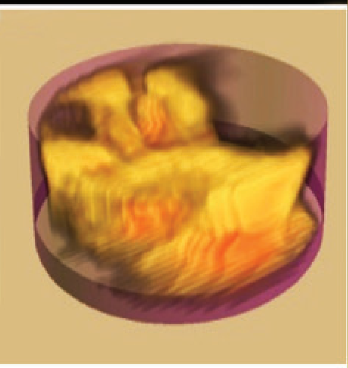
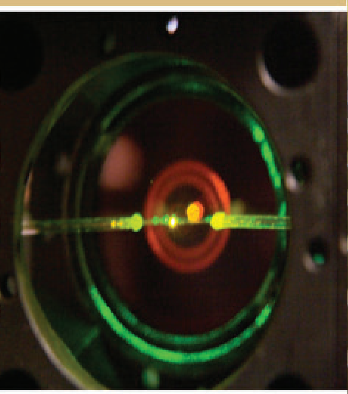
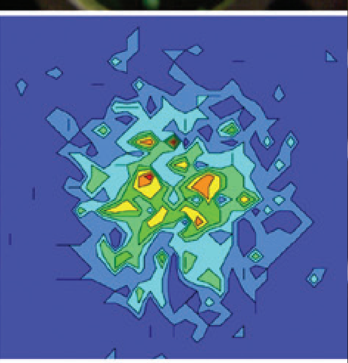
September 2012

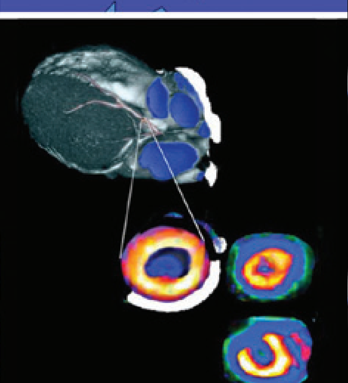
# The Los Alamos Science Pillars







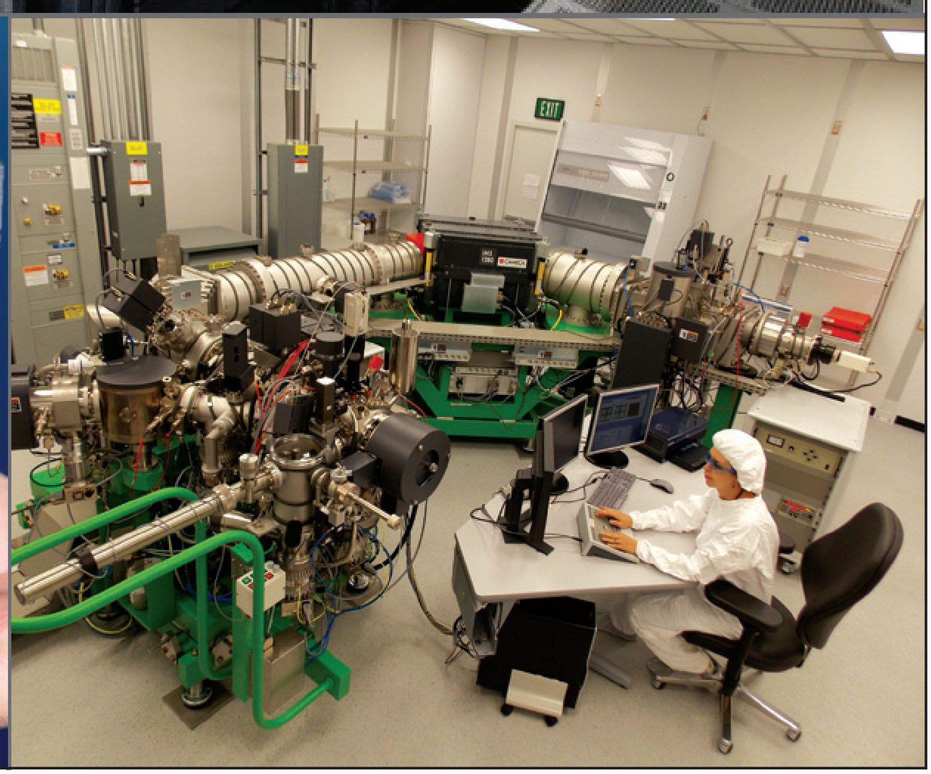





LOS ALAMOS NATIONAL LABORATORY

## Signatures at Los Alamos National Laboratory

Projects that involve signatures are taking place in every corner of the Laboratory. *Top.* One of the world's most powerful computers, the Roadrunner supercomputer exceeds a sustained speed of 1 petaflop per second, or 1 million billion calculations per second. *Inset.* Roadrunner simulates ion acceleration. *Bottom left.* "Cubesats" are satellites small enough to hold in one hand. They were put into orbit in December 2010 and have the potential to revolutionize space-based sensing. *Bottom right.* A Cameca secondary ion mass spectrometry (SIMS) instrument came online in July 2012 enabling staff to perform nuclear signature measurements with unprecedented flexibility and accuracy.


*Roadrunner and Cubesat: LANL Image Library. SIMS: Josh Smith.*

# Contents



### About the Cover

*Background: A conceptual image of how the Science of Signatures (SoS) interfaces with other LANL strengths. Technology images (top to bottom): 1. The Multispectral Thermal Imager satellite enables accurate quantitative analysis of thermal processes on the Earth's surface. It demonstrates the SoS themes of space remote sensing and forward technology deployment. 2. The MagViz technology uses magnetic resonance imaging to give signatures of potential threat liquids inside containers, illustrating the themes of signature discovery and forward technology deployment. 3. A HIGRAD model of a next-generation ecosystem experiment shows the application of SoS to problems in climate change. 4. Flow cytometry was developed at LANL and is used in basic cell biology research and drug discovery and is a leading example of signature discovery and forward technology deployment. 5. A LANL-developed, high resolution x-ray technique has led to improved plutonium assay and demonstrates signature discovery and forward technology deployment in the weapons mission area. 6. Positron Emission Tomography imaging of a heart using isotopes from LANL shows how the SoS theme of health is being pursued.*

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This document was written primarily by the Science of Signatures Leadership Team. Editing, document design, illustration, and additional writing by Josh Smith, CLES Directorate Office.

# Foreword

As a national security science laboratory, Los Alamos National Laboratory (LANL) is often asked to detect and measure the characteristics of complex systems and to use the resulting information to quantify the system's behavior. The Science of Signatures (SoS) pillar is the broad suite of technical expertise and capability that we use to accomplish this task. With it, we discover new signatures, develop new methods to detect and measure signatures, and deploy new detection technologies.

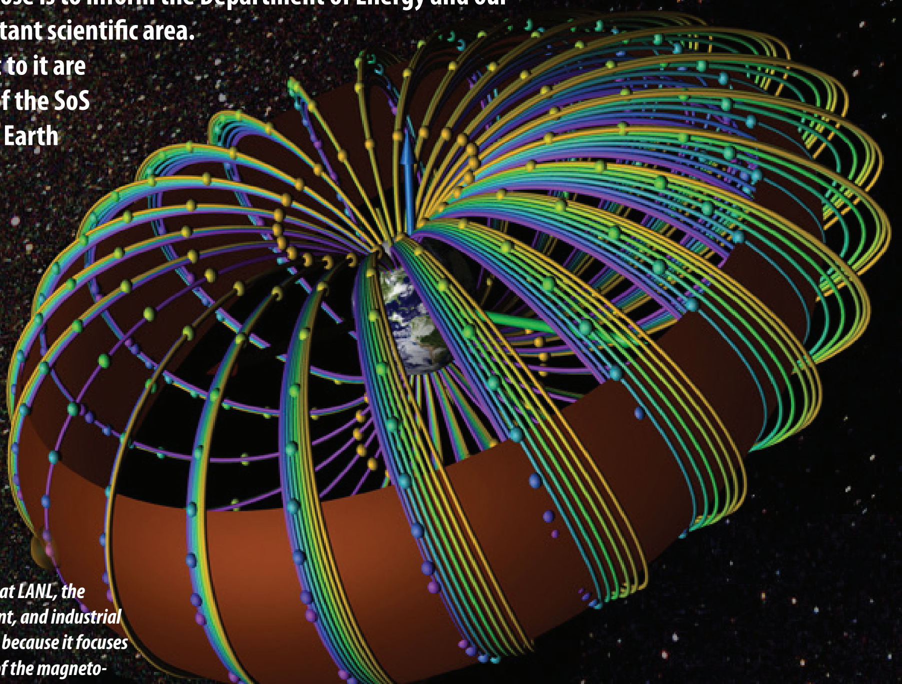
The breadth of work at LANL in SoS is impressive and spans from the initial understanding of nuclear weapon performance during the Manhattan Project, to unraveling the human genome, to deploying laser spectroscopy instrumentation on Mars. Clearly, SoS is a primary science area for LANL and we foresee that as it matures, new regimes of signatures will be discovered and new ways of extracting information from existing data streams will be developed. These advances in turn will drive the development of sensing instrumentation and sensor deployment.

The Science of Signatures is one of three science pillars championed by the Laboratory and is vital to supporting our status as a leading national security science laboratory. As with the other two pillars, Materials for the Future (Materials) and Information Science and Technology for Predictive Science (IS&T) , SoS relies on the integration of technical disciplines and the multidisciplinary science and engineering that is our hallmark to tackle the most difficult national security challenges.  Over nine months in 2011 and 2012, a team of science leaders from across the Laboratory has worked to develop a SoS strategy that positions us for the future. Although the crafting of this strategy has been championed by LANL's Chemistry, Life, and Earth Sciences Directorate, SoS is truly an Laboratory-wide effort—it has engagement from every organization at LANL. This process tapped the insight and imagination of many LANL staff and managers and resulted in a strategy that focuses on our strengths while recognizing that SoS is dynamic.

The following pages highlight the interdependence between SoS, advances in materials science, and advances in information technology. The intent is that SoS shape and inform Los Alamos investments in nuclear forensics, nuclear diagnostics, climate, space, energy, and biosurveillence; the areas of leadership that you will read about in this strategy document.

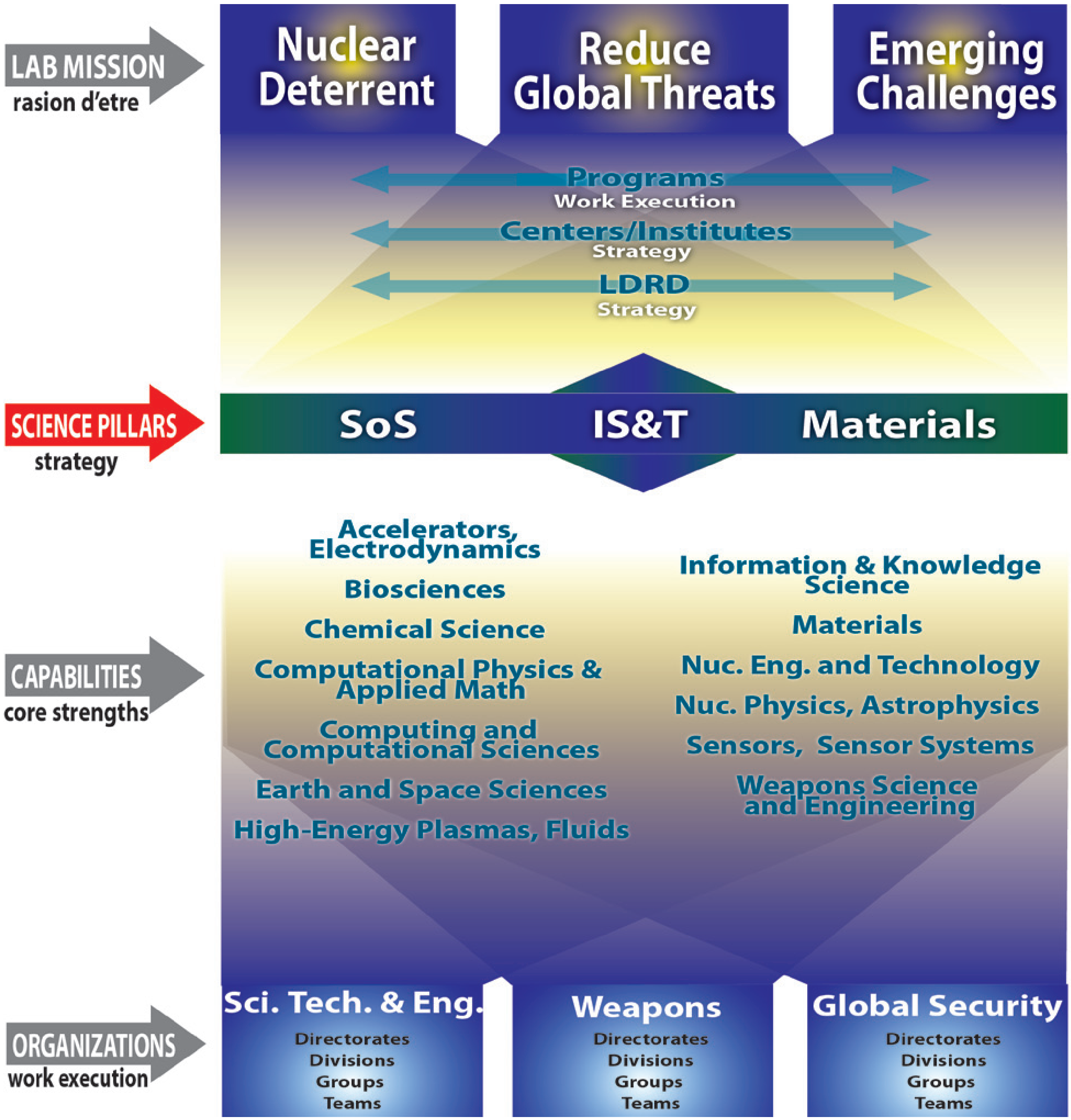
The Science of Signatures is still a relatively new strategic direction for the Laboratory. The primary purpose of this document is tell Laboratory staff how SoS is being managed and give them a chance to get involved. A second important purpose is to inform the Department of Energy and our customers of our capability growth in this important scientific area.
Questions concerning the SoS strategy and input to it are welcomed and may be directed to any member of the SoS Leadership Council or to the Chemistry, Life, and Earth Sciences Directorate Office.

