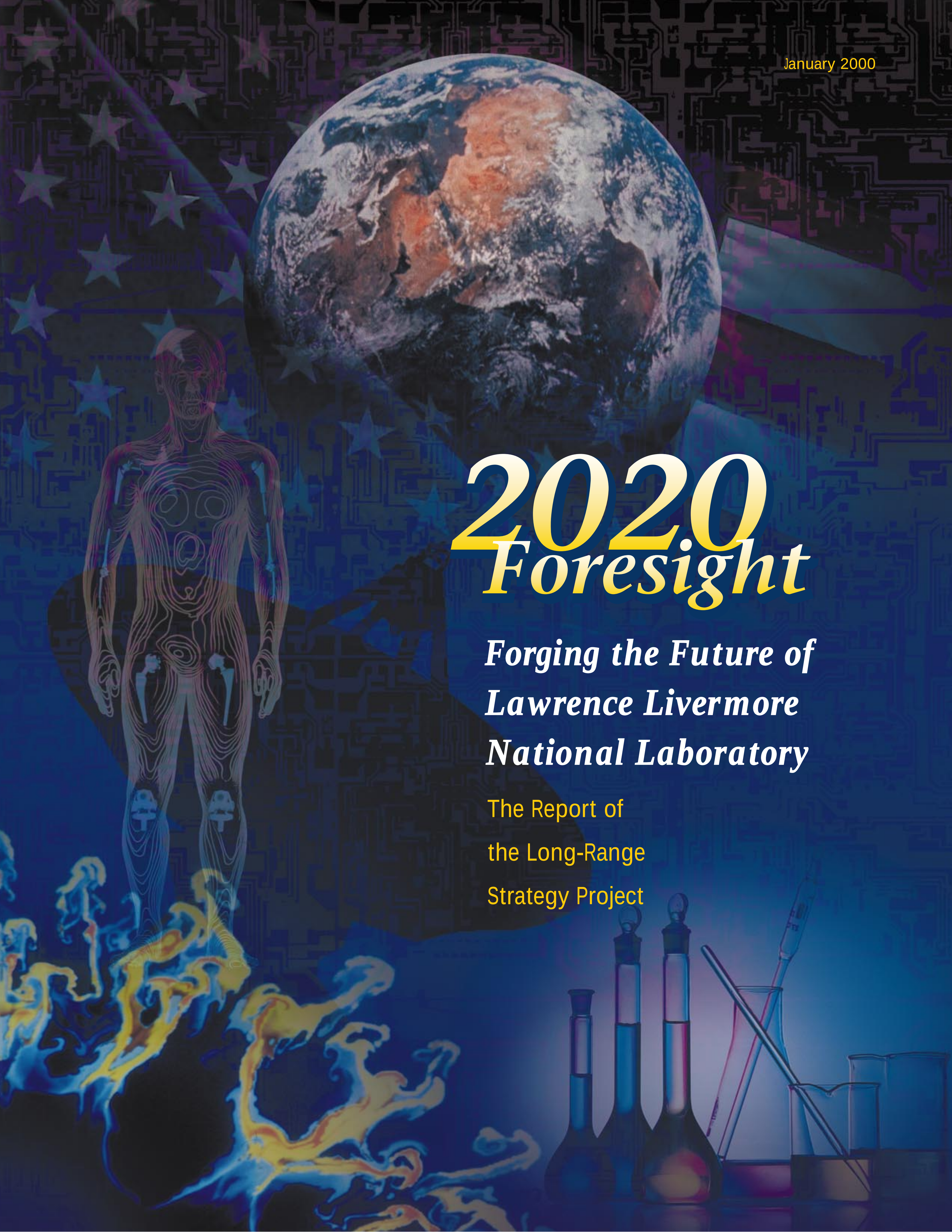


January 2000

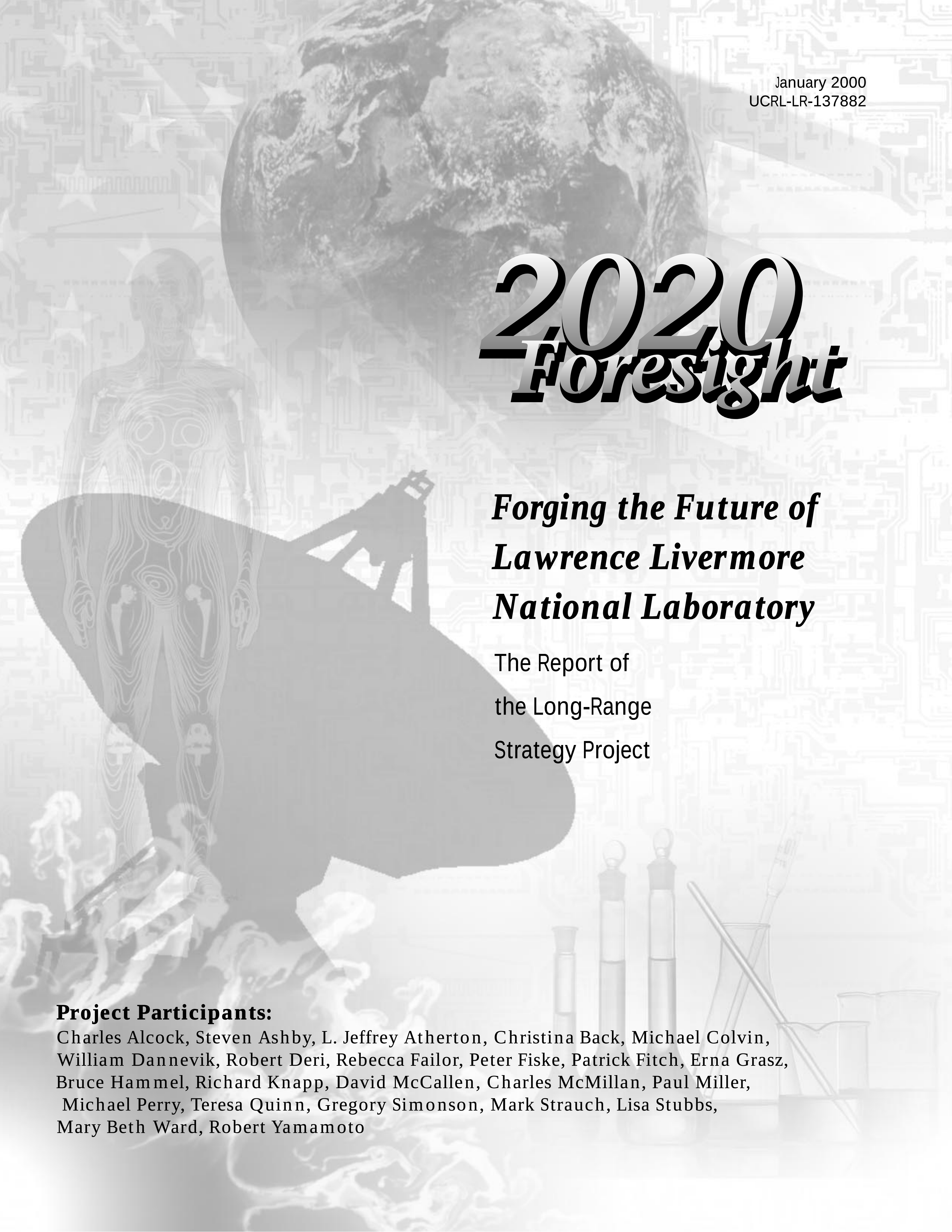
2020 Foresight

Forging the Future of Lawrence Livermore National Laboratory

The Report of
the Long-Range
Strategy Project

Work performed under the auspices of the U. S. Department of Energy by the University of California Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

January 2000
UCRL-LR-137882



2020 Foresight

Forging the Future of Lawrence Livermore National Laboratory

The Report of the Long-Range Strategy Project

Project Participants:
Charles Alcock, Steven Ashby, L. Jeffrey Atherton, Christina Back, Michael Colvin, William Dannevik, Robert Deri, Rebecca Failor, Peter Fiske, Patrick Fitch, Erna Grasz, Bruce Hammel, Richard Knapp, David McCallen, Charles McMillan, Paul Miller, Michael Perry, Teresa Quinn, Gregory Simonson, Mark Strauch, Lisa Stubbs, Mary Beth Ward, Robert Yamamoto

CONTENTS

PREFACE

In March 1998, Laboratory Director C. Bruce Tarter initiated the Long-Range Strategy Project to explore science and technology opportunities and national needs in the 2010-to-2020 time frame. The project was launched with the recognition that the Laboratory's prospects 10 to 20 years in the future are uncertain. Technology is evolving very rapidly, and programmatic uncertainties arise from the fact that post–Cold War national research and development priorities remain the subject of a national debate.

The specific charter of the Long-Range Strategy Project was to:

- Explore, analyze, and evaluate new scientific and technical opportunities that are appropriate for the Laboratory.
- Identify new programmatic needs where the Laboratory can play a significant role in the coming 10 to 20 years.
- Investigate effective ways of doing R&D business, including identifying potential future sponsors.

The project entailed the efforts of 22 younger to middle-career scientists and engineers who spanned disciplines and programs at the Laboratory. Team members devoted about 20 to 25 percent of their time to the project while continuing to fulfill their scientific and management responsibilities. Background information about project members is provided in Appendix B.

The efforts of the Long-Range Strategy Project team were guided by the Laboratory Director and administrative support and leadership were provided by the Office of Policy, Planning, and Special Studies. The project was also supported by a resource group consisting of selected senior Laboratory leaders: Director Emeritus John Nuckolls, Director of University Relations Claire Max, Laboratory Office of Science and Technology Director John Holzrichter, and Assistant to the Laboratory Director William Lokke.

The principal activities of the project were carried out through two sets of subgroup studies conducted sequentially and focused on selected topics. Each topic group was composed of five or six project members (including a selected leader or co-leaders) together with a senior member from the resource group. Topic group activities concluded with the preparation of a report and presentation of a briefing to Laboratory senior managers. The first set of topics for the project included:

- Nuclear Deterrence in the 21st Century.
- Computations and Communications.
- Bioscience and Biotechnology.
- The Future of Public and Private R&D.

Upon completion of the first set of reports, the team reorganized into a second set of topic groups, which were focused on:

- Emerging National Security Threats.
- The “Middle Third” of the Laboratory (e.g., energy, environment, and supporting disciplines).
- The Public Policy Landscape in 2015.
- The Laboratory Workplace in 2015.

As the second set of studies was concluding, a short study project group was also formed to examine the future of laser research and development.

In addition to these focused study efforts, the Long-Range Strategy Project met with the Associate Directors at the Laboratory and with a variety of distinguished visitors to the Laboratory (see Appendix C). The full project team also held two extended offsite meetings and worked as a body to prepare this final report and a final briefing to senior management at the Laboratory.

This final report synthesizes the results of the nine study project reports. It highlights principal points raised in the reports and ties them together with an overall set of conclusions and recommendations. In an overall report of manageable length, much of the detail in the project reports is not present—nor the variety of approaches taken and individual viewpoints. Some of that richness is recaptured by the sidebars in this report, which are possible future magazine articles, newspaper clippings, and press releases related to key issues discussed in this report. In addition, some project members have added personal statements. They comprise Appendix A.

It is widely appreciated by anyone who undertakes strategic planning that the process is as important as—often more important than—the product. The Long-Range Strategy Project provided an opportunity for a diverse group of the Laboratory’s technical staff, who will be making important decisions about Livermore’s programs and their direction over the coming decades, to get to know each other and the many issues that the Laboratory faces. This report is but one of the many important products of the project.

Tom Isaacs, Director
Office of Policy, Planning, and Special Studies

I. EXECUTIVE SUMMARY

The Lawrence Livermore National Laboratory (LLNL) of 2020 will look much different from the LLNL of today and vastly different from how it looked twenty years ago. We, the members of the Long-Range Strategy Project, envision a Laboratory not defined by one program—nuclear weapons research—but by several core programs related to or synergistic with LLNL's national security mission. We expect the Laboratory to be fully engaged with sponsors and the local community and closely partnering with other research and development (R&D) organizations and academia. Unclassified work will be a vital part of the Laboratory of 2020 and will visibly demonstrate LLNL's international science and technology strengths.

We firmly believe that there will be a critical and continuing role for the Laboratory. As a dynamic and versatile multipurpose laboratory with a national security focus, LLNL will be applying its capabilities in science and technology to meet the needs of the nation in the 21st century. With strategic investments in science, outstanding technical capabilities, and effective relationships, the Laboratory will, we believe, continue to play a key role in securing the nation's future.

LABORATORY MISSIONS AND CORE PROGRAMS

Now and in the future, an "LLNL signature project" involves a mix of scientists from different fields who apply their talents by combining experiments, theory, and computer simulations to accomplish the Laboratory's mission objectives through advances in science and technology. Many of these projects have high technical risk, with the potential of very high rewards. Many are of a scale larger than that achievable at universities or other federal R&D institutions. Because of its ability to pursue such projects, the Laboratory is a special resource for the country.

Since the Laboratory's inception, nuclear weapons R&D has been its core program. We believe that the nation will face other emerging threats and risks in the 21st century that call for the innovative approach to problem-solving that LLNL has demonstrated throughout its history. "To Secure the Nation's Future" provides the common focus for the Laboratory's core activities, which will likely include:

- Stewardship of the U.S. Nuclear Weapons Stockpile—by maintaining the weapons' safety, security, and reliability and developing new capabilities if needed. We expect that nuclear weapons will remain part of the national security landscape for at least the next 20 years. To meet the major challenge of stewardship without nuclear testing, the nation will continue to rely on the expertise and capabilities of the Department of Energy (DOE) national security laboratories. However, in the absence of a major crisis, we expect public interest in and support for the nuclear stockpile to decline substantially.

- Countering Significant Emerging Security Threats—to help prevent and defend against significant newly emerging threats and the proliferation and use of weapons of mass destruction. The future may hold a host of new potential threats to our nation's security—novel biotechnology-generated threats, conflict and chaos stemming from shortages of natural resources, proliferation of missiles carrying weapons of mass destruction, terrorist-style attacks on the nation's critical infrastructure. The Laboratory offers special capabilities to help meet the growing national need for better intelligence and defense. Work to stem emerging threats complements and builds on the skills, knowledge, and abilities LLNL researchers have developed for nuclear weapons stewardship.

- Safeguarding the Nation's Future—by developing advanced technologies to address sources of international insecurity and national risk (e.g., energy, environment, and human health concerns). The nation will benefit from an expanded bioscience effort at LLNL to meet rising human health and security needs. Significant innovations in energy production and usage are also needed, as are advanced tools for environmental characterization, management, and mitigation. With its large-scale, multidisciplinary approach, the Laboratory has much to contribute, particularly in areas where it possesses unique capabilities and special expertise.

The development and maintenance of significant core programs in these mission areas will be challenging for the reasons discussed in this report. The potential success of any core program depends on a variety of uncontrollable and unpredictable factors such as future national priorities, federal spending, and sudden events. Given these uncertainties, we believe that the development of several core programs, along with strategic investments in selected areas of science and technology, will enable LLNL to best serve the future needs of the nation.

LABORATORY SCIENCE AND TECHNOLOGY

The Laboratory must sustain excellence in high-energy-density physics and nuclear materials science and technology to meet important mission responsibilities in stockpile stewardship and in the management of nuclear materials worldwide. To meet its broader national security responsibilities, the Laboratory needs to select a few science and technology areas where LLNL can sustain a position of leadership. Three areas hold particular promise. The Laboratory should:

• Expand the Biology and Biotechnology Program Effort—to meet national security needs and to serve the community at large. Bioscience and biotechnology are likely to spawn major revolutions in industry, agriculture, health, and national security in the 21st century. Many of these advances will depend on the integration of the physical sciences, computations, and advanced engineering with the traditional biosciences. Within the life sciences, the technologies needed to address national security issues are similar to those for environmental and pharmaceutical applications. These new technologies may give rise to substantial new threats to national security that require effective defenses; at the same time, they may be critically important to developing effective biodefense capabilities and, more generally, improving human health. While national security applications motivate why biology is done at LLNL, a strong biosecurity program goes hand-in-hand with and cannot thrive without a strong civilian program.

• Vastly Improve Computer Simulations—by playing a leading role in the development of high-end computer simulations for a variety of scientific and systems applications. Scientific simulation has always been an important research tool in major programs at the Laboratory—one used in a mutually reinforcing way with laboratory experiments and theory. For stockpile stewardship, LLNL is acquiring successively more powerful computers that are allowing researchers to tackle scientific problems that had been totally unapproachable. The Laboratory is positioned to be at the forefront of and provide leadership in:

— The development and validation of high-end scientific computer simulations, together with the use of powerful model-development and data-analysis tools. An ability to develop validated computer simulation tools can be the deciding factor that creates opportunities for the Laboratory to pursue. The Laboratory could be at the leading edge in the simulation of a wide range of important physical phenomena, including the fundamental properties of materials, complex environmental processes such as contaminant transport and climate change, biological systems, and the evolution of stars and galaxies.

