Benefits of International Collaboration to U.S. National and Economic Security: Case Studies from Los Alamos National Laboratory

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Introduction

International collaboration[1] has been central to the scientific and engineering success of Los Alamos since its inception. The primary mission of Los Alamos remains focused on providing solutions to tough challenges facing the Nation in the context of national and global security. By their very nature, these challenges are complex, requiring innovations in science and technology that leverage and extend developments in academia and industry. Los Alamos has found success in tackling these challenges with multidisciplinary teams that bring diverse insights and perspectives.

This strategy has depended on international collaboration in a variety of forms. At one end of the spectrum, collaboration with international colleagues continues to enrich our teams; these collaborations create new ideas while also serving as effective recruiting opportunities. The other end includes organizational collaborations with international entities (governments, research organizations, and industry); these collaborations help to speed the advancement of fundamental discoveries that are important to our mission, and they do so through an efficient utilization of resources (funding, facilities, etc.). Furthermore, these collaborations can build international networks that are crucial to some aspects of our mission (e.g., nonproliferation).

Below we offer examples of the benefits to our mission delivery that have resulted from international collaboration. We begin by laying out a few benefits that have cross-cut many of our mission areas; many of these benefits mirror those observed in other assessments on the benefits to basic research in national security. We then present several Los Alamos case studies from specific mission areas. And we conclude with a discussion of steps we take to ensure our international collaborations maintain a secure environment that is consistent with our mission and role as a United States national laboratory.

Our assessment is based on the recognition that innovation in science and technology follows a pathway that begins with advances from basic research, some of which are then reduced to practice for a particular application. This pathway is consistent across broad areas in science and technology, both in the national-security space and in the context of commercial applications by the private sector. The early stages of this pathway—basic research—are accelerated through the sharing of information,

[1] Research security and the risks and benefits of international science collaboration in the future are a topic of discussion among all parties involved. Funding agencies, policymakers and research organizations. In preparation of a one day workshop on this specific question the authors assembled a list of case studies making a case for continuing to engage in them. The perspective of the US' largest NNSA funded laboratory making the case gave particular gravitas to the debate, which took place during a meeting at the Hoover Institution on Jan 22, 2024.

perspectives, ideas, and resources; and it is this stage where Los Alamos utilizes international collaborations. In the later stages of this pathway where innovations are extended to applications, Los Alamos limits information and collaboration to those with a need-to-know; in other words, information is protected in accordance with United States national-security protocols.

Cross-cutting Benefits from International Collaboration

In assessing benefits across a range of mission areas, several common themes emerge, including several that map to themes highlighted by Hottes et al. (2023) in an assessment of international collaborations in basic research for the United States Department of Defense[1]:

- *Accelerating Development of Science Base and Technology for Emerging Areas.* National and economic security rely on innovation and a strong science base, both of which benefit from international collaboration through sharing of ideas, data, open-source technology, facilities, and R&D costs. This is particularly true for the basic-research phase, whereas application of these findings often requires proprietary considerations.
    - A recent RAND assessment of international collaboration in basic research for US-DoD emphasizes the global nature of the research enterprise, noting that whereas the U.S. funded 69% of global basic research in 1960 it supported only 28% in 2016.[2] RAND notes 9 categories of beneficial considerations for international collaboration in basic research, many of which align with experience at Los Alamos in mission-relevant R&D.
    - At Los Alamos, one recent example is earthquake (seismic) monitoring and detection, where Los Alamos scientists have led the development of new theory and machine-learning methods that extract weak signals from seismic "noise", which is subsequently leading to crossover innovations in both nonproliferation (national security) and energy applications (economic security).

  While the U.S. could focus R&D domestically (exploiting international advances that are published), the sharing through collaboration with active U.S. engagement accelerates the overall beneficial developments for the US; further, direct international collaborations enhance the productivity of the U.S. researchers. Extending these research developments to practice/application is done domestically with appropriate protections for IP, classification, etc.

- *Sharing of Scientific Data to Build Sufficient Databases for Various Applications.* Machine-learning applications as well as physics-based predictive models require fundamental observations on a wide range of materials/environments/applications. Collection of these data can be expensive and time-consuming, and, in some cases, US-only research would be unable to collect needed data (e.g., on different geological environments and/or as tied to specific applications). International collaboration produces a range of data cost-effectively and more rapidly, allowing innovations that benefit U.S. national security and economic security. At Los Alamos, examples include seismic waveforms for various sizes/types of events in different

[2] Hottes, A. K. et al. (2023) International Basic Research Collaboration at the U.S. Department of Defense. RAND Report. International Basic Research Collaboration at the U.S. Department of Defense: An Overview | RAND.

geological environments and fundamental data on nuclear materials; in each case, the international collaborations build data that are often unique and always cost-effective, particularly in the case of field data and data collected at large experimental facilities.