– Nancy Sauer, Associate Director for
Chemistry, Life, and Earth Sciences



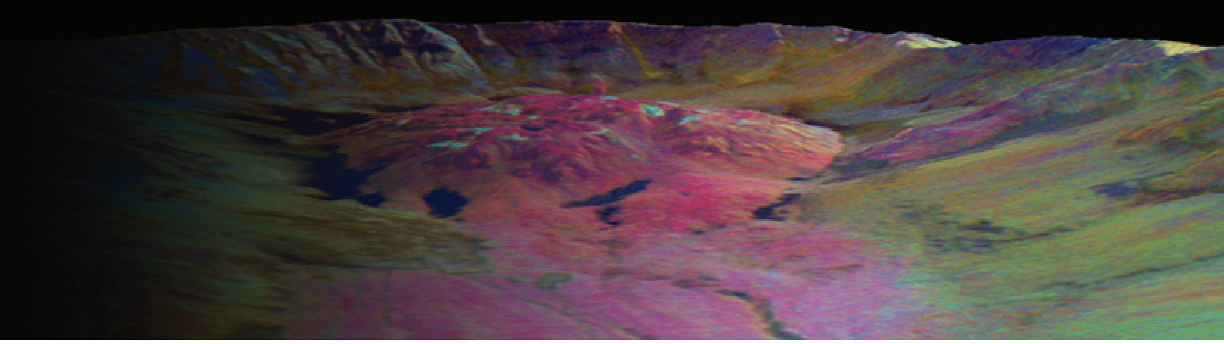
*Originally developed under the Laboratory-Directed Research and Development (LDRD) program at LANL, the Dynamic Radiation Environment Assimilation Model (DREAM) now includes academic, government, and industrial collaborators. DREAM represents an important part of the space situational-awareness portfolio because it focuses on assimilating disparate, sparse data streams to provide space weather in almost any location of the magneto-sphere, as well as providing predictions based on solar-wind input and its coupling to the magnetosphere.*

# How LANL Manages for the Future




Directorates, divisions, groups, and teams are organized into the three major areas of Science, Technology and Engineering; Weapons; and Global Security. Staff from these areas collaborate across those organizations to contribute to the core LANL capabilities. The Science Pillars are a conceptual framework that enables a cross-cut of both the capabilities (below) and the Grand Challenges (above), enabling strategic management of our strengths so that we may achieve success in the primary LANL mission areas.

# Signatures in Context



In its broadest and simplest sense, a "signature" is any information that is unique, recognizable, and useful. A handwritten mark as a means of demonstrating authorship and authenticity is a familiar example, as is the pattern-recognition skill that allows us to distinguish spinach from poison ivy. Phrased differently, signatures come from both raw signals and from information that can then be translated into knowledge.

By this definition, signatures are the way we interpret our world, and we have used them throughout history to guide our decisions. Today, advanced science and technology enables us to access unprecedented volumes of data related to previously inaccessible aspects of our environment. An accurate interpretation of this data allows us to perceive, predict, comprehend, and react appropriately to changing situations in the world around us. Given that the problems facing us today are among the most challenging in the history of our nation (perhaps of our species), understanding signatures is an important part of preserving our present and securing our future.

At Los Alamos, the Science of Signatures (SoS) is the application of our complete technological toolbox to intransigent problems in system identification and characterization for global security, nuclear defense, energy, and health. The vision of SoS is to use our tools to achieve meaningful measures and generate useful knowledge in complex environments. Examples with sweeping benefits range from observing and understanding the triggers and implications of climate change, to identifying the illicit manufacture or transportation of nuclear devices, to recognizing the onset and progress of disease.

Making significant headway against problems of this scope requires using a highly integrated, multidisciplinary approach that draws on all the traditional strengths of the Laboratory. In addition to the Science of Signatures, these strengths are gathered under the headings of the other two science pillars, Materials for the Future (Materials), and Integrating Information, Science, and Technology for Prediction (IS&T).

The Materials and IS&T pillars are tightly integrated with the SoS pillar; new materials and new instruments are required as new signature types and requirements are identified, and advances in information science are needed to extract meaningful information out of increasingly complex backgrounds. This relationship is described in greater detail in the following pages.

*At Los Alamos, the Science of Signatures is the application of our complete technological toolbox to intransigent problems in system identification and characterization for global security, nuclear defense, energy, and health.*

At Los Alamos, we believe that the biggest science breakthroughs will come as we work across boundaries and approach difficult problems in revolutionary ways. To solve specific problems, we draw upon physicists, biologists, computer scientists, chemists, materials scientists, earth scientists, space scientists, decision scientists, engineers, and numerous other disciplines as required.

The advantage of the three pillars approach is that it gives these experts a framework for applying their skills across traditional boundaries. The case studies in this strategy document describe some of the innovations that have already been achieved using this approach. Going forward, our challenge will be to nurture and grow the Science of Signatures and the other two pillars in ways that allow us to build on that history of innovation and achieve our mission with unprecedented excellence.

# Unprecedented in History

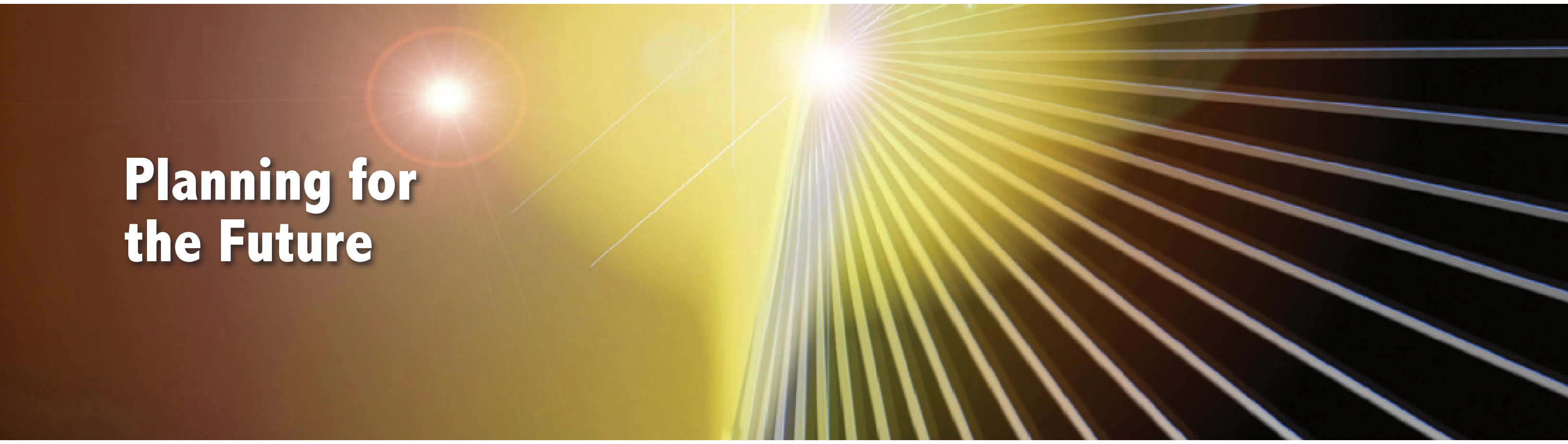
We can trace the roots of the Science of Signatures concept back to the Manhattan Project and the inception of the Laboratory. One of the science challenges during that time was to understand how a nuclear device performed. Although the theoretical underpinnings of performance were understood, there remained pressing questions. How did that theoretical understanding conform to the experimental reality of a nuclear explosion? What were the observables of value, or "signatures," that would verify and validate the theory? What were the prompt diagnostics (measurements in extreme conditions) that would give us information that would advance our ability to computationally model how the nuclear device worked? What were the radiochemical diagnostics (first air samples from atmospheric testing and then soil samples from underground testing) that would advance our understanding of the nuclear processes that occurred during a nuclear weapon explosion? How did those nuclear processes contribute to device performance? What isotopic tracers could we add to the device that would provide information, in addition to the information developed from the nuclear materials?

Robert Oppenheimer (left) with General Leslie Groves (right) at the Trinity Site, location of the first nuclear explosion, which took place on July 16, 1945.

These questions spurred the development of a completely new area of science–nuclear signatures. It evolved from first principles directed at developing the tools required to understand nuclear weapon performance, first in atmospheric testing and subsequently in the subsurface environment of the underground testing program. Many of today's recognized nuclear signature techniques directly tie to the science that was developed during that time.

The body of scientific knowledge that grew from these origins is foundational today to our stockpile stewardship mission of understanding nuclear weapons performance without testing. It is equally as important to our capabilities in nuclear and radiological forensics that have been and will be applied to understanding future nuclear events, such as reactor accidents, rogue state nuclear activities, and terrorist attacks. This history and current mission scope give us unique breadth and depth of knowledge applicable to understanding these types of nuclear events.


The Trinity Site from the air.



# Planning for the Future

Los Alamos National Laboratory (LANL) published the document *Building the Future of Los Alamos: The Premier National Security Science Laboratory* to codify its scientific strategy. This document described three strategic thrusts that crosscut the Laboratory's Grand Challenges: information science and technology enabling predictive science; experimental science focused on materials for the future; and fundamental forensic science for nuclear, biological, and chemical threats.

It was decided that forensic science focused on threats was too constraining, and the scope of that science pillar was expanded to include understanding and characterizing behavior and change in complex systems with relevance to our national security science missions. Specifically, we would focus on gathering and interpreting signals, measures, properties, or characteristics in or of complex systems with the goal of detecting change and predicting behavior across scales of space and time. This science pillar was renamed the Science of Signatures to reflect its broader scope.

Our vision for the SoS is expansive because the capabilities and tools we use are applicable to a broad range of national security issues and emerging national challenges. These challenges include nuclear forensics (a traditional strength), as well as global climate change, signatures of energy production and utilization for understanding environmental impacts, and global biosurveillance for infectious disease progression or other pathogen impacts. Equally important to armed forces and public security are the problems of detecting and mitigating chemical threat agents, and of detecting and characterizing explosives. The science challenges presented by these application areas validate the decision to establish the Science of Signatures as the third pillar of our Laboratory's science and technology base. To meet these challenges, we draw on our extensive experience in remote sensing and space signatures; in nuclear, chemical, biological, earth, and materials science; and in modeling and high-performance computing.

The pillar concept is a primary tool the Laboratory uses to plan for how we will accomplish both current and future missions. The graphic to the right shows how application needs (in blue) can be addressed using the SoS approach. National security/defense encompasses traditional core areas of strength, and energy and climate are areas of pressing national need. "Health" is included under the traditional LANL mission area of "emerging needs" and is called out explicitly because it is clear that many of the critical science challenges of the 21st century will come from this direction.