— The simulation of complex systems that have sensors for data gathering and require fusion and interpretation of massive amounts of data. National security applications arising from this technology area range from battlefield awareness, crisis management, and critical infrastructure protection to real-time response to natural and man-made hazards.

• Provide Leadership in Advanced Lasers Science and Technology—by building on LLNL's strengths in the development and use of high-power and high-energy solid-state lasers. National Ignition Facility (NIF) experiments over the next decade and beyond will provide critical support to stockpile stewardship and set the stage for further advances in fusion energy, plasma physics, astrophysics, and high-energy-density physics. In addition, LLNL's special expertise in high-average-power solid-state lasers has many potential military applications, and the further development and application of ultrahigh-brightness lasers can lead to important new capabilities to probe matter on molecular-physics time scales—an exciting frontier of materials science.

The Laboratory must keep its eyes open for other possibilities. It has a responsibility to comprehend what is technically possible and understand the impact of advanced technologies on the nation's security.

THE LABORATORY OF THE 21st CENTURY

The Laboratory has many strengths that must be sustained into the 21st century—a multidisciplinary approach to problem solving, a focus on tackling large-scale technical problems that matter to the country, and a culture that values risk taking to achieve groundbreaking results. But the Laboratory finds itself in a rapidly changing environment, and it has to adapt. Several areas, in particular, need attention:

• Attracting and Retaining Exceptional People—because they will remain the Laboratory's most important asset. Since its creation, LLNL has attracted men and women of extraordinary talent who are motivated to tackle the nation's critical technical challenges. Exceptional people thrive on challenge, delight in pushing the frontiers, and seek out the most difficult problems. They are attracted by more than generous compensation, but an attractive compensation package and a high-quality work-force environment are important. The Laboratory must create the kind of environment where creative and dynamic individuals can work with a maximum amount of support and a minimum level of bureaucracy. We also believe that continuation of the relationship with the University of California (UC) is important to the health of the Laboratory and to meeting these objectives.

• Providing Opportunities for Exploratory Research—to meet future security challenges through groundbreaking scientific work. The past has shown that creative and revolutionary technical solutions arise from a talented staff who are given the flexibility and the resources to explore novel ideas. However, the ability to conduct exploratory research is declining as a result of sponsors' more piecemeal, task-oriented approach to funding research activities. The Laboratory must work with sponsors to provide its scientists with a healthy amount of latitude in their research endeavors—both to solve national problems and to attract and retain creative individuals. LLNL must also ensure that fledgling technical areas that are well-aligned with its national security mission are nurtured and protected while they grow. In addition, novel means of incubating new programs must be explored.

• Expanding Working Relationships and Partnerships—with a variety of sponsors, other laboratories, universities, and private industry. A cultural change will be required. In too many interactions, outsiders perceive Laboratory staff as insensitive to their needs. Building long-term relationships and partnerships will require more than commitment and a long-term focus—it will require a fundamental change in culture and attitude. The Laboratory must more effectively communicate its strengths and capabilities to its federal sponsors, members of Congress, and senior leaders of federal agencies, as well as to industry, state, and local leaders, and, most critically, the public at large.

• Operating Openly with Intellectual Diversity and Greater Flexibility—or else LLNL will not succeed. Diversity in the Laboratory's ideas, staff, and technical skills is absolutely essential for technical progress and the future vitality of LLNL. So are interactions with others. The Laboratory cannot do its job alone. Interactions with other organizations provide new ideas, perspectives, and a public face to the scientific work performed here. Furthermore, because so many advances occur outside the Laboratory's fences, the staff must constantly interact with the broad scientific community. High-quality peer-reviewed scientific work keeps researchers sharp, showcases LLNL expertise, and bolsters the Laboratory's scientific credibility in the most demonstrable way possible. Even for classified research projects, the Laboratory will fail if it does not operate openly in dealing with unclassified issues and draw the best from its staff and others. In addition, because partnerships will be essential, business practices must become more agile and flexible, and they must be tailored to meet the needs of potential partners and customers. The Laboratory must adjust its operational practices to make significant portions of its staff and unclassified facilities more accessible to outsiders without compromising security, to be more affordable, and to allow greater flexibility and responsiveness in business arrangements.

CONCLUSIONS AND RECOMMENDATIONS

The members of the Long-Range Strategy Project conclude that the nation will continue to rely on a nuclear deterrent, but it is likely that the perceived importance of nuclear weapons in assuring our national security will decline along with the funding for nuclear weapons stewardship. It is also likely that other threats, both new and already emerging, will require innovative technical countermeasures.

The Laboratory's best strategy is to evolve with national priorities. To sustain the vibrant, dynamic research environment required to meet its commitments to the nation, LLNL must transition from a nuclear weapons laboratory with a small number of supporting programs to a national security laboratory with a small number of core programs, one of which is nuclear weapons stewardship. Each of these core programs will stand on its own in addressing an important national issue. Taken together, these programs will provide a world-class technical foundation spanning key disciplines.

Based on our perception of evolving national needs and our evaluation of the opportunities and challenges the Laboratory faces in meeting these needs, we developed ten principal conclusions and recommendations. They are presented in Section V.

II. THE LABORATORY'S MISSIONS AND CORE PROGRAMS

"To Secure the Nation's Future" will be the defining purpose of the Laboratory.

The Laboratory's R&D portfolio must evolve to reflect changing national priorities. Established in 1952, LLNL provided many of the advances in nuclear weapons technology that helped the U.S. to win the Cold War. The nation continues to depend on its nuclear deterrent, but security threats on the horizon require other responses. The advanced R&D capabilities of a national laboratory will be needed to respond to these new threats to national security.

The 10-to-20-year future is bound to include technical surprises and singular world events that dramatically reshape national priorities. "To Secure the Nation's Future" requires the Laboratory staff to be aware of emerging national security threats and to respond to challenges—either anticipated or unexpected—that demand creative technical solutions. We envision a Laboratory in 2020 with important responsibilities:

- To Provide Stewardship of the U.S. Nuclear Weapons Stockpile—by maintaining the weapons' safety, security, and reliability and developing new capabilities if needed.

- To Counter Significant Emerging Security Threats—to help to prevent and defend against significant newly emerging security threats and the proliferation and use of weapons of mass destruction.

From a future index of articles in the Laboratory's monthly publication:

Science & Technology REVIEW

Index of Articles: August–December 2018

August 2018
- Meeting the Geri-Ergonomics Challenge
- From Here to Eternity: U.S. Nuclear Materials Policy
- Arms Control Technologies for Trucekeeping in the Middle East

September 2018
- The Unexpected Consequences of the CTBT 10 Years after Ratification
- Data Enrichment: Applications for Astrophysics
- Biomanufacturing: The Fourth Industrial Revolution?

October 2018: Special Commemorative Laser Issue on the 10th Anniversary of NIF Ignition
- A Science and Technology Pathway to Fusion Energy by 2035
- Missile Defense: The Arms Race that Wasn't
- Science Spin-Offs from the U.S. Laser Program

November 2018
- Orthogonal Proliferation: Challenge for the 2020s and Beyond
- Real-Time Design of Biological Antidotes
- Cyber Security Lessons Learned from Hackergate '17

December 2018
- From Teraflops to Exaflops: A Restrospective on Computational Advances since 2000
- Root Causes of the 2017 Great Brazilian Drought
- Civilian Applications of Isomer Technology

• To Safeguard the Nation's Future—by developing advanced technologies to address sources of international insecurity and international risk (e.g., energy, environment, and human health concerns).

LLNL's specific activities in 2020 will depend on several key factors: How various threats evolve, the investment choices the Laboratory makes to develop new capabilities, and public and sponsor support for specific programs. The development of several major stable programs within the Laboratory's mission responsibilities will be important to institutional health and vitality in 2020. These core programs, with their accompanying special expertise and major research facilities, will define LLNL and shape opportunities to develop smaller, complementary programs.

A. Stewardship of the U.S. Nuclear Weapons Stockpile

The nation will continue to depend on the expertise at its national security laboratories to ensure the reliability and safety of the U.S. nuclear weapons stockpile.

We expect that nuclear weapons will continue to be part of the national security landscape for at least the next 20 years and that they will serve as a deterrent against major threats to the U.S. and its interests. The nation will continue to rely on the DOE national security laboratories to ensure the safety, security, and reliability of the U.S. nuclear weapons stockpile. The Laboratory is being called upon to maintain the arsenal well beyond the nominal lifetime of the weapons without the benefit of nuclear testing. The nation is relying on advances in the science of nuclear weapons and independent assessments by more than one laboratory as a basis for weapon performance certification. Therefore, we expect stockpile stewardship to remain a core mission of the Laboratory. The quality of LLNL's work and the value that it adds to the program will sustain the Laboratory's role as a central element of the nation's nuclear weapons program.

Events could transpire that refocus attention on the military utility of the U.S. nuclear arsenal, possibly even to the extent that new weapon designs will be required. Should a hostile superpower reemerge, the need for U.S. nuclear deterrence could become as immediate as it was during the Cold War. The more likely case is that interest and investments will increasingly focus on nonnuclear capabilities for national defense, and the size of the nuclear stockpile and the resources provided to maintain it will decline. Both cases present substantial programmatic challenges for the Laboratory, which has to be prepared for either. Moreover, as we consider the future of stockpile stewardship, several key factors loom important:

• ***The real possibility of serious erosion of support.*** Should public interest in nuclear weapons continue to decrease as we expect, it should be no surprise if funding follows the same path. The health of the nation's nuclear weapons program in 2020 may be very dependent on the emergence of an energetic new generation of champions in Washington for stockpile stewardship and, more generally, for an effective nuclear deterrent. LLNL's central role in the program will be severely challenged if its contributions are not widely perceived as critical to stewardship success. In any event, the Laboratory will also need to build other core programs that align with its national security mission and contribute to the core capabilities needed to maintain the nuclear weapons stockpile.

• ***The need for exceptional people in the program and the challenge of recruiting and retaining them.*** As the Laboratory moves even further from the era of nuclear testing, nuclear deterrence will rely increasingly on the credibility of the scientists in the program and their assessments. To the extent that judgments are poorly reasoned or the people are perceived to be less than first-rate, deterrence is weakened. The challenge of staff recruitment and retention can be expected to increase; this issue will require continuing attention by Laboratory management. What will help is the attraction of high-profile projects, such as NIF, the Accelerated Strategic Computing Initiative (ASCI), and other cutting-edge research efforts that provide the scientific underpinning to stewardship.

• ***New challenges and opportunities growing out of stockpile stewardship activities.*** By 2020, it will become much clearer how well stockpile stewardship without nuclear testing actually works. A largely successful program should place LLNL at the forefront of large-scale scientific simulation through ASCI. The Laboratory should have achieved fusion ignition and energy gain using NIF, thereby setting the stage for further scientific advances. Researchers should also have a much improved fundamental understanding of the properties of materials. The weapons program might still be a thriving research effort in 2020 with many challenges still on the horizon, or it might open many avenues for other funded activities at the Laboratory that serve to strengthen stockpile stewardship efforts.

• ***Science and technology input to decisions about the future of nuclear weapons.*** The nation faces difficult choices about how to move toward the long-standing goal of international nuclear disarmament in the face of existing and emerging security threats. For the nation's benefit, the Laboratory needs to be an active and effective participant in the national and international security communities. LLNL's role is to help ensure that technical considerations are thoroughly vetted and nuclear policy decisions are based on informed choices. In the process, Laboratory staff will gain information and skills that will help guide our research efforts and communicate their benefits.

B. Countering Significant Emerging Security Threats

Efforts should be made to expand the Laboratory's role in helping the nation to prevent and defend against significant emerging threats and the proliferation and use of weapons of mass destruction. In selected areas where it has particular technical expertise, LLNL can help to meet the growing need for better intelligence and defense, but there are numerous obstacles to expansion of activities.

In an increasingly complex world, the U.S. faces a range of emerging national security threats from many potential adversaries. International instabilities could spark conflicts that lead to the rise of a hostile power or further proliferation of weapons of mass destruction (WMD) and their use. Missile technologies and capabilities to produce WMD continue to spread. History provides many examples of the rise of aggressors that were only stopped by using extreme force. In addition, the possibility of terrorist use of biological or cyber weapons has received a great amount of attention recently. Opinions vary widely on the probability of these emerging threats, but preparation is the best deterrent. To this end, the nation must tackle head-on the emerging threats—through efforts to stem the proliferation of WMD, develop better intelligence-gathering capabilities, and improve defenses.

In step with the emergence of new threats, the Laboratory has markedly increased its R&D activities in nonproliferation during the 1990s by bringing to bear its special capabilities to address challenging problems. LLNL is making important contributions in many areas, notably WMD emergency-response capabilities, sensor technologies for detection and monitoring, and computer tools for characterization and analysis of proliferation activities. These research activities reinforce the Laboratory's nuclear weapons work by strengthening LLNL's technical base. They entail working with a variety of sponsors: the Department of Energy, the Department of Defense, the intelligence community, the Department of Justice, and a number of organizations responsible for emergency response. Other areas of national security R&D, such as ballistic missile defense and conventional munitions, have not experienced comparable growth to date. Future demands for the special capabilities available at the Laboratory may, however, provide the opportunity to change this situation.

Greater national security mission responsibilities and program growth are possible, in principal, in a number of areas where LLNL has special expertise and/or ongoing activities. They include:

• ***Defense against biowarfare and bioterrorism.*** The Laboratory has a broad-based program in bioscience and biotechnology together with a number of ongoing biological defense projects ranging from portable pathogen detection systems to basic research on the mechanisms of bacterial toxins. Additional projects could build on LLNL's capabilities in DNA sequencing, structural biology, bioarrays, sensors, and simulation. (See Section III.A and the box on p. 13 for a perspective of the bioterrorism threat.)

• ***Intelligence support technologies and information management.*** Intelligence plays an essential role in detecting and defending against emerging threats. LLNL can help to meet the diverse technical needs of the intelligence community

An abstract for an international security conference presentation in 2001:

Biological Terrorism: Where Is It?

A considerable amount of discussion—in the press and popular literature and within governmental and academic institutions—has suggested that biological weapons (BW) are of increasing concern because of factors such as their low cost of production, their ease of concealment, and assorted technological advances in biology. If so, why have we not experienced any significant BW events?

One answer is that there are substantial barriers, little interest, and few historical precedents for using BW, although hoaxes abound.

The BW threat is most often associated with subnational terrorist groups, because State actors are subject to conventional military and nuclear deterrence. Even if a State act, or State-sponsored act, is intended to be unattributed, there is the threat of being uncovered. However, the barriers are significant to the use of WMD even by non-State terrorist groups.

Although the nature and motivation of such organizations vary widely, those planning to use any type of WMD must fulfill all of the following criteria.[1] They must

- Have the technical expertise to make the weapon, or other access to one.
- Avoid detection during the planning, financing, acquisition, manufacture, transport, and dispersal phases.
- Have the delivery means.
- Be prepared to survive the attack themselves, or have suicidal agents.
- Be willing to kill innocent people.
- Be willing to antagonize their sponsors, if any, or have sponsors who don't care.
- Be willing to endure widespread international condemnation.
- Be willing to endure a perpetual international police dragnet after the attack.

Many terrorist groups with the capability to fulfill the first three criteria are hampered by the last five. Many analysts have concluded that the greatest threat is from small fanatical groups or individuals for whom technical expertise is typically an obstacle. But what about groups that might satisfy all eight criteria?

Historically, there has been little interest in BW from terrorist groups.[2] The terrorists consider BW difficult; where there has been any limited success, there has been a high skill level and very simple dissemination (i.e., localized, such as spraying salmonella on a salad bar). No successful aerosolization or water contamination is known. In the past several decades, only five (open source) documented uses of biological agents have occurred. Just one, involving a salmonella release, got someone sick. The anecdotal evidence suggests that BW is more difficult for terrorists than it is often portrayed.

Currently, the FBI is unaware of any BW-capable terrorist groups. Nevertheless, as the attention in the media has increased, the incidence of hoaxes and threats has risen, including over 200 worldwide anthrax hoaxes since 1998. The impact of such hoaxes can be significant, but the hoaxes should not, in themselves, lead us to conclude that the threat is growing (cf. the analogy with nuclear weapon threats, which have been numerous in past decades).

Following these arguments, we might conclude that there are still individuals or groups that might satisfy the above criteria, but that they are very much the exception and not the rule. A large-scale breakout of BW use by terrorists is not likely because BW does not make sense for most of them. Our concern lies, therefore, not with the mainstream, classically political groups, but with the half-crazy or the ideologically sociopathic (but financially sound and technically savvy) types. While we are fortunate that there are not many such individuals around, conventional terrorism has shown us that a few (e.g., Theodore Kaczynski) crop up every decade or so. Because of this low, but non-zero, probability threat, we feel we must prepare.