- *Building U.S. Capacity for Scientists and Engineers.* Direct capacity building from international collaborations occurs through early-career researchers who come to the U.S. as graduate students or postdoctoral fellows and subsequently become U.S. citizens and permanent employees at U.S. national laboratories, U.S. universities, and U.S. companies. At Los Alamos, one recent example falls in the area of seismic monitoring, which has resulted in numerous postdocs from our international collaborators who have since become U.S. citizens working on both national security and energy applications at Los Alamos and at U.S. energy companies. Indirect capacity building from international collaborations occurs through multi-national training programs, where U.S. scientists/engineers benefit from training by international colleagues.

- *Developing Transparency and International Relationships that Facilitate Global Security.* At Los Alamos, this benefit to international collaborations is particularly important in our nonproliferation mission. The international collaborations include sharing of data, best practices, etc., as well as training programs. In this latter case, U.S. scientists/engineers build capacity in other countries through training, which in turn builds international networks that strengthen our ability to ensure global security.

Case Studies on International Collaborations from Los Alamos

Below we present case studies on several research areas at Los Alamos where international collaborations have benefited our national security work, both directly and indirectly.

- Seismic methods & nonproliferation
- Nuclear science
- Fuel cells
- Computing (including Semiconductors, Chips, and Computational Architectures)
- CO_2 capture and storage

These research areas are not meant to be inclusive of all areas where international collaborations occur. Rather, they represent a spectrum of topic areas to illustrate the breadth of impacts across Los Alamos.

The assessments were qualitative, utilizing interviews with members of research teams that focused on the nature of and need for the collaborations, as well as the benefits to both U.S. economic security and U.S. national security.

Seismic Methods & Nonproliferation

Seismic methods constitute a suite of technologies with direct relevance to both economic security (energy) and national security (nonproliferation). International collaborations have been central to recent advances with direct benefits to the U.S. and with minimal risks.

Nature of LANL Collaborations:

- Researcher-to-researcher, which in turn leads to a pipeline of research fellows at Los Alamos.
- International collaborations contribute to almost half of LANLs publications in this area; principally with Italy, France, and Great Britain.
- Sharing of data, co-developments in theory and computational codes (often open source), and participation in larger (expensive) experiments.

Benefits and Relevance to U.S. Economic Security:

- Subsurface resources underpin U.S. energy security, which includes significant economic opportunities tied to oil and gas, geothermal energy, CO_2 storage, and critical mineral recovery. Accessing and utilizing these resources has relied heavily on seismic methods; new advances are transforming our ability to do this efficiently (e.g., providing higher level information on complex subsurface environments) and safely (e.g., avoiding induced seismicity, which has derailed many energy projects).
- A secondary longer-term benefit from these recent advances is the ability to forecast earthquakes to allow minimization of impacts (economic and otherwise) from natural events.

Benefits and Relevance to U.S. National Security:

- Seismic methods underpin U.S. national security in the context of nonproliferation. This requires detecting events (often remotely and increasingly smaller) and discriminating them from natural events.
- Recent seismic research has developed the science base to detect smaller events, even extracting information from "seismic noise". These developments rely on machine learning methods, which in turn rely on large amounts of data on different types of events in different geological environments.
- **International Network Building:** International collaborations help to strengthen relationships and to build a network that is central to nonproliferation and national security (as noted by RAND[1]).

Why International Collaborations Are Needed:

- International collaborations have accelerated the recent advances in seismic methods through sharing of data, ideas/theory, and methods, and they have been important in developing the expertise pipeline, both at Los Alamos and within U.S. industry and academia.
- **Data:** International collaborations have significantly reduced the cost associated with collecting sufficient seismic datasets (which are inherently expensive). In addition,

international collaborations have provided unique datasets needed to advance our nonproliferation methods (e.g., waveforms to differentiate natural and a variety of induced events in a range of geologic environments).

- **Pipeline:** International collaborations have contributed to workforce development at LANL in several areas, including nonproliferation and nondestructive evaluation methods. International postdocs and students have been part of our research teams, and many have become U.S. citizens and employees at LANL, U.S. oil/gas companies, and U.S. universities (building long-term U.S. capacity).
- **Theory and Computation:** International collaborations have been central to LANL's advancements in both theory and computation as needed to detect small events in background "noise" and to develop predictive methods for larger earthquakes.