## Science Thrusts Descriptors

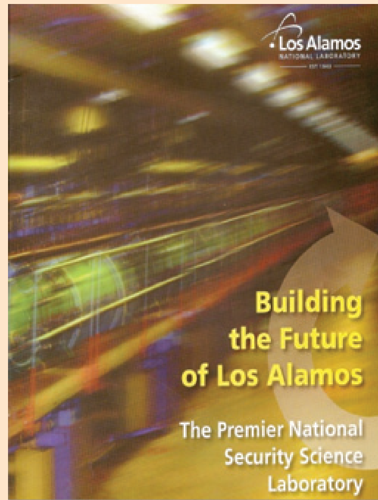
There are three science themes (next page) that guide the development of application in the areas of national security/defense, energy/climate, and health.

# SoS Vision

Achieve meaningful measures and knowledge generation in complex environments.

# SoS Mission

Characterize measures, signals, and properties in or of complex systems. Detect or attribute change and predict behavior and impact across scales of space (subatomic to astronomic) and time (femtosecond to geologic).




*Building the Future of Los Alamos* outlined the Laboratory's "three pillars" approach and set the foundation for the strategic science planning that has followed.

*1. Discover signatures*

Identify signatures of chemical, biological, radiological, nuclear, and explosives threats. Do the same for climate, energy, and health impacts. Determine those measurable phenomena that uniquely identify and characterize threats or impacts in complex environments.

*2. Revolutionize measurements*

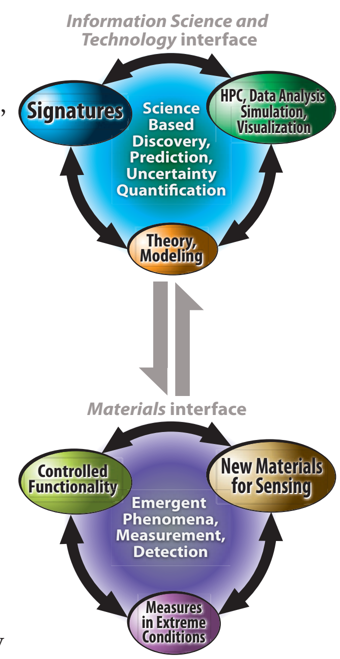
Develop new measurement technologies, methodologies, or strategies or develop transformational advances in the current state-of-the-art for threat/impact-specific signatures. Make sensitive and specific measurements in entirely new ways and/or measure new phenomena (signatures).

*3. Forward technology deployment*

Move measurement technologies and methodologies forward through engineering. Forwarding deployment includes prototyping of sensors and instruments for field deployment and systems integration of sensor networks. Bring science advances to the real world in a way that provides feedback into signature discovery and/or revolutionary measurement technologies.

## SoS and the Other Pillars

Each of the strategic pillars is distinct and has discrete science goals fundamental to the Laboratory's future science and technology base. However, they also overlap, and interfaces among the three pillars must be understood and leveraged for the benefit of all three. Within the Science of Signatures, each thrust within all six areas of leadership (described below) requires support from and advances in the Information Science and Technology pillar. For example, essential to signature discovery are data mining, data analysis, data fusion, information management, pattern recognition, uncertainty quantification, and many other IS&T capabilities. Data manipulation and analysis are key components to revolutionizing measurements, and IS&T is critical for real-time processing, compression, and communication during deployment of measurement technologies.




There is also significant interdependency between the SoS science thrusts and the Materials thrusts of emergent phenomena, materials in extremes, and defects and interfaces. Revolutionary measurements will require revolutionary materials. Examples where this interface is playing out range from advanced scintillators for nuclear detection, to biomimetic materials for pathogen detection, to new materials and approaches for making measurements in extreme environments.

Following are two case studies that illustrate the ways in which signature science helps us achieve our national security mission. Both case studies are taken from one of our core strengths: nuclear science. The first describes how basic science and first-principles yield new perspectives on difficult problems in nuclear forensics. It is intended to showcase LANL strengths in innovation and collaboration. The second describes an applied program in nuclear forensics that falls at the opposite end of the development scale. Together, they cover the sweep of discovering new signatures, revolutionizing measurements, and deploying technology.

## Case Study – Basic Research

# Novel Technologies for Nuclear Forensics

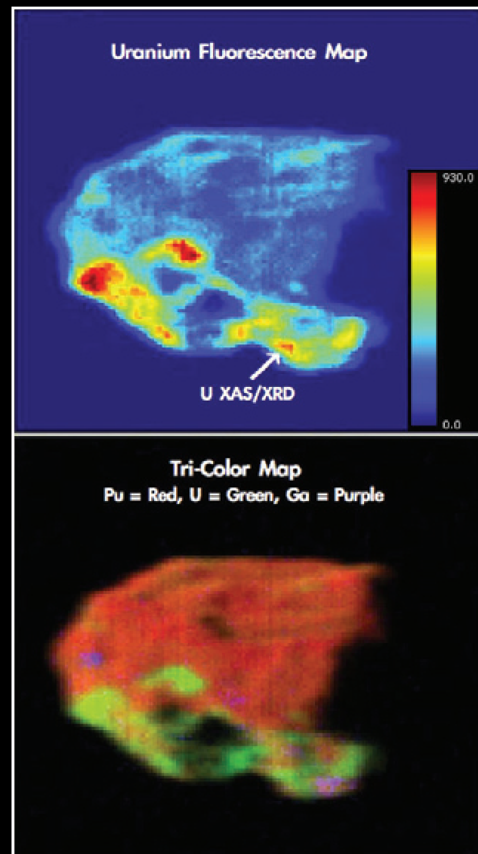
Illicit proliferation of nuclear weapons programs and the diversion of nuclear materials present serious challenges to national security. Detection and subsequent analysis is critical to our law enforcement branches, as is controlling interdicted nuclear materials. Nuclear forensic science is essentially the application of technical tools to investigate and establish relevant facts related to these materials, and it plays a key role in maintaining our nuclear security. Chemical analysis, a Los Alamos strength, reveals the provenance, age, process history, transport, or intended use of a given sample, thus providing decision makers with the forensic insight required to address the range and scale of nuclear threats.

Typically, accurate and robust analysis depends on information measured by several tools. Current techniques employed in nuclear forensics focus on isotopic and elemental characteristics averaged over the entire sample. What Los Alamos adds to this toolbox is additional signatures arising from production, conversion, and aging processes that result in chemical speciation signatures. Spatial relationships between chemical species within a sample can also provide clues regarding the history of a sample.

Exploitation of this information requires development of new analytical methods for measuring these signatures and spatially resolving them on materials. As an example, LANL scientists are employing particle analysis capabilities called µ-x-ray diffraction analysis, µ-x-ray absorption near-edge structure (µ-XANES) and µ-x-ray absorption fine structures (µ-EXAFS) to characterize the chemical speciation of nuclear materials. These techniques are the method of choice for measurement of oxidation state, chemical bonding, chemical speciation, and lattice order.

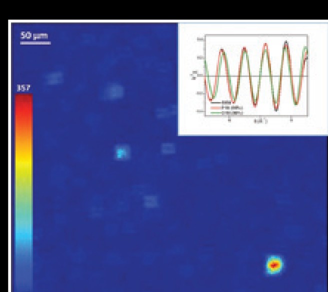
Other studies, all conducted using LANL Laboratory Directed Research and Development funding, are characterizing the chemical variability of uranium and plutonium oxides on a range of environmental samples. These include samples from a fire that occurred at an environmental remediation site, samples collected from a corrosive waste trench in the U.S., materials collected three months after the accident at the Chernobyl nuclear power facility in 1986, and soils collected from sediments at a Mayak waste site in Russia.

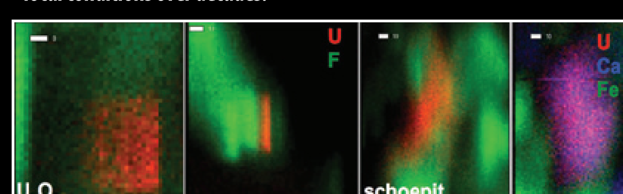
This project, as of 2012 in its third and final year, demonstrates the potential of molecular science to provide valuable technical information to the field of nuclear forensics. Outputs lay the groundwork for using synchrotron-based methods for characterization of chemical speciation on particulates and to evaluate the spatial relationships of these materials with components from the source versus the environment. The expertise and capabilities established under this work advance the field nuclear forensic science, as well as a larger class of materials identification and characterization.




*Above: Synchrotron-based x-ray fluorescence map of a 300-µm particle from an environmental sample collected from a remediation site. Micro-XRD measurements of particulates reveal elemental inhomogeneity.*

*Individual particulates formed under lower temperatures are smaller in size and are likely to be spatially correlated with other chemical species. As shown below left, plutonium oxide bearing samples from the Hanford Site are spatially correlated with chemical species bearing lighter elements characteristic of the waste process stream. Measurements of sediment material collected at the Mayak site (Russia ) for holding medium-level wastes (below) reveal the presence of more than one uranium oxide, and these particulates are characterized by a variety of spatial associations with materials from the natural environment. Initial results suggest that chemical composition of actinide materials is source dependent, such that chemical speciation is related to the source and release conditions and is less likely affected by weathering or local conditions over decades.*



## Case Study – Applied Science

# National Technical Nuclear Forensics

The U.S. National Technical Nuclear Forensics (TNF) program has three components:

1) Interdicted Materials,
2) Interdicted Devices, and
3) Post-detonation.

For each, nuclear and radiological analysis can provide critical information concerning nuclear material type, place of origin, process history, or system performance. These data in turn help authorities determine the "what, where, when, and how" associated with the event.

Technical nuclear forensic conclusions are an essential component of the broader process of attribution, which involves integration of nuclear with traditional forensics data. This, together with information from various other sources, can help identify those responsible for a planned or actual attack. In addition to attribution, nuclear forensics contributes strongly to deterrence and prevention and promotes the concept of nuclear accountability.

The National Technical Nuclear Forensics Center (NTNFC), by Presidential mandate, is tasked to develop and maintain national guidance for TNF issues. The overall NTNF program is implemented by a variety of governmental agencies that include the Department of Justice (DOJ)/Federal Bureau of Investigation (FBI), the Departments of Defense (DoD), Energy (DOE), State (DOS), Office of the Director of National Intelligence (ODNI), and the Department of Homeland Security (DHS). LANL and seven other DOE national laboratories contribute to NTNF as well.

Los Alamos is unique in that we support the breadth of the NTF programs, from collections to final analysis. One of LANL's strengths within the TNF arena is that the Laboratory leverages its broad technical disciplines to address TNF problems (fundamental signatures science) that include

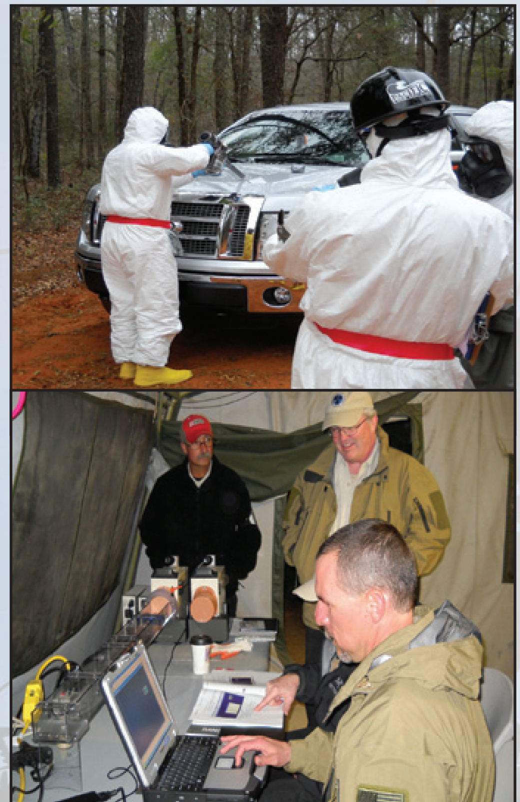
- radiological, chemical, and material analyses;
- materials and safeguards expertise;
- data evaluation and assessment,
- atmospheric and dispersion modeling;
- pre- and post-detonation field collections and analyses, and
- fundamental R&D for signature development.