---

[1] Modification of criteria posed by Dennis Pluchinsky, Department of State, at a conference "The New Terrorism" sponsored by the Chemical and Biological Arms Control Institute and the LLNL Center for Global Security Research, Washington, D.C., April 29–30, 1999.
[2] The following two paragraphs incorporate discussions by Seth Carus, National Defense University, and Amy Sands, Monterey Institute of International Studies, at the same meeting cited in note 1.

through new projects in data fusion and advanced surveillance technologies. The Laboratory is developing sophisticated sensors and capabilities to manage and analyze vast amounts of data—either computer generated or gathered by arrays of sensors. (See the 2010 newsclip below.)

- ***Infrastructure protection.*** The nation is growing ever more dependent on an increasingly sophisticated information infrastructure. An attack on it, while not necessarily entailing WMD, could have devastating consequences. The Laboratory could attain leadership in selected areas of infrastructure-protection R&D, including cyber-defense and large-scale simulation-based infrastructure analysis.

- ***Advanced conventional weapons (ACW).*** Long-range U.S. military planning is focusing on a new paradigm, the Revolution in Military Affairs, which envisions the use of leading-edge technologies such as ACW and greatly improved information management capabilities (see discussion above) to conduct military operations. The Laboratory is able to bring to bear many long-recognized strengths relevant to ACW, including expertise in energetic and advanced materials together with capability for rapid prototyping of demonstration test units.

- ***Missile defense and space.*** Twenty years hence, protection against ballistic missiles and protection of U.S. space-based assets will be significant national security challenges. While the Laboratory may have to overcome significant obstacles to be well-integrated into the ballistic missile defense community, its nuclear weapons expertise, experience with Brilliant Pebbles and Clementine, solid-state laser expertise, engineering and prototyping abilities, and sensor technology capabilities are all assets.

Each of these areas has potential for growth and should be explored. However, building a major Laboratory program, whether through expansion of current efforts or from the ground up, will involve significant challenges. Because of competition from other laboratories and overlap with the work of defense industries, LLNL must select specific thrust areas carefully, with a focus on areas where it can provide a unique capability. The Laboratory also must be mindful of the political sensitivities associated with certain areas, such as ballistic missile defense and biological weapons issues.

It will take committed, focused efforts to develop productive relationships with new sponsors, requiring patience, great attention to customer service, and

A 2010 newsclip:

War Games

Lawrence Livermore National Laboratory (LLNL) will soon introduce the first truly intelligent sentient systems for execution of Department of Defense operations, from humanitarian missions in the third world to peacekeeping in orbit. The coming technology integrates existing intelligence sources, ground- and space-based sensors, computer simulations, controllable assets in the field, weapons systems, and, to the extent desired, human input.

The new element in this network is LLNL's latest indigenous high-speed processor and software package, the L-066. This compact and powerful unit combines processing and communications capability to enable local decision-making on each sensor, vehicle, munition, or other platform. With this system, any individual remote asset can instantly bring to bear the capabilities of a global network for crisis management or force projection.

The integrated systems being readied at LLNL will be able to sense their environment, cue additional resources, reach back to existing databases and analysis worldwide, consider courses of action, and initiate simulations to assess possible outcomes and consequences. The same autonomous controller directs assets in the field—be they relief supply vehicles, defense systems, or weapons systems—and monitors results instantaneously.

This capability builds on the paradigm of "situational awareness" introduced by LLNL at the turn of the century. Such systems are now common, using smart sensors, database tools, and integrated simulations to provide a decision-maker (to date, a human being) with complete environmental information on which to base future action.

LLNL's latest systems obviate the need for a human in the loop. The L-066 can communicate and cue sensors faster, query relevant data more efficiently, execute pertinent simulations, and take actions more rapidly than any person. In some situations, this personal touch will always be preferable, so the system allows for any degree of human control desired. In many others, the benefits of acting rapidly, anticipating the unfolding of a situation rather than reacting to it, dictate use of these fully autonomous controllers.

possibly political champions. It is also important that LLNL's traditional DOE sponsors are satisfied that program diversification will benefit rather than detract from long-standing mission responsibilities. In many ways, the Laboratory continually faces these challenges for program areas outside its traditional national security mission, so it should draw on this experience for future program development.

C. Safeguarding the Nation's Future

The Laboratory's mission responsibilities include application of special capabilities to meet a variety of enduring national needs. Directed at improving energy security, environmental quality, human health, and the nation's science and technology base, LLNL's R&D activities will address a broad range of risks to the U.S. and improve the well-being of its populace in the 21st century. These projects are a critical part of an intellectually vital national laboratory, and as a strategically managed portfolio, they enhance the Laboratory's capabilities to fulfill its defining national security responsibilities.

The world is getting smaller because of the complex interdependence of regions of the world and countries within regions. And as a world leader, the U.S. has global interests, influence, and responsibilities. Significant national and international challenges are arising in the areas of energy, economic growth, environment, and public health. They can be sources of tension and conflict. Where the best of science and technology can make a difference, we see a continuing role for the Laboratory in safeguarding the nation's future. LLNL has special capabilities and research facilities, and with its multidisciplinary approach, its researchers are able to devise creative solutions to problems.

LLNL's pursuit of R&D activities to safeguard the nation's future is mutually beneficial to the country and the Laboratory. The Laboratory is able to provide unique capabilities and a multidisciplinary approach to problems where there are enduring national needs. LLNL also benefits. In particular, because of these almost entirely unclassified projects:

- National recognition for LLNL's scientific excellence is generated. The quality of the work helps to bolster confidence in the classified national security work performed at the Laboratory.

- The Laboratory addresses problems that improve the quality of life here and abroad, thus helping to broaden local and national support for LLNL.

- The Laboratory has greater scientific breadth and a more vital scientific base that supports critical national security work and spins back technologies for defense applications.

- LLNL has a much greater draw for exceptional talent by providing a larger window for engaging the broad scientific and technical community.

The Laboratory can undertake valuable and unique R&D activities that contribute to producing clean, affordable energy, understanding and managing the environment, and improving public health. LLNL will focus on problems that require the capabilities of a national laboratory and that either capitalize on a competitive advantage of the Laboratory or significantly strengthen its technical base. LLNL offers not just its special capabilities and multidisciplinary approach to problem solving, but a national security focus and perspective. Increasingly, the major issues the nation faces that technology can address have a national security dimension that must be factored into the solutions. Potential major areas include:

• ***The management of nuclear materials.*** In the early 21st century, the Laboratory should be actively involved and provide leadership in nuclear materials management, both for the legacy materials of first-generation civilian nuclear power and nuclear weapons and for the wise management of nuclear materials in future nuclear systems, especially those incorporating proliferation resistance as an objective.

• ***The development, validation, and application of large-scale simulation for environmental assessment and prediction.*** Applications include subsurface reactive transport, seismic event characterization, climate change predictions, and hazardous materials dispersion. The Laboratory is positioned to pursue a comprehensive, integrated program in environmental simulation and observation, including fusion of real-time data streams from mobile sensor arrays, high-end simulation models, and advanced communication systems. The capability will provide dual-use applications in national security (e.g., battlefield awareness) and a framework for broad research partnerships with academia.

• ***The development of fusion energy.*** With a functioning NIF, which is currently under construction, LLNL will be at the forefront of research on inertial confinement fusion. The Laboratory could position itself to be the national laboratory for fusion energy, providing leadership in all aspects of inertial confinement fusion (targets, target chamber, and driver) and alternative concepts to magnetic fusion energy (e.g., pulsed reactors).

• ***Areas of basic and applied science closely tied to the Laboratory's national security mission.*** Examples include astrophysics, bioscience and biotechnology, high-energy-density physics, lasers and electro-optics, scientific simulations, and materials science. These activities, some of which are discussed in more detail in Section III, help to better connect LLNL to the broad scientific community and draw new talent to the Laboratory.

In each of these areas, LLNL will be positioned to make valuable contributions. However, as in the case of work for national security sponsors, success will depend on focusing efforts wisely, offering unique but affordable multidisciplinary capabilities, and building long-term partnerships and relationships. (See Section IV.B and C.)

D. Future Core Programs and Major Research Facilities at the Laboratory

A multidisciplinary approach to science and technology dedicated to public service is and should remain the central strength of the Laboratory, with large core programs and major research facilities serving as its foundation. The development of several major stable programs will be important to the future health and vitality of the Laboratory. However, the changing research-funding environment and public policy landscape are making it more difficult to pursue large-scale programs aimed at long-term benefits for the nation.

The DOE national laboratories were born out of an urgent need to direct the best that science and technology could offer to the most pressing

An LLNL Press Release, August 15, 2015:

Virtual Valley System Alerts Region to Meteorite Impact

Scientists at the Regional Environmental Assessment and Prediction Center at Lawrence Livermore National Laboratory announced that the extraordinary sequence of events in the Sierra foothills east of Merced last week was initiated by the impact of a small meteorite.

"The direct impact was first detected on the array of 8,000 low-cost seismic sensors that the Laboratory has placed throughout the Northern California Central Valley as part of its Multiscale Monitoring and Simulation Program (dubbed the Virtual Valley)," explained center leader Janet Bekavic. "Our wireless network of weather sensors subsequently detected a barometric wave and a dust plume consistent with the impact. We have, as yet, no eyewitnesses to this extraordinary event."

According to Bekavic, the Virtual Valley system immediately used the sensor data as input to simulation models and predicted rockslides south of Yosemite National Park and several grassland fires. National Park Service personnel confirmed both the landslides and the grass fires. The fires damaged an agricultural chemical storage facility and caused an uncontrolled release of chemicals. The Virtual Valley's system of soil and groundwater detectors is tracking the plume of contamination. Bekavic reported that the Virtual Valley system has already developed a pump-and-treat plan, which is being implemented by emergency crews.

While cost estimates of the event are still being assessed, County Commissioner Dan Fernandez extolled the value of the Virtual Valley system. "It probably saved us $2 million in emergency response and clean up costs," he estimated.

The Virtual Valley, an integrated sensor and simulation system, is operated in partnership with the University of California at Merced and is an unclassified version of a similar system first delivered to the Department of Defense in 2010. The military version, dubbed Big Brother, uses thousands of self-directed airborne sensors, called "bees," to determine battlefield conditions, including vehicle movements, environmental impacts on signal propagation and imaging, targeting scenarios, and bomb damage. The current version of Virtual Valley is operated on the Laboratory's newest petascale computing platform, capable of over 1 trillion operations per millisecond.

national issues. Experience has shown that these laboratories are most valuable when:

- The national interest is at stake.
- The best of science and technology is required.
- Large and complex research facilities are needed.
- Expertise in a variety of disciplines must be integrated.
- The technical risk is high, with the potential of very high rewards.
- The job will go undone if the national laboratories don't do it.

These are the attributes of "LLNL signature projects." The projects involve a mix of scientists from different fields who iterate experiments, theory, and simulations to find solutions. If needed, they can carry concepts all the way from scientific discovery to fully developed prototype products. The Laboratory's ability to succeed at these signature projects is an institutional strength that stimulates creativity and sets LLNL apart from others.

An important feature of some LLNL signature projects is that they are large-scale R&D efforts. The Laboratory takes on large, multiyear projects that could not be tackled without the resources of a national laboratory. Taking on such large projects is a public service that we believe the nation will need in the 21st century and a distinction that LLNL will lose if its core mission does not demand science-of-scale and the presence of a few Laboratory-defining major research capabilities. Since its inception, nuclear weapons R&D has been a core program at LLNL. For many years, it was largely self-contained (vertically integrated) and dominant at the Laboratory. We believe that 21st-century national needs exist that create opportunities for additional or expanded major core activities in LLNL's mission areas. These activities will be needed for a healthy, vibrant Laboratory in the 2020 time frame. In the future, LLNL might be serving diverse customers and succeeding only if it has several large-scale signature projects serving as its foundation.

A major challenge to developing and sustaining major core programs stems from the changing R&D landscape. During the Cold War, funding for the Laboratory came largely from a single, dominant sponsor. This situation is giving way to a national problem-solving environment that involves a broader range of R&D funding sources and more widely distributed special expertise. As a consequence, funding for Laboratory programs in the future will tend to come from a more diverse set of sponsors, generally in smaller chunks of money, and require more specific and nearer-term deliverables.

Adding to this challenge, shifts in public policy make the development and retention of stable, long-term programs difficult. The stockpile stewardship of nuclear weapons is founded on broad, but potentially unstable, support. In other areas where LLNL is poised to make major contributions to the nation's benefit, such as energy and environment, opinions shift about the size and shape of the public investment portfolio in long-term research at the national laboratories and the role of the laboratories in interacting with U.S. industry. This overall lack of consensus brings an unusually high level of attention to the national laboratories, their purpose and programs, and their operations.

What will be the core signature programs for the Laboratory in 2020? We expect to have the Stockpile Stewardship Program and with it the National Ignition Facility and a major computing capability that might approach one exaops (10^{18} operations per second). We expect additional core programs in the mission areas discussed above (e.g., WMD nonproliferation) and from projects growing out of the science and technology thrusts discussed in Section III. We believe LLNL will need more than one core program to be a healthy, vibrant laboratory.

We are not in a position to identify specific winners, but possibilities for core programs at the Laboratory in 2020 are raised throughout the report. During its deliberations, the Long-Range Planning Committee at LLNL in 1981–1983 developed selection criteria that a candidate large-scale signature project must meet:

- It must be technically sound.
- It must meet a real need (either present or future).
- Funding must be reasonably assured in the longer term.
- The work should be suitable for a national laboratory and LLNL in particular.
- It should be compatible with other Laboratory activities and goals.
- The Laboratory should be in a good competitive position relative to others who might do the work.

We reviewed these criteria and believe that they remain sound for large-scale projects. For smaller projects, the criteria need to be relaxed somewhat. Assurance of funding for project duration suffices, but growth potential is important in today's environment and projects should be tied to theme areas that meet the criteria. In addition, with a lack of national consensus today about the role of national laboratories vis-à-vis industrial R&D, possible shifts in public policy and political considerations must also be weighed.

The potential projects discussed in Sections II and III (and likely others that we have not considered) have a reasonable chance of passing the test after more careful scrutiny. Various combinations of these projects are particularly compatible because they draw on similar core capabilities and skills, which are and will continue to be present at LLNL for stockpile stewardship. It is important for the Laboratory to further screen the options and set the foundations for growth in several selected areas, with the weight of the institution behind the efforts.

From a local Livermore newspaper in 2015:

Experimental Facilities of the Future

Lawrence Livermore National Laboratory (LLNL) announced a multiyear effort to upgrade its experimental facilities. The Secretary of the Department of Energy and LLNL's Director jointly unveiled the $1.56-billion program.

DOE Secretary Stephen Higgs stated, "This administration is committed to the future of LLNL. Over the next 10 years we will renovate, move, or decommission 40 percent of LLNL's experimental facilities."

LLNL's Director Karen Lee stated, "Experimentation has been at the core of LLNL's ability to secure the nation's future with the best science and technology has to offer. This investment will assure we have state-of-the-art facilities to meet national needs."

Critical to this plan is the creation of the National Nuclear Center to be built at the Nevada Test Site north of Las Vegas (see the box).

A new facility for high-explosives work will be constructed at the LLNL-operated Site 300 near Tracy. The 30-year old High Explosives Applications Facility (HEAF) will close. The Associate Director for Physical Sciences, Mary Widonour, said this would consolidate all the work with high explosives at Site 300 and provide expanded facilities to work with the new, extremely powerful insensitive explosives developed in 2005.

Older buildings at the Livermore site will be cleared to build the Nuckolls Institute for Advanced Laser Research. Thirteen existing buildings will be renovated for research in nanotechnologies, sensor development, and material science advancements.

Local engineering and construction firms were pleased to hear their bids will be given special consideration. Laboratory Site Manager, Rusty Pipes, said local companies might provide over two-thirds of the work.

The National Nuclear Complex

The National Nuclear Complex is under construction at the Nevada Test Site, north of Las Vegas. This multibuilding complex will house reactors, accelerators, and nuclear-material-handling equipment.

Secretary Higgs explained, "The NNC will be used to extract medical isotopes, build the reactor for the manned mission to Mars, and use photo-fission to destroy nuclear waste."

In four years, LLNL's plutonium work will be transferred to the NNC. Tri-Valley CARES executive director Sarita Fusse expressed dismay. "Plutonium work is not needed. They promised with ASCI and NIF they would be able to use computers to understand the weapons without these experiments. I'm glad the plutonium will leave the Livermore Valley, but I feel sorry for the people of Nevada who will soon have more of this deadly material in their backyards."

