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LAWRENCE LIVERMORE NATIONAL LABORATORY

Technical Summaries Director's Review Committee April 29-May 1, 2008

Jay Zucca, Cindy Atkins-Duffin

April 24, 2008

Global Security Principal Directorate Directorate Review Committee Meeting
Livermore, CA, United States
April 28, 2008 through May 1, 2008

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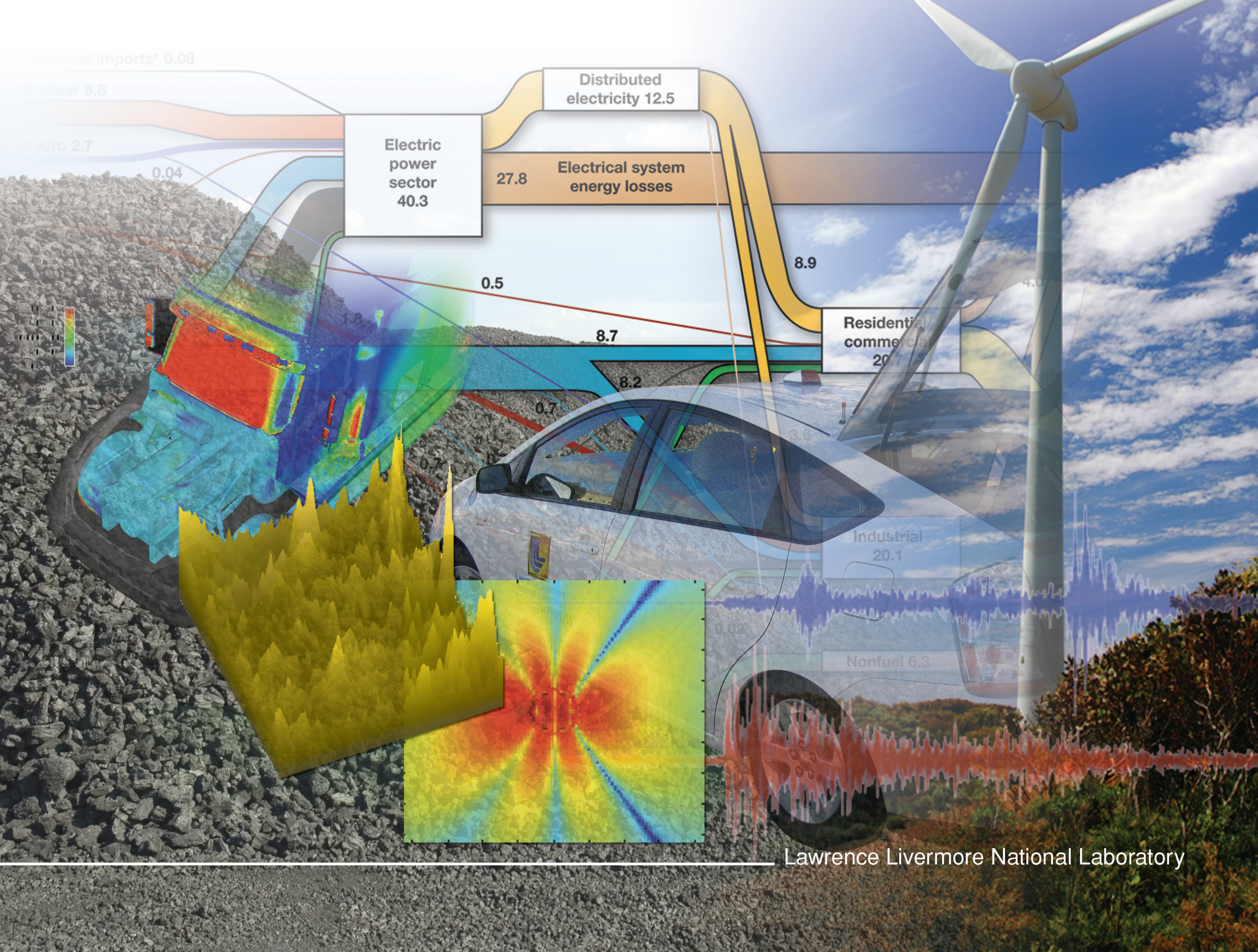
Technical Summaries

Director's Review Committee
April 29 – May 1, 2008



Lawrence Livermore National Laboratory

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DRAFT AGENDA
Global Security Principal Directorate
DIRECTORATE REVIEW COMMITTEE MEETING
April 28 – May 1, 2008

MONDAY, APRIL 28, 2008

6:30 p.m.	Transport from Hotel to Laboratory	LLNL Driver
7:00 p.m.	Committee Dinner	By Invitation Jade Room
	Overall Global Security Goals, Philosophy Behind Organization and Realignment. What we want from you	John C. Doesburg
	Charge to Committee – Assignments	Penrose Albright and Michael Nacht, Committee Co-Chairs
9:00 p.m.	Adjourn and transport from LLNL to Hotel	LLNL Driver

TUESDAY, APRIL 29, 2008

7:30 a.m.	Transport from Hotel to Laboratory	LLNL Driver
8:00 a.m.	Arrival and Hospitality	Bldg. 132S, Room 1102
8:15 a.m.	Welcome and Director's Update	George H. Miller
8:45 a.m.	Global Security Overview	John C. Doesburg
9:15 a.m.	Strategic Planning and Strategic Roadmap	T.R. Koncher
9:45 a.m.	Break	
10:00 a.m.	Energy and Environmental Security Program Development Priorities	Douglas Rotman
10:30 a.m.	Nonproliferation Program Development Priorities	David McCallen
11:00 a.m.	E Program	Cynthia Atkins-Duffin

Host:	John C. Doesburg, Principal Associate Director, Global Security
Technical Host:	Michael R. Carter, Deputy Principal Associate Director, Programs
Admin contacts:	Terry Garrigan (925) 423-6209, garrigan2@llnl.gov
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11:45 a.m.	Lunch	By Invitation Only
	Energy and Environment: Why LLNL?	Cynthia Atkins-Duffin
1:00 p.m.	Hydrogen Car Demonstration	Salvador Aceves
2:00 p.m.	How the Climate Will Change Over the Next 50-100 Years	Benjamin Santer
3:00 p.m.	Energy Flow	Nalu Kaahaaina
3:30 p.m.	Wind Energy Research at LLNL	Julie Lundquist
4:00 p.m.	Break	
4:15 p.m.	Posters: Geothermal, Hydrogen, Biofuels, Aerodynamics, and Solar-Mechanical Engine	Jeffery Roberts, Salvador Aceves, Robert Glass, Kambiz Salari, Charles Bennett
5:45 p.m.	Walk to Jade Room	
6:00 p.m.	Reception and Dinner	By Invitation Jade Room
8:00 p.m.	Transport to Hotel	LLNL Driver

WEDNESDAY, APRIL 30, 2008

7:30 a.m.	Transport from Hotel to Laboratory	LLNL Driver
8:00 a.m.	Arrival and Hospitality	Bldg. 132S, Room 1102
8:15 a.m.	Underground Coal Gasification	Julio Friedmann
8:45 a.m.	Carbon Capture Sequestration	Roger Aines
9:15 a.m.	Poster Session: Weyburn, Capture, Stochastic Engine, Geomechanics, Carbon Dioxide Dispersion	James Johnson, Abelardo Ramirez, Joseph Morris/Russell Detwiler, Martin Leach
10:15 a.m.	Energy and Environmental Security Wrap-Up	Committee Chair

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10:45 a.m.	Break	
11:00 a.m.	Nonproliferation Overview and Vision	John J. Zucca
11:45 a.m.	Securing Nuclear Materials Worldwide	Moussaddak Bissani
12:15 p.m.	Lunch	By invitation
	Role of Intelligence in Supporting E Program Activities	Mary Beth Ward
1:00 p.m.	DPRK	George Anzelon
1:30 p.m.	Posters: Sonoma, Nuclear Materials Signatures, Cooperative International Engagement, Hyperspectral Imaging	June Yu, Erick Ramon/Ian Hutcheon, Eileen Vergino, Robert Priest
2:30 p.m.	Nuclear Explosion Monitoring	William Walter
3:00 p.m.	Break	
3:15 pm	Next Generation Safeguard Initiatives – Opportunities for LLNL	Mona Dreicer
3:45 p.m.	Advanced Safeguards Technology Concepts	Adam Bernstein
4:15 p.m.	Advanced Nuclear Fuel Cycles	Keith Bradley
4:45 p.m.	Potential for the Re-Emergence of Treaty Verification	David McCallen
5:15 pm	Proliferation Signatures	August Droege
5:45 p.m.	Walk to Jade Room	
6:00 p.m.	Reception and Dinner Work on Report	Committee Only Jade Room
8:00 p.m.	Transport to Hotel	LLNL Driver

Host: John C. Doesburg, Principal Associate Director, Global Security
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THURSDAY, MAY 1, 2008

7:30 a.m.	Transport from Hotel to Laboratory	LLNL Driver
8:00 a.m.	Arrival and Hospitality	Bldg. 132S, Room 1102
8:15 a.m.	Nonproliferation Wrap-Up	Committee Chair
8:45 a.m.	Walk to Building 140	
9:00 a.m.	Intelligence Update (or CAMS Tour)	Bldg. 140, Room 2028 Location TBD
10:30 a.m.	Break and Walk to Building 132S, Room 1102	
11:00 a.m.	Recap	John Doesburg, Michael Carter
12:00 p.m.	Executive Session	Committee Only
2:00 p.m.	Report out to Global Security Management	Committee and Global Security Senior Managers
3:00 p.m.	Adjourn	

Host: John C. Doesburg, Principal Associate Director, Global Security
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<u>Global Security DRC Membership</u>

Dr. Penrose (Parney) Albright, Co-Chair
Civitas Group LLC

Dr. Michael Nacht, Co-Chair
University of California, Berkeley

Dr. Victor E. Alessi
Computer Sciences Corporation (CSC)

Dr. James R. Burnett (unable to attend)
TRW

Prof. Per F. Peterson
University of California, Berkeley

Dr. Bill Priedhorsky
Los Alamos National Laboratory

Dr. William Schneider, Jr.
International Planning Services, Inc.

Peter J. Weinberger
Google, Inc.

<u>External Invitees</u>

John Birely
Rita Colwell, Point-of-Contact for the LLNS, LLC Science & Technology Committee
Bill Frazer (unable to attend)
Gen. John Gordon
Raymond Jeanloz
Lee Peddicord
Darrell Long, Point-of-Contact for the LLNS, LLC Science & Technology Committee
Rochus (Robbie) E. Vogt (unable to attend)

Host:	John C. Doesburg, Principal Associate Director, Global Security
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Prepared by LLNL under Contract DE-AC52-07NA27344.

Technology Summary: Energy and Environmental Security Program

Introduction

Providing the essential energy and water systems to support human needs while understanding and addressing their environmental consequences is perhaps the greatest challenge ever faced by mankind. The energy systems developed and deployed in the last century have advanced the standard of living in the developed world. Yet these systems are a source of national security concerns, including geopolitics, conflicts, and possible macroeconomic disruption. In addition, a new dimension of energy security is emerging: human-driven climate change. As a nation we face a new potential agitator in the form of anthropogenic global, potentially abrupt, climate change that will affect natural resources, infrastructure, and social organization.

Fossil fuel remains the least expensive and most available resource of energy and the basis of our economy. The use of fossil fuels, especially over the last 100 years, has led to a 30% increase in CO_2 in the atmosphere causing climate change with large global, regional, and local implications. The problem is growing. The population of the Earth will increase by several billion people in the next 50 years. To continue economic growth, the demand for energy is projected to nearly double in the next 50 years to 25TWs of required energy resources. This problem is even greater in developing countries, where extreme growth (>11%GDP) is producing both environmental crises and demands for new technology. Additional resources of clean, sustainable, and secure energy must be developed and deployed all the while improving the environment through reduced impacts from energy production and use.

Project/Program Description

The Energy and Environmental Security Program proposes a three-component solution:

- *Assess*: Understand climate and energy systems including security concerns and ramifications
- *Mitigate*: Develop energy technologies that mitigate climate change and protect our environment
- *Verify*: Deploy observation systems that verify GHG emission reductions and stewardship of the environment

The needs and requirements to achieve this solution set are enormous; solutions will take national laboratory-scale capabilities and facilities and multiple strategic partnerships to bring together the right expertise. LLNL cannot do this alone.