### *The Opal Tiger*

In October 2011, the DOE and the National Nuclear Security Administration successfully participated in the first international TNF exercise, nicknamed "Opal Tiger." In it, U.S. and United Kingdom laboratories tested both technical nuclear forensic analyses and the overall program. The exercise was based upon a "notional detonation" of an improvised nuclear device over the United Kingdom.

*Opal Tiger* was part of a much larger TNF program that included a number of federal departments and agency participation. The U.S. component was led by DOE, in partnership with the DoD, the DOJ, and the FBI. The program also included the DOS, DHS, and ODNI. The range of personnel that participated indicates the breadth of the Los Alamos contribution to the National Technical Nuclear Forensics program. Nine Los Alamos groups and approximately 55 people Laboratory-wide participated. Work included sample fabrication of the test matrices, sample analysis, and debris diagnostics. The exercise was highly successful and LANL was well reviewed.

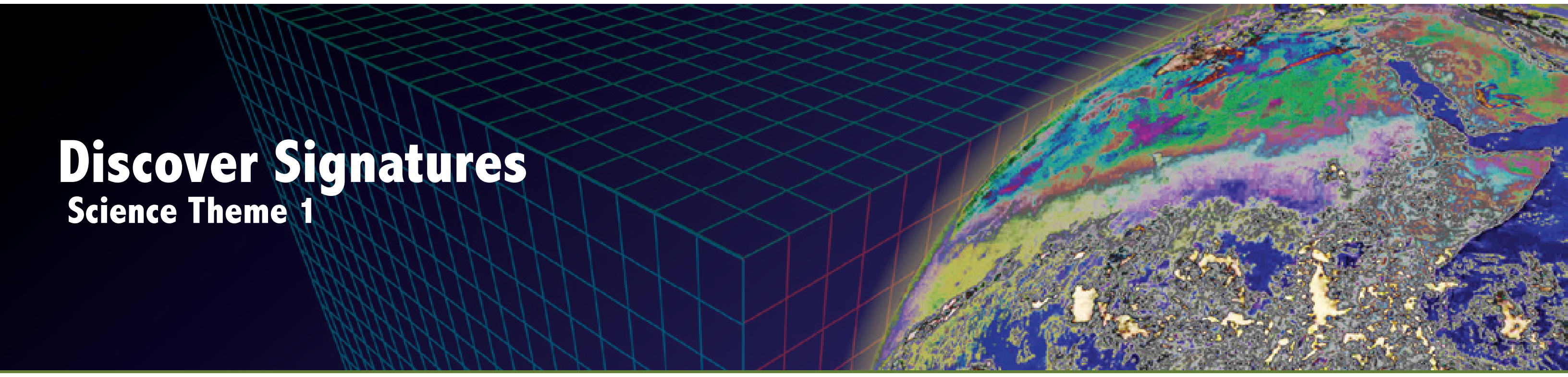
When combined with information from law enforcement and intelligence programs, technical nuclear forensics conclusions will help support one important facet of the overall program that will identify those responsible for planned or actual attacks. Most importantly, effective international collaboration creates a stronger deterrent by increasing the likelihood that perpetrators are identified and held accountable.



*Top: A team collects simulated "debris samples" from the hood of a vehicle during a recent NTNF field exercise called Trinity Oak at Fort Gordon, Georgia. Bottom: LANL staff analyze samples as part of field analytical operations.*

> "An international approach to develop nuclear forensics capabilities and train experts strengthens nuclear security cooperation, builds confidence among states, and contributes to the global efforts to prevent nuclear and radiological smuggling."
>
> \- Anne Harrington,
> NNSA Deputy Administrator for Defense Nuclear Nonproliferation

The discovery theme seeks what is unique about a threat or impact. It involves extracting signatures needed to detect and characterize chemical, biological, radiological, nuclear, and explosives threats; as well as addressing challenges in climate, energy, and health security.



# Discover Signatures

## Science Theme 1

The objective of discovery is to find and measure phenomena that identify national security threats, relevant energy/climate signatures, or health impacts of interest, as well as provide information and knowledge about them.

Signature discovery also draws on predictive information science and technology for a model-based understanding of complex systems. In a nutshell, what can you measure, how is what you measure affected by backgrounds, and what does that measurement mean? Difficulties lie in extracting relevant information out of a complex environment cluttered with numerous irrelevant phenomena that obscure meaningful signatures or in mining new information from existing data or instrument signals. Cyber signatures, for example, can arise from subtle differences in information signals, or new technical capability may bring out a cyber signature from what was previously background.

Technical advances come from data fusion and analysis techniques that can extract useful signatures that lead to new knowledge about the complex environment under study. Further IS&T capabilities can lead to coupling of multiple signatures that in turn lead to other knowledge not available from individual signatures. The ultimate end state is for forward technology deployment of measurement capabilities (theme 3) that when coupled with expert guidance can adapt to the environment and feed back into the discovery of entirely new signatures.

This theme looks at how the threat or impact is uniquely identified and if surrogate signals or indicator signatures can be used. Specificity is attained when signatures are identified within natural or anthropogenic backgrounds, or are differentiated from related but benign signatures. New composite signatures may also be discovered by combining multiple distinct signals that must be analyzed together to generate knowledge or to increase precision or specificity to a meaningful level. Practical advances must take into account that signatures can change over time through exposure to environmental conditions, movement within the system being measured, and other physical, chemical, and biological effects.

### Science Challenges

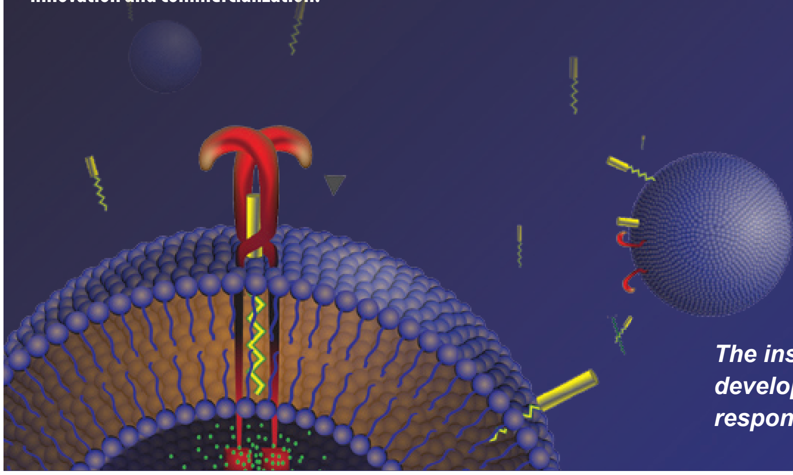
This theme has two key challenges: (1) signatures can change and (2) accurate threat characterization can require multimodal signature discovery. In the first, signatures (chemical, biological, infrastructure, cyber, and others) either evolve with time, or they change by virtue of their interaction with the complex system for which they are characteristic. In each case, complete knowledge of change within the context of the system must be understood in order to guide signature identity and measurement.

The second challenge arises because a threat can rarely be characterized by the measurement of a single signature. Characterization sometimes requires multiple signatures, often of very different signature types that, in turn, require distinctly different sensing materials and signal transducers. By way of example, characterization of a potential illicit production facility (chemical/nuclear/biological) may require information on electrical use, acoustic signatures, and waste chemicals. Thus, this challenge focuses on multiplexed signal transduction in which differing or orthogonal signal types are integrated for subsequent analysis.

# Signatures of Human Health and Disease

Mortality associated with disease can be decreased with early diagnosis. However, current technologies for early detection are inadequate, creating a need for rapid, sensitive and specific detection methods. The Los Alamos Biosensor Team is developing new biosensor technologies capable of detecting signature biological molecules such as proteins, carbohydrates, and intact pathogens using sensitive, specific, and responsive biological agents. Applications span from detecting national security threats such as anthrax or botulism, to medically important organisms and conditions such as influenza, breast cancer, and tuberculosis. One novel approach uses planar optical waveguides as a platform for protein and ligonucleotide detection.

This project requires the participation of chemists, biologists, engineers, and materials experts alike. Such an integrated effort is possible because of extensive collaboration, both amongst scientists at LANL and with external organizations. This Science of Signatures technology has won numerous awards for scientific innovation and commercialization.



*The inset image shows an experimental apparatus developed to mimic the natural cellular recognition responses triggered in cells (background image).*

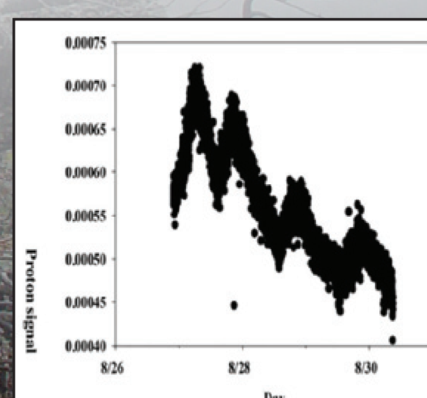
# Signatures of Drought and Tree Mortality

A technology originally designed to detect national security threats has been adapted to advance understanding of the mechanisms of plant mortality.

A team of physicists, biologists, and plant scientists has shown that water content can be monitored noninvasively and unobtrusively in intact trees using ultra-low-field nuclear magnetic resonance (NMR). The scientists' goal is to provide basic insights into questions such as how plants die, especially during drought. Understanding the mechanisms of mortality, especially the tipping points, will provide important input to forecasts of future climate because current models cannot simulate vegetation change and related climate effects. The LANL research represents a first step towards fieldable, non-invasive monitoring to answer these fundamental questions.

Ultra-low field NMR instruments can be made so that they are easy to operate, portable, and adapt noninvasively to the tree. The work demonstrates that the combination of LANL's unique abilities in ultra-low-frequency magnetic resonance imaging and climate-driven vegetation mortality research can provide an understanding of plant function and mortality. Validation with traditionally accepted environmental methods is underway in 2012.

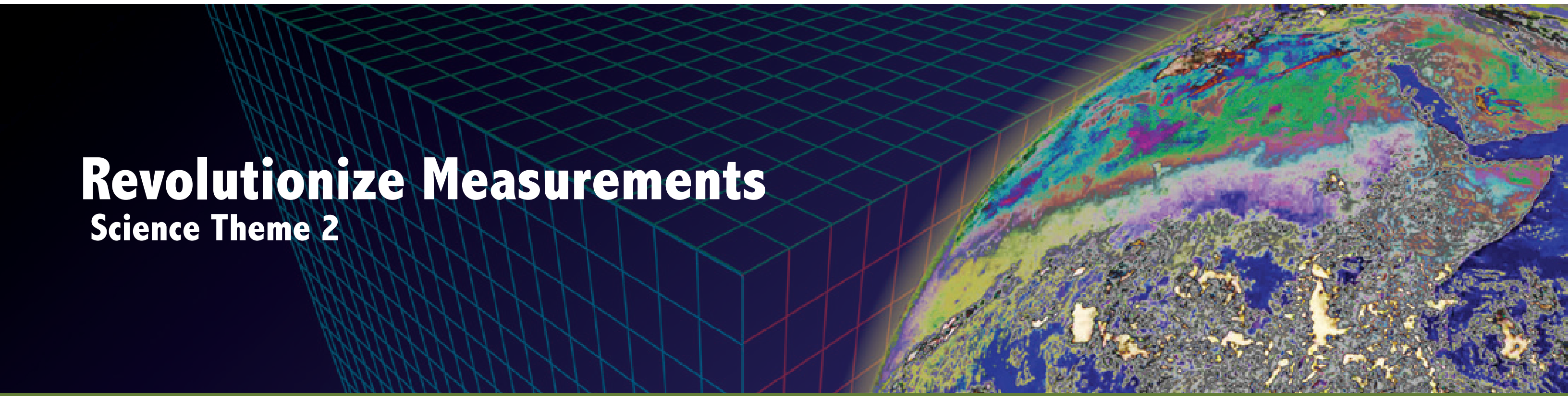
*The experimental apparatus, left, shows that water content correlates with the NMR signal (right). During three days of continuously monitoring an aspen tree suffering from drought, researchers saw evidence of changes in water content for day versus night, as well as the overall decline in water content as the tree's health declined.*



The focus of this theme is radically improving sensitivity and selectivity in existing measurements and developing new and transformational measurement technologies, methodologies, and strategies.

# Revolutionize Measurements

## Science Theme 2



Such increased specificity and sensitivity enable the gathering of new information and knowledge of substantially higher fidelity than is currently possible. One example is extracting a weak signature from masking backgrounds; another example is spatial/temporal domain measurement of dynamic phenomena that can lead to new or radically improved understanding of processes. Challenges come from developing measurement methods for fundamentally new phenomena associated with existing and emerging threats (creating revolutionary sensors) and from identifying completely new signatures.