Members of the Nevada Coalition Against Everything Nuclear protested the DOE Secretary's announcement in Las Vegas. "The good people of Nevada were poisoned in the middle of the last century with nuclear weapons testing, and now they want to perform their horrible nuclear alchemy here, too."

The United Nations leader on power production, Jorge Watt, praised the NNC, saying that finally there would be a place to test the new proliferation-resistant nuclear power reactor that will help avoid the expected power shortage of 2040.

III. SCIENCE AND TECHNOLOGY AT THE LABORATORY

The ever-accelerating advance of science and technology increases both the challenge of being at the forefront and the opportunity to make exciting breakthroughs. LLNL's investment choices and program-building should be guided by strategic considerations. The Laboratory needs to pick a few areas where it can attain a position of leadership and build partnerships to gain access to the best in other areas. The Laboratory also needs to maintain expertise in areas of science and technology that are mission-critical and in which it has singular responsibilities to be the best.

The members of the Long-Range Strategy Project are bound to be surprised by the direction of the advance of science and technology over the next 20 years. The Laboratory will have opportunities to make breakthroughs that lead to major advances in its mission areas and create new programs to meet national needs. In the past, the Laboratory has taken advantage of certain newly emerging technologies—such as scientific computing in the 1950s and lasers in the 1960s—to pursue leading-edge R&D in support of its mission. LLNL needs to be strategic and selective about the opportunities that it chooses to pursue in the future. We examined in some detail a few possibilities that appear particularly promising:

- Expand the Biology and Biotechnology Program Effort—LLNL should make a conscious and sustained effort to grow its program in biology and biotechnology to meet national security needs and to serve the community at large.

- Vastly Improve Computer Simulations—The Laboratory should play a leading role in developing high-end computer simulations for a variety of scientific and systems applications by building on its efforts for stockpile stewardship.

- Provide Leadership in Advanced Lasers Science and Technology—The Laboratory has significant opportunities for new major programs that build on its leadership in the development and use of high-power and high-energy solid-state lasers.

Other opportunities that we did not consider doubtless exist, and the Laboratory must keep its eyes open for other possibilities. LLNL has a responsibility to understand what is technically possible and the impact of advanced technologies on the nation's security.

The Laboratory also has a singular responsibility to be the best in science and technology in areas that directly pertain to nuclear weapons performance and, more generally, high-energy-density physics and nuclear materials management. To support this continuing responsibility, LLNL must maintain modern facilities for conducting experiments with special nuclear materials, exceptional computers (see Section III.B), and unique research capabilities for investigating the properties of matter at extreme conditions and the interaction of matter with intense radiation (see Section III.C).

A. An Expanded Biology and Biotechnology Program

We should make a conscious and sustained effort to grow the Laboratory's program in biology and biotechnology to meet national security needs and to serve the community at large.

Sparked by technological advances that have enabled the sequencing of the human genome, bioscience and biotechnology have undergone tremendous change and can be expected to advance rapidly in the early 21st century. The world is at the beginning of a revolution in agriculture, environment, public health, and security. This revolution began as a life-science endeavor, but it is accelerating through appropriate use and creation of engineering, computational, and experimental tools from the physical sciences. The combination of exciting science and an important emerging national security need (biodefense) offers a tremendous opportunity for the Laboratory. A multidisciplinary approach, in which physicists, chemists, engineers, and computer scientists work side by side with biologists, brings a range of expertise to solve problems that few other institutions can match.

A window of opportunity for aggressively building LLNL's biology programs exists right now. A foundation for the expanded effort would be national security. However, a strong biosecurity program must be built together with a strong civilian biology–biotechnology program. National security applications motivate why biology is done at LLNL but should not be the only driver for a scientific area at such an early stage. Within the life sciences, the technologies needed to address national security issues are similar to those in environmental and pharmaceutical applications.

The Laboratory has a good start. The collective life-science activities at LLNL currently represent over $50 million in funding including a few large programs and numerous investigator-initiated grants for less than $500,000. A robust program will need access to both size projects. Significant partnerships are needed with industry and academia as well as recruiting of new talent at all levels. A particular challenge will be the need to work with a variety of sponsors. The National Institutes of Health (NIH) is the principal source of federal funding for biology R&D. The Laboratory needs to establish business practices that make NIH feel as if it is a preferred sponsor of R&D. Overall, a principal issue will be affordability, particularly if the Laboratory seeks support from foundations, which are the source of billions of dollars of early-stage high-risk R&D. Much more creative approaches to program management may be needed (see Section IV.C for further discussion).

New talent is needed to expand a quality life-science program. There are different expectations and definitions of success in biology—sponsorship, career, and reward mechanisms are different in biology than in engineering and the physical sciences. As the biology program expands, the Laboratory needs to be receptive to the input of external experts and attentive to the needs of the life-science staff. Opinions from advisory boards, consultants, post-doctoral fellows, new recruits, and recruits that elected not to come to LLNL should be elicited with consideration to the differences between life and physical sciences.

LLNL also needs to help DOE deliver on the life-science-related programs under way and use these programs as the stepping stones for future DOE programs. At the moment, parts of DOE have established well-defined life-science missions, and other parts are simply filling gaps in the NIH plan. The Laboratory should make a deliberate effort, working with the other DOE laboratories, to help DOE have well-defined missions in every area. One particularly significant niche for DOE might be

From a British newsweekly, February 29, 2019:

United States: The New California Gold Rush

In a technology rush that has not been seen since the “.com” craze of the last century, several acquisitions and public offerings recently pushed the NASDAQ to its highest point ever. At the heart of this frenzy is a collection of technologies and protocols known as physiomics. A combination of physiology (the science of living organisms and how they function) and genomics (the entire genetic information of a living organism), physiomics allows physicians and pharmacologists to leverage recent and past science discoveries in treating patients.

Leading the celebration is Dr. Robert N. Acid, colourful founder and CEO of PGnomics. “We’re excited with our recent growth and the potential benefit that will be derived from the 100 FDA approvals we received this year,” he stated in front of their golf course-like campus in the hills near Livermore, California. “Industry has taken the science breakthroughs from academia and the national labs and demonstrated safety and efficacy that will change human health care.”

Nearby, Lawrence Livermore National Laboratory was also celebrating. Physiomics has been a focus at LLNL for over a decade, and resulted in several licensed patents at the heart of the market rush today. Market insiders say the Lab’s “instant antidote” intellectual property will quickly follow. In a press release, the Secretary of Energy praised the national labs for “an innovative multidisciplinary approach that leveraged the large-scale computing and biodefense-derived capabilities from our national security missions to catalyze this great benefit to humankind.”

Physiomics had its beginning with the Human Genome Project initiated by the DOE in the 1980s. DOE has distinguished itself for four decades with initiatives that require new science, protocols, and instrumentation in order to succeed. In physiomics, this included the Human Genome Project, the Protein Production Program, the Functional Pathology Consortium, the Pathway Pilot Project, and the Physio-Genomics Initiative. The DOE labs are also breaking new ground in FY2020 with an initiative to understand human consciousness.

characterization of microbes and their study for bioremediation applications. It is also important that at least part of DOE's program use a sponsorship model different from the typical NIH grant to make effective use of the multidisciplinary research potential and capabilities of its national laboratories.

To succeed, the Laboratory needs to focus on a few core areas to develop a superior reputation and attain critical mass. We specifically identify biodefense and the post-genomics program as the top priorities. Major areas that may be good investments because they are synergistic with other LLNL activities, fit the Laboratory's mission profile, and may be able to attract external funding include:

- ***Biodefense.*** This area leverages existing competencies in biology, miniaturization, and bioinstrumentation and could be the basis for a diagnostics program as well. Sensor systems and new science to detect and identify microorganisms will continue to be important in biodefense. LLNL's Center for Accelerator Mass Spectrometry is a unique capability that could be more aggressively integrated into biodefense projects. The Laboratory should also seek approval for a BSL-3 facility in preparation to expand its capability for doing biocharacterization and possibly bioforensics. Large-scale programs aimed at providing the government with technologies for rapid pathogen characterization, pathogen databases, and broad-area monitoring for pathogens should be considered. Other possibilities include programs to investigate the feasibility of broadly applicable antibiotics or the potential for rapid vaccine development. The Laboratory's goal should be to become intellectual leaders for the country in the area of biodefense.

- ***Post-genomics.*** The current techniques for measuring the shape and function of proteins could be greatly improved. Opportunities exist for teams of biologists, engineers, and physical scientists to create the future for this area. Potential applications include understanding pathways like virulence, pharmacogenetics, antibiotic resistance, and toxicity. The scope of potential projects should have direct influence on biodefense and bioremediation applications.

- ***Bioinformatics.*** Today, scientists can obtain significant results without ever entering a wet laboratory. LLNL should seek to expand bioinformatics at all levels ranging from sensor/instrument data processing and database creation through ASCI-scale modeling and analysis. We expect information management and analysis to be a major part of the biotechnology revolution. Anticipated computational resources at the Laboratory would distinguish the program.

B. Vastly Improved Computer Simulations

The Laboratory should lead in the development of high-end computer simulations for a variety of scientific applications by building on its efforts for stockpile stewardship.

Scientific simulation has always been an important research tool at the Laboratory—one used in a mutually reinforcing way with laboratory experiments and theory. Simulation is an essential part of virtually every major program at LLNL. In many areas of scientific endeavor, simulations are moving from a supportive role for theory and experiments to a starring role—they are becoming a principal tool for scientific discovery and analysis. LLNL needs to stay at the forefront of and provide leadership in the development and validation of high-end computer simulations and the use of powerful model-development and data-analysis tools.

We fully expect the importance of scientific simulations to grow at LLNL for two reasons. First, success in the Stockpile Stewardship Program depends on the Laboratory's ability to develop validated simulation models of nuclear weapon physics and use those models as an integral tool to assess weapon performance. To this end, the Laboratory is acquiring successively more powerful computers as part of DOE Defense Programs' ASCI Program. Second, rapidly increasing computational power is enabling simulations to tackle important scientific problems that were previously totally unapproachable.

Over the next 10 to 20 years, we anticipate that the computational power available in desktop and mainframe machines will continue to grow at roughly the current rate, and the Laboratory's demand for computational power will continue to exceed the power available in state-of-the-art machines. Extrapolations suggest that by 2020, LLNL researchers will have tera-scale (a teraops or 10^{12} operations per second) desktop computers capable of running simulations comparable to those performed on today's ASCI machines—and might have mainframe machines that approach exa-scale (an exaops or 10^{18} operations per second).

LLNL's simulation capabilities can be the deciding factor in the opportunities the Laboratory will be given to pursue problems of national importance. The will also provide scientists with the opportunity to explore and understand nature in unprecedented ways. The possibilities for making dramatic advances include:

- ***Modeling of fundamental physics and chemistry.*** Possibilities that support national security and other applications include quantum-mechanical calculations to model shock-induced high-explosive initiation, to determine the equation of state of plutonium, and to determine the plasticity of metals using dislocation dynamics.

- ***Environmental simulations.*** Together with exa-scale machines, advances in sensors and communications technologies will enable a new era in computer-based assessment and prediction of complex, multiscale environmental processes such as contamination transport, global and regional climate change, and seismic activity. Real-time fusion of measurement data will engender new tools to mitigate environmental consequences and optimize industrial processes.

- ***Biological simulations.*** Although atomic-level simulations may never be feasible at the largest biological size and time scales, simulations of component processes could have a vast influence on biological research. Exa-scale computers will allow simulations of million-atom systems for microseconds, which should permit the study of fundamental, self-contained biochemical processes, such as the initial stages of protein folding.

- ***Astrophysical simulations.*** The universe has evolved into an entity that is very diverse and complex. A detailed understanding of it depends on complex numerical simulations. Exa-scale computers will just be able to represent the full range of important structures in a galaxy or in a cluster of galaxies; and they may be coming on line at a time when a new generation of telescopes will be collecting data to provide initial conditions for the simulation models that will be studied.

In addition, the Laboratory will have significant future opportunities to apply its simulations expertise to national security issues involving crisis management and critical infrastructure protection. Simulation and modeling can be used to mitigate the effects of crises and disasters by advanced scenario planning, consequence analysis, and preparation of response plans and by "responsive computing" to provide real-time guidance on how to deal with a crisis that has occurred. The development of vastly improved capabilities to manage, fuse, and display data will also open up other program opportunities.

Even if technically feasible, exa-scale machines—and teraops-scale desktop computers—might not be produced. The Laboratory will likely need to play a role in their development, absent sufficient market forces. LLNL needs to push aggressively for the development of extremely powerful computers and their use for applications of interest to the Laboratory. An edge in computational capability is important to its national security role.

Unless the scientific computing community dramatically changes the way it develops and uses simulation codes, it will be unable to fully exploit exa-scale computing power. The path to success is much more than bigger and faster computing platforms. Smarter solution and analysis methodologies are also needed. As the leading scientific simulation practitioners, DOE in general, and the Laboratory in particular, must ensure that these capabilities are in place. Specifically, LLNL must take steps to simplify and accelerate the process of developing and employing simulation technology. This task includes automating problem setup, inventing robust scalable numerical algorithms, and ensuring that the resulting simulation codes run efficiently on massively parallel computers. The Laboratory also must develop and deploy intelligent data exploration technologies that will allow scientists to cull scientific grains of insight from the chaff of simulation output.

To succeed, the Laboratory will have to attract exceptional people with a broad range of computer skills. This challenge will be complicated by the anticipated rapid pace of change, which will create additional difficulties in maintaining an up-to-date work force. The Laboratory will have to depend on a variety of alliances, partnerships, and consortia to keep pace with change, to recruit needed skills, and (in all likelihood) to pay for the future leading-edge computers. Making each of these relationships work is an important task for all levels of Laboratory management.

C. Leadership in Advanced Lasers Technology

The Laboratory has significant opportunities for new major programs that build on its leadership in the development and use of high-power and high-energy solid-state lasers.

LLNL's leadership in the development and use of high-power and high-energy solid-state lasers has grown out of a 30-year history of the development of high-power laser drivers for the Inertial Confinement Fusion (ICF) program. From this core activity, other programs and technologies have spun off, including atomic vapor laser isotope separation (for the U.S. Enrichment Corporation until program cancellation), extreme ultraviolet lithography (with an industrial consortium), ultrashort-pulse lasers, diffractive optics, laser–matter interaction modeling, and adaptive optics (including laser-guide-star adaptive optics for the Keck II Telescope in Hawaii).

The Laboratory's largest ongoing laser project is the construction and future use of NIF. NIF experiments will provide critical support to stockpile stewardship, make crucial progress in inertial confinement fusion, and advance science in many areas through groundbreaking experiments. NIF will be the only facility capable of well-diagnosed experiments to examine fusion burn and study the thermonuclear properties of primaries and secondaries in nuclear weapons. What researchers learn during the next decade using NIF will set the stage for further advances in fusion energy, plasma physics, astrophysics, and high-energy-density physics.

LLNL is poised to apply its laser- and optics-technology capabilities to a variety of new or expanded missions:

• ***For national security.*** Today, the Laboratory has a dominant role in many of the base technologies required for the development of high-average-power diode-pumped solid-state lasers. The technology has potential military applications ranging from point defense to advanced ballistic missile defense (and the technology may serve as a driver for future inertial confinement fusion systems). LLNL's expertise in advanced optics can be applied to meet far-reaching defense needs for imaging target designation systems that work through clouds and high-resolution imaging from platforms in space.

• ***Fusion energy.*** In 20 years' time, the nation should be at a decision point in the ICF program—either lasers or ion drivers—and the Laboratory is partnering with Lawrence Berkeley National Laboratory on ion-driver research. Moreover, as noted in Section III.C, LLNL could position itself to be the national laboratory for fusion energy, providing leadership in all aspects of ICF (targets, target chamber, and the driver) and alternative concepts to magnetic fusion energy (e.g., pulsed reactors).

• ***Laser-based large-scale science.*** The Nova/Petawatt laser demonstrated an ability to perform dramatic science experiments in a completely new regime of physics and opened astrophysical research to experimentation with high-power lasers. These efforts can be dramatically extended with NIF. The Laboratory should also build on its leadership in the development and application of high-peak-power, ultrahigh-brightness lasers (10^{15} watts in 10^{-12} second pulses). The ability to probe matter on molecular-physics time scales with femtosecond light sources is clearly a new frontier of materials science. Continued leadership in ultrahigh-brightness lasers depends on the Laboratory making new investments in this area.

D. The Next Breakthrough?

Laboratory researchers must continually seek opportunities and be prepared to make breakthroughs that lead to major advancements in LLNL's mission areas and create new major programs at the Laboratory to meet national needs.

Most certainly, the Laboratory will also face opportunities to make breakthroughs that have a profound influence on its mission in science and technology areas that we did not consider or did not highlight in this report. The Laboratory has a responsibility to comprehend what is technically possible and understand the impact of advanced technologies on the nation's security. And the prospect of conducting breakthrough research attracts, motivates, and helps to retain the best people.