Leveraging Laboratory Capabilities

To achieve a growing program that addresses the national need, we are applying science and technology, capabilities, and facilities that stem from our historical LLNL mission in weapons and national security. These include:

- Atmospheric and climate science
- Complex systems integration
- Intelligence data and analysis
- Geoscience
- Nuclear weapons expertise
- Proliferation science

Technology Summary:
Energy and Environmental Security Program

- Materials science and materials behavior at extreme conditions
- Isotope chemistry
- World class computing

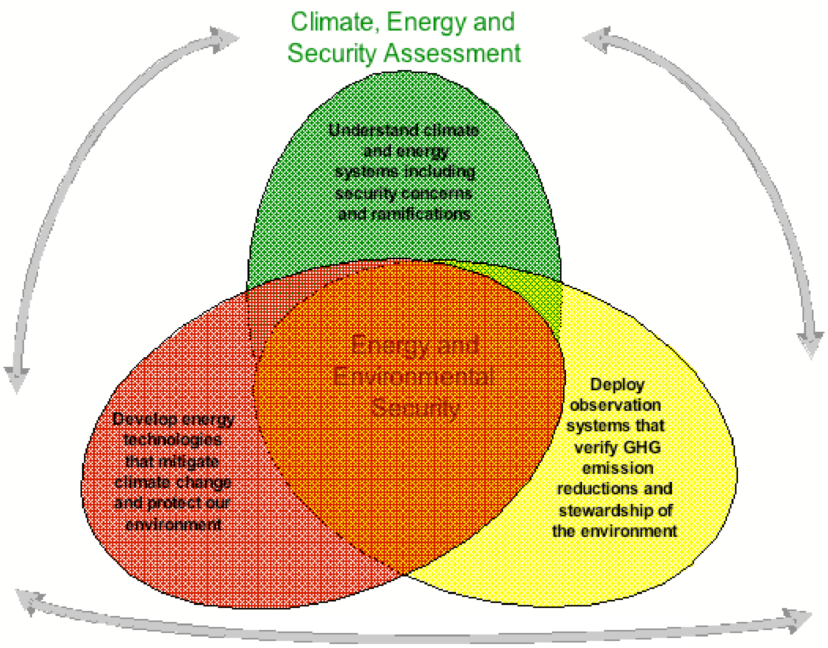
Peers and Partners

In atmospheric science and climate science, LLNL stands as a premier DOE national laboratory. Indeed, LLNL would rate as a top institution across the entire government laboratory complex; our science and programs are internationally renowned. In energy technologies, we are a smaller player, albeit with a select few unique world-class capabilities, including, for example, carbon sequestration and hydrogen storage.

In areas of strength and relative weakness, strategic partnerships are essential. Our partnerships reach across universities, sister DOE national laboratories, other federal agency and international laboratories, and industry.

Looking Forward

Our program activities are focused on developing a portfolio of work that highlights the unique skills/capabilities at LLNL, forming strategic partnerships, investing internal monies to develop S&T and improve laboratory capabilities, and engaging potential clients that will lead to a growing program. Partnerships across LLNL are equally important. Our success will rest on the S&T organization building a science base that provides the skills and expertise to achieve client requirements.



Program Summary: Nonproliferation

Introduction

The proliferation of materials and technologies required to construct a weapon of mass destruction is, and will continue to be, one of the primary national security challenges facing the United States. The importance of this problem was recently noted in the 2008 U.S. House of Representatives Omnibus bill

> "*… nuclear weapons materials in the hands of terrorists poses the greatest threat to the United States. The most effective protection from this is to ensure that nuclear material is well-monitored and protected so that it does not fall into the hands of terrorists …*"

Many elements contribute to the nonproliferation challenge. They include the vast volumes of legacy nuclear materials from weapon and nuclear research programs, inadequately protected and inadequately safeguarded materials in declared nuclear activities, and undeclared nuclear activities carried out by a state or group with malevolent intent.

There are two fundamental means to address these problems. The first involves international cooperation whereby nations engage in mutually agreed upon activities to prevent the spread of nuclear materials and technologies that can be used for nuclear weapons (e.g,. international safeguards, physical protection, export controls). The second is to develop advanced technical means that can be used to monitor and detect signatures of proliferation. Emergent proliferation activities can be identified and dealt with in accordance with informed U.S. policy decisions.

Globalization has meant an increasingly free flow of goods and people. At the same time, accessing weapon material from dual-use technologies has become easier. Proliferation challenges will persist and require focused attention well into the foreseeable future.

Project/Program Description

LLNL's nonproliferation program supports the NNSA Office of Defense Nuclear Nonproliferation (NA-20) in its nuclear nonproliferation mission. LLNL program activities are aligned with the three NNSA strategic mission areas:

- Advance the technologies to detect the proliferation of weapons of mass destruction worldwide
- Eliminate or secure inventories of surplus materials and infrastructure usable for weapons of mass destruction
- Limit or prevent the spread of materials and expertise relating to weapons of mass destruction

In support of these mission areas, the LLNL program characterizes tell-tale signatures of proliferation activities and applies science, engineering and computations expertise to new remote and ground-based sensing technologies that can locate and analyze signatures. LLNL supports the development and sustainment of physical security measures in the Former Soviet Union and other countries. We also participate in international engagements aimed at the cooperative development and enforcement of appropriate security and nonproliferation norms. LLNL has been a leader engaging North African countries as they move towards peaceful uses of nuclear technology. LLNL has assisted in the elimination of nuclear proliferation activities in Libya and continues to work on proliferation in DPRK. LLNL is intimately involved in the development of emerging advanced international safeguards roadmaps within multiple NA-20 offices.

Leveraging Laboratory Capabilities

The LLNL nonproliferation program relies strongly on the melding of science, engineering, and computations capabilities within the laboratory with special focus on:

- Seismology and geophysics for ground-based nuclear explosion monitoring
- Optics, communications, and on-the-fly computations for sensor platforms
- Radiation sensing and material signature characterization for safeguards
- High-performance computations for regional simulations of ground and atmospheric transport
- Nuclear weapons knowledge for assessment of material attractiveness and assessment of proliferation threat

The LLNL program also relies significantly on intelligence analysis and international policy expertise related to:

- Analysis of proliferation networks
- Implementation of effective export controls
- Technology pull and implementation processes in accordance with international treaties and agreements
- Protocols and procedures for international engagements

Peers and Partners

LLNL has collaborated and competed with other national laboratories in the nonproliferation area. As a result of historical decisions, LLNL's program is more focused on proliferation detection R&D, selected cooperative international engagements, and proliferation analysis. LLNL is a smaller, albeit important, contributor to large, hardware- intensive overseas activities such as MPC&A. LLNL is recognized for outstanding scientific and engineering competency in its proliferation detection programs, and LLNL's intelligence analysis capability is highly regarding throughout the national security community. Our nonproliferation program leverages LLNL's Center for Global Security Research in executing high-level international workshops and international engagements.

Since LLNL began to be managed by LLNS, the Laboratory has placed an increased emphasis on strategic partnering with other laboratories. Our nonproliferation program has engaged extensively with ORNL and LANL on joint proposals and strategic discussions about program direction.

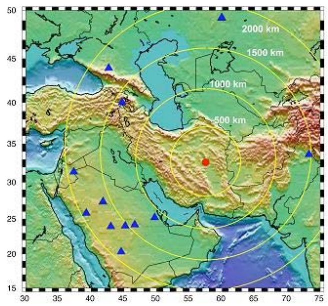
Looking Forward

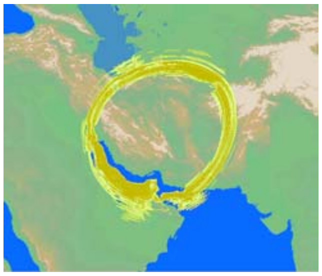
It appears likely that the next administration will have renewed interest in treaties and associated discussions of verification technologies. The upcoming election could thus make a substantial difference in the focus of U.S. nonproliferation policy over the next 5-10 years.

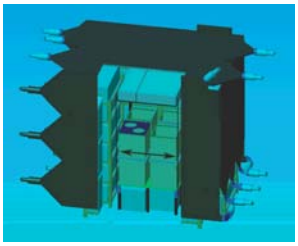
Programs to secure materials and provide transportation screening technologies will likely complete in the 2013-2015 timeframe. We expect to make increasing contributions in this area. For example, LLNL was recently named lead laboratory for securing and removing rad sources in the Former Soviet Union.

Program Summary: Nonproliferation

We expect to participate in discussions on how the U.S. will address the rapidly expanding international nuclear energy enterprise and associated proliferation challenges. LLNL is part of planning and road mapping exercises for a major national initiative in advanced safeguards technology.







Nonproliferation Activities: Monitoring and detection, advanced safeguards, and international engagement

Technology Summary: E Program

Introduction

Securing proliferation-free, carbon neutral energy for the world is the work of the newly formed E Program. This $140M program was formed by merging the former Energy and Environmental Security (E&ES) Division with the former Nonproliferation (NP) Division. Nearly 150 FTE's provide insight into a number of aspects in the nuclear materials, carbon fuel and alternative energy cycles.

Project/Program Description

LLNL's history is in it's systems understanding of the nuclear materials cycle, including both civilian and defense aspects. E Program will apply this systems thinking to the carbon and alternative energy fuel cycles and exploit the common issues to all fuel cycles: resource management; technology development and implementation; impacts, consequence management, risk assessment; regulatory, policy, compliance monitoring; and waste management.

The Program is organized into six project areas:

- Nuclear Fuel Cycle – proliferation resistant fuel design, Global Nuclear Energy Partnership, Yucca Mountain Program, Waste Isolation Pilot Plant, and the Nuclear Regulatory Commission
- Nonproliferation and International Security – dismantlement and transparency, global security engagement and cooperation, international regimes and agreements, and international safeguards
- Nuclear Materials – Physical protection and accounting, securing of radiological materials, plutonium disposition and packaging/transportation
- Nuclear Proliferation Monitoring – Explosion monitoring, materials situational awareness, Environmental Sampling, and NA-22 management and coordination
- Carbon Fuel Cycle – Fossil fuel emission verification, Monitoring - Measurement - Verification, carbon sequestration, underground coal gasification, combustion, and reduction of aerodynamic drag
- Alternative Resource Cycles – Renewables (geothermal, biofuels, wind, solar), hydrogen, energy systems analysis and climate

Leveraging Laboratory Capabilities

LLNL has a long history in a variety of technologies that have been derived from the nuclear weapons testing program. Examples of expertise that is used in E Program today that has its genesis in nuclear weapons design and testing include:

- Seismology and geoscience for ground-based nuclear explosion monitoring
- Nuclear weapons knowledge
- Atmospheric modeling
- Large-scale computing
- Optics
- Radiation detection

Our geoscience and seismology programs have engendered world-class programs in geothermal energy, nuclear explosion monitoring, underground coal gasification and carbon sequestration. Our deep knowledge of nuclear weapons allows us to think innovatively about international safeguards technologies, assess material attractiveness for physical protection and accounting, and securing of radiological materials.

Large-scale computing and the unique resources at the laboratory are being applied to such diverse programs as nuclear explosion monitoring, climate modeling and the design of proliferation-resistant power technology and nuclear fuels.

The radiation detection and optics expertise, derived from both the nuclear weapons program and the astrophysics program is being used to design new radiation detection and remote sensing capabilities for nonproliferation applications.

Peers and Partners

LLNL has both collaboration and competition with other national laboratories in the nonproliferation area. We continue to be leaders in the ground-based nuclear explosion monitoring program as we compete with LANL and SNL in this area. SNL efforts tend to be engineering and software based, while LLNL and LANL focus on science. In proliferation detection, LLNL is the recognized leader in remote sensing and persistent surveillance. LANL competes with us, as does SNL.

LLNL is a recognized leader in climate modeling. We compete with other DOE laboratories in the areas of energy research, but we believe our unique background in both pioneering energy research, coupled with our nuclear weapons expertise will allow us to become the integrating laboratory for advanced energy research in both renewable energy and carbon management.

We seek to partner with other laboratories where our capabilities are complementary. One example is partnering ORNL for materials analysis, where we have unique analytic capabilities and ORNL has extensive experience in handling of HEU.

Looking Forward

As the administration changes with the next election, the potential exists for huge policy shifts in energy, climate and nonproliferation. Our expertise in all three areas poises us to make significant contributions in all three areas no matter what the policy. More importantly, the ability to understand the nexus of all three and their impact on the security of the United States puts E Program in a unique position to contribute.

Technology Summary: Why LLNL?

Introduction

Providing sufficient proliferation-free, carbon-neutral energy and understanding the impacts of these choices on global climate are national security imperatives. Energy choices will affect our economy, our international political posture, resource availability, and our quality of life for years to come. Global leaders must make informed, scientifically defensible decisions both in terms of technologies and policy. LLNL offers decision makers unique capabilities and expertise and is developing partnerships that will help address this extraordinary challenge.

Many organizations contribute to understanding energy and climate issues and a "path forward." For example, governments develop and implement changes in policy by levying taxes and issuing financial incentives or credits. Industry responds to and drives the marketplace while answering to their stockholders. Universities train future practitioners and provide an understanding of important issues.

Leveraging Laboratory Capabilities

National laboratories are neutral, honest brokers and are thus a highly appropriate choice for leadership of energy and climate issues. National laboratories are more S&T oriented than industry, more mission-oriented than universities, and are a clear choice for long-term research. A number of federal, single-purpose laboratories provide the competition for leadership roles. However, the DOE weapons laboratories are a logical choice based on their long-term experience in understanding complex systems, especially those whose understanding comes from the use of sophisticated models built from and validated by large data sets.

LLNL is unique in its California location. California is a leader in addressing energy and climate issues, including water availability and quality, air quality resulting from Asian energy choices, understanding climate change impacts on agriculture, and understanding the coupled impact on its large economy.

We also have a strong history and excellent reputation in energy and environmental security research. We were leaders in the field during the 1970s and 80s. We successfully harnessed tools developed for nuclear weapons research and applied them to energy issues. Because of the unclassified nature of this work, our program has functioned as the LLNL "portal" to the external community in a variety of forums. While these efforts have been necessary to keep us in the energy game, they are not sufficient to return to a leadership role. We must develop new tools to address energy problems. In addition, sponsors must return to funding large, focused efforts.

LLNL has a window of opportunity to rise to the leadership role again. LLNL director George Miller has identified energy and environmental security as an enduring mission, to which we apply "world-class

Technology Summary: Why LLNL?

science, technology and engineering to important national problems.” LLNL has a reputation for offering a stimulating and challenging working environment along with intellectual freedom and the opportunity to extend one’s limits, which makes the laboratory attractive to new, young talent. LLNL has also historically been home to unique capabilities and the opportunity to solve important national problems. This working environment must be preserved if LLNL is to become a leader again.