This goal draws on the IS&T pillar to move data and information processing into the sensor (or instrument) and on the Materials pillar for new sensor materials. In essence, this theme seeks to answer the following question: How can measurements be made in entirely new ways and/or how can new phenomena be measured? Are there detectors and sensors that can be combined to produce a valuable signature? Can high-throughput tools measure the signatures? What isotopic or species attributes can be used to directly or indirectly detect the signature? Can conventional separations be replaced by faster methods or separations that can discover a signature for the analyte? Can remote, field-deployable, multi-scale detection methods be developed?

To find answers, we must develop methods and technologies that measure fundamentally new signatures or uniquely identify sparse signatures in cluttered environments. Revolutionary advances in elements such as sensitivity, required sample size, speed of measurement, and spectral resolution are required, as is the ability to quantify and uniquely remove background from primary measurement of targeted threat signature. Measurements must span in situ and remote sensing, with some emphasis on enabling measurements of activities or events in locations of denied access. Time and space must be considered, including networked sensing, sensor arrays, perimeter monitoring, and space-based coverage.

### Science Challenges

Key challenges in this area are to quantitate specific, actionable signatures in a noisy background of nonspecific signatures and to implement unattended and remote sensing. Specific desirable signatures are often weak and obscured by stronger undesired signatures. In other instances, undesired signatures mimic desired signatures and give rise to false positives. An example is biological pathogens in an environment where nearly identical non-pathogenic organisms predominate. Such cases require the ability to sensitively measure multiple signatures simultaneously and necessitate advances in sensors and sensor networks.

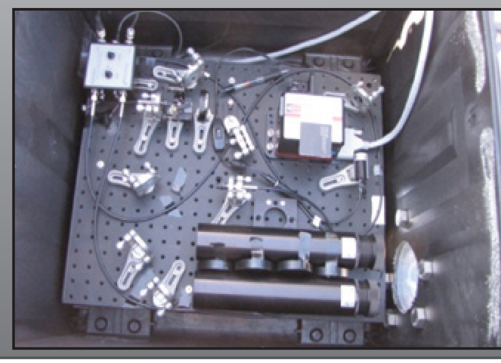
Additional enduring technology gaps come from remote signal measurement (e.g., detecting greenhouse gases in the atmosphere) and measurement at excluded/denied sites (e.g., sites of illicit production). Passive and active optical interrogation can be used to remotely detect some threats, but others (e.g., biological threats) have no specific spectral signatures. In such cases, novel sample collection strategies have great potential. Moreover, even for those threats that have specific spectral/optical signatures, improved standoff distance for detection and robustness and fidelity of the signal require revolutionary improvement.

# Chemical Signatures of Processing/Reprocessing

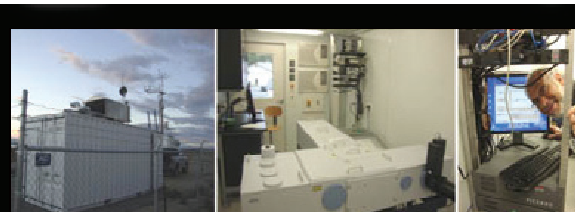
**A key national security need is to identify and locate nuclear-processing activities. Chemical signatures of bulk materials, particulates and effluents released from facilities are being used to identify reprocessing and processing activities, determine the origin of interdicted materials, and understand and re-create post-detonation material properties. Safeguarding nuclear stockpiles, attribution, nonproliferation, and nuclear detection are all areas being supported by material characterization and chemical signature research.**

**These chemical signatures include chemical and isotopic composition, chemical form identification, morphology changes at the surface and subsurface, fission track measurements, particulate sizing and characterization, and liquid and gas effluent measurements. Radiochemistry and actinide isotope analysis are the foundation for the chemical signature research associated with nuclear materials and particulates. One new signature approach is to use the stable isotope ratios of chemicals and trace gases produced from a nuclear facility to determine threats within it. Stable isotopes provide a novel way to identify and locate covert nuclear processing. They can also indicate what methods are being used within the facility to isolate actinides. Los Alamos is exploring light stable isotopes as a detector for nuclear processing by (1) identifying the range of stable isotope ratios of C, N, O, and H produced at each step within the plutonium purification stream during yellowcake processing; (2) determining how these signatures vary with plutonium purification; and (3) determining the fate and transport of these signatures in other natural environments. The Los Alamos work is identifying new chemical signatures and observables, increasing the sensitivity of existing signatures, and expanding the range and temporal resolution of signature detection for nonproliferation efforts.**

*Left: LANL stable Isotope instrument to detect C, H, N, O, and S. Right: LANL laser to detect isotopes of $CO_2$, $NO_x$, $CH_4$, at 250 meters standoff. Below: Yellowcake uranium creates unique production signatures.*



# Greenhouse Gases and Pollution Monitoring in the Four Corners



*Left: The Remote Sensing Verification Project robotic solar observatory for regional-scale greenhouse gas monitoring deployed at the San Juan substation site near Farmington, NM. Center: In situ laser sensor monitors $CO_2$ and $CH_4$ continuously from inside the observatory. Right: Instrumentation.*

**A team of LANL researchers worked with the New Mexico Environment Department to design and assemble a multiscale greenhouse gas and air-pollution autonomous robotic measurement system for continuous air monitoring in the Four Corners area of New Mexico. The region contains the San Juan and Four Corners power plants that together are the largest point source of nitrogen oxides ($NO_x$) and carbon dioxide ($CO_2$) in the U.S., plus a midsized urban center comprised of Farmington and Bloomfield. These provide a high signal-to-noise ratio that is ideal for monitoring.**

**The core of the measurement system is a robotic laboratory housing a solar tracking Fourier transform spectrometer, which measures the absorption spectra of sunlight at high resolution. A suite of in situ laser sensors provides continuous greenhouse gas and pollution monitoring. The atmospheric spectra are fitted using laboratory spectra of individual greenhouse gases ($CO_2$, $CH_4$, $N_2O$) and pollutants (CO, $NO_2$, $SO_2$) to determine their abundances at 10-km to 100-km scales.**

**The continuous greenhouse gas and pollution monitoring creates a validated science base for the attribution of greenhouse gases. The instrumentation enables the development of next-generation regional-scale air quality monitoring.**

# Forward Technology Deployment

## Science Theme 3

The focus of this theme is to use engineering to advance the practical application of measurement technologies and methodologies. It broadly includes the prototyping of sensors and instruments for field deployment and the development and deployment of integrated sensor networks. Deployment scenarios include extreme environments (space, other planets, the Arctic, nuclear reactors) and extreme operational conditions (unattended operation for extended periods; continuous, real-time data streams). Sensors must be made within extreme size, weight, power, and cost constraints (unmanned aerial vehicles, aircraft, small satellites, sensor-in-a-cellphone), and within a complex framework of other sensors (DoD deployment, sensor networks and arrays). Measurements demonstrated in controlled environments must also be possible in exotic, diverse, and noisy environments.

Data fusion, analysis, and learning algorithms are key components to extracting information and knowledge about the environment being sampled. Adaptive sampling and measuring technologies will be needed to address changing conditions. IS&T is critical for real-time processing, compression, and communication, where as Materials promises new lightweight components and power sources.

In essence, this theme explores how we bring measurement to the real world and how we learn about complex environments in a way that provides feedback into new signature discovery and/or new revolutionary measurement technologies. It asks if signatures detected in complex environments can be attributed to a specific source for a given magnitude, natural background, or anthropogenic noise.

To be effective, we must identify relevant, sparse information within enormous data volumes. We must also have sufficient confidence in our conclusions that they can serve as a basis for attribution and subsequent action/response. Achieving sufficient confidence requires new ways to process raw data streams to directly convert data to information, new models for interpreting data, and new methods for deriving information.

## Science Challenges

The key challenge in forward technology deployment is delivering novel engineered systems underpinned by advances in both signature discovery and signature measurement. Prototype sensors and sensing systems must be designed, built, and demonstrated based upon the adaptation of measurement technologies to relevant field applications. ChemCam is an excellent example of where the Laboratory did this well (see facing page).

Success will require advancing several essential engineering capabilities, as well as employing new product realization strategies to address the deployment challenge. In particular, evolving benchtop proof-of-concept devices through the component and field validation processes will require specific fundamental attention. Essential engineering capabilities that require investment include

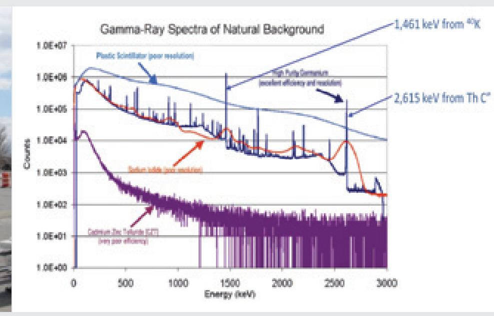
- miniaturization (micro and nanofabrication);
- ruggedness (thermal, vibration, radiation);
- onboard energy harvesting and storage;
- sensor reliability, including diagnostics and self-healing response;
- sensor networking;
- robust, optimal sensor system design; and
- adaptable, tunable, and reconfigurable sensing systems.

# Second Line of Defense - Nuclear Signatures

**Los Alamos National Laboratory is a major player in the NNSA Second Line of Defense (SLD) Program, whose mission is to strengthen the overall capability of foreign countries to deter, detect, and interdict illicit trafficking of nuclear and other radioactive materials across international borders and points of entry/exit, as well as through the global maritime shipping network. This mission is accomplished through deployment of radiation portal monitors and other radiation detection equipment at foreign sites throughout the world, based on agreements developed with each host nation. The major challenges for SLD are to quickly and with minimal impact on border-crossing operations detect and identify clandestine shipments of highly enriched uranium, plutonium, depleted uranium, and potential radioactive dispersal device sources in luggage, cargo containers, trucks, automobiles, trains, and carried by pedestrians.**

- **in the presence of background radiation,**
- **through purposeful shielding and shielding from cargo,**
- **in the presence of masking from naturally occurring radiological material in cargo,**

**The Los Alamos SLD science team plays the leading role for SLD in evaluating performance of the various domestic and foreign technology components employed by SLD, in developing optimum conduct of operations for their use, and in testing new equipment under consideration for SLD deployment. The team has tested more than 25 systems over the last five years. In addition, the science team trains personnel at LANL and other laboratories to perform adjudication of alarms from SLD equipment deployed across the globe. Other Los Alamos personnel support installation and field acceptance testing at new SLD deployments.**

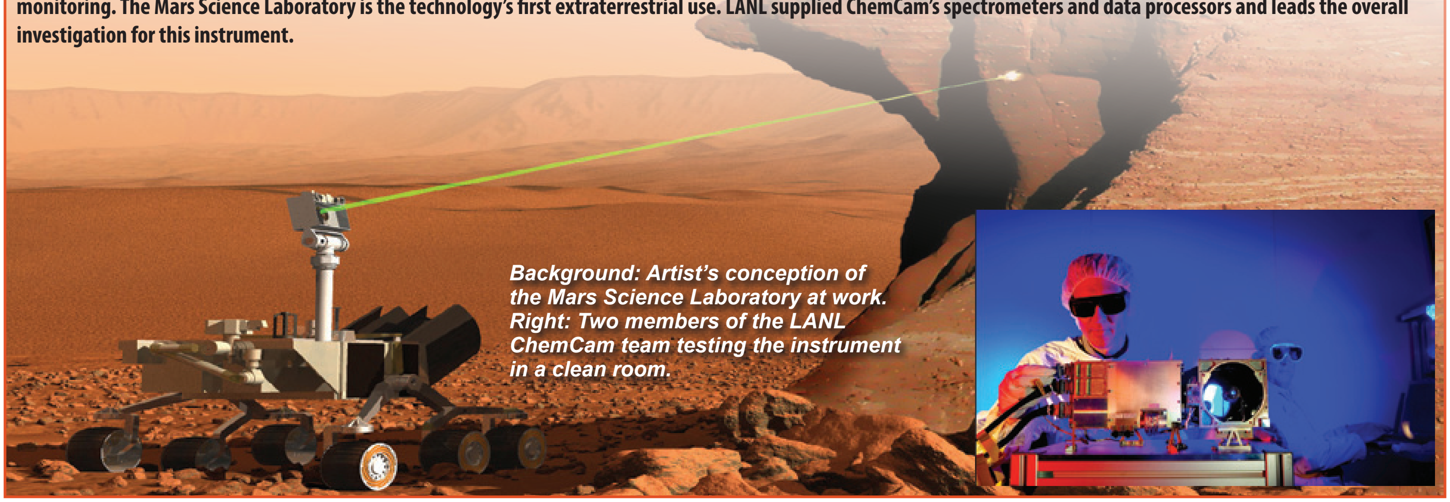



*Left: Indoor test bed for the SLD effort. Middle: Outdoor test bed. Right: Sample spectrum of natural background gamma radiation.*