IV. THE 21st CENTURY LABORATORY

The Laboratory has many strengths that must be sustained into the 21st century: a multidisciplinary approach to problem solving, a focus on tackling large-scale technical problems that matter to the country, and a culture that values risk taking to achieve groundbreaking results. But the situation in which the Laboratory finds itself is rapidly changing, and it has to adapt.

Several areas, in particular, need attention:

• Exceptional People—Exceptional people will remain the Laboratory's most important asset; LLNL must be positioned to attract and retain them in the face of greater competition for their skills.

• Focused Investments in Exploratory Research—To meet future challenges, the Laboratory must provide opportunities for exploratory research, focus its research investments, and foster an environment that values groundbreaking scientific work. To reach these goals is particularly difficult because the Laboratory finds itself in a program-sponsorship environment where the latitude to conduct exploratory research is declining.

• Expanded Working Relationships and Partnerships—Increasingly, success will depend on developing and maintaining major partnerships and effective working relationships with a variety of sponsors, other laboratories, universities, and private industry. LLNL will have to change. A Laboratory with an expanded base of sponsors and more extensive partnering will not be a straightforward transition, and LLNL must lay the foundation for such a transition internally and within the public policy community.

• Customer-Oriented and Flexible Laboratory Operations—The Laboratory will not succeed unless its operations meet the needs of internal and external customers through accessibility to facilities, flexibility in business practices, and reductions in unnecessary administrative burdens.

A. Exceptional People

Exceptional people will remain the Laboratory's most important asset; LLNL must be positioned to attract and retain them in the face of greater competition for their skills.

The Laboratory's successes are due to the efforts of an outstanding, dedicated technical staff. Demanding responsibilities require exceptional people. LLNL relies on having highly qualified and experienced people who are motivated by the opportunity to do something important for the country, by technical challenges in their careers, and by ready access to the tools needed to get the job done.

Continued recruitment and retention of a high-quality staff will be a challenge. Demographic trends suggest that the pool of graduating scientific and technical talent from which to draw will be smaller in 2020 than it is today, so the Laboratory should expect much greater competition for the best people. In addition, the cultural, gender, and ethnic composition of the technical talent pool will grow increasingly diverse. LLNL needs a vigorous work-force diversity program designed to help it attract and retain the best talent available, irrespective of individual cultural affiliations. With a diverse work force, the Laboratory will benefit from a wider range of perspectives and creative approaches to solving problems. It is crucial for the Laboratory to be viewed as an attractive place to work by employees from many different backgrounds, and it must provide a working environment that is conducive to promoting optimal performance for all employees. The Laboratory will also need to strengthen its ability to recruit and retain foreign nationals, who will be an increasingly important component of the emerging work force.

A strong attraction for the technical staff—and prospective employees—is the association with the University of California (UC), which has led to an array of scientific and technical ties to academia that would not have been achievable otherwise. We believe that continuation of the UC relationship is important to the health of the Laboratory. Continued UC management cannot be taken for granted. A number of factors could put at risk renewal of the contract between DOE and UC to manage the Laboratory—one major factor relates to the worst-case liability the University might incur. As a hedge, an exploratory investigation should be conducted of the feasibility of a hybrid company–university contractor model. For example, the company might accept financial liability in exchange for a management fee, and the University might manage the people in exchange for access to Laboratory facilities and researchers. A possible implementation could entail establishment of a "UC National Laboratory" composed of the staffs of the Berkeley, Lawrence Livermore, and Los Alamos national laboratories in an arrangement that would foster more interlaboratory cooperation and exchange of personnel.

It is important that the Laboratory take steps to reinforce the UC bond. UC institutes at LLNL provide an important connection with the University, and the Laboratory should vigorously pursue connections with UC Merced and strengthen existing ties to UC Davis. The recent refocusing of the UC Davis extension at LLNL and the planning under way for UC Merced offer opportunities to build strong research connections in a variety of disciplines. Joint appointments must be an attractive possibility.

UC management of LLNL provides employees an excellent benefits package and the underlying policy framework for the Laboratory's human resources program. As part of its working relationship with UC, the Laboratory needs to continually review and update personnel practices to meet changing work-force needs. For example, the feasibility of flexible personalized compensation plans should be explored and adopted if possible. In such an arrangement, the total cost of compensation is fixed (to control costs), but the employee is given some degree of freedom in specifying how the compensation is divided among component pieces (e.g., salary, health insurance, retirement benefits, etc.). Other anticipated needs in the 21st century include increased emphasis on term appointments for work-force flexibility, joint campus–Laboratory appointments, senior fellowships, greater sabbatical opportunities, and incentive programs for new hires.

From a prestigious business magazine's rating of the best companies to work for:

9. Lawrence Livermore National Laboratory, Livermore, California

For the first time, a public-sector organization has made our Top 10 Best List. How did it do it?

"Creating a shared vision is key," says Director Karen Lee.

Starting in 2001, Lawrence Livermore National Laboratory (LLNL) began rebuilding personnel and management policies. "We were being clobbered," explains Lee, "and the best folks were walking out the door to great jobs in Silicon Valley." LLNL adopted cafeteria-style benefits, cut its internal bureaucracy, outsourced some administrative functions, and began a serious campaign to address its demoralized and factionalized work force.

"Our most serious recruitment and retention problems were not with benefits," explains Lee. "It was with morale. Our organization was buffeted by scandals and directorates fought among themselves for funding. We realized that we needed to turn that situation around or risk losing the Lab altogether."

Livermore developed innovative leadership and professional development training for all its work force, pairing scientists with administrators and technicians in order to break down cultural and communication barriers. At the same time, it inaugurated its now famous "Get A Life" recruiting campaign, a witty and irreverent PR and recruiting effort that portrayed LLNL as a family-friendly workplace with great pay and benefits. "We realized that we were at a competitive advantage with Silicon Valley and academia for all those people who did not want to work insane hours and suffer the commute from hell," explains Lee.

LLNL also began an active public outreach campaign to win over the hearts of a suspicious Bay Area. "Actually, that wasn't hard at all," explains Director for Public Affairs, Cheryl Crowe. "We do great and fascinating work out here—all the public knew about was nuclear weapons."

By 2006 their efforts began to pay off. LLNL successfully recruited several leading researchers from Intel, Merck, Harvard, and CalTech.

Today, LLNL is the model of a successful high-tech organization. "The benefits are great," says Jan Tosco, a physicist and father of two. "We have on-site day care, a great youth program, and great amenities right on site. But best of all, we know we're doing tremendously important work for our country. There's a lot of pride in this place."

One element of LLNL's workplace hasn't changed at all in the last 15 years; they still ride around their Lab on orange bicycles!

B. Focused Investments in Exploratory Research

To meet future challenges, the Laboratory must provide opportunities for exploratory research, focus its research investments, and foster an environment that values groundbreaking scientific work. To do so is particularly difficult because LLNL finds itself in a program–sponsorship environment where the latitude to conduct exploratory research is declining.

A culture that values risk taking to achieve groundbreaking results fundamentally depends on the presence of three factors: high-caliber employees, access to state-of-the-art research capabilities, and sufficient opportunity to conduct exploratory research. LLNL must be able to attract employees that value conducting science of national importance, seek out creative solutions, and believe in taking risks to achieve breakthrough results that have lasting impact. In the face of emerging threats that are far from predictable, creativity is of paramount importance in R&D activities to protect national security.

At the same time, the latitude to conduct exploratory research is declining. This change is a result of a piecemeal, specific-task-oriented approach that sponsors are adopting in funding research activities as well as congressionally mandated reductions in Laboratory Directed Research and Development (LDRD). Such exploratory research is often the seed for new programs or new directions in existing programs. The dilemma has no easy solutions, but LLNL must demonstrate clearly to the public and sponsors the importance of providing Laboratory scientists a healthy amount of latitude in their research endeavors.

In addition, the Laboratory's intellectual climate should promote research. Postdoctoral scholars are important and productive contributors to research programs, and the Laboratory should increase the number of postdoctoral and graduate students on site. Research programs, especially newly emerging ones, should be evaluated to ensure that each has a proper focus, a critical mass of people, and sufficient facilities and funding. In particular, internal research investments such as LDRD should be strategically focused and largely directed at projects of scale.

One way to focus investments and foster a creative environment for groundbreaking work is to institute one or more "skunk works" at LLNL, that is, teams of motivated, high-performing research staff, usually working in complete isolation from the rest of the organization and from normal bureaucratic burdens. Such an organization could become the nexus for diverse Laboratory talents and serve as an incubator for new programs.

C. Expanded Working Relationships and Partnerships

Increasingly, LLNL's success will depend on developing and maintaining major partnerships and effective working relationships with a variety of sponsors, other laboratories, universities, and private industry. We will have to change. Becoming a Laboratory with an expanded base of sponsors and more extensive partnering will not be a straightforward transition, and LLNL must lay the foundation for such a transition internally and within the public policy community.

Partnering will play an increasingly significant role in research activities at LLNL. The Laboratory's partnerships will be varied—ranging from close working relationships with sponsors and cooperative research ventures to communications with various stakeholders. Working with DOE and other government organizations, other laboratories, universities, and industry strengthens and adds vitality to the Laboratory, enabling it to better meet sponsors' needs.

To succeed, LLNL will have to improve the way it interacts with sponsors and partners. Too often, sponsors perceive Laboratory contacts as inattentive of their real needs. A cultural change will be required, together with a committed, focused effort to build long-term relationships. Particular attention must be paid to a number of issues concerning partnerships with:

- ***Sponsors and potential sponsors.*** Meeting sponsors' needs and helping them to achieve their goals must be important to Laboratory staff. Researchers and managers alike must work harder to understand and anticipate sponsors' needs, to develop long-term, trusted working relationships with them, and to provide quality—but affordable—products. The Laboratory should take actions designed to build stronger relationships with other federal sponsors, such as DoD. For example, the Laboratory could more strongly encourage individuals to take temporary assignments at sponsors' facilities and see that they are strategically placed. Exchange working groups among technical staff could be established with sponsors. The Laboratory could also make greater use of outside advisory boards (e.g., an emerging threats board to help identify new opportunities for applying LLNL capabilities).

• ***Other laboratories.*** Too often, collaborations among national laboratories are determined more by equality of funding than by thoughtful determination of how to best meet project goals. This must change. To this end, we are encouraged by early successes with the "virtual national laboratory" approach, which provides seamless integration of interlaboratory cooperative efforts for sponsors and can reduce micromanagement.

• ***Universities.*** The Laboratory must increase the range and number of opportunities for cutting-edge collaborative research, which serves as a pipeline for infusion of new ideas and new talent into the Laboratory. LLNL would benefit from a greater number of graduate students, postdoctoral fellows, and faculty sabbatical opportunities on site. In addition, the Laboratory must further strengthen its relationship with the University of California (see discussion on pp. 24–25).

• ***Private industry.*** The Laboratory forms partnerships with private industry in order to make use of the best technology available to advance program goals and, in other cases, to spin off for public benefit novel technologies developed at the Laboratory. It is likely that LLNL will become

From a venture capital magazine, May 12, 2010:

Livermore Science Fund Tops $100M

Livermore CA—The Livermore Science Foundation (LSF) announced today that it has surpassed its 10-year goal of reaching a fund valuation of $100 million, two years earlier than the founders had planned.

"We are extremely pleased with how the fund has performed and plan to make the first cash disbursement to the Lab before the end of the year," reported managing partner Richard Fish.

Senator Manuel Gonzalez, Lawrence Livermore National Laboratory (LLNL) Director Karen Lee, CEOs of two of LSF's spin-off companies, and Dean of UC Berkeley's Haas School of Business Larry Poulet were on hand for the announcement and reception at LSF headquarters in Livermore. "LSF has really shown America how to make the most of its publicly funded intellectual property," Gonzalez said.

Started in 2001 with seed capital from the Hertz Foundation, the LSF has developed an impressive track record of spin-offs and start-ups based on technology from the national labs. "Starting the LSF as a nonprofit gave us, and the Lab, some important advantages including the ability to take equity stakes in outside companies and leverage our core fund with investments from other partner. It also gave the Lab a new source of funding," explained Fish. Intel, Enron, and the UC pension system are also partners in the fund.

"Our first goal has been, and remains, to assist in the development of new ventures and partnerships based on national lab technology. Our charter calls for regular disbursements of the funds back to the Lab to support research." So far, the record is good. The LSF has an 18.5percent annualized ROI, lower than that of most private venture funds but higher than all other public sector incubators, according to Fish.

The bulk of LSF's success has come from two ventures—both based on LLNL technology. Cardiospec, a medical technologies company started by LLNL scientist Joe Maxwell, was acquired three years ago by Merck in a stock swap valued at $200 million. Advanced Machining, which develops laser cutting tools now used throughout the aerospace industry, went public in 2006. The company now has a market valuation of $900 million. Together, the companies employ over 1,100 people, two-thirds of whom live in the Tri-Valley area.

According to its charter, the fund will hold its value at about $100 million and disburse its earnings back to the Laboratory. "The first disbursement couldn't have come at a better time," says Director Lee. "This new funding stream will help us develop new technologies to tackle a wide range of critical national security needs."

increasing involved in the latter because industry is reducing its investment in long-term “blue-sky” R&D and may turn to the national laboratories for exploratory research. Partnerships that integrate teams of LLNL and private-sector technologists will expose the staff to best business practices and the fast-paced, results-oriented culture of industry. The Laboratory must continue to seek partnerships that provide access to industry and exercise the talents of researchers, while recognizing that even an even-handed approach to dealing with private industry will occasionally draw criticism.

• ***Various stakeholders.*** Partnerships with stakeholders must not be viewed as possible sources of interference but as means for understanding others' interests and needs and working with them. This focus will be most true with regulators and the local community. Giving information often builds bonds.

The foundation also has to be laid within the public policy community for the transition to a Laboratory that has several core programs (in addition to stockpile stewardship) and works routinely with a broader range of sponsors. The Laboratory must be open with and clearly communicate its strengths, capabilities, accomplishments, and shortcomings to its federal and state sponsors, collaborative partners, and the public at large. And it must learn to listen better to their concerns. A broader understanding of and support for LLNL will be helpful as the Laboratory attempts to develop new core programs and even more helpful when it faces significant problems.

Excerpts from a prestigious business review magazine article in 2015:

The Changing Face of Lawrence Livermore National Laboratory

. . . As the Laboratory moved from a monolithic entity focused on nuclear weapons to a broader enterprise serving a plethora of national security needs with a vibrant “Middle Third” of unclassified programs, the nature of business practices evolved as well. The historical one-size-fits-all Defense Program model yielded to a greater variety of business practices that reflected the diversity of sponsors with widely varying needs. These changes not only reflected structural financial changes (such as off-site G&A rates of 1995), but cultural ones as well. These cultural changes were driven by the need to effectively couple into, and partner with, entities that operated far differently than LLNL's traditional defense program sponsor. Most of LLNL's staff and leadership had been derived from the defense program culture, and this transformation was a significant challenge in the years 2000–2012.

. . . With enhanced computing and communication, LLNL's ability to resolve costs to benefiting entities in a transparent way resulted in lower institutional G&A rates. In the pursuit of technology transfer and strategic partnerships, novel structures arose, including, for example, the Tri-Valley Commercialization Center, serving as a conduit between the Laboratory and industry. Nearby off-site programs were established, each with different business practices to match particular industrial/technical sectors, with costs matched to their circumstances. The biotechnology program has been especially successful in license revenue streams from civilian commercialization, approaching the level of internally directed R&D ($75 million), while maintaining a robust biosecurity capability for defense purposes.

. . . As the institution evolved into the 21st century, LLNL has continued to have dominant programmatic anchors: nuclear weapons, lasers, and nonproliferation. As in the past, these continue to be the LLNL hallmark: signature programs employing multidisciplinary teams involved in science of scale. However, and as has been the trend since 1980, increasing numbers of smaller programs address additional national issues. These interstitial entities, with distinct business and cultural attributes, have proven to be an essential element of a vibrant enterprise solving national problems on multiple fronts. Such programmatic richness helped attract superb technical staff during a difficult demographic period and augmented the anchor programs by surrounding them with a sea of diverse intellectual prowess that can be drawn upon. Unlike many national security R&D institutions in the post–Cold War period that were unable to respond quickly enough to a rapidly changing world, LLNL applied modern business principles to position itself not only to secure the nation's future but also to be an engine of unprecedented innovation.

The Laboratory should also seek ways to be better informed on nontechnical aspects of national security policy and simultaneously work to become a stronger player in the policy community. Developing a better sense for the interplay of technical and nontechnical issues will make LLNL more credible on issues, even those that are predominantly technical. In addition, the Laboratory should take measures such as increased placement of staff in key Washington assignments, which serve to strengthen connections with government officials and provide greater visibility for the Laboratory. Such measures will bolster the Laboratory's image and improve its ability to provide timely and effective technical input in support of policy decision making.