Technology Summary: Global Climate Change

Introduction

Human activities have significantly altered both the chemical composition of the atmosphere and Earth's climate. Understanding and responding to human-caused climate change constitutes one of the major environmental challenges of the 21st century. Over the past two decades, LLNL research has provided clear and compelling evidence of a human "fingerprint" on climate. LLNL has also been at the forefront of efforts to evaluate and improve computer models of the climate system. These models are essential tools for understanding the climate changes we are likely to experience over the 21st century.

Project/Program Description

Human-caused changes in atmospheric composition are immutable fact. Human activities have led to increases in greenhouse gases, decreases in stratospheric ozone, and changes in atmospheric loadings of soot and sulfate aerosol particles. Changes in these constituents modify Earth's natural radiative balance, and thereby perturb the climate. Computer models are an essential tool for studying the impact of human activities on climate. In 1989, the U.S. D.O.E. established the Program for Climate Model Diagnosis and Intercomparison (PCMDI) at LLNL. PCMDI's goal was to assess the fidelity of climate model simulations and quantify uncertainties in model projections of future climate change. Over the past 19 years, PCMDI has coordinated international efforts to provide standard "benchmark" experiments for climate models, and has made output from these experiments available to a broad scientific community. This has transformed the way the climate science community does business. Climate scientists are now able to:

- Identify errors common to many different models
- Track changes in model performance over time (in individual models and collectively)
- Make informed statements about the relative quality of different models
- Quantify uncertainties in model projections of future climate change

Full community involvement has led to more thorough model diagnosis, and ultimately to improved models.

PCMDI has also demonstrated scientific leadership in the analysis of climate model simulations, and in research directed towards unraveling the causes of historical climate change. This work, often referred to as "fingerprinting", involves rigorous statistical comparisons of modeled and observed geographical patterns of climate change. The premise in fingerprinting is that each factor which influences climate (such as human-caused changes in greenhouse gases, or purely natural changes in the Sun's energy output) has a unique climate fingerprint. Climate models can be used to study the impact of individual "forcing factors", and hence to understand and quantify the contributions of these different factors to observed climate change. PCMDI scientists have pioneered the development and application of fingerprint methods. The LLNL team has led research resulting in first identification of a human fingerprint in:

- Surface temperature (1995)
- Zonal-mean vertical profiles of atmospheric temperature change (1996)
- Satellite records of stratospheric and tropospheric temperature change (2003)
- The height of the thermal tropopause (2003, 2004)

- Sea-surface temperature changes in hurricane formation regions (2006)
- Atmospheric water vapor over oceans (2007)

We have also contributed to research (jointly with Scripps) resulting in first identification of a human fingerprint in:

- The vertical structure of upper-ocean temperature changes (2005)
- Hydrologically-relevant climate variables in the western U.S. (2008)

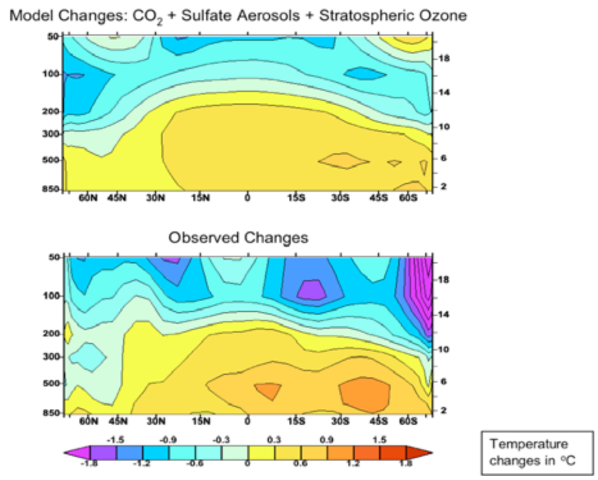
In addition, LLNL research has helped to remove a major stumbling block in our understanding of the causes of climate change. For over a decade, critics of “discernible human influence” conclusions have argued that satellite data show cooling of the tropical troposphere, while climate model simulations indicate that this region of the atmosphere should be warming in response to increases in greenhouse gases. It is now known that the satellite data contained a serious error. A seminal LLNL paper in Science (Santer *et al*., 2005) demonstrated that when the effects of this error were accounted for, both models and observations show warming of the tropical troposphere, in accord with basic theory.

Leveraging Laboratory Capabilities

The LLNL-led (PCMDI) has made major contributions to the “discernible human influence” conclusions of national and international assessments, such as those produced by the U.S. National Academy of Sciences, the U.S. Climate Change Science Program (CCSP), and the Intergovernmental Panel on Climate Change (IPCC). These contributions have been achieved through PCMDI’s scientific leadership (over nearly two decades) in “fingerprinting” and model evaluation research, by providing Convening Lead Authors and Lead Authors of various IPCC and CCSP Assessment Reports, by hosting climate model databases at PCMDI, and by distributing climate model output to the entire climate science community. Model output archived at PCMDI was key to the success of the IPCC Fourth Assessment Report.

Peers and Partners

The LLNL-led PCMDI serves as a national and international resource for climate model intercomparison and benchmarking. This includes collaborations with over literally dozens of universities, modeling centers, and national laboratories worldwide.



“Fingerprinting” with temperature changes in Earth’s atmosphere. (Santer *et al*., 1996)

Technology Summary: Global Climate Change

Looking Forward

Although PCMDI has had success in improving our scientific understanding of the nature and causes of climate change, the science is not "settled". There are still significant uncertainties in estimates of the size and geographical distribution of climate changes projected to occur over the 21st century. These uncertainties make it difficult for us to assess the magnitude of the mitigation and adaptation problem that faces us. PCMDI, with over two decades of expertise in model diagnosis, could help to reduce these uncertainties.

The IPCC Fifth Assessment Report will appear in early 2013. It will rely heavily on more complex "Earth System Models" (ESMs), with integrated carbon cycles and interactive atmospheric chemisty. Diagnosis of ESMs will provide PCMDI and LLNL with future challenges and and future opportunities.

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Technology Summary: Energy Flow Charts

Introduction

Achieving energy and environmental security requires a comprehensive understanding of large-scale systems. The complexities of energy systems—details that are crucial for proposing effective solutions—defy simple categorization. Energy flow charts, or EFCs, are energy-specific Sankey diagrams that are used to visualize these systems. EFCs enable users to more rapidly comprehend system operation and performance.

Project/Program Description

For energy and environmental security efforts, flow charts are used not only to analyze energy but also carbon, water, and other relevant "networks." These analyses provide insights that simultaneously enable system optimization (e.g., underutilized resources, need for better technology) and identify cross-system couplings (e.g., carbon embedded in energy, water demand for electricity generation).

Leveraging Laboratory Capabilities

Livermore has generated EFCs for over 30 years using several tools over that period. The next-generation software, currently under development, harnesses laboratory expertise in algorithm design, physics-based modeling, and system analysis to produce increasingly refined assessments.

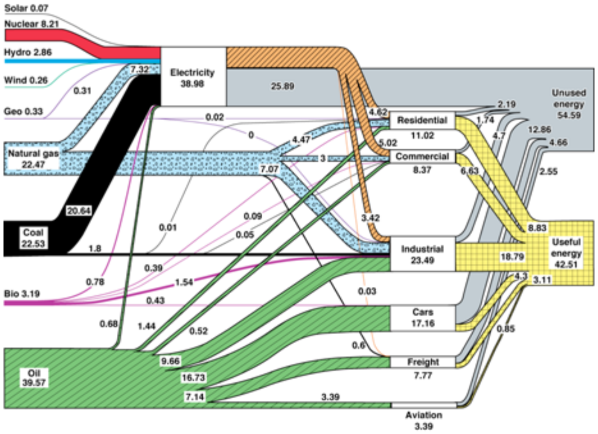
Peers and Partners

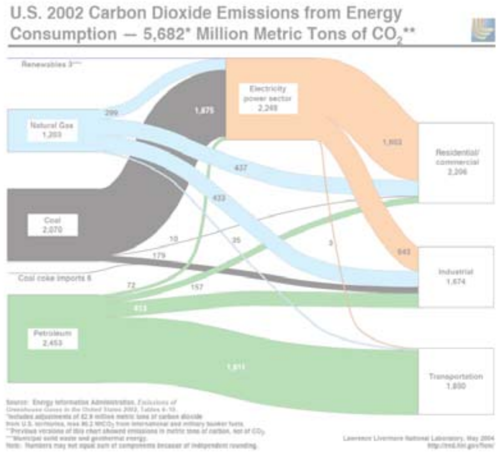
Several institutions analyze energy systems, with a subset focusing jointly on energy–climate. Livermore has been in discussions with Stanford University's Global Climate and Energy Project to add exergy analysis capabilities. We also recently launched an initiative to partner with PNNL's Joint Climate Change Research Institute. This second collaboration would extend beyond EFCs, providing additional richness to Livermore's systems analysis.

Looking Forward

We expect to continue working with public and private stakeholders in the related areas of energy and climate. New features will include exergy analysis, argicultural systems, and more refined descriptions of energy demand (i.e., specific applications within each sector).

Technology Summary: Energy Flow Charts





The roles of energy and carbon are pivotal in energy and environmental security. The figure on the left depicts the magnitude of energy flows in the United States. The figure on the right displays the carbon dioxide emissions associated with these energy services.

Relevant Publications and Requests for Energy Flow Charts

National Research Council (2008), *What You Need To Know About Energy*, National Academies Press.

Whitesides, G.M., Crabtree, G.W. (2007), Don't Forget Long-Term Fundamental Research In Energy, *Science* 315, 796, DOI: 10.1126/science.1140362.

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Request from United States Congressman Nick Lampson (2007), 22nd Congressional District, State of Texas.

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Technology Summary: Wind Energy

Introduction

To fulfill its national security mission, LLNL hosts the National Atmospheric Release Advisory Center (NARAC), which excels at predicting lower atmosphere winds and the hazardous materials they carry. This same expertise is applicable to addressing urgent energy problems by predicting winds for wind energy generation. Wind power in the United States currently provides about 15 GW, or less than 1% of total US electricity generation. Nearly 30 states have called for significant increases in this percentage, setting goals of "20-% renewable energy by 2020." Congress has considered passing a similar federal renewable portfolio standard. A recent analysis by DOE, NREL and the American Wind Energy Association demonstrated that the 20-percent goal is possible. However, many steps are needed for success, especially regarding wind-energy forecasting at multiple timescales to integrate large quantity of renewable energy into power grids.

Project/Program Description

These wind forecasts must account for complexities of microclimates, with very high spatial resolution, grid cells with horizontal resolution on the order of 10 m, and vertical resolution of approximately 2 m near the surface. Such high-resolution simulations are more complicated than "conventional" weather forecasts because the existing parameterizations, designed for coarser-resolution simulations, fail at such high resolution. LLNL, with LDRD support, has incorporated very-high-resolution turbulence parameterizations into the community numerical weather prediction model, WRF (Weather Research and Forecasting, http://www.wrf-model.org). Not only do our parameterizations work for all types of atmospheric stability conditions, both day and night, but we also have found that we can capture relevant physics at coarser resolution, which can save 25% or more on computational time.

These forecasts provide useful information to wind-energy plant operators, wind energy developers, and utility operators. Plant operators use weather predictions to guide bids on energy production contracts: overestimates of their "harvests" result in fines, and underestimates mean they will not be compensated for all the energy they produce. Wind energy developers also depend on accurate forecasts to determine optimal sites for their turbines. Utility operators with significant fractions of renewable energy need forecasts to understand if and when they will need to supplement with other forms of energy.

Leveraging Laboratory Capabilities

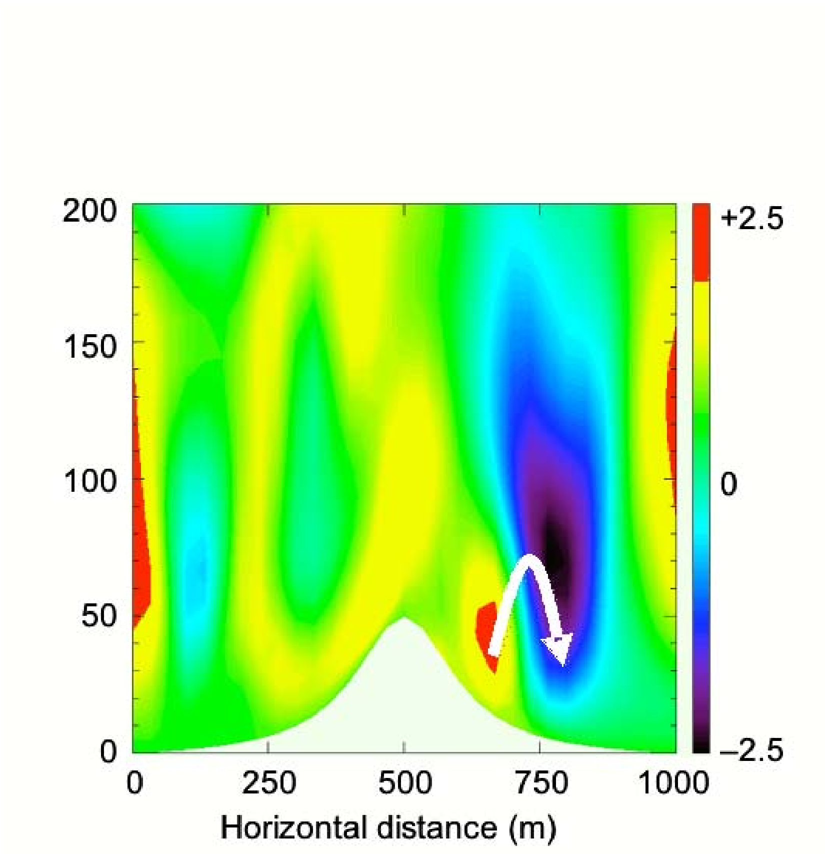
NARAC's weather prediction expertise is coupled with high-resolution databases and scientific expertise in atmospheric boundary-layer meteorology. Our team uses these resources with LLNL's high-performance computing facilities to address the needs of both energy resource predictions and atmospheric hazardous release predictions.