# Space Signatures

**The Mars Science Laboratory launched by NASA in early 2012 is relying in part on an instrument originally developed at Los Alamos called ChemCam, which will use a laser to probe Mars' surface. The ChemCam laser pulse vaporizes an area the size of a pinhead. The system's telescope examines the glowing plasma created by the vaporized material, then records the colors of light contained within it. Colors are analyzed by a spectrometer, which yields the elemental composition of the vaporized material. ChemCam is designed to look for lighter elements such as carbon, nitrogen, and oxygen, all of which are crucial for life. The system can provide immediate, unambiguous detection of carbon or water from frost or other sources on the planet's surface. ChemCam has the ability to detect any element on the periodic table and can zap an area about 23 feet away from the rover vehicle.**

**The system relies on a technology primarily developed at Los Alamos called laser-induced breakdown spectroscopy (LIBS). At the heart of the technology is an infrared laser that focuses more than a million watts of power onto a tiny area for five-billionths of a second. LIBS has successfully been used on Earth to determine the composition of objects within extreme environments such as inside nuclear reactors and on the sea floor. Other applications for LIBS include cancer detection and environmental monitoring. The Mars Science Laboratory is the technology's first extraterrestrial use. LANL supplied ChemCam's spectrometers and data processors and leads the overall investigation for this instrument.**

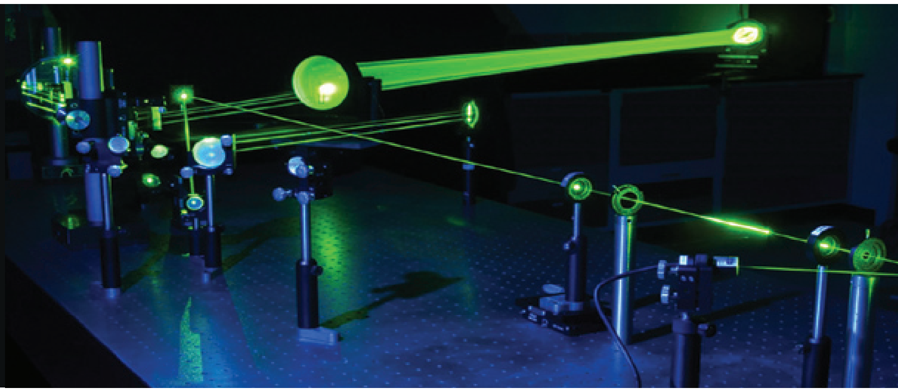


*Background: Artist's conception of the Mars Science Laboratory at work. Right: Two members of the LANL ChemCam team testing the instrument in a clean room.*

The key to Science of Signatures planning was to identify areas where the Laboratory believes it can lead nationally and internationally within the context of the three SoS science themes.

# Areas of Leadership

## Strategic Goals



These focused areas of leadership also must connect to the Laboratory's current mission and anticipate future missions. The planning team decided that a laundry list of capabilities was less useful than a smaller set of broadly defined strengths. They evaluated LANL's strengths as a national security science laboratory and chose six *Areas of Leadership* in signatures to for the Laboratory to pursue. These leadership areas are

- Radiological and Nuclear,
- Chemistry and Materials (including explosives)
- Biological,
- Climate,
- Energy, and
- Space.

Some of these (Radiological and Nuclear, Chemistry and Materials, and Space) encompass traditional strengths and enduring national security missions. Others (Energy, Climate, and Biological) are developing or nascent strengths required to meet emerging missions. We are aware that these areas may appear orthogonal to the traditional Department of Defense/ Intelligence Community definition of signature type (signals intelligence/SIGINT, etc.), but we feel that the melding of our scientific strengths with the SoS science themes of discover signatures, revolutionize measurements, and forward technology deployment is in fact the best way to organize internally so that we may meet the needs of these traditional sponsor bases.

The planning process has resulted in a focused strategy consistent with our identity as a national security science laboratory and can be presented coherently both internally at the Laboratory and to our external stakeholders.

Workshops were held to take a forward-look at how to develop each area over a ten-year time horizon. This forward-look proved difficult because of the richness of the possibilities. Scientific advances in materials, chemistry, miniaturized and distributed sensing, and in other areas create unprecedented opportunities to advance the Science of Signatures. The strategic challenge faced by the Laboratory is to narrow the many options down to a manageable number that directly mesh with LANL strengths and support the LANL mission. It was this challenge that was tackled by the SoS workshop series.

Each of the following summaries describes why we believe the area of leadership is appropriate for LANL and how we believe it ties directly to our mission. For each, we also briefly describe how we selected the goals we did from the myriad possibilities.

**Some Los Alamos Strengths**

- Weapons design expertise enables the characterization and understanding of nuclear threats.
- Isotope and nuclear materials handling expertise does the same.
- Energetic materials expertise enables detection and understanding of explosive threats.
- Chemical, materials, and bioscience expertise facilitates the detection, characterization, and understanding of chemical and biological threats.
  - – Capabilities enable understanding of signature transformations in the environment.
- National security science requires innovative instruments and measures.
  - – Open National User Facilities are available for national security science.
- Experience deploying instruments/ diagnostics in extreme environments (e.g., space, a bomb) enables development of unique and robust detection and sensing capabilities.
- The extent of our theoretical, computational, and simulation expertise facilitates the prediction of complex system behavior and impacts.
  - – Enables global-scale security science.
- Secure space and a cleared workforce enable national security science.
- Extraordinarily broad, multidisciplinary science and engineering teaming.

## Overarching Challenges

There are science challenges that crosscut all areas of leadership:

- Science over wide-ranging scales of length and time.
- Signature evolution in space and time.
- Signal-to-noise in measurement technologies.
- Processing at the sensor head.
- Uncertainty quantification.
- Bridging the technology maturation "valley of death" during deployment of young technologies.
- Distribution and networking.
- Realizing fieldable devices.

The list is not all-inclusive, but nearly the complete set of challenges listed above will apply to, and be address in, the detailed strategy for the individual areas of leadership. The following summaries were extracted from detailed workshop reports.

## Nuclear and Radiological Signatures

Nuclear detection is without question the broadest and strongest area of leadership for the Laboratory. The complexity of scope and current investment require that the area be broken into the subcategories of (1) nuclear detection/nuclear and radiological materials characterization, and (2) nuclear event characterization.

Our strengths in the nuclear and radiological area arise from a demonstrated capability and proficiency in the analysis and characterization of both bulk and particle radiological materials. The special nuclear materials bulk characterization capability integrates with technical nuclear-forensics-related programs and assets, which include the Department of Energy's Surplus Plutonium Disposition program. We also have the capability to receive, analyze, and process large quantities of special nuclear materials at our plutonium facility and the ability to do other types for radiological analysis at a host of other facilities.

Because a significant portion of the activities and science associated with radiological and nuclear work is classified, the goal descriptions included here are less specific than for those areas in which classification is not an issue. Each goal has an associated action plan, and more details are included there.

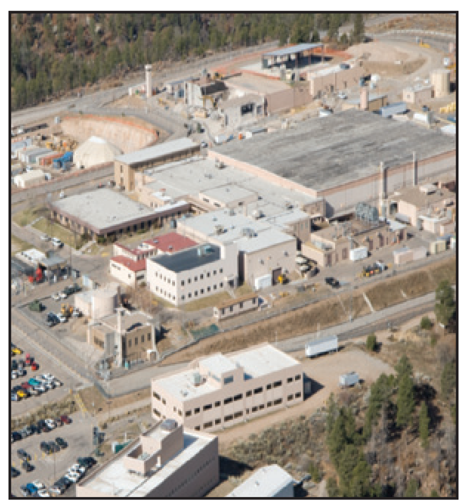

*A muon tracking detector invented by LANL scientists and manufactured and sold by Decision Sciences Corporation uses natural cosmic rays to detect smuggled nuclear material in vehicles.*

### *Nuclear Detection/Nuclear and Radiological Materials Characterization:*

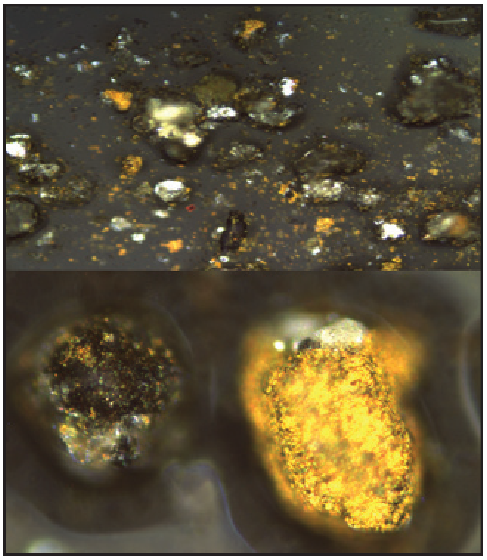
An important part of the nuclear and radiological detection mission in the United States is the interception and tracing of unknown nuclear materials. These materials might be discovered at border crossings or during international inspections. Shutting down the pathways that lead to their production and distribution is the key to international nuclear security. Radiological and nuclear materials characterization work emphasizes field deployment of personnel and techniques with extremely rapid turnaround. In 2010, the NA-45 Office of National Technical Nuclear Forensics announced the selection of Los Alamos National Laboratory as one of two "hub" laboratories for analysis of bulk special nuclear material to support the national predetonation nuclear forensics program. Our chosen goals mesh with this mission space.

**Goal 1:** Achieve standoff detection of structures that yields valuable/actionable information about radiological and nuclear materials that we wish to observe but cannot access.

**Goal 2:** Create a suite of capabilities that enable process characterization and monitoring of special nuclear materials production facilities for a variety of applications.



*The LANL plutonium facility, center, has the capability of receiving large quantities of nuclear material and provides a unique opportunity for nuclear signature testing.*



*Nuclear forensics can be accomplished with a wide variety of analytical techniques, including light microscopy. Shown here are particles of uranium analyzed during a training exercise. The physical particle characteristics give information about the*

**Goal 3:** Field novel methods or quantum improvements in actinide analysis for safeguards applications.

**Goal 4:** Discover, design, and deliver the next generation of monitors and algorithms to detect special nuclear materials or weapons of mass effect when they are in movement.

*Nuclear Event Characterization:*
Currently, nuclear event characterization analysis concentrates more on laboratory techniques with a longer relative time frame than does our predetonation work. In the future, it will be important to shorten the time to achieve results and ideally move the analytical tools to the event. This is a decadal challenge.

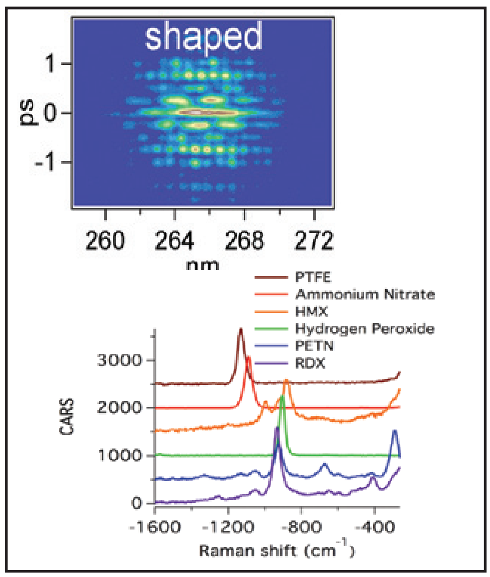
Los Alamos boasts some of the best and most well trained weapons scientists in the world, which in turn means that we have strong qualifications for developing the forensics signatures for use in attribution following a nuclear event. These signatures might be physical, chemical, or isotopic in nature and may be integrated with nuclear device designs. The strategy is to develop a library of nuclear forensics signatures and techniques that will enable investigators to analyze materials from a nuclear event and attribute both what nuclear materials were used and how they were produced. The ability to confidently attribute a nuclear event after the fact is itself a deterrent.