Nuclear Science

Fundamental research data on nuclear materials is needed for U.S. national security, safeguards, nonproliferation, and U.S. energy security. International collaborations help to generate these data (which have been considered open/unclassified) cost effectively and often generate unique datasets that could not be obtained domestically. The data include a range of information needed for accurate simulations as well as for developing and testing monitoring instruments; the latter also benefits from international development of standards. Training of international collaborators/inspectors (which can include sharing of technology) is central to a strong safeguards program.

Nature of LANL Collaborations:

- Data sharing (e.g., through Brookhaven's National Nuclear Data Center, the International Atomic Energy Agency, and other mechanisms). Data include fundamental nuclear data—e.g., nuclear structure (cross-sections) and nuclear reactions, etc. This is particularly important for data collected at unique facilities that are expensive and limited in number.
- Training and technology development (for monitoring and measurement). LANL trains virtually every IAEA inspector.
- Development and sharing of standards.
- Multinational with Italy, France, UK, Israel, Armenia, Japan, and Canada.
- Sharing of data, co-developments in theory and computational codes (often open source), participation in larger (expensive) experiments

Benefits and Relevance to U.S. Economic Security:

- These data and collaborations are leading to innovations in new energy technologies (e.g., fusion, novel nuclear reactors, etc.). Although open to other countries, these developments are also important options for U.S. energy transition (which underpins U.S. economic security).

Benefits and Relevance to U.S. National Security:

- Fundamental nuclear data (e.g., Evaluated Nuclear Data Files, which are unclassified) are needed for neutronics simulations for national security and nonproliferation.

- Training experience gives LANL unique insight into the technical requirements for equipment needs for detecting/analyzing a range of nuclear material, which in turn allows LANL to develop improved tools for international inspectors as part of safeguards and security.

Why International Collaborations Are Needed:

- **Data:** International collaborations have significantly reduced the cost associated with collecting sufficient nuclear datasets (which are inherently expensive). In addition, international collaborations have provided unique datasets needed to advance our nonproliferation methods (e.g., data on nuclear isotopes from processes beyond those conducted domestically).
- **International Capacity Building:** International collaborations (particularly training) help to build international capacity and a global network of inspectors, both of which improve U.S. national security through a more effective safeguards program.
- **Prevention of Proliferation Far from U.S. Borders:** U.S. national security is improved by addressing concerns as far as possible from our borders. To the extent that we are sharing intellectual property (IP), it is generally IP that does not have a large market and, thus, has minimal impact on U.S. economic interests.

Fuel Cells for Transportation

Los Alamos has been a driver in fuel-cell development since its inception as a DOE focus for the transportation sector (starting at LANL in 1977).[3] International collaborations have been central to accelerating development of this clean-energy technology, which benefits U.S. energy and economic security (e.g., by providing an option for long-haul trucking to meet emission-reduction targets). Additional benefits tie to domestic manufacturing.

Nature of LANL Collaborations:

- Fuel-cell technology for transportation originated at LANL as an internally funded LDRD project in 1977 and greatly expanded in 1990 with a partnership involving GM and DOE.
- CRADA projects with Toyota, Hyundai, and others to make better fuel cell stacks and components.
- International collaborations contribute significantly to LANL's publications in this area.

Benefits and Relevance to U.S. Economic Security:

- **Domestic Manufacturing:** One success story is a LANL project under DOE's L'Innovator program, which was funded by DOE to speed commercialization with 50% cost share required as cash from partners. LANL partnered with Advent (a Greek company), and they have subsequently opened a manufacturing center in Massachusetts. Another example is an international collaboration with IRD Fuel Cells (Denmark), which now has a manufacturing facility in Albuquerque.

[3] All current transportation fuel-cell technologies (PEM based) contain technology originally invented and developed at LANL.

- For clean energy technology, there is a U.S. benefit for an accelerated shift to lower carbon globally. For clean fuels, there is a win-win for producing fuel near the consumption to eliminate transport.

Benefits and Relevance to U.S. National Security:

- Growing the U.S. manufacturing base for clean energy helps to make the U.S. more competitive as a global exporter.

Why International Collaborations Are Needed:

- International collaborations accelerate technology development cost effectively—particularly with DOE funding that requires cost share.
- International collaborations also help the U.S. to remain abreast of global developments. Both Europe and Asia have moved ahead of the U.S. in terms of manufacturing and deployment of these technologies because those regions have a bigger emphasis on clean energy and decarbonization, and the collaborations help the U.S. to monitor world progress in new economies where the U.S. may choose to become active in the future.
- **Pipeline:** International collaborations in fuel cells have contributed to workforce development at LANL in several areas. International postdocs and students have been a major part of our research teams, and many have become U.S. citizens and employees at LANL.