Peers and Partners

LLNL's high-resolution wind forecasting capability is unique; the National Weather Service provides much coarser forecasts, with grid cells on the order of 4 km. Wind energy forecasting companies have not yet developed the parameterizations that apply at this level of resolution. We are currently developing a CRADA with a major turbine manufacturer/wind park developer so that our forecasting tools may be used their wind-park management software. We have a collegial relationship with NREL's National Wind Technology Center but have not yet collaborated on a project related to this forecasting tool.

Looking Forward

In addition to the upcoming CRADA, we are pursuing other relationships with wind energy forecasting companies and other wind park developers. Useful technical developments would include the incorporation of upwind turbines and other structures into our modeling capability. Most useful would be a connection with a large utility interested in such forecasting and dedicated computational time to demonstrate the long-term feasibility of a routine forecasting operation at this resolution for grid stability modeling purposes.



These contours of vertical velocity from a simulation of flow over a small hill show that LLNL's Nonlinear Backscatter with Anisotropy WRF closure correctly predicts recirculations at ¼ the computational expense previously required.

Technology Summary: Geothermal Energy

Introduction

Geothermal energy is a large national energy resource that is currently underutilized. Development of this resource is advantageous because there are no proliferation issues and the energy has a low carbon imprint.

Project/Program Description

LLNL can contribute to developing geothermal energy in a number of ways. Improved exploration techniques are needed to identify the best sites for drilling. We are using InSAR and other geophysical techniques and datasets as input to the Stochastic Engine. In addition, research supporting Enhanced Geothermal Systems is critical to make more sites economical and to extend the life of the reservoir.

Leveraging Laboratory Capabilities

The laboratory has a unique combination of computational, theoretical, modeling, and experimental capabilities that directly address a number of energy research and technology problems, including geothermal energy. Without one of these capabilities, such as geochemical modeling or experiments in reactive transport and fracture permeability evolution, we lose uniqueness and competitive advantage.

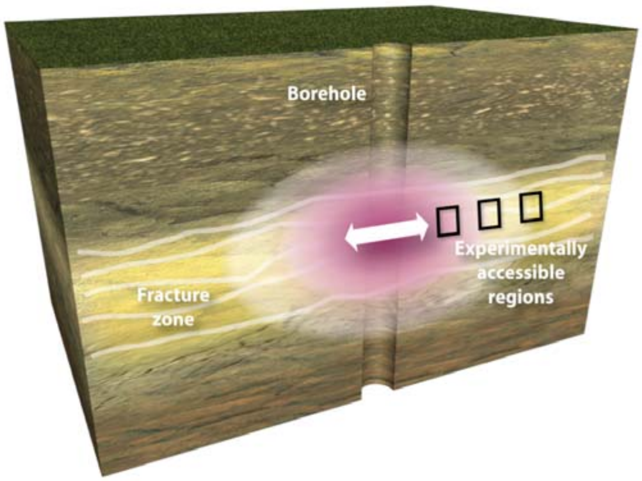
Peers and Partners

With the right kinds of investment we can preserve and strengthen our advantage over that of our competitors. We compare favorably to our competitors in terms of expertise and capability, but we need to preserve and strengthen expertise through recruitment of new talent and retention of the best scientists. We need to improve our competitiveness by improving our costs. We have strong partnerships and collaborations with industry, universities, and LBNL.

Looking Forward

To be most relevant, we need to reestablish a working relationship with DOE Geothermal and continue our activities with industry partners and the CEC. Understanding their specific research needs will better prepare LLNL to contribute to this effort.

Schematic showing an enhanced geothermal reservoir. Permeability is increased in the hot region and fluids are pumped into the reservoir. Creating and maintaining fracture permeability requires careful experiments and geochemical modeling to determine the correct fluid chemistry, flow rates, and injection strategies.



Technology Summary: Reducing Aerodynamic Drag in Heavy Vehicles

Introduction

Class 8 tractor-trailers consume 11–12% of the total US petroleum use. At highway speeds, 65% of the energy expenditure for a Class 8 truck is used to overcome aerodynamic drag. Our objective is to improve the fuel economy of Class 8 tractor-trailers. We are providing guidance on methods for reducing drag by at least 25%. This 25% reduction in drag would represent a 12% improvement in fuel economy at highway speeds, equivalent to the oil in 130 midsize tanker ships per year. The specific goals of this project are to:

- Provide guidance to industry on reducing the aerodynamic drag in heavy truck vehicles
- Develop innovative drag reducing concepts that are operationally and economically sound
- Establish a database of experimental, computational, and conceptual design information
- Demonstrate the potential of new drag-reduction concepts

Project/Program Description

We are:

- Simulating and analyzing the aerodynamic flow around heavy vehicles using advanced computational fluid dynamics tools
- Generating an experimental database for code validation and for understanding the drag-producing phenomena present in the flow about a heavy vehicle
- Providing industry with design guidance and insight into the flow physics about a heavy vehicle from experiments and computations
- Providing industry with conceptual designs of drag reducing devices
- Demonstrating the full-scale potential of these devices through fuel economy track tests

Leveraging Laboratory Capabilities

The Heavy Vehicle Aerodynamic Drag Reduction Program uses the Laboratory's high-performance supercomputing capability to model the complex, three-dimensional, turbulent flow field about heavy vehicles. With this capability, we can readily assess the performance of various drag reduction devices at highway conditions.

Peers and Partners

We have collaborated with Freightliner Trucks, International Truck and Engine Corporation, NASA Ames Research Center, Argonne National Laboratory, Sandia National Laboratories, the National Research Council of Canada, Michelin Tires, the University of Southern California, California Institute of Technology, Auburn University, Georgia Tech Research Institute, and the University of Tennessee at Chattanooga.

Technology Summary: Reducing Aerodynamic Drag in Heavy Vehicles

Looking Forward

We will continue to develop operationally-minded drag reduction concepts. We plan to conduct a full-scale wind-tunnel test at the NASA Ames 80’ x 120’ wind-tunnel using support from the Department of Energy, International Trucks, and Michelin Tires. We are seeking collaborative feedback and demonstrations of drag reduction devices from fleet owners and operators. Our program will also continue to develop technologies that can be transferred to industry.

Technology Summary: Biofuels

Introduction

The U.S. has an ever-increasing need for foreign oil imports to meet transportation fuel needs. These imports are subject to disruption because the major oil reserves are in politically unstable regions of the world. In addition, global development is increasing the competition for resources. From an environmental standpoint, the current use of fossil fuels is not sustainable because they contribute to the greenhouse gas inventory in the atmosphere. *Energy supply is a critical national security issue and an important role for LLNL.*

Project/Program Description

Biofuels provide alternative transportation fuels and can be produced using entirely domestic resources. In addition, large-scale use of biofuels has the potential to mitigate climate change. Innovative bioenergy technologies will enhance U.S. economic competitiveness.

LLNL has a long history of proven programs for secure, sustainable, clean energy. Our investments in multidisciplinary scientific capability and world-class infrastructure have well positioned us for opportunities in bioenergy.

Leveraging Laboratory Capabilities

LLNL has world-class capability in the areas of chemical, isotopic, and molecular imaging; genomics; computational biochemistry; microbial systems biology; chemical kinetic combustion modeling; and, environmental impact assessment. For instance, our laser scanning confocal microscope/atomic force microscope is one of the few of its kind in the world. This system will allow us to visualize biological structures and processes (e.g., enzymatic action on plant cell walls) in three dimensions and in real time. Our nanoSIMS instrument offers unprecedented spatial resolution. These instruments can be used to gain better understanding of biomass deconstruction that will improve the efficiency of biofuels production. LLNL also has unrivaled computational resources. We can use these resources to gain fundamental understanding of biological structures and processes.

Bioenergy science at LLNL enhances the technical base needed for other key laboratory programs, such as biodefense.

Peers and Partners

There are, of course, numerous peers among the national laboratories in the area of bioenergy. However, LLNL can develop a strong position because of our multidisciplinary talent and leading infrastructure. In addition, we are geographically located in the world-leading area for bioenergy research.

We have partnered with numerous universities and labs, including UC Berkeley, Stanford, UC Davis, Louisiana State University, Sandia National Laboratories, Lawrence Berkeley National Laboratory, NASA Ames Research Center, and several others. In addition, our industrial partners include Chevron and Mendel Biotechnology. These partnerships will allow us to cover the breadth of biofuels science—from plants to end use.

Technology Summary: Biofuels

Looking Forward

We will work with industry and university partners to develop the tools to understand and improve the efficiency of biofuels production and understand lifecycle environmental impacts**.**

Technology Summary:
Distributed Solar Thermal Power

Introduction

The resource-limited production rate of oil and natural gas, in the face of exponentially increasing demand, is leading to record high prices and has the potential to precipitate global depression or even global conflicts. The development of alternative energy sources is crucial for long-term global security. A most promising potential solution to this problem is the use of widely distributed solar thermal power, located sufficiently close to the point of consumption that heat normally wasted in the production of electricity may be used as heat, per se. The abundance of solar illumination is more than sufficient for long-term global energy needs. With LLNL technology, solar energy may be inexpensively stored in the form of heat, to be used when needed and in the form needed. Heating, cooling, and electric power may be produced at costs that are market competitive without government subsidy.

Project/Program Description

The patented and trademarked LLNL GyroSolé™ technology is the centerpiece of our attempts to effectuate the distributed solar thermal power solution to the emerging global energy crisis.

Our strategy is to work with private industry to commercialize this technology and establish an economically compelling market for it. Once market acceptance is reached, and as distributed solar thermal power becomes an increasingly large fraction of the global energy market, U.S. reliance on foreign fossil fuels will decrease and the climate-changing emissions produced by the burning of fossil fuels will fall as well. With an economically favorable, technologically benign alternative to nuclear power available to countries such as Iran, tensions associated with indigenous nuclear power developments could be reduced.

Our work is unique, because we have developed a portfolio of intellectual property that shows the path towards alternative energy that is economically feasible, environmentally benign, and technologically benign (and thus readily exported to even hostile nations).

Leveraging Laboratory Capabilities

The most important Laboratory resource involved in the initial development of this innovative technology was the generous and open minded support, through LDRD investment, in this technology for the purposes of persistent surveillance. This institutional support, coupled with ready access to the widely diverse needs for high-quality engineering, design, and technical support enabled the preliminary development of the intellectual property underpinning this technology. The most important laboratory resource for moving this technology into the private sector has been the Industrial Partnerships Office.

Peers and Partners

There are currently many startup companies involved in alternative energy, and a great deal of venture capital investment. Investment in solar technology in 2008 in the U.S. is projected to exceed $500M. Our technology is uniquely suited for deployment even at the smallest usage scale and at individual residence. If we can make our case successfully, we anticipate the ability to attract substantial investment from the private sector.

We are currently negotiating with several companies for commercial partnership.

Technology Summary: Distributed Solar Thermal Power

Looking Forward

It is important to increase the attractiveness of our technology for large-scale venture capital investment. The missing link is the development of a market-worthy demonstration system so that reliability and cost effectiveness can be explicitly demonstrated. A weakness our laboratory infrastructure is the bottleneck in the transition of exciting intellectual property to a well protected, patented and trademarked resource. The lack of quality intellectual property protection makes it less appealing to commercial enterprises.

Strategic investment in the development of technologies such as this one would shorten the time to acceptance by the mass market, resulting in a reduction in our reliance on foreign fossil fuel and potentially reducing the risk of run-away global climate change. Increased staffing and support for patent attorneys and business development personnel will greatly enhance the ability to commercialize our technology.

Technology Summary: Underground Coal Gasification

Introduction

There continues to be a need for low-cost power, natural gas, H2, and chemical feedstocks for economic security. They all need to have small carbon and water footprints for climate mitigation and environmental security and ideally domestic supply for energy security.

Project/Program Description

We have embarked on technology development and industrial partnerships program around underground coal gasification (UCG), which converts deep unmineable coals to syngas in situ. This technology has several benefits:

- Effectively triples or quadruples US coal reserves.
- Cuts the cost of syngas production by 30-50%
- Dramatically reduces the costs of capture and sequestration for carbon management.
- Dramatically reduces criteria pollution emissions and mitigation costs.
- Dramatically increases the penetration rate of gasification technologies

UCG is unique in that it uses the earth's crust as a reactor vessel, relying on the hydrological, physical, and chemical characteristics of coal seams and related rocks to reach a quasi-steady state. This reduces capital cost, operating cost, water consumption, and environmental impacts while it increases access to reserves

Leveraging Laboratory Capabilities

For three decades, LLNL has been an international leader in field testing and deployment, running 16 field pilots and developing engineering and modeling capabilities that are still used worldwide. We have continued to work to develop novel simulation tools and apply modern geophysical and environmental approaches to UCG technical problems. We currently leverage tools and capabilities developed for nuclear containment, defense applications, the weapons program, and carbon capture and sequestration (CCS) to provide new technologies and unique insights to industry engaged in UCG development and deployment.