D. Customer-Oriented and Flexible Laboratory Operations

The Laboratory will not succeed unless its operations meet the needs of both internal and external customers. LLNL must provide greater accessibility to facilities, adopt even more flexibility in business practices, and reduce unnecessary administrative burdens.

The Laboratory needs to make more of its campus readily accessible to outside visitors, including foreign nationals. Interactions with others are essential to LLNL's future vitality. They provide new ideas, fresh people, and a public face to the scientific work performed here. Because so many technological advances occur outside the Laboratory's fences, national security researchers at LLNL require constant interactions with the broad scientific community. And scientific contacts are vital to the growth of unclassified programs in areas where the Laboratory is technically strong. These activities increase the vitality of all programs. The Laboratory's need for accessibility is accentuated by student population trends in major universities. The proportion of students who are foreign nationals is large and growing. In addition, without greater accessibility, interactions with the staffs of universities and private industry will become increasingly difficult because they increasingly are made up of foreign nationals.

We fully recognize that a sizeable portion of the Laboratory—currently about 25% of its area—must be secure and well-guarded. Most of the rest of the area is "Red Badge" (controlled access, requiring the badging of visitors and a variety of restrictions on the activities of foreign nationals, particularly those from sensitive countries). The Laboratory should open up more of this real estate to quasi-public access, with the security like that of a typical modern business. The possibility of satellite operations should also be considered to open up access.

LLNL also must continue to lower the cost and increase the flexibility of operations. To work with a broader set of customers, it needs to be more flexible and responsive in business operations—and more affordable. Creative options, such as setting up an associated not-for-profit institute or opening up satellite operations, should be further explored.

The Laboratory must also be attentive to the workplace needs of its internal customers—the employees. It must work with DOE Defense Programs and major program sponsors to ensure sufficient funding to provide employees (and visitors) with a quality work environment. The one-square-mile campus is nearly full, with too many of the staff working in less-than-adequate office space. Through a properly funded program of building rehabilitation and replacement, the Laboratory should strive to provide every employee modern office space and open up areas of the campus for construction of future, major facilities that are appropriate for an increasingly urban environment.

Finally, the Laboratory must also address the broader range of quality-of-life issues related to the support for high-quality research. Quality of life for the staff of the national security laboratories was raised by the Chiles Commission. A principal concern is the ever-increasing administrative burden required to conduct research—much of it bureaucratic and contributing to an atmosphere of frustration, inefficiency, and resentment among employees. It is a "creeping negative" effect because each individual issue is small but the collection of the burden is becoming heavy. Oversight and accountability are valuable and necessary functions for a public-sector organization. However, some of the administrative and bureaucratic requirements the Laboratory now complies with are ineffective, add no value, and contribute negatively to the work environment. The Laboratory must work with UC and DOE to reduce the administrative burden by continually streamlining practices and working to eliminate unnecessary requirements and obligations.

V. CONCLUSIONS AND RECOMMENDATIONS

U.S. national security policies have evolved considerably since the end of the Cold War and will continue to evolve. We conclude that the nation will continue to rely on a nuclear deterrent, but it is likely that the perceived importance of nuclear weapons in assuring our national security will decline along with the funding allocations for nuclear weapons stewardship. It is also likely that other threats, both new and already emerging, will require innovative technical countermeasures.

The Laboratory's best strategy is to evolve with national priorities. To sustain the vibrant, dynamic research environment required to meet its commitments to the nation, LLNL must transition from a nuclear weapons laboratory with a small number of supporting programs to a national security laboratory with a small number of core programs, one of which is nuclear weapons stewardship. Each of these core programs will stand on its own in addressing an important national issue. Taken together, these programs will provide a world-class technical foundation spanning key disciplines.

1. The Laboratory must embrace a new institutional paradigm: That we are a national security laboratory with a small number of core programs, one of which is nuclear weapons stewardship. Ideally, the research strengths that support these core programs will effectively enable the Laboratory to anticipate and help address emerging national needs and to exploit technical opportunities for public benefit.

2. To meet future stockpile requirements, the Laboratory must continue to exercise its abilities to design new weapons. The Laboratory must also be prepared to resume testing.

In addition, the Laboratory needs to provide unimpeachable scientific and technical input to the debate on U.S. nuclear weapons policy for the foreseeable future. LLNL should ensure that it provides sophisticated, useful input to policy makers.

LLNL must work with other members of the nuclear weapons community to identify strategies in the best interest of the nation in light of the strong possibility of future funding cuts for stockpile stewardship.

Long-range planning (beyond the 2005 focus of the current Stockpile Stewardship Program) is needed to define specific goals, facility needs, and activities.

3. The Laboratory must identify and articulate national security activities in addition to stockpile stewardship that can become long-term major core programs. It should consider expansion of its current programs in nonproliferation, intelligence, biological defense, and advanced conventional weapons as candidate activities for core programs.

The intelligence community is a potential customer for and sponsor of major research programs at the Laboratory because of its technical breadth and because better intelligence is fundamental to living with uncertain threats. Potential activities include development of information management and real-time analysis capabilities, advanced sensor systems, and infrastructure simulation.

The Department of Defense is a potential customer for and sponsor of major research programs at LLNL in biological defense (including agricultural protection), battlefield planning and data fusion, ballistic missile defense and directed-energy weapons, and "brilliant" munitions.

Success in building major programs based on funding from outside LLNL's traditional sponsor base will require a clearly needed Laboratory expertise, a strong customer focus, patience, productive partnerships with defense contractors and others, and possibly a political champion.

4. The Laboratory must maintain a vigorous portfolio of unclassified R&D programs, which are vital to the success of all of the Laboratory programs, including those that are classified.

Institutional investments in unclassified programs or capabilities must be tightly focused, with the goal of achieving international recognition in two or three program areas. Selection of these program areas should be based on the institutional criteria used for all Laboratory programs (as discussed in the body of this report). Selection should also be based on the program's ability to capitalize on or contribute to a discipline or capability that is essential to the national security mission of the Laboratory and/or to have dual-use application, with one application being in a national security mission area.

Examples of strong candidates include nuclear materials management, including legacy materials from nuclear power and nuclear weapons as well as materials from future nuclear systems, and an integrated, comprehensive program in environmental simulation and observation, including data fusion, high-end simulation, and advanced communications.

5. To take advantage of the tremendous advances in bioscience and biotechnology, the Laboratory should commit resources to increase its expertise and to help DOE position itself for success in these fields.

The Laboratory should initiate a few signature campaigns at the Laboratory. Biosecurity is an obvious campaign that is already under way. But a successful biosecurity program needs synergistic programs in applications such as health, environment, and agriculture.

LLNL must also recognize that biosponsors are unlike our traditional sponsors. Biosponsors need accessible facilities, minimal barriers to international collaborations (including employment of foreign nationals), and appropriate business practices.

The Laboratory needs to recruit and listen to new talent and outside experts to build new programs in bioscience and biotechnology.

6. The Laboratory must be at the forefront of simulation science. LLNL must continue to push for continued development of extremely powerful computers to meet the simulation demands of stockpile maintenance, environmental management, bioscience, and basic science. The Laboratory must also maintain and strengthen our capabilities in using these computers.

Absent sufficient market forces, the Laboratory must play a role in the development of future leading-edge computers. It should establish alliances, partnerships, and/or consortia to promote the development and pay for the production of future leading-edge computing systems.

The Laboratory must strategically invest in a long-term effort to acquire software applications that are needed to exploit the more powerful machines. If these applications are not available from the marketplace, develop them.

The Laboratory must expand its capabilities in data management, analysis, and visualization. These capabilities should be integrated with physical experimental facilities to help advance validated computational science.

7. The Laboratory should build on its leadership in the development and use of high-power and high-energy solid-state lasers. The nation must take advantage of the opportunities for further advances in fusion energy, plasma physics, astrophysics, and high-energy-density physics that the National Ignition Facility offers. Other potential opportunities include developing national security applications of high-average-power solid-state lasers, becoming the national laboratory for fusion, and exploring new vistas of using ultrahigh-brightness lasers.

8. The Laboratory must adopt new practices to be effective in an evolving national R&D environment. Trends that are likely to continue include more oversight, funding in smaller chunks, rapidly changing priorities, and more industrial outsourcing of R&D.

To be effective, LLNL must increase the use of partnerships in executing and building the constituency for research programs. Potential partners include academia, industry, and non-DOE government institutions as well as other DOE laboratories. Partnering will become a standard practice in most programs.

To help preserve the Laboratory's technical creativity, the Laboratory should consider developing a "skunk-works" tradition—a mechanism where teams of top employees are assembled as needed to work specific challenging problems.

A much more flexible business model should be implemented to lower costs and accommodate the specific needs of a wide variety of sponsors. The Laboratory site should also be reconfigured to provide greater access to nonsecure facilities.

9. To recruit and retain the strongest possible work force, the Laboratory must have important and technically challenging missions and provide employees first-rate research capabilities and facilities.

In addition, LLNL must strengthen its connections with academia, particularly the University of California. Joint academic–Laboratory appointments should be encouraged and rewarded, and LLNL should make every effort to include university students in its research programs.

LLNL must work with UC to modernize the Laboratory's compensation package to include flexible benefits for all and housing assistance for top recruits.

A workplace must be provided that is attractive to employees and reflects changing programmatic needs by providing convenient access to modern facilities for partners and visitors. Continued vigilance in planning and securing funds for modernization of the physical site is required.

10. The nation benefits from scientific and technical input from the Laboratory as the U.S. government considers difficult policy choices. To better meet this responsibility, the Laboratory must become more adept at and effective in our communication of information.

The Laboratory must make strategic use of Washington assignments to help Laboratory staff better understand customer needs and how technical input supports political decision-making and to increase the visibility of LLNL and its capabilities. It is imperative that Laboratory staff see these assignments as career-enhancing.

A Laboratory culture must be promoted that values understanding the nontechnical aspects of policy decisions related to LLNL's missions.

The Laboratory must be open with and clearly communicate its strengths, capabilities, accomplishments, and shortcomings to its federal and state sponsors, collaborative partners, and the public at large.

APPENDIX A: PERSONAL STATEMENTS

A short final report with consensus conclusions and recommendations cannot portray the wide-ranging deliberations of the Long-Range Strategy Project team or convey the diversity of viewpoints expressed. This appendix includes personal statements from project members who chose to emphasize particular issues about the future of the Laboratory.

Simulation, Science, and the Importance of "Big Iron"

Steven Ashby

The United States has long been recognized as the world's foremost supercomputing power. This status has helped the nation to attract the world's best computational science talent and, in so doing, has helped to propel us to the forefront in many scientific endeavors. This supercomputing prowess also has played an important role in preserving our national security. In light of the Comprehensive Test Ban Treaty, one might even argue that supercomputing dominance is a strategic asset. As such, it is incumbent upon the nation to preserve our dominant position in this area. Given the DOE's long history of computational excellence, it is likely that it will be given responsibility for supercomputing stewardship. The question, then, is who within DOE will emerge as the premiere computational science leader. In my view, it should be LLNL.

Large-scale scientific simulation already plays a central role in nearly every program at the Laboratory. LLNL scientists are using the Lab's tera-scale computing capabilities to simulate physical and biological processes in ways heretofore impossible. Our programs are increasingly relying upon these simulations to supplement—and in some cases supplant—traditional experiments. This reliance, in turn, is transforming the way computational science is viewed. In the past, computing was an adjunct to theory and experiment. One- and two-dimensional calculations were largely used in a diagnostic fashion. In the future, we will use exa-scale computing power and scalable application codes to perform predictive three-dimensional simulations. Simulation will have emerged as a peer to theory and experiment; and computational science will be recognized as a discipline in its own right. The Laboratory is well positioned to hasten this simulation revolution—and it should act today to insure that in 2020 it is acknowledged as a key player in the maturation of computational science.

Large experimental facilities play an essential role in modern science and engineering; large computing facilities play a similar role in computational science. Such facilities are extremely valuable institutional resources. In addition to enabling world-class research, these facilities enhance the reputation of their owner/operators. It is difficult to imagine how LLNL could have achieved recognition as the world's premiere laser laboratory without having "big lasers" on site. Similarly, it will be difficult for LLNL to earn recognition as the premiere computational science laboratory without siting "big iron" at LLNL.

Some would argue that the Laboratory can realize this ambition without having its own big iron, but this position ignores acknowledged technical, political, and sociological considerations that favor local big iron. In the early part of a supercomputer's brief life span, it is notoriously difficult to use; the hardware is flaky and the software is spotty. It is primarily an R&D facility, and consequently, access is limited to a few brave alpha users. Despite these frustrations, it is during this period of time that results are the most novel and interesting. The heroes who tame the beast often win the accolades. By the time the machine has made the transition to production status, it has lost its allure as the scientific computing community becomes infatuated with newer machines. Historically, these alpha users are drawn from the local talent pool. This means that the early results—and success stories—belong to the host institution. It is thus important, in my view, that LLNL own local big iron. This ownership will help ensure that tomorrow's scientific breakthroughs are made by LLNL researchers—and that LLNL is widely acclaimed as the leading computational science laboratory.

The LLNL Character

Christina Back

As the dizzying pace of change continues, national security must address a wider range of possibilities than it has in the past. As an example, intelligent information synthesis will, I believe, radically impact defense systems. In the same way that wireless communications has revolutionized national security systems and strategies, the merging of technologies with sophisticated communications will create new paths. We might imagine a fusion of biotechnology and material sciences that creates “brilliant sensor networks” capable of going beyond passive data collection. These networks might actively energize materials to morph from active to passive, lethal to nonlethal, or sensing to nonsensing agents. From environmental monitoring to more traditional defense applications, intelligent networking can affect decision-making and may create new strategic options.

In this post–Cold War age, a national laboratory must embrace a vision that goes beyond reliance on nuclear weapons to include newly emerging technologies that defend and support the nation. I envision the LLNL of 2020 as an institution where scientific breakthroughs of national importance continue to push the nation forward. To fuel scientific discovery and technological innovation, we must consciously preserve creativity and risk taking in the research at LLNL.

Three aspects of the LLNL character are crucial to foster imagination and research. First, our successful projects have relied in part on the balance of experiment, theory, and simulation. These allow us to remain well-grounded in technical realities as well as inspire us to dream of new possibilities. Exponential growth in simulation capabilities is inevitable over the next few years. Yet, the interplay between prediction, data, and analysis is still critical to exploring scientific frontiers. Computations-based research must not totally eclipse experimental research that provides hard data to critically test our knowledge. I believe that future success will depend on how successfully we integrate this new power in simulations with experiments and theory.

Second, scientific breadth is needed to execute even the most narrowly defined view of the Laboratory’s mission—stockpile stewardship. Future technologies are difficult to predict but may range from instant antidotes to surgical-strike directed-energy technologies. Development of these will most certainly draw from creative interactions between different disciplines and different partners. LLNL must actively develop internal and external bonds, perhaps by a mechanism like “skunk-works” groups. I firmly believe that a vibrant Laboratory must deliberately reseed, continually weed, and consciously cultivate scientific ideas and projects. The key to attracting and developing talented people is in the germination cycle, while the key to remaining focused on national needs is in the conscious cultivation and tailoring of the scientific portfolio.

Finally, LLNL must exploit its ability to invest in long-term research to meet national needs. Competing pressures on universities, industries, and DoD labs will increase the need for a national research-oriented laboratory to provide continuity and a long-range security focus. This depth cannot be achieved overnight or be successful if maintained at subcritical levels. Diverse personnel and a mix of business models are essential to sustain research in the long-term and to remain competitive in the future.

LLNL must preserve and actively develop a sustained, multidisciplinary research approach. Only by embracing creativity and risk will LLNL continue to make a difference in securing the future prosperity and safety of this nation.

Preserving Research at LLNL

Michael Colvin

LLNL's mission has changed during its first half century and will likely continue to follow our country's evolving needs and priorities. In the face of this continuing change, the Lab's essential activity remains the same: the development and implementation of new technical ideas. Despite the Lab's past success, it is by no means certain that it will maintain its position as a prominent scientific and engineering laboratory. An important lesson of history is that successful research involves a precarious balance of human talent, physical resources, high standards, intellectual credibility, and the freedom to critique ideas, whatever their source. Additionally, the funding must be neither so low as to cause chronic uncertainty nor so high as to undermine healthy competition.

The difficulties in maintaining a strong research environment have increased for several reasons. In the short term, the Lab is facing an extraordinary level of oversight and criticism, which, combined with the strong technical job market, has increased the difficulty of hiring and retaining a world-class research staff. In the longer term, LLNL faces the continuing challenge of maintaining a healthy research environment while answering to many, sometimes irreconcilable constituencies, some of which are willing to sacrifice the Laboratory itself if their interests are not satisfied.