Computing

Accelerating advances in computing is central to the missions of Los Alamos and its sister national laboratories. National security depends on the abilities of the national lab complex to elucidate the nature and behavior of complex systems through the fast and accurate simulation of complex physics and, more recently, through the exploitation of complex data analysis (often in tandem with advanced simulation) via machine learning and artificial intelligence.

In considering the impacts of international collaborations on computation, it became clear that a complete picture requires a discussion of both early enabling semiconductor technology to advance chips (specifically lithography) as well as the use of this technology to advance the computational architectures and specialized methods for the scientific computing done by Los Alamos. In the former case, we've taken a broader perspective to incorporate collaborations beyond Los Alamos and across the DOE national lab complex.

Computing: Extreme Ultra Violet Lithography (EUV)

Nature of collaborations

- DOE national-lab complex (LLNL, LBNL, LANL, later SLAC, JLAB) in strong partnership with U.S. and foreign countries, especially Japan, South Korea, Europe (mostly Germany, Netherlands, Switzerland).

- An important partnership between the lab complex and private actors was the 1990s EUV CRADA between SNL, LLNL, and LBNL with the EUV consortium made up of Intel, AMD, Motorola, Micron, Infineon, and IBM.

Benefits and Relevance to U.S. Economic Security:

- It is essential for the U.S. economy to have access to the highest performing chips, but they do not need to be built in the US.
- It is hard to estimate that secondary value created in the U.S. economy by using chips (software, hardware, AI, cars and other industrial products, etc). Using chips and developing applications is far more valuable than producing them.

Benefits and Relevance to U.S. National Security:

- International collaboration addresses a growing performance constraint in computing– movement of data. Producing them in the U.S. might be the only way to guarantee there are no backdoors.

Why International Collaborations Are Needed:

- **Lack of U.S. Capacity.** International collaboration enables advances from other countries to be imported, accelerating the growth of U.S. capacity. Even if all the new foundries in the U.S. would work at full capacity, only 6% of all chips required would be delivered by them.

Computing: Computational Architectures and Methods

Nature of LANL Collaborations:

- Partnerships with international industrial collaborators (SK in Korea; Swiss Center for Scientific Computing) to develop new computational architectures, which could lead to future manufacturing/production in the US.
- Additional major U.S. industry players (e.g. Seagate, Nvidia, SK, etc.) anticipated to have a joint announcement towards the end of 2023. Its intent is to establish an open architecture which will allow multiple chip/storage/memory vendors to provide new programmable products within an enduring, community defined architecture.

Benefits and Relevance to U.S. Economic Security:

- These computational advances are also transforming methods to probe complex subsurface environments that will enhance both U.S. national security and U.S. economic security. These transformations—which will require new computational architectures—are akin to the transformation that occurred in medicine with the shift from 2D x-ray images to MRI.

Benefits and Relevance to U.S. National Security:

- International collaboration addresses a growing performance constraint in computing—the movement of data.

Why International Collaborations Are Needed:

- **Lack of U.S. Capacity.** International collaboration enables advances from other countries to be imported, accelerating the growth of U.S. capacity. Collaboration with LANL is aligned

with a targeted technology growth area in the US. By working with South Korea's SK Hynix the lab is encouraging a larger R&D presence in the U.S. of a world technology leader and SK Hynix is expanding its investment and presence in the U.S. While there is certainly general risk that they will not achieve their intended expansion in the U.S., the hope is SK Hynix will initiate U.S. production assuming our technical project proceeds well and the new architecture shows value to other industry markets.

- LANL worked with Nvidia to be the first U.S. customer to receive the new Nvidia Grace CPU, with HPE as the system integrator (Venado)[4]. The laboratory is working with them on the development of new capabilities (e.g. CPU, GPU designs) for future systems. These capabilities are intended to advance U.S. nuclear deterrence. The collaboration with Nvidia also involves a separate collaboration with Swiss ETH/CSCS who is also receiving an HPE/Nvidia system similar to Venado.

CO_2 Capture and Storage (CCS)

The Intergovernmental Panel on Climate Change has concluded that capturing carbon dioxide and storing it permanently and safely in geologic reservoirs is a critical option for curbing climate change.[5] International collaboration in CCS has been recognized as central to U.S. economic and national security central since the early 2000s (Bush Administration). While the U.S. has been a leader in CCS research & development, international collaboration has helped to build international consensus and capacity while accelerating the development of technology and demonstrating feasibility at field scale (which is expensive).