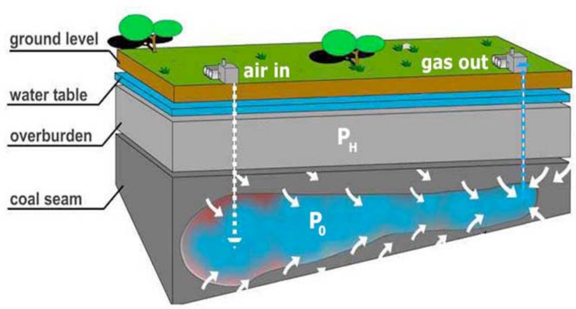
Peers and Partners

LLNL is one of two institutions in North America and one of five worldwide that has any practical experience and technical knowledge in UCG. No other national labs are engaged in UCG. We are the only global institution that has looked to combine UCG and CCS.

Industrial partners: BP, ErgoExergy *(Petrobras, XinAo, Reliance Industries Ltd. Pending)*
Other partners: NETL, PURCS, MIT, (*U. Wyoming)*

Looking Forward

To be most relevant, UCG needs to be demonstrated at a commercial scale with CCS and without negative environmental impacts. To this end, we are investing internally in LDRD and SMS, trying to rejuvenate the DOE program, and aligning ourselves with companies and potential sponsors pursuing field projects.



Schematic diagram of UCG reaction. Note that the coal is below the water table & flows into the cavity.

Technology Summary: Carbon Capture and Sequestration

Introduction

Carbon capture and sequestration (CCS) provides a way to use the advantages of fossil energy and its existing infrastructure while dramatically reducing the greenhouse gas emissions that cause global warming. In CCS, CO_2 is captured from industrial emissions such as the flue gas in a power plant, compressed to a supercritical liquid, and injected deep underground where it remains. Major issues include the operation, economics, and safety of large injection facilities handling millions of tons of CO_2 per year, and injecting it at depths of 3000 to 15,000 ft, a depth that makes monitoring and control challenging. More than 100 GW of coal-fired electric generation in the United States are now on hold, largely because they are awaiting the resolution of technical and regulatory concerns surrounding CO_2 emissions. Capture and sequestration is the principal means to resolve these issues.

Project/Program Description

LLNL is working to resolve remaining technical issues surrounding chemical changes, rock fracturing, monitoring, permanence, and economics. The program has three foci:

- Advanced simulation and related experimental calibration
- Monitoring and verification, with an emphasis on integration and inversion
- Site characterization, hazard assessment, and impact quantification

LLNL is working with DOE and an increasing number of private parties (oil companies and electric generators) to help plan, conduct, and develop technology for large-scale demonstrations of CO_2 sequestration, including use of the CO_2 for enhanced oil recovery. These million-ton or greater demonstrations are necessary to build engineering experience and public confidence in the process. We are also working with other companies, NGOs, and potential regulators to transfer the most important technical findings into the evolving legal and regulatory milieu.

Leveraging Laboratory Capabilities

LLNL's experience, tools, and capabilities in containment, rock fracturing, underground imaging, and nuclear waste disposal are directly applicable to these large-scale projects.

Peers and Partners

Our private partners are conducting very large demonstration projects that can answer the critical feasibility and cost questions over the next few years. Our major partners in these industry projects are BP, Chevron, and Xcel energy. LLNL brings state-of-the-art science to the immediate problems of designing and operating facilities that are hundreds of times bigger than the current experience base. We are also maintaining a strong role in government funded projects that will answer longer-term scientific questions. Our peers comprise several national laboratories, including LBL, PNNL, and LANL. We have established ourselves early both as players and as unique contributors within this group.

LLNL is helping BP predict and monitor the mechanical and chemical effects of CO_2 injection at its In Salah gas field in Algeria.

Technology Summary:
Carbon Capture and Sequestration

Looking Forward

Building major industrial partnerships is a new challenge for the Laboratory. But our participation with these key players is essential. National laboratories were designed to solve precisely the kind of science, engineering and policy issues that the nation now faces in carbon management. Over the next 10 years the directions to be taken by the energy sector will be set in the form of long term-capital planning, and many of those initial decisions will be made in the next few years. LLNL must move CCS solutions forward on a time scale that is useful for national decision-makers and for long-term capital planning by the energy sector.

References

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Technology Summary: Geomechanics

Introduction

Energy security and climate stability are among the most significant threats faced by our nation today. We are employing our state-of-the-art geomechanical expertise to support better use of domestic energy sources while minimizing environmental impact.

Project/Program Description

We are using combinations of numerical and experimental techniques to study several applications related directly to energy and climate security. In particular, CO_2 sequestration is a key element of reducing the carbon footprint of the U.S., allowing us to further exploit domestic fossil fuel reserves. The geomechanical response of the host rock is a major source of risk to successful long-term containment of CO_2; however, most analysis performed to date has used rudimentary geomechanical approaches.

Leveraging Laboratory Capabilities

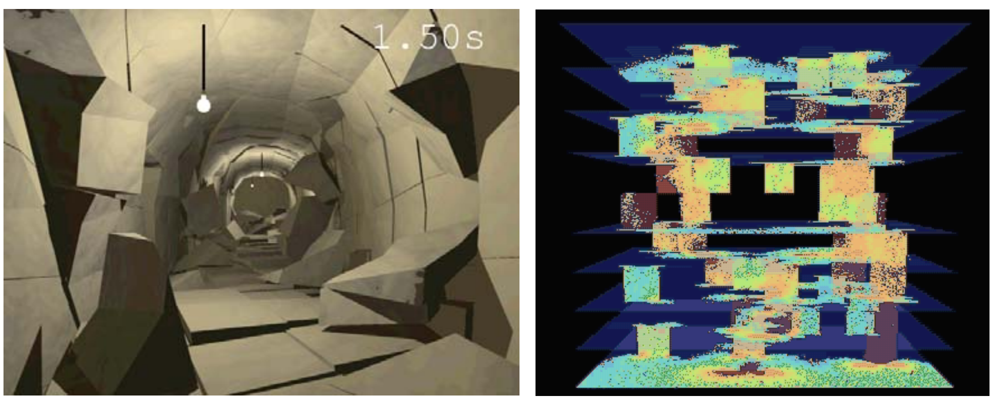
Tools developed for defense applications are being used for simulating the response of geologic material to a range of effects. For example, the massively parallel code LDEC has been successfully used to simulate the collapse of underground tunnels in jointed rock masses. The combination of sophisticated physics codes and access to world-class computational platforms allows us to simulate extensive problem domains without resorting to small, representative volumes.

Peers and Partners

Livermore has developed a unique suite of computational tools to address the large-strain response of large rock masses. Tools commonly used in the energy sector are built upon limiting assumptions that often break down under conditions of interest. We have partnered with industry on a number of projects where our expertise provided new insight. For example, a NGOTP-funded project involving Halliburton led to improved understanding of wellbore completion technologies. Currently, we are collaborating with BP to apply our expertise to simulation of CO_2 sequestration at a site of interest to them.

Looking Forward

Our continuing work with WFO sponsors is guiding the direction of our internal investment to ensure that our code capabilities remain both relevant and leaders in the world.



Tools developed for defense applications are being applied to evaluate the performance of CO2 sequestration technologies at a large scale.

Technology Summary: Geomechanics

Relevant Publications

Detwiler, R.L. and H. Rajaram (2007), Predicting dissolution patterns in variable aperture fractures: Development and evaluation of an enhanced depth-averaged computational model, *Water Resources Research*, 43, W04403, doi:10.1029/2006WR005147.

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Technology Summary: Carbon Dioxide Dispersion Modeling

Introduction
Carbon capture and sequestration provides a way to use the advantages of fossil energy and its existing infrastructure while dramatically reducing the greenhouse gas emissions that cause global warming. However, sequestering carbon as carbon dioxide has hazards associated with it, either due to movement of the earth's crust during the sequestering process or due to a sudden, unexpected release of carbon dioxide to the earth's atmosphere.

Project/Program Description
The project examines the accidental release of carbon dioxide (CO_2) into the atmosphere. Several sources of accidental release of CO_2 were considered, including well failure, fault leakage, caprock leakage and caprock failure. We determined that well failure would lead to the greatest amount of CO_2, injecting massive amounts (225 Kg/s for 6 hours) into the atmosphere and leading to the highest concentrations at breathing level. The project used the Laboratory's multidisciplinary approach, including geologists and geophysicists to investigate the underground structure of the proposed site, engineers to determine the amount of CO_2 that would be released due to well failure, and atmospheric scientists to calculate the concentration and toxicity of CO_2 in the area near the well failure.

Leveraging Laboratory Capabilities
A multidisciplinary team considered all aspects of the problem of sequestering large amounts of CO_2 and analyzed the associated hazards. The National Atmospheric Release Advisory Center (NARAC) was used to calculate the concentrations of CO_2 near the release point and associated toxicity.

Peers and Partners
NARAC is an internationally respected capability at Lawrence Livermore National Laboratory. In additionally, the Laboratory is one of the few centers where a true multidisciplinary approach is possible.

Looking Forward
A more comprehensive study would encompass the full range of conditions, the atmosphere, and varying geology. Investigating the range of conditions could result in a coherent plan for sequestering CO_2 that minimizes the hazards to people, livestock and the atmosphere.

The Temporary Emergency Exposure Limit (TEEL), level 3 (red) and level 2 (orange) due to CO_2 concentration at breathing level. At TEEL level 3, permanent health damage or death is expected. At TEEL level 2, temporary health deterioration is expected. The domain in the figure is about 1000m by 1000m.

Technology Summary: Monte Carlo Markov Chain

Introduction

We are using a stochastic inversion technique that integrates disparate data to address energy needs as well as homeland and national security.

Project/Program Description

Our approach is based on a Bayesian technique known as Monte Carlo Markov Chain (MCMC). We refer to our implementation as the stochastic engine (SE). We have developed versions of the SE that map oil recovery zones (energy security), map subsurface plumes in CO_2 sequestration applications, provide rapid estimates of yield (homeland security), and locate/discriminate nuclear explosions (national security). There are also potential applications in 3D seismic inversion and monitoring underground coal gasification sites.

The SE offers several key benefits. It allows joint inversion of disparate data types using non-linear models. For example, to estimate yield, various air blast and seismic measurements are used in the inversion. This typically reduces solution uncertainty. Second, SE samples the entire space of possible models consistent with all of the data. As a result, rigorous measures of uncertainty can be computed and alternative models that are consistent with the data are identified and ranked. Finally, the SE method can handle inversions with many local minima, such as those associated with noisy data.

Leveraging Laboratory Capabilities

This approach takes advantage of LLNL's large computer clusters and associated support. It also takes advantage of another LLNL strength, which is the ability to conduct multidisciplinary research using geophysicists, statisticians, and computer scientists. LDRD funds were used to develop the seminal set of tools on which the current tools are based.

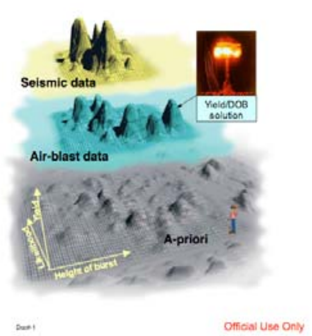
Peers and Partners

We currently have a CRADA with Chevron with the goal of optimizing heavy oil recovery from reservoirs located in the U.S.A. thereby improving energy security**.**

LLNL is the only organization using MCMC for the applications described above.

Looking Forward

At present, several groups within Global Security are using MCMC to solve a variety of problems. These groups are working largely independently from one another as LLNL forges a reputation as the leader in this field. Better integration of these efforts would benefit the Lab's ability to promote MCMC as a unique core capability.



Our MCMC approach jointly inverts air blast and seismic data to quickly produce robust estimates of yield.

Technology Summary:
Overview of Nonproliferation Programs

Introduction

LLNL works across the broad spectrum of nonproliferation activities. Our work in this area grew out our early treaty verification efforts that were focused on nuclear test monitoring until the fall of the Soviet Union. At that time, there was an urgent need to secure nuclear materials, weapons, and weapons expertise in the Former Soviet Union. Using connections developed during the Nuclear Testing Talks in Geneva, the LLNL program grew rapidly during the 90s by developing collaborations with the Russian weapons laboratories and associated institutions. Since those early days, the LLNL program has developed new technologies to detect proliferation for international safeguards applications and for national technical means applications.

Project/Program Description

LLNL applies its unique capabilities and technologies to NA-20 and WFO customer needs to detect and deter the proliferation of nuclear materials, technology, and expertise. LLNL developed the original codes used to assess the physical protection requirements at facilities designated for security upgrades in Russia. We lead the ground-based nuclear explosion monitoring community. LLNL developed the kriging technology that is the current basis for computing seismic event solutions. We are currently leading the community in the development of three-dimensional earthmodels to enable enhanced monitoring capabilities. We led the development of hyperspectral remote sensing techniques for proliferation detection. Recent innovations have led to the development of a persistent surveillance capability for ground-based hyperspectral imaging. LLNL originated the persistent surveillance concept and developed the initial capability demonstration for overhead imagery from aircraft, which is named Sonoma. This technology is now spinning off into other sponsors and is continuing to be developed for proliferation detection purposes by NA22. LLNL is not one of the original leaders in the development of international safeguards technology, but we are using our leadership in radiation detection technology to develop novel safeguards concepts that are gaining international acceptance, for example our antineutrino detector for reactor monitoring. Through our lab-to-lab contacts, we became leaders in the early programs to keep the FSU nuclear weapons expertise from migrating to proliferant countries. We are now using this experience to create collaborations with nuclear scientists in countries beyond the FSU to promote nuclear material best practices.