An additional challenge is that the Lab has no clear outside exemplars for guidance. As the world's premier scientific institutions, research universities clearly provide one model for Lab policies, but universities enjoy academic freedoms based on centuries of chartered independence. Although the unique missions of LLNL do not permit full independence from oversight, many academic values, such as the importance of career research positions, are relevant to the Lab. Another model was once provided by the great corporate research laboratories; however, the increasingly competitive global marketplace has led to an emphasis on short-term product development that has significantly degraded corporate laboratories. This loss offers an example to LLNL of the needed synergism between basic research and applied development.

Given these challenges and an uncertain future, what actions can the Lab take to best ensure the vitality of its research programs? First, the Lab must maintain its policies that bring in and retain top-quality research staff. These range from providing fellowships for world-class postdocs, to ensuring that technical careers remain attractive alternatives to nonresearch paths. Second, the Lab must continue to use the outside community as the measure of its scientific quality, through peer-reviewed articles and research grants and oversight by outside advisory boards. Third, the Lab must be sufficiently insulated from political pressures to retain its objectivity in technical evaluation, even at the expense of passing up deeper roles in policy making. Ultimately, all institutions are recognized and remembered not for their daily struggles, but for the good services they provide their people and societies. Hence, LLNL must continue to use as its guide star the long-term public good, a strategy that will provide the best possible chance for the Lab's continued vitality and will absolutely guarantee a proud legacy.

Scientific Research in a Risk-Averse Environment

Rebecca Failor

The ability of LLNL to perform world-class science in the future is in jeopardy unless we change how we manage risk. The conundrum is how scientific exploration that is inherently risky can be performed in an increasingly risk-averse environment. Whereas, we must operate in a failure-free manner with respect to ES&H, security, and our fiduciary responsibilities, scientific exploration is inherently based on risk taking. How we control operational risks while still supporting scientific exploration is the challenge.

LLNL cannot take uncontrolled risks in our ES&H, security, and fiduciary responsibilities. Failure to control operational risk can affect our workers' lives, our environment, the security of our nuclear stockpile and our nation, and LLNL's credibility in managing business operations. We understand that a major failure in these areas could potentially result in the closure of LLNL.

We need to carefully examine the means by which we are controlling operational risks. At this time, the cumulative burden of self-imposed risk controlling requirements and processes is sapping the creative energy of our technical staff. We can and must devise methods to control operational risks without consuming the resources and drive we have for scientific exploration.

Scientific exploration demands risk taking. Testing each new hypothesis places us in the realm of the unknown. We are "reared" knowing that some of the best scientific breakthroughs happened when creative people did not let the naysayers stop them. Sometimes testing the hypotheses can require substantial resources with no assurance of a breakthrough. But often, if we are right, the payoffs are worth it. Science cannot be advanced without spending resources for which there is no certain payback.

Increasingly our sponsors seem less willing to accept scientific risk. They want assurance that they will get something concrete for every investment. The result is less and less "free energy" to explore ideas and create hypotheses. Spending "free energy" is risky. It does not always pay off in terms of a product the sponsor can see. Sometimes, nothing comes of it. It is difficult to "Gant chart" or manage. We cannot, as was once requested, list the new discoveries that will be made in the next fiscal year. In my opinion, an overly risk-averse approach to science will limit our ability to generate and explore new ideas.

LLNL should be held accountable for how resources are spent or for failures to control operational risks. We also must have the freedom to pursue the boundaries of science, to explore the unknown. By understanding the inherent risks of scientific endeavor and carefully controlling operational risk, we can have scientific advancement that rewards our sponsors without negative consequences.

The R&D Ecosystem of the 21st Century

Peter Fiske

As the youngest member of the Long-Range Strategy Project, I may have the greatest stake in the future of the Laboratory and the contributions it makes to the nation. While I grew up during the final years of the Cold War, I have spent most of my adult life in the post–Cold War world. As a new century begins, the nation faces a myriad new threats, challenges, and opportunities. The degree to which Lawrence Livermore National Laboratory can make positive contributions to meeting these new challenges will largely determine whether our Laboratory grows and thrives or sinks into obsolescence.

Lawrence Livermore National Laboratory was created at the dawn of the Cold War, when the United States faced a single monolithic threat. The Laboratory itself was a monolithic and isolated institution, focused on a single technology. Over time, offshoots of that technology sprouted new technologies, and new missions and national challenges broadened the Laboratory's intellectual focus. In most cases, this diversification has brought strength. New ideas and new technologies stimulate improvements in existing areas. Growth and vibrancy attract world-class people—the true fuel of innovation.

In a world where funding is tight and nervous sponsors demand closer oversight, many public-sector R&D facilities are retreating to their "core competencies" and developing captive relationships with sole sponsors. Lawrence Livermore National Laboratory could easily choose this well-worn road, too.

However, we must choose the road less traveled; the road toward broader scientific and technical excellence. We must choose this road because we have developed a unique set of capabilities and culture that promote genuinely interdisciplinary, large-scale R&D. Such capabilities exist in few other institutions in the world. We must choose this road because the constellation of threats and challenges facing our nation is constantly changing. Intellectual breadth is the best insurance policy our country can have as new and unforeseen threats emerge from unexpected directions.

The healthy and vibrant national laboratory of the 21st century will be a large and diverse R&D ecosystem. That ecosystem will include many research programs of different sizes, all of which must be well suited to the climate of the Laboratory, its competencies and facilities. The vibrant national laboratory will have scores of long-term visitors—professors on sabbatical, students, researchers from industry. It would have a large and diverse post-doctoral program, with alumni in top R&D positions in academia, other national laboratories, and industry. It will have a dynamic and growing business community next door, where promising technology ideas are transformed into new businesses.

Lawrence Livermore National Laboratory must vigorously defend and justify to all constituents its intellectual breadth. It must establish strong and long-lasting relationships with sponsors from the public and private sectors, based on technical excellence, creativity, and economic value. It must be a visible contributor to public welfare at the local, regional, and national level. It must constantly strive to work on the toughest and most important problems for the nation and the world. Our path must be the road less taken. And that will make all the difference.

Computing and Communication Technology and Human Creativity

Charles McMillan

While we have explored many interesting topics during the LRSP, one that interests me most has not been explored at any length—the impact of computing and communication technology on human creativity. At its base, I believe the Laboratory's strength lies in its creativity, whether applied to issues affecting national security or to problems of pure science and engineering. I suspect that some of the greatest changes at the Laboratory in the next 20 years will be in how its work force exercises creativity.

The current growth of the World Wide Web as a medium for the rapid exchange of ideas is only the beginning. As techniques to organize the Web mature, it is becoming possible to rapidly examine existing work, something that could previously only happen in a library. This existing work is the base from which new ideas are frequently built. The Web also enables connections between people with common interests and expertise. It fosters dialog—another source of creativity—that has historically occurred only in hallways and around whiteboards at the Laboratory. How will Laboratory employees in classified programs engage in this widening intellectual milieu? Will we make deposits in the reservoir of ideas or will we only make withdrawals? Will location continue to be important as people generate ideas, or will places other than the Laboratory become important creators of ideas that dominate the Laboratory's business. How will the give and take of one mind stimulating another take place when network bandwidth and latency are not issues? I believe that encouraging the vigorous participation of Laboratory personnel in burgeoning global dialogues will be an amplifier for creativity at the Laboratory.

A second amplifier for creativity may well be the computers on our desks. While we examined the roles these machines will play in simulation during the LRSP, we have not examined how they will help us think. How will we use the increasing neural equivalents that sit on our desks to aid our own creativity? Will our computers, in conjunction with the Web, help us by asking questions that will stimulate thought? Might they draw inferences from our conjectures that will enable us to quickly weed out implausible ideas in favor of those more likely to lead to fruitful new research?

As we create the Laboratory of the future, I believe it is critical that we be constantly alert to the impact of policy and technology on our creativity. We must leverage evolving technologies to enhance creativity in areas that are vital to the Laboratory as we design information-management policies to protect the national interest. While creative technologies and policy may at times be in tension, I believe our ingenuity will be sufficient to keep the Laboratory at the forefront of creativity.

Some Specific Recommendations

Paul Miller

I am using this opportunity to outline some recommendations I have developed but that did not make it into the main report. The following five span a range of sizes and difficulties of implementation.

R&D Shop. The DoD's and DoD contractors' labs are under a lot of pressure, and many have specialized, downsized, or even closed. They may not retain the technical capabilities required to implement the proposed Revolution in Military Affairs. LLNL could fill part of the growing gap by partnering with major defense contractors to provide front-end R&D services, innovative project conceptualization, prototyping, and system design. Benefits to the Lab include a broader base of work for our R&D infrastructure and a more intimate connection with industry and DoD. Partnering needs to be done from the earliest phases, and the partners could be selected through competition by DOE/DoD to mitigate concerns that the process unfairly favors particular companies.

Directed LDRD. Researchers could be solicited to tackle selected topics of interest to the Laboratory and our sponsors, through a process like an internal Request for Proposals. Each project would be defined by a description of a problem and associated requirements, and winning proposals would be selected based upon their approaches to a solution. Such a "Directed LDRD" program would be a hybrid of LDRD and programmatic work that could harness the Lab's creativity and lead it toward specific goals while maintaining an additional degree of innovative freedom. On several occasions, I heard from people outside the Lab that they would not only value highly such an activity, they expect it. Successful Directed LDRD projects could be further developed by the "skunk works" described in the main report.

National Resource for Technical Expertise. As an organization serving the nation in science and technology, we should adopt a principle to provide as much (free) requested assistance as feasible (primarily in the form of consultations) to related government projects and organizations. The money for this could be solicited from DOE, expressly for this purpose. A Lab-wide committee could be formed to prioritize requests for expertise and identify potential advisors.

Cyber Water Coolers. A key strength of LLNL is the breadth of its technical expertise and the willingness of local experts to assist with interesting technical questions. But sometimes technical questions do not find the local experts. Internal, Lab-wide Web sites could post key technical hurdles to ongoing projects and solicit technical advice. The underlying idea of using electronically connected, informal teams of expertise has been well validated by the revolution in publicly developed software such as LINUX. Additionally, the online database of problems could provide a source of projects for Directed LDRD.

Redesign the Weapons Complex. LLNL has never shrunk from difficult problems, so we should consider taking the technical lead in a revamping of the entire DOE weapons complex, a job that goes begging. Of course, there are considerable political and technical hurdles, but the task will not get done if someone does not offer to take it on.

Some Unpopular Thoughts on National Security in 2020

Teresa Quinn

During the two years the Long-Range Strategy Project convened, we concluded nine subprojects, each with a report of its own. The final main report delivered tended to become the least common denominator of those individual reports. To find some more interesting discussion and provocative suggestions, I encourage you to read the nine reports of the subgroups. The groups that wrote them felt comfortable putting down uncommon thoughts.

I felt that one important debate was not well represented in the final report. This debate centered on national security. Our Lab is a national security lab, and we believe it will remain so for the next 20 years. What caused significant debate within our group was what will be considered national security in the year 2020. Some felt that national security meant military defense and military offense only, including traditional nuclear weapons work, NAI, and missile defense. Others in the group felt this might possibly change.

One possible driver for change is a reduction in this Lab's funding for nuclear weapons, possibly even to zero. A few paths might lead us there. One is a lessening of the perceived importance of nuclear deterrence by the nation leading to budget pressures on stockpile stewardship, raising the question of why the nation needs two nuclear physics labs. The arguments supporting the two-lab requirement were not compelling to the last group of citizens—the Galvin Commission—that looked at this question. It is also possible that this could happen again.

Another possible path is one in which our technical accomplishments in the next 20 years could open up a new strategy for nuclear weapon stewardship, again lessening the need for stockpile stewardship funding. Because nuclear weapons work is synonymous with LLNL, I find this line of thought disturbing but one that I believe this Lab needs to consider. If these paths are deemed highly unlikely, then no further concern is needed.

It is also possible that in 2020 nuclear weapons may not be our nation's biggest security threat. Our nation may be faced with nontraditional threats to our security that will require technical assistance from a national lab such as LLNL. The winds of change are already here. For example, the United Nations Security Council recently convened a session to consider AIDS, a health issue, as a security threat to Africa. There is increased concern over global climate changes. Energy security has already been at the root of one military action, and oil prices are rising. Recently Internet hackers managed to bring down some of the most popular Internet commercial sites, threatening our economic vitality. It is possible, though not necessarily probable, that these nonmilitary threats may become much more important than they are today—perhaps even more so than the threat of military attacks. This Lab could have much to offer the nation in understanding and mitigating these threats. I think we ought to examine this as a possible scenario for the future.

Nuclear Weapons Work as a Signature Mission

Gregory Simonson

There is cause for optimism that the first hundred years of the new millennium will be the brightest yet in human history. In the century coming to a close, mankind has for the first time possessed the technology to destroy civilization but has prudently declined to do so. Society, at least in the West, is at an historical high, and it should continue to climb in terms of prosperity, security, and quality of life. The basis for this optimism—globalization among humans and humans' emerging domination of nature (disease, hunger, aging, etc.)—yields a world in which we have little to fear in the next century, except human nature.

The national security laboratories provide a hedge against a part of the remaining danger. Their one enduring mission is to provide a credible, safe, and reliable nuclear deterrent against threats from foreign states. The inevitable proliferation of nuclear weapons technology and other weapons of mass destruction requires that the U.S. nuclear deterrent be maintained for the foreseeable future, hopefully with a much-reduced number of weapons in the stockpile. The only plausible way to do so is to sustain an unrivaled weapons program at these laboratories with the best available minds, computational tools, and experimental facilities. From the standpoint of good science, the most credible deterrent far in the future would arise from a robust weapons R&D program, complete with integrated testing. Given the overwhelming political benefits of not testing, the coming U.S. program should be limited to design, simulation, subcritical experimentation, and assessments of others' capabilities.

LLNL was created for its weapons program contribution to national security. If, in the most optimistic of possible futures, the need for that work truly vanishes, the continued existence of the DOE Defense Programs laboratories should be questioned. Until then, weapons work should be our signature mission, in a program configured as described above.

It also makes sense for LLNL to support additional work related to national security, as described in the body of the LRSP report. For the next two decades, our attention may extend to biology and biotechnology, or to lasers, or to generalized technical support to the DoD and intelligence communities. These are worthwhile pursuits, deserving of a national security laboratory's attention. However, none of these alone would be sufficient to justify the continuing need for a laboratory of this scale. The weapons work is unique in that the need is the most enduring and it could only be transferred to smaller labs, industry, or academia with considerable difficulty and risk.

The weapons labs have played a role in securing a bright future. They should continue to do so by providing the technical underpinnings for deterrence with small numbers of weapons. We need to be responsive to a world in which the pace of political and technical revolution is accelerating, and we need to be prepared for all plausible contingencies. For the foreseeable future, this means invariably that the one essential and continuing core mission of the Laboratory will be its nuclear weapons program.

Securing the Nation's Future

Mark Strauch

Because it is too hard to predict the future, we must invent and shape it to our desires. LLNL has always been an energy laboratory: we've designed nuclear amplifiers (weapons/fusion), atomic amplifiers (lasers/accelerators), and chemical amplifiers (insensitive high explosives). We have done a good job of combining materials to manipulate and impart/extract energy from elaborate systems. Reflecting 20 years from now, we will realize how crude some of these approaches were: explosives crushing nuclear materials and flashlamps torturing glass being but two examples.

In 2015, our manipulation of energy will be more precise and elegant. Using neutrons as blunt force tools to smash nuclei will yield to surgical manipulation employing photons. Nuclear power will employ such techniques to eliminate long-lived waste. Similarly, existing nuclear weapons, with their indiscriminate destruction, will transition to much smaller yield isomer weapons delivered with superb precision. We will literally hold every square hectometer on the face of the earth at near real-time risk.

Abundant, proliferation-resistant nuclear energy sources will allow us to stop the experiment of global warming and assist in the reversal of environmental damage wrought by our commercial, industrial, and transportation sectors. Such sources will also be credited with avoiding the seemingly inevitable conflict over oil and water and help developing nations lift their standards of living without damage to the environment and conflict with their neighbors. Nuclear systems will quench our thirst, provide our transportation energy, and take us to Mars.

The continued mastery of energy storage and conversion will dramatically affect the generation and distribution of energy and profoundly impact transportation. Microdistributed generation/storage will occur and will reshape the energy sector. Vehicles will not only move us; they will scrub the air via catalytic coatings and serve as computational and power plant adjuncts to our homes. Our parking lots will become test beds for novel, wireless distributed sensing, computing, and communication developments, including self-configuration, as vehicles come and go. Cars will be our environmental monitors on a national scale.

Biology will be profoundly important—for the Laboratory as well as the nation. Others will speak to this more eloquently, but advancements in this area are necessary to address both the social and military needs that will arise in the early 21st century.