*The Los Alamos Counting Room has a comprehensive suite of radiation detection instruments and is a unique resource for nuclear material and event characterization.*

**Goal 5:** Drive next-generation material measurements to generate actionable data, directed by interpretation goals while meeting specific time and quality goals.

**Goal 6:** Provide the technical basis for predicting and interpreting all energy outputs by integrating expertise, models, and measurement systems.

**Goal 7:** Provide forefront modeling capabilities to guide decision making, as well as to turn data and signatures into knowledge.




*LANL's Optimal Dynamic Detection of Explosives technology uses a femtosecond laser with shaped pulses to rapidly detect a wide range of explosives at trace concentrations.*

## Chemical and Materials Signatures (including explosives)

The chemical and materials sciences are traditional strengths of the Laboratory. Taken together, they represent about 25% of the Laboratory's budget. Specific strengths are in state-of-the-art materials and analytical characterization tools that are used in R&D that is relevant to Science of Signatures. There are also national user facilities such as the Lujan Neutron Scattering Center at the Los Alamos Neutron Science Center, the Center for Integrated Nanotechnologies, and the National High

Magnetic Field Laboratory that are applied to chemical and materials signature science.

Having these open user facilities reside alongside specialized classified facilities creates a unique opportunity to apply the Science of Signatures to national security. The goals we have chosen to pursue reflect the opportunities created by that interface.

> **Goal 1:** Discover the next generation of chemical signatures, models, and detection platforms for chemical weapons identification and forensics.
>
> **Goal 2:** Engineer and model the next generation of materials for sensing.
>
> **Goal 3:** Build an enduring capability to predict/address emerging threats relevant to explosives detection, forensics, and attribution.
>
> **Goal 4:** Create the next generation of signatures, models, and detection platforms to characterize nonradiological materials of interest for national security concerns.

One of the many challenges in this area is to develop a science-based understanding of materials and their interactions to identify changes in the aging stockpile for performance, reliability, or safety.

## Biological Signatures

The SoS Leadership Team sees biosurvellience, in the areas of both biothreat and public health, as a primary national security concern in the coming decades. The Laboratory's historical and current strengths in bioscience and related technologies resident in a national security science laboratory place it in a unique position to make contributions to biosurvellience.

The biological and related sciences are undergoing revolutionary changes driven by factors such as availability of high-content/high-throughput bioanalytical systems yielding vast amounts of inexpensive data, computational power to manage that data, mathematical/statistical tools for analyzing the data, computational models for organizing information into functional systems, and communication systems for data exchange and access. Equally revolutionary advances in fields such as materials science and chemistry are providing new opportunities to develop bioscience research tools and applications.

*The High Throughput Laboratory Network for monitoring influenza is an example of long-term commitment to concept-to-execution science by Los Alamos.*

The planning workshop examined biological signatures within the context of the SoS application area of "Health," under the premise that the definition of biosurvellience and detection of infectious agents for this workshop was detecting host and pathogen signatures in a given scenario. Historical Laboratory strengths in the development of assay systems, wet chemistry, surveillance networks, IS&T, and epidemiological modeling provided the remainder of the context.

The planning effort identified classes of disease with common surveillance needs and used those to bound their strategic recommendations. The diseases themselves and the specific technological advances required are described in the workshop output report.

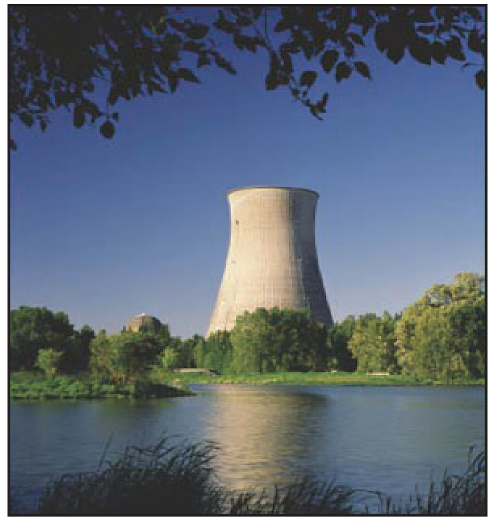
> **Goal 1:** Identify and detect pathogens quickly, accurately, and inexpensively using signature validation, molecular assays, detection platforms and sensor networks with the intent of informing epidemiology.
>
> **Goal 2:** Develop new tools for epidemiology and disease modeling that enable us to predict disease progression and transmission by determining pathogen lifecycles, mechanisms of disease onset and progression, and mechanisms of transmission.
>
> **Goal 3:** Enable disease management and response with knowledge-based decision

tools that describe the characteristics of primary disease scenarios, analyze approaches and possible actions, and integrate data streams and modeling to predict outcomes.

## Energy Signatures

Energy security is one of the core mission areas of the Laboratory, thus making it important that we pursue it as an SoS area of leadership. There are currently numerous active energy-security-related efforts underway at Los Alamos. These efforts focus on identifying critical national needs, maintenance, enhancement of capabilities, and on developing new programs. The SoS strategy in this area is coherent with the Laboratory's energy security strategy, which states that we will help the nation meet energy challenges through fundamental scientific discovery, harnessing our unique experimental and modeling facilities, and partnering to accelerate commercial implementation of clean, safe, and secure energy solutions.

To that end, energy research at Los Alamos is grouped into three general categories. (1) *Sustainable Nuclear Energy*: America currently derives 20% of its electricity from nuclear power, a number that is likely to rise as nuclear technologies evolve and as new plants come online. (2) *Materials and concepts for clean energy*: Innovation is required to sustain and economically generate, store, transmit, and use the massive amounts of additional energy we will require in the future. (3) *Mitigating impacts of global energy demand*: Anticipated growth in global energy demand will put increasing pressure on the environment, foster global competition for energy resources, and drive massive infrastructure growth in developing nations. The SoS goals address these categories.

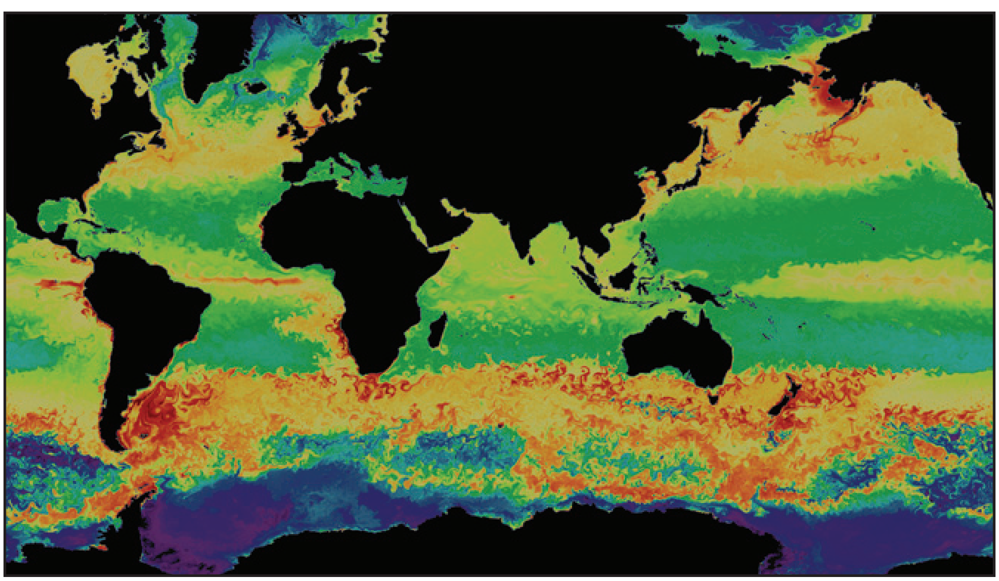


*Signature science is one of the keys to sustainable nuclear energy because it enables both process analysis and environmental monitoring for impacts.*

**Goal 1:** Pioneer new approaches to extracting/attributing signatures of energy from living organisms, geological environments, or manmade systems under conditions that are remote, inaccessible, and/or extreme

**Goal 2:** Develop materials for energy and environmental systems that respond and/or report back on signature-induced stimuli.

**Goal 3:** Integrate sensing, modeling, and analysis science and technology to support decisions and investments, protect systems and anticipate risks/degradation, and respond to disruptions, impacts, and consequences.



*This image shows chlorophyll concentrations in a high-resolution, eddy-resolving Community Earth System Model ocean with a full ecosystem model. Such simulations can help scientists explore natural emissions and discover sinks of carbon and sulfur for sequestration.*

## Climate Signatures

The 2009 Department of Energy Climate Change Strategic Plan opens by saying, "Today there is a strong scientific consensus that Earth's climate is changing and that the main causes of global temperature changes in recent decades are anthropogenic... improving the scientific understanding of ongoing climatic change is a priority for the U.S. Department of Energy."

This broad recognition that climate science is and will continue to be a national priority for scientific research, when combined with the fact that it is an area of historical strength at Los Alamos, dictated that it be pursued as an SoS area of leadership.

Our areas of expertise span from science-based national decision support and assessment for policy makers, to understanding and predicting the impacts of changing energy sources on climate, climate uncertainty quantification, infrastructure assessment and planning, and climate modeling.

**Goal 1:** Become the leader in those signatures of greatest value to climate science by developing computational and analytical techniques applicable to multi-variable data sets and by developing signal detection systems that span software to hardware (prototype to mature).

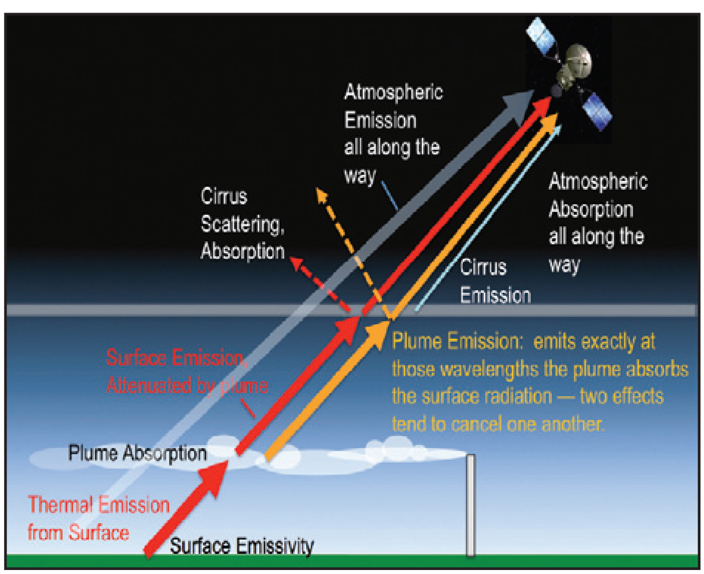
**Goal 2**: Achieve excellence in integrating observational data sets with analytic and computational models and use these models to develop new observations and signatures that increase the accuracy of climate predictions.

**Goal 3:** Become a trusted science advisor to energy and national security policy makers who draw upon our expertise to integrate signatures, regional climate prediction, climate impacts assessment, and energy infrastructure and policy analysis.

## Space Signatures

For 50 years, LANL has flown missions in space to globally detect and assess nuclear detonations and to understand the natural space environment and its effects on radiation detection instruments. This historic treaty-monitoring mission has expanded to two additional areas: space situational awareness (comprehensive understanding of existing and emerging threats, both natural and manmade, to the national space infrastructure) and space-based remote sensing of weapons of mass destruction development and proliferation, primarily nuclear. An emerging area of national security importance is global monitoring of greenhouse gases relevant to global climate change. Key signatures for these programs include radiation detection ($n^o$, $\gamma$-rays, x-rays), plasma and high energy charged particles, and photons (from radio waves to optical). Physics-based models are routinely developed, validated, and applied, for example, to understand instrument performance, signature generation, signature transport (from source to measurement), event geolocation, and space weather.

To develop the expertise, tools, and innovation in support of the Laboratory's national security mission performed in space, a robust research base spans multiple disciplines, including plasma science, astrophysics, space physics, planetary physics, earth sciences, chemistry, and space systems engineering. Current signature discovery and analysis research includes high-altitude lightning phenomena, gamma-ray burst dynamics, radiation belt energization, supernova shock propagation, chemistry and mineralogy of Mars's surface, and solar wind microstructure.