Leveraging Laboratory Capabilities

We take advantage of unique capabilities at LLNL to further nonproliferation programs. From our early treaty verification efforts we developed policy analysis capability and nuclear explosion monitoring capability that have established us as leaders in the ground-based nuclear explosion monitoring and NA24 programs. A critical aspect of our leadership in these areas is close ties to Z Program that allow us to ensure that our work is intelligence and informed. The link to Z Program was important for our early work in the MPC&A program and continues to inform our work in this area. As we move forward into the future our leadership in high-performance computing and radiation detection will be critical in maintaining leadership in nuclear explosion monitoring and developing a leadership position in safeguards. Furthermore, we are developing a leadership position now in nuclear material particle analysis using our unique analytical capabilities such as the nanosims.

Technology Summary: Overview of Nonproliferation Programs

Peers and Partners

LLNL's ground-based nuclear explosion monitoring effort is one of the longest standing programs at LLNL. We continue to be leaders as we compete with LANL and SNL in this area. SNL efforts tend to be engineering and software based, while LLNL and LANL focus on science. In proliferation detection, LLNL is the recognized leader in remote sensing and persistent surveillance. LANL competes with us, as does SNL. Regarding materials analysis, we are competing with ORNL and SRNL who have the large more established programs because of their nuclear materials backgrounds. Our approach is to partner with these laboratories and bring in unique capabilities such as the nanosims. In the Russian programs, our programs are smaller than big three: ORNL, PNNL, and SNL. Part of the budget disparity is due to some execution issues under the previous MPC&A manager that have since been addressed. Another part is due to the LLNL cost structure that taxes procurements at a higher rate than the other laboratories. LANL has been the recognized leader in cooperative nuclear safeguards with SNL also a recognized leader. LLNL's strategy is to slowly win market share by using unique expertise, for example radiation detection, to develop novel technologies such as the antineutrino detector. We are also using our policy expertise to play a leadership role in the safeguards policy development efforts that are taking place in NA24. Our recognized leadership in international cooperation will also play a key role in safeguards as more and more emphasis is put on best practices training in countries that are developing nuclear energy.

Looking Forward

As the Soviet Legacy programs complete their work over the next five to ten years, LLNL is well poised to take advantage of the increased emphasis in international safeguards. Although we are not currently leading the international safeguards efforts we are now established players. Furthermore, the role we are playing in the NA24 policy development will position us to have a deep understanding of customer needs in the near term. Looking further, our experience with nuclear explosion monitoring and proliferation detection will enable us to take advantage of the broader effort of integrating NTM with international safeguards to track nuclear materials worldwide and estimate proliferation and diversion risk.

Collage of LLNL nonproliferation projects

Technology Summary: Material Protection, Control, and Accounting Program

Introduction

At the end of the Cold War, Russia was left with hundreds of tons of unsecured plutonium-239 and highly enriched uranium, both of which can be used to create nuclear weapons. As the centralized Soviet authority crumbled, so did the rigorous security practices governing its fissile materials and nuclear weapons. sRussia's weakened economy and its poorly secured nuclear infrastructure placed its weapons complex at risk of becoming a "Shopping Center" for terrorist organizations and rogue states.

Unprotected or unaccounted-for nuclear weapons and material are a grave threat to the national security of the United States and indeed to the entire civilized world. Access to these nuclear weapons and materials offers a shortcut that terrorist organizations and their supporters could use to circumvent the more technically complex, expensive, and detectable steps necessary to develop a nuclear weapon and quickly obtain enormous destructive capability. Since September 11th, 2001, events have shown that non-state terrorist organizations such as Al Qaeda are not only interested in obtaining nuclear weapons but they are also far more capable and determined than had previously been assumed.

Project/Program Description

The LLNL Materials Protection, Control, and Accounting (MPC&A) program has been in existence since 1994 in support of National Nuclear Security Administration's (NA-25). The mission of this program is to enhance the security of vulnerable stockpiles of nuclear weapons and weapons-usable nuclear material in countries of concern and to deny terrorist organizations the vital materials needed to engage in acts of nuclear terror.

The primary focus of MPC&A program is to install building- and site-level physical security systems, implement material control and accounting upgrades, and consolidate material into fewer buildings. These projects provide the first layer of defense against the theft of warheads or special nuclear material. In addition, the MPC&A program provides technical assistance and professional collaboration at the national level on cross-cutting issues such as transportation security, equipping and training protective forces, and developing a regulatory infrastructure.

Leveraging Laboratory Capabilities

The MPC&A Program draws on LLNL resources from the Global Security; Chemistry, Materials, Earth & Life Sciences; Computation; and Engineering organizations. LLNL experts team up with their Russian counterparts to secure Russia's weapons-usable nuclear materials, help improve safeguards and security systems, and improve nuclear material accounting systems. LLNL offers unique capabilities to efforts related to regulatory development for the Russian Ministry of Defense, a new Federal Information System for nuclear material control, accounting and reporting, and implementation of various in-house vulnerability assessments tools such as Analytical System and Software and Evaluation for Safeguard and Security (ASSESS), and Analytical Conflict and Technical Simulation (ACAT). Other relevant LLNL capabilities include material characterization and nondestructive analysis, analyses of insider threats, and, finally, the ability to transfer knowledge based on long experience of how the Russians can best sustain the protections and controls that have been put in place.

Technology Summary: Material Protection, Control, and Accounting Program

Looking Forward

Two goals beneficial to the growth and expansion of the LLNL's MPC&A program are to:

- Reduce the tax burden applied to the Russian pass-through contracts for purchasing equipment to a reasonable level.
- Engage the Second Line of Defense Program of NA-25 in some activities.

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Technical Summary: Denuclearization in DPRK

Introduction

Halting and verifiably rolling back North Korea's nuclear weapon program have been high-priority but elusive nonproliferation goals for nearly two decades. In February 2007, the Six-Party talks finally reached agreement on initial actions to implement a Joint Statement on Denuclearization of the Korean Peninsula. Since last fall, personnel from DOE and its laboratories have been on the ground in the DPRK working to implement those initial steps.

Project/Program Description

LLNL has a long history of supporting the investigation and verified elimination of non-compliant nuclear activities. On Iraq, Libya, and other significant cases, we have provided intelligence analysis, analysis of environmental samples and other forensic signatures, and direct participation in inspection and elimination activities in the field.

In the DPRK, the focus of denuclearization activity for the last six months has been to complete negotiated disablement steps at three key facilities at North Korea's main nuclear center at Yongbyon. Two LLNL staff have been part of the DOE and multilaboratory team engaged in this effort. Most of that work is now complete, except for discharging the remaining fuel from the graphite reactor and removing the control rod drives.

As the "disablement" phase draws closer to completion, we are increasingly turning our attention to the larger challenges of verification and permanent dismantlement. This effort will include verifying the cumulative plutonium production at Yongbyon, as well as verifying the status of suspected uranium enrichment research and of the nuclear weaponization program.

Leveraging Laboratory Capabilities

Our work in the DPRK draws on LLNL's recognized strengths in investigating and rolling back undeclared nuclear programs.

Peers and Partners

LANL and PNNL are better positioned to contribute to the Yongbyon-based disablement and verification activities, because of their safeguards-instrument and graphite-reactor expertise, respectively. LLNL's strength, and our anticipated major contribution, lies in meeting the challenges of investigating and verifying undeclared program elements, potentially at locations other than Yongbyon.

We team closely with NNSA, colleagues at other laboratories, the State Department, and, as appropriate, the IAEA.

Ongoing defueling activity at the Yongbyon gas-graphite reactor

Technology Summary: HyperSpectral Imaging

Introduction
LongWave InfraRed HyperSpectral Imaging systems have the potential to support remote technical collections addressing detection, identification and characterization of production activities for weapons of mass destruction. LWIR HSI systems are useful in day and night.

Project/Program Description
For over 12 years, LLNL has been developing LWIR HSI systems for remote, stand-off detection and identification. Early efforts focused on establishing the viability of airborne HSI and understanding the phenomenology associated with the sensing capability. Today we provide state-of-the-art, compact, automated LWIR HSI instruments, and processing and exploitation algorithms and software tools. Efforts include modeling, hardware developments, field tests, and data exploitation leading to comprehensive understanding of the capabilities. We have developed seven instruments used in the air and on the ground.

LWIR HSI systems remotely detect and identify gases by their “fingerprint” signatures. Our systems also have the ability to measure temperature. In the future, LWIR HSI instruments may be able to detect and identify solid targets such as tanks and camouflage.

LWIR instruments developed at LLNL are unique because of their combination of compact size, low weight, and excellent sensitivity. LLNL’s LWIR HSI processing and exploitation software is unique because it is automated, rapid, and accurate. Its results show where gases are located, identifies the gases, and provides attribution of confidence through Receiver Operator Characteristic curves.

Leveraging Laboratory Capabilities
We draw on LLNL expertise in nuclear and chemical WMD proliferation intelligence analysis, WMD observables and signatures, remote sensing phenomena and physics, spectroscopy, optical designs, algorithm developments, software innovations, field test and experimentation, and feedback to the intelligence community. The sum of these activities provides an end-to-end systems capability at LLNL.

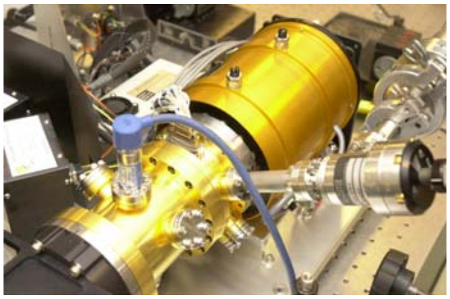
Peers and Partners
LLNL is the premier organization developing compact, cryogenically-cooled spectrometers with excellent sensitivity and automated processing through ROC curves. The Aerospace Corporation is the premier organization for producing LWIR HSI spectrometers with the best sensitivity when size, weight and power are not performance drivers.

LLNL partners with NGA/IBE in system developments and with ITT Space Systems Division to transfer the DS2 dispersive spectrometer technology. LLNL has a CRADA with ITT Space Systems for future applications where wide-area coverage is a premium. We collaborate with LANL, Special Technologies Laboratory, Space Computing Corp, TRA Associates, BYU, and Utah State University.

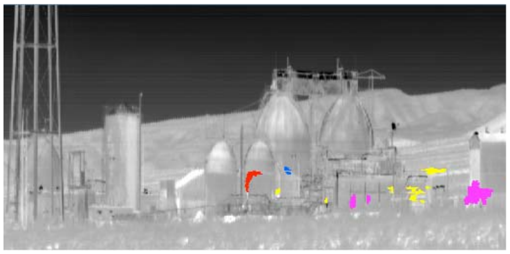
Technology Summary: HyperSpectral Imaging

Looking Forward

In the future, we expect to provide more rugged hand-held spectrometers that are low-power, automated, and highly user-friendly. These instruments will provide automated identification of materials. We also expect to advance the state of the art in compact cryogenically cooled spectrometers for broad area coverage from aircraft. Hand-held and airborne systems support persistent surveillance applications. These advances take advantage of new technologies—such as FPGAs for low-power computing and microbolometer detectors for low-power detection systems—and will be accessible remotely using the XML data description language. Through the development and use of each new instrument, we continue to provide key understanding of the capabilities, science, and phenomenology associated with these evolving instruments.



The DS2 spectrometer module employs a 1-lb precision engineered cold cartridge (HgCdTe focal plane array, immersed grating and cold optics), vacuum dewar, and commercial Stirling cycle cryocooler



Use of ground-based HSI instruments collecting data once per minute for multiple days allows us to determine confidence in our results. Red gas – 99.1% confidence, Yellow gas – 99.3% confidence, Pink gas – 94.9% confidence, Blue gas – 42% confidence (known false alarm)

Contact: Bob Priest, priest1@llnl.gov, 925-422-8677

Technology Summary: Ground-Based Nuclear Explosion Monitoring

Introduction

The Ground-based Nuclear Explosion Monitoring (GNEM) Program researches and develops techniques and geophysical calibrations for the United States Government to improve monitoring of subsurface nuclear explosions.

Project/Program Description

The GNEM program collects and measures empirical data and develops physical models to correct for the effects of the Earth's heterogeneity on seismic signals. These calibrations improve the ability to detect, locate, identify, and determine the yield of underground nuclear tests. This work improves the accuracy and lowers the yield level of the monitoring analysis. The GNEM program directly supports the US National Data Center (US NDC) at the Air Force Technical Applications Center (AFTAC). US NDC is responsible for operational nuclear explosion monitoring.

GNEM has seismic calibration responsibilities for the Middle East, the European Arctic, and the Korean Peninsula. In addition, we perform basic research on Earth structure and the physics of seismic sources. Some of our work has spin-off applications in the area of earthquake hazards and adds to the discipline of geophysics.

Leveraging Laboratory Capabilities

LLNL has always been a recognized leader in the field of nuclear explosion monitoring seismology. Our history extends from the establishment of a seismic network around the Nevada Test Site for yield estimation in the 1960s, to treaty verification work in the 1970s and 1980s, to support of the Comprehensive Test Ban Treaty (CTBT) in the 1990s, to today's GNEM program.

We have developed for this task one of the largest and most capable integrated seismic database/software systems in the world. It contains several million seismic events recorded at thousands of stations, and through it we manage more than half a billion measurements and data objects.

Finally, the national laboratories in general, and LLNL in particular, are heir to more than fifty years of nuclear weapon design and testing experience coupled with world-class computational facilities, including BlueGene/L, and an interdisciplinary mix of experts familiar with developing results and getting them to work in an operational setting. The combination of all of these factors continues to make GNEM highly effective.