Nature of LANL Collaborations:

- Bilateral Collaborations (e.g., US-Norway Bilateral Collaboration): For example the US-Norway bilateral (with US-DOE) is a decade-long, government-sponsored collaboration to promote sharing of knowledge and lessons learned through the respective country's CCUS-focused R&D and commercial efforts.
- Multinational Data Sharing: CO2DataShare is portal for sharing CCS related data that is supported jointly by US-DOE and Norwegian Government.
- Multinational Research Collaborations: The ACT Initiative (Accelerating CCS Technologies) is an international initiative jointly funded by the US-DOE and 15 countries. The International Energy Agency's Greenhouse Gas R&D Programme (IEAGHG) sponsors international R&D networks, topical reports on technical and policy issues and advances related to CCUS, and international capacity building; US-DOE is a member of IEAGHG's executive committee.

Benefits and Relevance to U.S. Economic Security:

- Building Insight and Capacity: The Norwegian experience in CO_2 injection and storage in offshore environments has provided insights into developing safe and successful commercial scale projects in offshore Gulf of Mexico where multiple commercial U.S. projects are currently under development. While the U.S. has been the international leader in CCS

[4] https://discover.lanl.gov/news/0530-venado/
[5] https://www.ipcc.ch/sr15/

research, Norway has been the international leader in field-scale demonstrations of storage (particularly in offshore environments); Norway's sharing of data and lessons learned helps to build U.S. capacity.

- Improved Monitoring Technology: Development of new monitoring technologies has been accelerated through international collaboration—by sharing of data with the U.S. and vice versa. Monitoring data from multiple commercial-scale storage projects in Norway has led to improvements of modeling technologies and monitoring technologies which has benefited the US-DOE research efforts. Similarly, monitoring data from US-DOE efforts have been shared internationally to improve monitoring technologies.

Why International Collaborations Are Needed:

- **Need for International Cooperation and Capacity Building:** Deployment of CCS will need to occur globally, requiring international capacity as well as agreements on relevant policies.
- **Pipeline:** International collaborations in CCS have contributed to workforce development at LANL in several areas. International postdocs and students have been major part of our research teams, and many have become U.S. citizens and employees at LANL.

Maintaining a Secure Environment

Los Alamos utilizes a number of strategies to maintain a secure environment, which work in tandem with additional processes that are specific to collaborations with foreign nationals. In general, many of these fall into a few broad categories.

- **Controlled Access for Individual Collaborators.** Collaborations involving on-site access require badging. If the collaborator is a foreign national, the badging process that aligns with DOE's requirements under its unclassified foreign national access program,[6] which has been established to protect assets and to ensure that unauthorized access to sites, information, and technologies is denied. The process is a risk-based review that is consistent with U.S. law; national and economic security; and DOE program-specific policies, requirements, and objectives. This includes an explicit consideration of sensitive subjects (topic areas). The process also involves assessment of the individual as well as the development of a site-security plan.
- **Restricted Access to Information, Technology, and Spaces.** One component of site-security plans is to ensure access is granted only to specific areas/spaces, technologies, and information. Complying with this access is the responsibility of the visitor, host, and line managers. Badging is also used to control access to spaces. It is also part of how all employees ensure security within their workspaces (e.g., by access to spaces/technology/information is restricted to authorized individuals). Appropriate access to internet and computers is also identified and controlled as part of the site-security plan.
- **Training.** A variety of training is used to ensure LANL employees and visitors are aware of safety and security considerations, processes, and responsibilities. This training is renewed on a frequent basis, and maintaining an up-to-date status on required training is a requirement for site access.

[6] DOE O 142.3B.

- **Approval Requirements for Inter-organizational Agreements.** A variety of agreement mechanisms are utilized to control collaborations with outside organizations, including foreign entities and/or entities with foreign nationals. These agreement mechanisms include considerations, assessments, and stipulations similar to those used in controlling access at the individual level as noted above.

The categories above are not intended to be comprehensive or detailed. As with other national labs, Los Alamos uses a number of mechanisms and processes to ensure the safe and secure handling of access to information, facilities, networks, etc. Rather, these are intended to illustrate the types of considerations that are used to maintain a secure environment for collaborative research.

Summary

The case studies in the paper represent only a small fraction of more cases that could be made. What all of them have in common is that they point to particular cases requiring major advances in the open science application needing researchers in the US and elsewhere as well as benefitting national security interests in the US, sometimes advancing commercial aspects for industries in the US. They are meant to demonstrate the ability to achieve both: retrieving the benefit and managing the risk at the same time.