How will this happen? It will happen because we at Livermore believe such steps are necessary to secure our nation's future, and we have the vision, means, and passion to make it so. While securing the future in 1952 meant a nuclear arms race in a bipolar world, the period from now to 2015 and beyond will be much more complicated. The challenges to the nation's well-being will extend well beyond the traditional military threats posed by nation-states. They will include terrorists and subnational groups inimical to our interests, resource contention among nations, an aging population with attendant economic and health demands, trade friction, and transborder environmental conflicts, among others.

To do this, LLNL will link the campaigns of Phenomenal Physics, Bold Bioscience, Extreme Engineering, Material Mastery, and Crushing Computations in programmatic ways that attract the best and brightest in an evolving Laboratory environment that reflects the diversity of sponsors, relationships, and employees, pursuing exciting endeavors of national importance and delivering solutions. As we deliver solutions to secure the nation's future, we will also be delivering opportunity, and creating opportunity is the best tool to ensure the Laboratory's future.

Arms Control and Arms Development

Mary Beth Ward

A central consideration for LLNL planning is the future of U.S. national security: the threats we face, the technology development efforts that can help address those threats, and the policies that determine how these technologies are used. The breadth of perspectives among LRSP members on these topics proved fascinating but unfortunately is not included in our consensus report, which reflects a less provocative middle ground. My own opinion is that while appropriate caution and bureaucratic inertia will together preserve many of our current defense practices, a likely trend is that U.S. defense planning will increasingly favor multilateral arms control over arms development. As technology advancements allow ever more devastating weapons to be developed by ever increasing numbers of countries, it becomes ever more difficult to guarantee U.S. security with a technical or numerical advantage. More and more, the “ounce of prevention” to stem the spread of weapon capabilities will be judged more effective than the “pound of cure” implicit in a strong deterrent, nuclear or otherwise. The policy community will more often ask LLNL and others to help promote U.S. security by giving up weapons options and to develop technology to maximize the benefits and minimize the costs of these concessions.

Like other U.S. defense laboratories, LLNL has a long and proud tradition of technical development to support production and deployment of increasingly capable weapons. Over the same time period, the U.S. has foresworn certain weapons activities to advance its overall security—examples include biological and chemical weapons as well as nuclear testing. The country may rethink these commitments, but in my opinion, the more likely path is that this trend will continue and the list of prohibited weapons and weapons-related R&D activities will expand. In the future, we may join international agreements that prohibit classes of weapons not yet envisioned and/or that restrict some current activities, such as certain aspects of stockpile stewardship, intelligence collection, missile testing, cyber warfare, or even defensive biological or chemical weapons work. As the CTBT demonstrates, an inability to perfectly verify such agreements will be a consideration but not a “showstopper.”

Ultimately, the decisions on what weapons and weapons R&D the U.S. gives up will be made by politicians. But LLNL and others will be called on to advise the decision makers, and our national security programs will be greatly affected by the consequences of these decisions. Scientists often resist the notion of limiting research, and many LLNL employees have political leanings that are not generally supportive of arms control. However, the Laboratory will benefit if we promote a culture that deliberately considers all perspectives. As we assess the technical costs of giving up certain activities and the ways that others can cheat, we should give equal consideration to the potential security benefits of coercing others to make the same commitments and the alternative technology measures that can minimize these costs. Our credibility will be enhanced and our program planning will benefit from this broader perspective. We should be neither too slow nor too quick to embrace arms control proposals that affect our work, but adapt as needed while providing the best possible technical support and counsel.

The LRSP Experience: Reflections and Perspectives

Robert Yamamoto

I would like to express my sincere appreciation to senior laboratory management for selecting me as one of the LRSP participants. It has been a most mind-broadening experience and one that will benefit me throughout my career. This experience has been a very positive one for me—so much, in fact, that often the highlight of my day was the LRSP meeting that I attended or an interaction with my LRSP subgroup. I genuinely looked forward to these activities and I am somewhat saddened that they will officially come to an end shortly.

A few thoughts that I would like to share:

• One of the key “take-aways” of being a part of the LRSP is the many relationships that have developed between the LRSPers. Working with such high-quality people from across all directorates of the Laboratory has provided me a keener sense of perspective and understanding in new and interesting subject areas (i.e., bioscience and biotechnology , public policy).

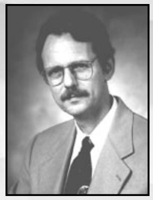
• From an event standpoint, our trip to Washington, D.C., this past March was definitely a highlight. Having the opportunity to meet and talk with senior members of the Department of Energy, the Department of Defense, the Office of Management and Budget, the Office of Science & Technology, and members of various House and Senate committees was quite exhilarating.

• The future of the Laboratory revolves around a world of change. The next 20 years will provide a sea change the likes of which the world has never seen before. The Laboratory must acknowledge that the status quo will not sustain us as a premier national laboratory as we move into the 21st century. What has worked for us over the past 40+ years will not necessarily be the right answer in the future. The Laboratory must be cognizant of this changing environment and embrace change as opportunities to do things differently and not just lament about the good old days of yesteryear.

• The Laboratory must also be flexible to ensure timely responsiveness to the needs of the nation. The Laboratory’s ability to move quickly into new frontiers where our expertise and skill is required will be essential if we are to maintain the type of scientific leadership roles we have become accustomed to. Flexibility comes in all forms; from developing new technical expertise to acknowledging that a more contemporary approach to project management and business practices is required. Let us not let our egotistical and sometimes arrogant attitudes prevent us from having an opportunity to provide real solutions to problems of national need.

• Although mine is certainly a minority opinion within the LRSP, I strongly believe that the Laboratory should support technical areas that relate to securing our nation’s economic security. National security is at risk if our economy is not strong. Technology is the engine of economic growth. The nation should be able to tap into our technical capabilities and knowledge base to help solve problems that promote our economic health and well-being.

APPENDIX B: BRIEF BIOGRAPHIES OF LONG-RANGE STRATEGY PROJECT TEAM MEMBERS



Charles Alcock: Deputy associate director in the Physics Directorate. Head of the LLNL branch of the University of California's Institute of Geophysics and Planetary Physics. Trained in astronomy and physics at California Institute of Technology; works on experimental searches for cosmic dark matter. Principal investigator of the Macho Project, which is the most successful dark matter experiment in the world. Ph.D. in astronomy.

Steven Ashby: Founding director of the Center for Applied Scientific Computing (CASC) within the Computation Directorate. CASC conducts collaborative research in computer science, numerical mathematics, and computational science in support of terascale scientific simulation. A computational mathematician; research interests include numerical linear algebra, scalable parallel algorithms, and subsurface simulation. Ph.D. in computer science.

L Jeffrey Atherton: Chemical engineer working in the Laser Programs Directorate on the NIF Program as the associate project leader for Laser Materials and Optics Technology. Assignment involves technology development; establishing production facilities at optics materials, finishing, and coating vendors based on this technology; executing a pilot production program to demonstrate the specifications, production rate, and cost basis for production; and production of optics for NIF. Ph.D. in chemical engineering.

Christina Back: Physicist in the Laser Programs Directorate responsible for radiation transport and x-ray source development research. Specializes in using high-powered laser experiments to study radiative heating and atomic processes in plasmas generated for inertial confinement fusion and stockpile stewardship applications. Research ranges from developing spectroscopic x-ray diagnostics of hohlraums to benchmarking radiation wave propagation in high-energy-density plasmas. Active in collaborations with universities using lasers. Ph.D. in physics.

Michael Colvin: Team leader for Computational Biology Group in the Biology and Biotechnology Research Program. This group is involved in collaborative projects with several experimental biology groups at LLNL and universities, as well as collaborations with the LLNL Physics and Computation directorates to develop new parallel quantum chemistry methods. Research interests include environmental mutagens, DNA-alkylating anticancer drugs, protein-binding ligands, and parallel algorithms for computational chemistry. Ph.D. in chemistry.

William Dannevik: Atmospheric Science Division leader and deputy associate director (acting) in the Earth and Environmental Sciences Directorate. Joined the Laboratory in 1988 following positions at the National Center for Atmospheric Research and Princeton University. Research interests include the theory, computation, and modeling of turbulent flow and the numerical simulation of complex physics processes on massively parallel computing systems. Ph.D. in meteorology.

Robert Deri: Associate division leader for Electronics Engineering Technology and acting center director for Engineering's Complex Distributed Systems Center until leaving the Laboratory in 1999. Technical background and interests include microfabrication, photonics, and the interplay of hardware and information systems. Ph.D. in physics.

Rebecca Failor: Division leader for ES&H Team 3, which is responsible for providing expert guidance and direction to LLNL programs on environment, safety, and health compliance. Major area of expertise is measurement of low-level radionuclides and natural radioactivity. Has for the past six years focused on ES&H activities at LLNL to assure high-quality support for LLNL programs and institutional needs. Ph.D. in nuclear engineering.

Peter Fiske: Experimental physicist in the Shock Physics Group in the Physics Directorate. Research combines laboratory-scale impact experiments and equation-of-state measurements on materials with applications to stockpile stewardship, high-pressure science, meteorite impact cratering, and planetary science. Selected in 1996 for the White House Fellowship Program; served one year in Washington, D.C., as Assistant to the Secretary of Defense for Special Projects. Ph.D. in geochemistry and materials science and engineering.

Patrick Fitch: Division leader in the Biology and Biotechnology Research Program responsible for genomics and bioengineering laboratories and personnel for DNA sequencing and genomic, microbial biology, and nonproliferation applications. Currently investigating information and automation technology applications in biology and medicine. Has also led medical device, air- and space-based radar, speckle imaging, nondestructive evaluation, and digital imaging projects. Ph.D. in electrical engineering.

Erna Grasz: Recently became a scientific advisor to the U.S. State Department for the Science and Technology Centers in Russia and Ukraine. Is also the deputy program manager for the Second Line of Defense Program. Previously, was a senior project leader for NIF; focused on large optics assembly and automated handling systems. Has been the group leader for Engineering’s Automation and Intelligent Systems Group, as well as a project leader for numerous environmental and hazardous material projects at LLNL. Interests include professional societies, Society of Women Engineers, and developing professional growth programs to assist young students and professionals. B.S. and M.S. in electrical engineering, with emphasis on automated controls and robotic systems.

Bruce Hammel: Program leader for Target Ignition Physics in the NIF Program. Responsible for coordinating the experiment, design, and target fabrication activities associated with achieving ignition on NIF. Ph.D. in physics.

Richard Knapp: Geophysicist in the Earth and Environmental Sciences Directorate currently working on the development of the environmental security program. Research activities focus on exploring heat and mass transfer in Earth’s subsurface. Ph.D. in earth sciences.

David McCallen: Director of the Engineering Center for Complex Distributed Systems. This center plans and develops the Engineering Directorate’s capabilities in sensing, wireless communication, and simulation of large engineering systems. Research interests include computational simulation and distributed sensing of large structures. Ph.D. in structural mechanics.

Charles McMillan: Leading the project at LLNL to enable the transfer of responsibility for the W80 from Los Alamos to LLNL. Because a decision has not yet been made to effect this transfer, this project has focused on the planning necessary to accomplish such a transfer. At the beginning of the LRSP, was the associate division leader for Computational Physics in B Division, leading the team responsible for supporting B Division's weapons codes and developing new ASCI codes, including the code that completed the ASCI burn-code milestone in 1999. Ph.D. in physics.

Paul Miller: Applied physicist and hydrodynamics in A Program/ A Division. Actively involved in the A Program AGEX work (such as the Nova weapon-physics experiments), secondary design, A Division recruiting, university interactions, and mentoring of postdocs and summer students. Ph.D. in applied physics.

Michael Perry: Associate program leader for Short-Pulse Lasers Applications and Technology in the Laser Programs Directorate. Responsible for experiments to investigate the interaction of intense laser radiation with matter; designs and develops high-power short-pulse laser systems; contributes to design and fabrication of diffractive optics in support of various Laboratory missions; responsible for developing advanced laser materials processing. Ph.D. in nuclear engineering.

Teresa Quinn: Assistant department head, Scientific Computing and Communications Department. Present assignment is to lead the VIEWS program for the Accelerated Strategic Computing Initiative. This program is an end-to-end program responsible for R&D, deployment, and operations of scientific visualization and data management systems for ASCI's high-performance computers. Has been a computer scientist and software engineer at the Lab for 15 years, working in the Nuclear Weapons Program, Treaty Verification Program, and Yucca Mountain Program. Education is in mathematics and applied science. M.S. in engineering and applied science. Was a Naval officer prior to entering graduate school.

Gregory Simonson: Deputy Q Division leader in the Nonproliferation, Arms Control, and International Security Directorate. This division, Proliferation Detection and Defense Systems, focuses on remote sensing and analysis of proliferant activities, modeling of battlefield systems, and technical support in a number of areas for DoD and DOE Defense Programs. Background in astrophysics, with interest in dynamics of elliptical galaxies. In 17 years at LLNL, spent first 10 in weapons program on calculations of atmospheric nuclear effects and phenomenology. Ph.D. in astronomy.

Mark Strauch: Deputy associate director for the Energy Programs Directorate. The directorate enhances energy and environmental security through innovation and the application of science to the stewardship of nuclear materials and systems and to advanced energy systems. In addressing national energy issues, this directorate is focused on a few key themes: cleaning up the nuclear and carbon legacies of energy production, reducing the security issues posed by nuclear materials and oil dependency, and designing future energy systems that wisely use and manage nuclear materials and fossil fuels. An electrical engineer by education/training, has worked in the energy and weapon program areas of the Laboratory for 20 years.

Lisa Stubbs: Mouse geneticist; leader of a small group in the Biology and Biotechnology Research Program with primary assignment to the Human Genome Center. Interests are comparative genomics, specifically, the comparative analysis of structure, function, and evolution of genes in related mouse and human chromosome regions; and the generation, biological characterization, and molecular mapping of mouse mutants that provide useful models for the study of acquired and inherited human diseases. Ph.D. in biological sciences.

Mary Beth Ward: Actively involved in Z Division technical assessments of proliferant reactors and related fuel cycle activities, analysis of proliferant nuclear weapons programs, technical studies of many other aspects of proliferant activities, assessments of nuclear suppliers and nuclear export controls, and management of other analysts. Work is expanding to include assessments of foreign biological and chemical weapons programs. Ph.D. in nuclear engineering.

Robert Yamamoto: Deputy division leader for the Laser Science Engineering Division. Expertise is in the design of working hardware supporting the high-energy/nuclear physics and accelerator communities, with particular emphasis in the fields of magnetics; cryogenics; high-vacuum, high-pressure and general mechanical structures/devices. B.S. in mechanical engineering; MBA.

APPENDIX C: Long-Range Strategy Project Outside Speakers

March 23, 1998	**Dr. Michael M. May**, Co-Director, Center for International Security and Arms Control (CISAC)
April 16, 1998	**Professor John L. Hennessy**, Dean, School of Engineering, Stanford University
May 14, 1998	**Professor Mildred S. Dresselhaus**, Institute Professor of Electrical Engineering and Physics, Massachusetts Institute of Technology
May 18, 1998	**Dr. Victor H. Reis**, Assistant Secretary of Energy for Defense Programs, U.S. Department of Energy
June 2, 1998	**Dr. William J. Perry**, Professor, Department of Engineering-Economic Systems/Operations Research and the Institute for International Studies, Stanford University
June 5, 1998	**Dr. Hans Mark**, Deputy Director for Research and Engineering, Department of Defense
July 28, 1998	**Senator Bennett Johnston**, Johnston and Associates, Proctor Jones
October 20, 1998	**Dr. Frank McCormick**, Director of the UCSF Cancer Center & Cancer Research Institute
January 6, 1999	**Dr. Siegfried Hecker**, Director, Los Alamos National Laboratory
February 3, 1999	**Dr. John F. Ahearne**, Executive Director of Sigma Xi, The Scientific Research Society
March 5, 1999	**Dr. John M. Deutch**, Institute Professor, Massachusetts Institute of Technology
April 13, 1999	**Dr. Donald M. Kerr**, Assistant Director of the Federal Bureau of Investigation, Laboratory Division
April 19, 1999	**Dr. Jay C. Davis**, Director, Defense Threat Reduction Agency (DTRA)
May 10, 1999	**Dr. Gordon Moore**, Chairman Emeritus of Intel Corporation
May 27, 1999	**Mr. Vincent Vitto**, President and CEO, The Charles Stark Draper Laboratory
June 7, 1999	**Lloyd D. Salvetti**, Director, Center for the Study of Intelligence, Central Intelligence Agency
June 17, 1999	**Dr. George Abrahamson**, Senior Technical Advisor, SRI International
October 12, 1999	**Dr. Jay C. Davis**, Director of the Defense Threat Reduction Agency (DTRA)

Lawrence Livermore National Laboratory is managed by the
University of California for the Department of Energy