Peers and Partners

The GNEM program is part of a four laboratory (LLNL, LANL, SNL, PNNL) DOE/NNSA-funded effort. LLNL and LANL focus on seismic analysis and calibration, and we have divided the calibration regions. GNEM also partners with many academic, government, and private-sector institutions—including UC Berkeley, CalTech, M.I.T., Weston Geophysics, Inc. and NORSAR (a Norwegian nonprofit research institute) among others—through the competitively reviewed and funded Broad Area Announcement (BAA) process. Although the national laboratories cannot be the lead principal investigators on BAA proposals, we have found participating as BAA team members to be one of the most effective ways to transition research results into operational capability, because all parties are directly funded to work together. GNEM staff are team members on six new BAAs awarded in FY08 and currently participate in 23 active BAA projects, the most of any national laboratory. We also use the extensive seismic data that is collected by other entities, including regional networks and research institutions when openly available, and through partnerships when data is restricted.

Looking Forward

We have identified three target areas in which basic research investments can lead to significant improvement in national nuclear monitoring capabilities:

- 3-D Earth model development and associated computational infrastructure
- Physics-based explosion source model development
- Geophysical data exploitation research and development

We are working to build peer and funding advocacy for these ideas through workshops, presentations, papers, proposals, and demonstration calculations.

Recent Peer Reviewed Publications

In addition to the publications listed below, we have four papers currently in review.

2007

Di Luccio, F. and M. Pasyanos, 2007. Crustal and upper-mantle structure in the Eastern Mediterranean from the analysis of surface wave dispersion curves, *Geophys. J. Int*, doi:10.1111/j.1365-246.2007.03332.

Flanagan, M. P., S. C. Myers, and K. D. Koper, 2007. Regional travel-time uncertainty and seismic location improvement using a 3-dimensional a priori velocity model, *Bull. Seism. Soc. Amer.,* 97, 3, 804-825, doi:10.1785/0120060079.

Gök, R., H. Mahdi, H. Al-Shukri and A. J. Rodgers, 2007. Crustal structure of Iraq from receiver functions and surface wave dispersion: implications for understanding the deformation history of the Arabian–Eurasian collision, *Geophys J. Int,* doi: 10.1111/j.1365-246X.2007.03670.x

Gök, R., M. E. Pasyanos, and E. Zor, 2007. Lithospheric structure of the continent-continent collision zone: Eastern Turkey, *Geophys. J. Int*., doi: 10.1111/j.1365-246X.2006.03288.x.

Hansen, S., A. Rodgers, S. Schwartz and A. Al-Amri, 2007. Imaging ruptured lithosphere beneath the Red Sea and Arabian Peninsula, *Earth Planet. Sci. Lett.*, 259 (2007) 256-265.

Hansen, S., S. Schwartz, A. Al-Amri, and A. Rodgers, 2007. Combined plate motion and density-driven flow in the asthenosphere beneath Saudi Arabia: Evidence from shear-wave splitting and seismic anisotropy, *Geological Society of America*, October 2006; 34, 10, p. 869-872; doi: 10.1130/G22713.1;3.

Mayeda, K., L. Malagnini, and W. R. Walter, 2007. A new spectral ratio method using narrow band coda envelopes: Evidence for non-self similarity in the Hector Mine sequence, *Geophys. Res. Lett.* 34, L11303, doi:10.1029/2007GL030041, 2007.

Myers, S. C., G. Johannesson and W. Hanley, 2007. A Bayesian hierarchical method for multiple-event seismic location, *Geophys. J. Int.* 2007. doi: 10.1111/j.1365-246X.2007.03555.x

Park, Y., A. Nyblade, A. Rodgers and A. Al-Amri, 2007. Upper mantle structure beneath the Arabian Peninsula from regional body-wave tomography: Implications for the origin of Cenozoic uplift and volcanism in the Arabian Shield, *Geophysics, Geochemistry and Geosystems* 8, 6, Q06021 doi:10.1029/2006GC001566.

Pasyanos, M. E. and A. A. Nyblade, 2007. A top to bottom lithospheric study of Africa and Arabia, *Tectonophysics*, doi:10.1016/j.tecto.2007.07.008.

Pasyanos, M. E., H. Tkalcic, R. Gök, A. Al-Enezi and A. J. Rodgers, 2007. Seismic structure of Kuwait, *Geophys. J. Int*. doi:10.1111/j.1365-246X. 2007-03398.x

Phillips, W. S., M. L. Begnaud, C. A. Rowe, L. K. Steck, S. C. Myers, M. E. Pasyanos, and S. E. Ballard, 2007. Accounting for lateral variations of the upper mantle gradient in Pn tomography studies, *Geophys. Res. Lett*., 34, L14312, doi:10.1029/2007GL029338.

Walter, W. R., K. Mayeda, L. Malagnini, and L. Scognamiglio, 2007. Regional body-wave attenuation using a coda source normalization method: application to MEDNET records of earthquakes in Italy, *Geophys. Res. Lett., 34, L10308, doi:10.1029/2007GL029990*, 2007.

2006

Akinci, A., L. Malagnini, R. B. Herrmann, R. Gök and M. B. Sørensen, 2006. Ground motion scaling in the Marmara region, Turkey. *Geophys. J. Int*., 166, 635-651.

Benoit, M. H., A. A. Nyblade, and M. E. Pasyanos 2006. Crustal thinning between the Ethiopian and East African Plateaus from modeling Rayleigh wave dispersion, *Geophys. Res. Lett*., 33, L13301, doi:10.1029/2006GL025687.

Engdahl, E. R., J. Jackson, S. C. Myers, E. A. Bergman, and K. Priestley, 2006. Relocation and assessment of seismicity in the Iran region, *Geophys. J. Int*., 167, 761-778 2006.

Pasyanos, M. E., G. A. Franz, and A. L. Ramirez, 2006. Reconciling data using Markov Chain Monte Carlo: An application to the Yellow Sea – Korean Peninsula region, *J. Geophys Res*, 111, doi:10.1029/2005JB003851.

Rodgers, A. A., A-R Fowler, A. M. S. Al-Amri, A. Al-Enezi, 2006. The March 11, 2002 Masafi, United Arab Emirates earthquake: Insights into the seismotectonics of the Northern Oman Mountains, *Tectonics*, 415 (2006) 57-64.

Tkalcic, H., M. Pasyanos, A. Rodgers, R. Gök, W. Walter and A. Al-Amri, 2006. A multi-step approach in joint modeling of surface wave dispersion and teleseismic receiver functions: Implications for lithospheric structure of the Arabian peninsula, *J. Geophys Res. 111, B11311*, doi:10.1029/2005JB004130.

Walter, W. R., K. Mayeda, R. Gök and A. Hofstetter, 2006. The scaling of seismic energy with moment: simple models compared with observations, in "*Earthquakes: Radiated energy and the physics of faulting", AGU Monograph 170,* doi:10.1029/170GM05 2006.

2005

Flanagan, M. P. and S. C. Myers, 2005. Regional Seismic Location Improvement and Statistical Assessment of Nonstationary Travel-time Uncertainty in Western Eurasia, *Seismol. Res. Let*., 76, 255, 2005.

Mayeda, K., R. Gök, W. R. Walter, and A. Hofstetter, 2005. Evidence for Non-Constant Energy/Moment Scaling From Coda-Derived Source Spectra, *Geophys. Res. Lett.*, Vol. 32, L10306, doi:10.1029/2005GL022405 May 2005.

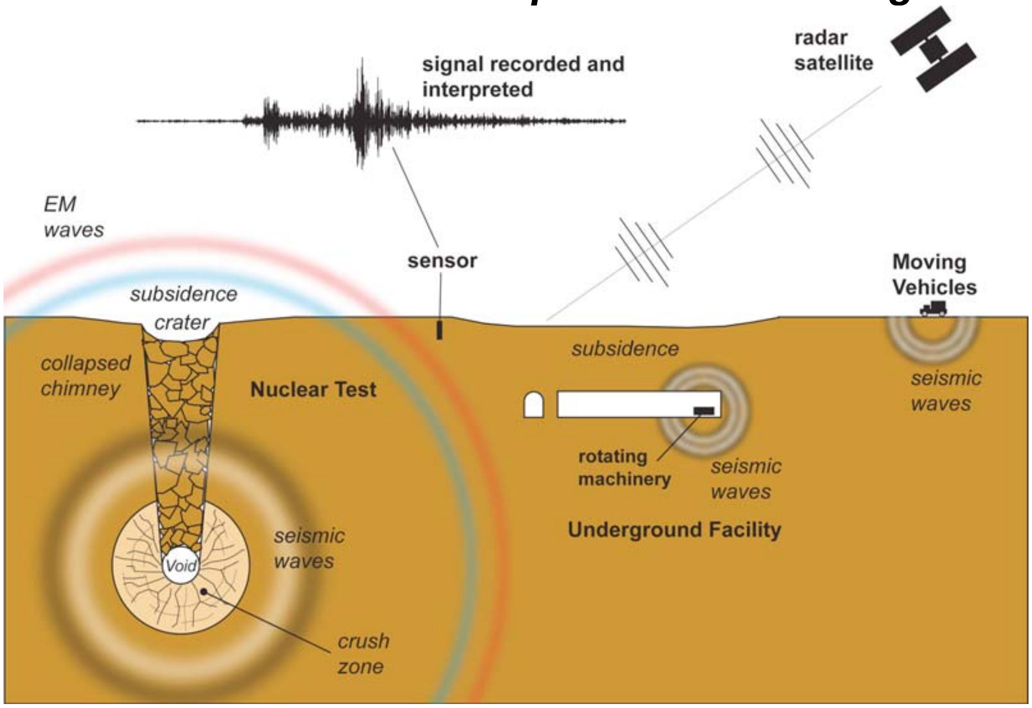
Mayeda, K., L. Malagnini, W. S. Phillips, W. R. Walter, and D. Dreger, 2005. 2-D or not 2-D, that is the question: A northern California test. *Geophys. Res. Lett*, Vol. 32, doi:10.1029/2005GL022882, in June 2005.

Morasca, P., K. Mayeda, L. Malagnini, and W. R. Walter, 2005. Coda-derived source spectra, moment magnitudes, and energy-moment scaling in the western Alps, *Geophys. J. Int*., 160, 263-275, 2005.

Myers, S. C., 2005. Reply to comment on Improving Sparse Network Seismic Location with Bayesian Kriging and Teleseismically Constrained Calibration, *Bull. Seismol. Soc. Am*., 95, 370-372.

Pasyanos, M. E., 2005. A variable-resolution surface wave dispersion study of Eurasia, North Africa, and surrounding regions, *J. Geophys. Res*., 110, B12301, doi:10.1029/2005JB003749.

Technology Summary: Ground-Based Nuclear Explosion Monitoring



The LLNL geophysics staff researches a variety of signals, including seismic, EM, and InSAR in service of national security programs. The GNEM program's largest component examines seismic waves to improve the US capability to detect, location, identify and determine the yield of underground nuclear explosions.

Technology Summary:
Next Generation Safeguards Initiative

Introduction

International Atomic Energy Agency (IAEA) safeguards serve as the only international mechanism to monitor compliance with Nuclear Nonproliferation Treaty commitments. It must remain effective if we are to have confidence in the expanded peaceful uses of nuclear energy. Safeguards should deter noncompliant behavior and provide an early warning of any undeclared nuclear weapons programs. Over the past 25 years of essentially a flat budget, the number of facilities under IAEA safeguards has tripled, and the amount of safeguarded highly enriched uranium (HEU) and plutonium has increased six-fold. The NNSA Strategic Planning Guidance for FY 2010 - FY 2014 considers the initiative to revitalize the international safeguards system as a high priority for Defense Nuclear Nonproliferation, particularly as the existing threat reduction program move towards sustainability.

Project/Program Description

The October 2007 *International Safeguards – Challenges and Opportunities for the 21st Century* outlined a U.S. view of the policy and authorities, technology, and resource needs to support a successful international safeguards regime. LLNL staff are playing key roles in the effort to develop a Next Generation (NGSI) Roadmap that will set out a five-year NA-24 (Nonproliferation and International Security) international safeguards program plan in the areas of policy/outreach, concepts and planning, technology/analytical development, human resources, and infrastructure development (international).

Leveraging Laboratory Capabilities

LLNL strengths reside in:

- safeguards and NPT policy support,
- information analysis in support of evaluating a State's nuclear programs,
- development of novel technologies for advanced safeguards needs,
- innovative technical methods and methods to interpret environmental signatures for environmental sampling and other nonproliferation applications, and
- adapting technologies for international safeguards applications.

GS safeguards programs reach across GS and the Lab (i.e. Z Program, CMELS, PAT) to engage the best technical experts to support these safeguards priorities.