*Measuring greenhouse gases from a satellite is a difficult task. Complications arise as light moves from the surface to the satellites, which requires instruments that have maximum possible sensitivity.*

Thinking telescopes are being developed for space situational awareness and as a discovery-science platform to answer fundamental questions about transient astrophysical events such as gamma-ray bursts.

Launches of LANL scientific instruments in 2012 include NASA's Mars Science Laboratory and Radiation Belt Storm Probes missions. The robust scientific portfolio additionally enhances the necessary expertise and tools to distinguish national security signatures from background signatures associated with natural benign manmade phenomena.

**Goal 1:** Use signatures to understand, assess, quantify, and predict natural and manmade threats to the United States space infrastructure.

**Goal 2:** Field advanced detection technologies on space and airborne payloads or other platforms that have restrictions on mass, power, and volume.

**Goal 3:** Create smart sensors and sensor systems that are configured for space and that use autonomous measurement strategies for onboard conversion of data to information.

## Crosscutting Los Alamos Needs

Because of the relatively new nature of the framework, SoS will need extra attention and sustained commitment from the Laboratory if it is to thrive as a science pillar. The following cross-cutting recommendations arose during SoS workshop discussions. It will be the ongoing responsibility of the SoS Leadership Team to ensure that these needs are addressed as SoS continues to evolve.

- Formalize the ongoing role of the SoS Leadership Team in ensuring the longevity and vitality of the SoS effort. This effort includes weaving SoS into the existing structures and science strategies for the following institutes and centers.
    - Engineering Institute,
    - Information Science & Technology Institute,
    - Materials Design Institute,
    - Institute of Geophysics and Planetary Physics,
    - Seaborg Institute, and
    - Energy Security and Biosecurity Centers.
- Seamlessly integrate SoS with the Signatures and Sensing LDRD call to ensure ongoing innovation.
- Integrate SoS planning formally and on an ongoing basis with IS&T and Materials planning. Give semi-annual cooperative briefs to the LANL Team.
- Explore ways to share information and high-value resources related to SoS. These might include an internal database of equipment and expertise or the integration of SoS into the planning of the LANL capability reviews.
- Create an ongoing Laboratory investment strategy and process to purchase mid-range capital equipment of importance to the Science of Signatures.
- Explore the options for SoS infrastructure: a micro-fab facility that has a joint SoS/Materials focus was repeatedly suggested.
- Consistently employ systems engineering to more efficiently move sensing devices from the bench to the field.
- Ensure that some portion of Laboratory engineering investments support the SoS forward-deployment thrust.

## Conclusions and Next Steps

The key integrating factor across the six Science of Signatures focus areas is the SoS mission statement: "Characterize measures, signals and properties in/of complex systems to detect/attribute change and predict behavior and impact across scales of space (subatomic to astronomic) and time (femtosecond to geologic)." This science challenge is general and is shared by all six areas of leadership. Similarly, the three science themes for SoS–Discover Signatures, Revolutionize

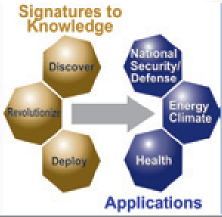
Measurements, and Forward Technology Deployment–cut across the six focus areas and provide a unifying framework for understanding the key science challenges in each focus area.

The key science challenges in each science theme also relate across the six focus areas of the strategy. Science goals in each focus area are framed as capability maintenance and development statements and represent the desired state of evolution of each capability in the focus area over a ten year time horizon. Over the six focus areas, there are 20 science goals that we aspire to achieve. This would be a daunting task for a ten-year time period, but we recognize that the Science of Signatures pillar must endure well beyond the scope of a single decade. It must be managed actively for the next 30 to 50 years, similar to how we plan for and manage the Materials and IS&T pillars currently (and in consonance with them). With that scope of commitment, we are confident that we can realize our vision and goals for the SoS pillar.

However, our science strategy is only achievable if we have comparable enabling strategies for facilities and infrastructure and for workforce development. We expect that the complete Science of Signatures strategy will help the Laboratory leadership to structure, prioritize, and justify the following types of investments:

- **Major Los Alamos Science Investments**
  - Laboratory Directed Research and Development–Directed Research Investments (LDRD-DR)
  - Laboratory Directed Research and Development–Exploratory Research Investments (LDRD-ER)
- **Major Institutional Capital Equipment Investment**.
  - Cameca SIMS (FY09)
  - 700 MHz NMR (FY11)
- **Major Institutional Facility Investments**.
  - TA-48 Radiological Sciences Modernization
  - Biologial science laboratory (level 3)
  - Radiological Laboratory/Utility/Office Building Occupancy
  - TA-51 Atmosphere, Climate, and Ecosystem Science Facility
  - TA-46 Chemical Security Initiative Laboratory
  - Materials Science Laboratory infill
  - Los Alamos Neutron Science Center test station
- **External Programmatic Requests**
  - New facilities investments
  - Capital equipment
  - Strategic programs and operations

*The National Security Sciences Building at LANL.*




# SoS Strategy at a Glance

## Nuclear and Radiological Signatures

*Nuclear Detection/Nuclear and Radiological Materials Characterization*

**Goal 1:** Achieve standoff detection of structures that yields valuable/actionable information about radiological and nuclear materials that we wish to observe but cannot access.

**Goal 2:** Create a suite of capabilities that enable process characterization and monitoring of special nuclear materials production facilities for a variety of applications.

**Goal 3**: Field novel methods or quantum improvements in actinide analysis for various applications.

**Goal 4:** Discover, design, and deliver the next generation of monitors and algorithms to detect special nuclear materials or weapons of mass effect when they are in movement.

*Nuclear Event Charazterization*

**Goal 5:** Drive next-generation material measurements to generate actionable data, directed by interpretation goals while meeting specific time and quality goals.

**Goal 6:** Provide the technical basis for predicting and interpreting all energy outputs by integrating expertise, models, and measurement systems.

**Goal 7:** Provide forefront modeling capabilities to guide decision making, as well as to turn data and signatures into knowledge.

## Chemical and Materials Signatures (including explosives)

**Goal 1:** Discover the next generation of chemical signatures, models, and detection platforms for chemical weapons identification and forensics.

**Goal 2:** Engineer and model the next generation of materials for sensing.

**Goal 3:** Build an enduring capability to predict/address emerging threats relevant to explosives detection, forensics, and attribution.

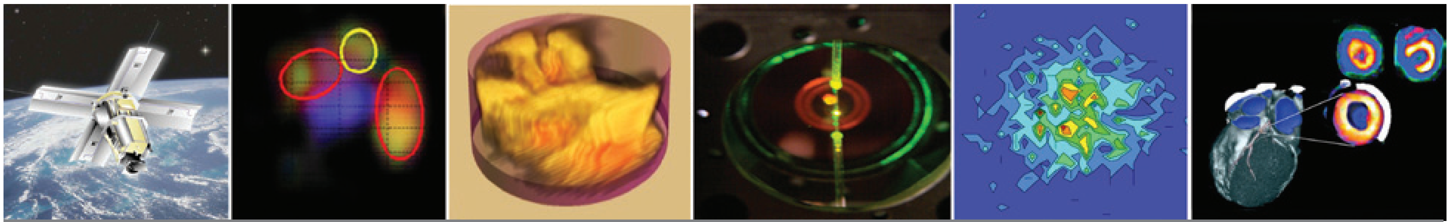
**Goal 4:** Create the next generation of signatures, models, and detection platforms to characterize nonradiological materials of interest for national security concerns.

## Biological Signatures

**Goal 1:** Identify and detect pathogens quickly, accurately, and inexpensively using signature validation, molecular assays, detection platforms, and sensor networks with the intent of informing epidemiology.

**Goal 2:** Develop new tools for epidemiology and disease modeling that enable us to predict disease progression and transmission by determining pathogen lifecycles, mechanisms of disease onset and progression, and mechanisms of transmission.

**Goal 3:** Enable disease management and response with knowledge-based decision tools that describe the characteristics of primary disease scenarios, analyze approaches and possible actions, and integrate data streams and modeling to predict outcomes.



## Energy Signatures

**Goal 1:** Pioneer new approaches to extracting/attributing signatures of energy from living organisms, geological environments, or manmade systems under conditions that are remote, inaccessible, and/or extreme.

**Goal 2:** Develop materials for energy and environmental systems that respond and/or report back on signature-induced stimuli.

**Goal 3:** Integrate sensing, modeling, and analysis science and technology to support decisions and investments, to protect systems and anticipate risks/degradation, and respond to disruptions, impacts, and consequences.

## Climate Signatures

**Goal 1:** Become the leader in those signatures of greatest value to climate science by developing computational and analytical techniques applicable to multi-variable data sets and by developing signal detection systems that span software to hardware (prototype to mature).

**Goal 2**: Achieve excellence in integrating observational data sets with analytic and computational models and use these models to develop new observations and signatures that increase the accuracy of climate predictions.

**Goal 3:** Become a trusted science advisor to energy and national security policy makers who draw upon our expertise to integrate the Science of Signatures, regional climate prediction, climate impacts assessment, and energy infrastructure and policy analysis.

## Space Signatures

**Goal 1:** Use signatures to understand, assess, quantify, and predict natural and man-made threats to the U.S. space infrastructure.

**Goal 2:** Field advanced detection technologies on space and airborne payloads or other platforms that have restrictions on mass, power, and volume.

**Goal 3:** Create smart sensors and sensor systems that are configured for space and that use autonomous measurement strategies for onboard conversion of data to information.

## Crosscutting Institutional Needs

- Formalize the ongoing role of the SoS Leadership Team in ensuring the longevity and vitality of the SoS effort, including weaving SoS into the existing structures and science strategies for the institutes/centers.
- Seamlessly integrate SoS with the Signatures and Sensing LDRD call to ensure ongoing research and vitality.
- Integrate SoS planning formally and on an ongoing basis with IS&T and Materials planning.
- Create a cross-organizational mechanism to inform and share high-value resources such as equipment and expertise.
- Create an ongoing Institutional investment strategy and process to purchase midrange capital equipment of importance to signature science.
- Explore the options for SoS infrastructure a microfab facility that has a joint SoS/Materials focus was repeatedly suggested.
- Start a SoS seminar series in collaboration with the Institutes Office.
- Employ a systems engineering methodology and discipline to the realization of fieldable sensing devices.
- Influence institutional engineering capability investments toward advances in SoS forward technology deployment.

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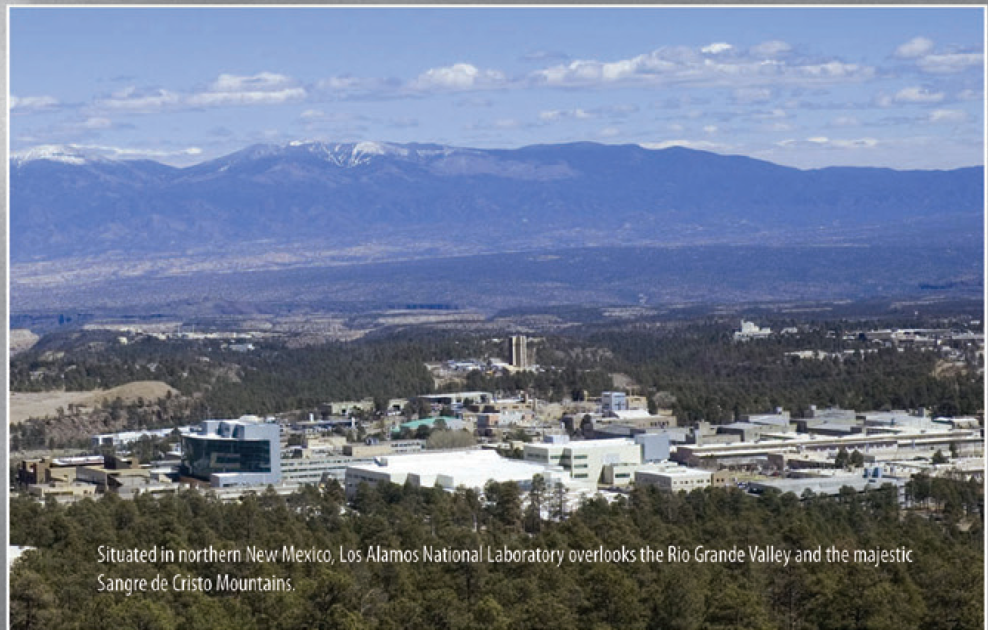

Situated in northern New Mexico, Los Alamos National Laboratory overlooks the Rio Grande Valley and the majestic Sangre de Cristo Mountains.