Peers and Partners

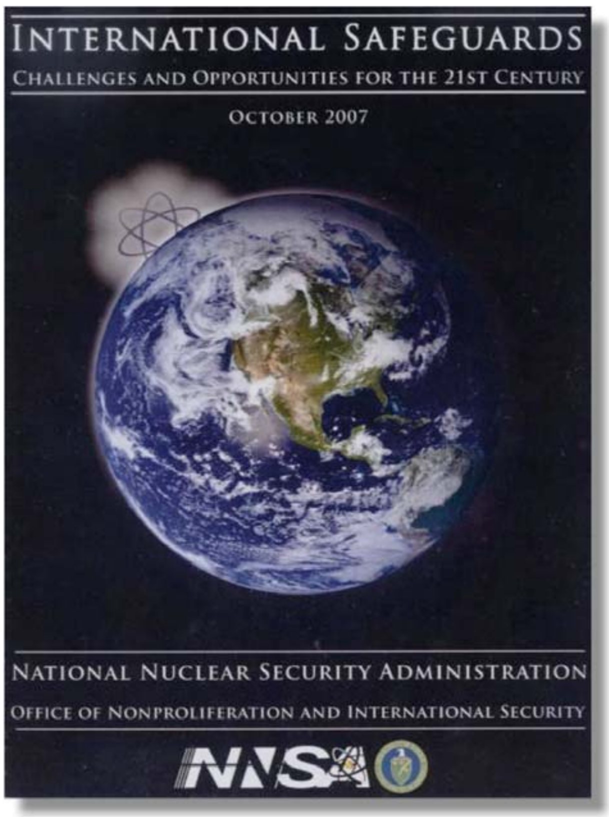
LLNL can make a substantial contribution using its extraordinary tech base and weapons expertise. We are at a disadvantage due to the small number of LLNL staff with direct IAEA safeguards implementation experience. Understanding of actual implementation challenges is needed to guide the best technological development to meet IAEA needs and help develop new cutting edge proposals. Key competitors are LANL, ORNL and PNNL. Their staff have a greater breadth of international safeguards experience, including IAEA training and technology implementation, and on-site fuel cycle expertise.

Technology Summary: Next Generation Safeguards Initiative

Besides working cooperatively on many multi-lab safeguards projects, we are presently working to establish two new pilot summer human resource development courses: (1) LLNL-LANL on summer safeguards technology course and internships with Texas A&M University and safeguards policy and (2) information analysis summer course with Monterey Institute of International Studies.

Looking Forward

To best take advantage of the new NNSA focus on support of the international safeguards system, GS will be developing its own strategic plan taking into account the NGSI Roadmap to be released in June 2008. To be better position LLNL as having safeguards expertise, it is proposed that consideration be given to funding a strategic hire to bolster our safeguards expertise and support LLNL staff training in order to elevate our profile in the technical and sponsor communities.



GlobalSecurity
Anticipate • Innovate • Deliver

Technology Summary: Safeguards Technologies

Introduction

We are developing a new method for real time monitoring of nuclear reactors, in order to strengthen the IAEA reactor safeguards regime.

Project/Program Description

We have developed robust and simple cubic-meter-scale antineutrino detectors that can monitor the operational status, power, and plutonium content of nuclear reactors, from outside of containment, and without interfering with reactor operations. The nation and the world need improved reactor monitoring capability, as more reactors come online in coming decades. In addition, the nuclear fuel cycle as a whole must have better safeguards.

Our detector represents the first practical demonstration at a commercial reactor of a nonintrusive monitoring capability. The detector provides information that is of direct interest to the IAEA, since it reports the real-time status and plutonium/uranium content of the reactor being monitored.

Leveraging Laboratory Capabilities

LLNL scientists have a deep understanding of nuclear physics, while other experts have a thorough understanding of the nonproliferation problematic. The combination of these two skill sets has resulted in the development of this unusual but highly effective safeguards solution, drawn directly from fundamental physics. This technology expands LLNL's presence as a supporter of the IAEA and a provider of nonproliferation technologies in service of national needs, and has enabled us to recruit top-ranked physicists with an interest in solving nonproliferation problems.

Peers and Partners

We are without doubt world leaders in this area. This leadership is recognized both within the global neutrino scientific communit—as evidenced by the invitation of one of us to speak at the world's most important neutrino conference (Neutrino '08) in Christchurch, New Zealand—and by the IAEA, as the following link attests:
http://www.spectrum.ieee.org/print/6129

We have partnered effectively with SNL and with the San Onofre Nuclear Generating station to pursue this demonstration. We have also made use of our close ties to the basic neutrino physics community to pursue and develop these ideas.

LLNL possesses an unusual combination of nuclear physics and nuclear security know-how that is built into the culture and structure of the Laboratory. It is this combination that makes us unique.

Looking Forward

We need to cooperate more closely with the IAEA, and with the US agencies that support the IAEA. We plan to initiate further discussions with other US sponsors to consider the possibility of increased standoff monitoring of reactors. We also plan on continued and expanded involvement in basic physics experiments that are relevant for nonproliferation, including neutrino and dark matter search experiments. These efforts are important because they provide the staff and technologies that can help us develop the next generation of nonproliferation technology.

Technology Summary: Advanced Nuclear Fuel Cycles

Introduction

Global dependence on nuclear power is widely predicted to at least triple in the next 40 years. The benefits of reducing dependence upon fossil fuels are quite clear. Yet this dramatic growth in nuclear power will exacerbate such challenges as waste management and nuclear proliferation and could introduce new ones, such as depletion of fuel resources. LLNL is addressing the nuclear fuel cycle with the goal of optimizing the benefits of nuclear power while minimizing its undesirable consequences.

Project/Program Description

One globally advocated approach to the fuel cycle is to “close” it—that is, adopt a fuel recycling strategy. Since 1977, the US has avoided recycling because of the proliferation risks associated with reprocessing spent fuel. The current administration is advocating a policy shift toward recycling spent fuel, but in a way that does not exacerbate proliferation of nuclear materials and technology. LLNL is leveraging its expertise in scientific computing and nuclear weapons science to contribute to the vision of a new, more efficient and proliferation-resistant closed nuclear fuel cycle.

Leveraging Laboratory Capabilities

LLNL’s experience in designing, maintaining, assessing, and certifying the nuclear arsenal has given its scientists a unique understanding of nuclear physics, thermodynamics and hydrodynamics, as well as thermal and mechanical properties and radiation-induced damage of materials. We are combining this expertise with the world’s largest supercomputers to develop new fuel systems, reactors, and reprocessing facilities. We have the knowledge basis necessary to assess the utility of proposed nuclear fuel cycles and the materials mixtures they will generate, materials that could be used as nuclear explosives by terrorists or nation-state adversaries. We can explore new ways to diminish the utility of recycled output to ensure that any future fuel cycle does not exacerbate nuclear proliferation.

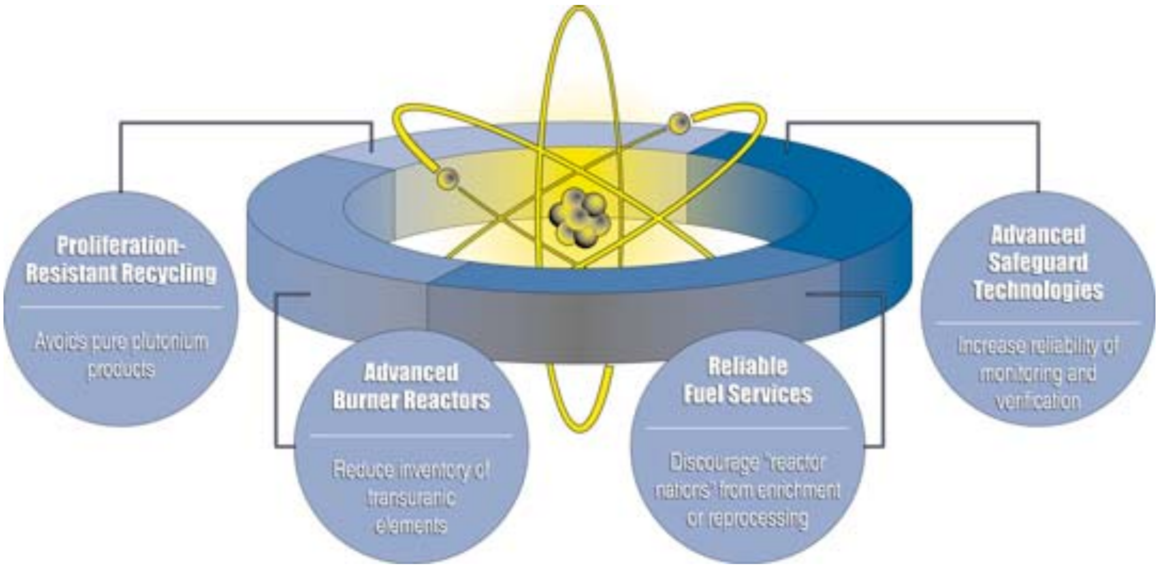
Peers and Partners

The concern about the misuse of nuclear materials is one best addressed by nuclear weapons experts. Yet LLNL is broadly perceived as an outsider by the civilian nuclear power community. For this and other reasons, we recognize the value of partnering with other DOE laboratories as well as private industry. We are enjoying fruitful partnerships with ANL and ORNL, and we continue to seek additional partnerships. We also seek partnerships with the domestic nuclear power industry, as we recognize that any domestic renaissance will necessarily be driven by that sector.

Technology Summary: Advanced Nuclear Fuel Cycles

Looking Forward

Our greatest barrier to sustained contribution is the lack of stable, multi-year support from our USG stakeholders, such as DOE, NNSA and NRC. A diversified funding base comprising USG and industrial support is the most promising approach. We are leveraging internal investments and working closely with our LLC partners to seek that support.



Technology Summary: Proliferation Signatures

Introduction

The US. has a critical need to improve its ability to detect and characterize WMD proliferation-related processes through technical collections. The optimization of sensor technology and sensor deployment is strongly dependent on our understanding of proliferation processes and their signatures. LLNL's proliferation signature program is designed to provide this insight and guide the development of sensor technology and the optimal deployment of sensors.

Project/Program Description

LLNL addresses the full range of proliferation signature issues. We are a national leader in detailed, site-specific, temporally resolved models for nuclear and chemical weapon proliferation processes. Through the use of these models, we can identify and quantify signatures that range from process effluents, acoustic, thermal and electrical equipment signatures to facility staffing signatures and facility connections in an overall proliferation program. The models are supported by laboratory and field measurements for a detailed understanding of the process as well as for model validation. We support a number of collection campaigns for a variety of sensor types both in the US and abroad.

We have developed a flexible gas centrifuge toolkit that incorporates modern computational fluid dynamics, advanced computational tools, realistic cascade and facility modeling, and user-interface tools. This toolkit is for assessing performance and signatures for proliferator centrifuges and cascades. This capability closes a 25-year gap in developing codes for analyzing gas-centrifuge enrichment.

Technical collections are often designed for facilities where access is limited. Understanding how signatures propagate from a source is critical to designing the collection as well as the sensors to be deployed. LLNL is the national leader in efforts to understand how electric and magnetic fields propagate from a source. Our modeling capabilities are being used to determine specific signature propagations for a number of government agencies.

Signatures of proliferation activities can be few, difficult to measure, and sometimes difficult to distinguish from legitimate industrial processes. Single signatures that can locate, identify, and confidently characterize a proliferation process and that are readily accessible do not exist. LLNL's proliferation signatures program is working to identify new signatures, multiple signatures, and indirect signatures that can enhance our ability to detect proliferation processes from extended ranges and with increased confidence.

Leveraging Laboratory Capabilities

Our program leverages LLNL's expertise in international assessments to guide our process selection and assessment of process specifics. We also make use of the laboratory's capability in chemical process modeling to produce our detailed models. Investment by DOE's Office of Science in Overture software for PDE solvers on overlapping grids forms the basis for much of our Centrifuge Toolkit. Advanced codes originally developed to model radar propagation—Eiger and EM-Solve—form the basis of our E&M propagation modeling effort. The expertise for all of these efforts was developed for other programs. Our program is contributing to these programs in the form of new expertise, increased capabilities, and improved analysis tools.

Peers and Partners

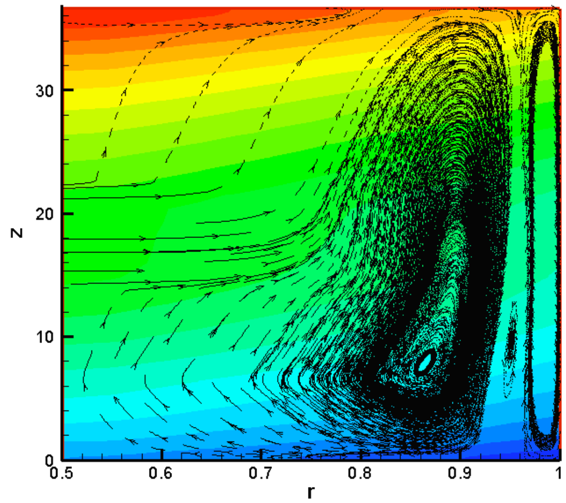
LLNL leads the nation in the area of temporally resolved chemical process models. We have long-standing programs with a number of government sponsors to provide detailed, site-specific process information for selected sensors and sensor deployments. We partner with Aerospace Corporation, Savannah River, and many government agencies in this effort.

The US has not had a centrifuge and centrifuge cascade modeling effort in 25 years. LLNL leads the current effort in conjunction with multiple partners. ORNL and the United States Enrichment Corporation provide us with centrifuge experience and code evaluation. We work with UC Davis on 3D computational fluid dynamics solutions and with UC Berkeley on application of our Overture software suite. In addition, we work with the National Counter Proliferation Center and the Defense Threat Reduction Agency to couple our models to machine stability and process interdiction models.

We are also collaborating with Michigan Technical University on our E&M propagation efforts and are a member of their Power and Energy Consortium.

Looking Forward

For this program to remain relevant, we need to expand our signature suites to include signature interactions and secondary signatures. We have started to look at multiple signatures to understand signature relationships and to help define collection concepts. We have several proposals to look at secondary signatures and to evaluate how multiple signatures can increase detection confidence limits.



Modeled two-dimensional flow field in a gas centrifuge